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ORIGINAL PAPER

A holistic sustainability assessment of a university campus using life cycle approach

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Abstract
The sustainability performances of campuses are of importance as it could model the effective sustainable initiatives that could be then applied to campuses by decision-makers and designers. Studies have been conducted on the environmental and economic assessment of campuses in specification with the identification of their carbon footprint and cost analysis, respectively. The studies have lacked a showcase of an ideal sustainable campus along with its urban and architectural features, facilities, and services through analyzing their social aspects as well. The objective of this study was to evaluate the sustainability of the Abdullah Gul University Sumer Campus to model a sustainable campus integrating the Environmental Life Cycle Assessment(E-LCA), the Life Cycle Costing (LCC) and the Social Life Cycle Assessment using life cycle sustainability assessment approaches for the use-phase analysis of the campus. E-LCA was applied to quantify the global warming potential and cumulative energy demand based on International Organization for Standardization 14,040 and 14,044 by considering the gate-to-gate approach. The environmental assessment results showed that the global warming potential of the campus was 2.92 tCO_2 eq./person, and the cumulative energy demand was found as 15.4 GJ/person. In LCC, the total cost of the campus was calculated as 200 US Dollars/person, and the energy cost is found as a major contributor with 86% of the total cost for the year of 2019. In the social performance assessment, it is found that the university has a weak social performance for the local community, the consumer, the worker, and the society.

Keywords Environmental assessment · Higher education institution · Integrated sustainability assessment · Life cycle cost · Social life cycle · University campus

Introduction

A university campus features elements and characteristics of a small city, given its large reserves and the movement of individuals, materials, and finance (Ai et al. 2019). Besides, universities can be observed as a dynamic building unit in terms of waste generation, distribution, water, energy, and electricity use, considering the science, social and educational activities that take place within their structure (Ragazzi and Ghidini 2017). Since sustainable development has been an increasing need with the rapid global urbanization growth of 5.95% between 2030 and 2050 (United Nations the Department of Economic and Social Affairs 2012). Consecutively, to increase the awareness, ranking systems for universities also started to emerge, for instance, the Times Higher Education (THE) provides performance ratings for universities while concerning the sustainability indicators made official from the United Nations for the Sustainable Development Goals (SDGs) (Times Higher Education 2019). For quality education, decent work and economic growth, reduced inequality, sustainable cities, and communities are the main SDGs used for the performance rating of universities (Abad-Segura and González-Zamar 2021). The solution is to promote the number of universities developing

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and implementing resource efficiency, disaster resilience, quality management, and climate change adaptation plans and policies by 2020 (Adenle et al. 2021).

A sustainable assessment can assist universities in determining what decisions could be made by policy-makers to effectively implement sustainable practices (Sala et al. 2015). The need for assessing and analyzing the energy and resources consumption in huge building organizations such as campuses can help raise awareness on the rapidly growing issue of climate change (International Energy Agency and United Nation Environment Programme 2019). The sooner realization of the harmful environmental impacts, as a result, can bring about a change in the operations and facilities and energy demand by the campuses (Chau et al. 2015). Due to this, the institutions can adopt the green initiative aiming at reducing the consumption of non-renewable energy resources, systems, and models of having energy services to reduce emissions (Clabeaux et al. 2020; Shuqin et al. 2019). While considering the campus sustainability development programs, the environmental and cost impacts of campuses are widely investigated; however, the third aspect of sustainability deals with the social impact is the least evaluated. The sustainable development programs for campuses should further be focusing on the social study of managing and identifying impacts on employees, students, teachers, and other personnel working on campuses (Too and Bajracharya 2015).

Life Cycle Sustainability Assessment (LCSA) approach could help campus decision-makers in evaluating the sustainability efficiency of various applications such as technology, facilities, transport, and selecting the most sustainable choice. Also, through recognizing the cost, environmental and social impacts in the life cycle of their campus units, sustainable changes could be made in their designing and operation processes (Hannouf and Assefa 2018). The LCSA methodology is a holistic approach, whereby it is defined as the integration of the Environmental Life Cycle Assessment (E-LCA), the Life Cycle Costing (LCC), and the Social Life Cycle Assessment (S-LCA). Both the LCEA and LCCA are mainly studied under the guidelines of International Organization for Standardization (ISO) 14,040 and 14,044 and S-LCA is conducting through the process following the guideline published by the United Nations Environmental Programme (UNEP) and Society of Environmental Toxicology and Chemistry (SETAC) (UNEP-SETAC 2009). S-LCA utilizes conventional and site-explicit information, can be quantitative, semi-quantitative, or subjective, and supplements the fundamental LCA and LCC (ISO 2006a; Stanford University 2005).

In the literature, several published studies on the sustainability of university campuses are usually focused on determining the carbon footprints of these campuses using a life cycle assessment approach (Ai et al. 2019; Chang et al. 2019; Clabeaux et al. 2020; Ragazzi and Ghidini 2017; Yañez et al. 2020; Zhou et al. 2013). Clabeaux et al. (2020) assessed the carbon footprint of Clemson University's campus by using the life cycle assessment (LCA) approach between the year of 2014 and 2017. Their results revealed that the main contributors of greenhouse gas emissions are electricity generation with 41% and automotive commuting with 18% of the total (Clabeaux et al. 2020). Yañez et al. (2020) focused on determining the carbon footprint of the University of Talca in Chile based on the Greenhouse Gas (GHG) Protocol for all its five campuses. Their results show that Scope 3 which covers indirect emissions generated by activities like transportation of people has the highest contribution to carbon footprint in 2016. The operation of boilers was found as another activity contributing highly to the carbon footprint of the university (Yañez et al. 2020). Additionally, Chang et al. (2019) applied a life cycle energy assessment on Singapore's Nanyang Technological University (NTU) based on the assumed lifetime of 40 years. All life cycle phases from material phase to end of life phase are considered to conduct life cycle energy assessment of 22 buildings in NTU. They found that the largest source of total energy is operational energy with 90%, while the remaining 10% is from embodied energy (Chang et al. 2019). Zhou et al. (2013) studied on measuring the energy consumption of colleges and universities in Guangdong province of China. They applied survey on 98 colleges and universities to calculate the energy consumption per student, including electricity, water, gas, and cooling energy, from 2006 to 2010. Their results revealed that there is a great difference in energy consumption for electricity and natural gas per student between the universities; thus, they suggested that the energy consumption evaluation indexes showed that the conservation-oriented campus should take the influence of school type into consideration (Zhou et al. 2013). Besides, Ai et al. (2019) studied on sustainability assessment of universities to identify and apply appropriate techniques. Fisher Information (FI) and Data Envelopment Analysis (DEA) are selected for comparative analysis in this study. Data analysis is applied in an urban university, and they concluded that these two methods can be valuable yet complementary for an integrated system analysis (Ai et al. 2019). Ragazzi and Ghidini (2017) studied on the environmental sustainability of universities by carrying out a constructive analysis of the GreenMetric Ranking to improve the ranking method. Their analysis shows that the GreenMetric Ranking has a good foundation for the combination of the principles of sustainability and reflects the need to quantify the efforts toward sustainability. They also concluded that there is a need to make this method more scientific and rigorous (Ragazzi and Ghidini 2017).

Even though there are studies on the evaluation environmental performance of universities, studies about the economic and social performance of universities are scarce in the literature. Huang et al. (2018) investigated the environmental and economic performance of university dormitories in southeast China considering the construction, operation, maintenance, and demolition phases by using LCA and LCC approaches. Their findings indicate that the use phase covers the operation and maintenance is the hotspot of the life cycle environmental impacts and cost of university dormitories (Huang et al. 2018). Legorburu and Smith (2020) propose a technique with incorporating observed data into early design energy models for life cycle cost and carbon emissions analysis of campus buildings. Their proposed technique is a discrete multi-objective optimization framework to choose the optimal HVAC system for each building to minimize life cycle cost and emissions. Their results indicate that it is possible to decrease overall carbon emissions of the buildings by 15% while only increasing the life cycle cost by 2.4% by the implementation of a combination of systems rather than a single HVAC system type (Legorburu and Smith 2020). Bueno et al. (2021) quantified the environmental and social footprint of the University of the Basque Country in 2016 and identified some hotspots in the organization. Their environmental results revealed that transport is the main contributor with a 60% share of the total environmental impacts. From a social perspective, their results indicated that traces of child labor and illiteracy are detected in the social footprint that supports the academic activity of the university (Bueno et al. 2021). Although several studies related to environmental, economic, or social assessment of the universities are available, there is no study related to life cycle sustainability assessments of the universities by concurrently integrating E-LCA, LCC, and S-LCA in the literature. The main objective of this study is to conduct the LCSA of AGU Sumer Campus with a holistic approach. In this study, the sustainability performance of the campus is evaluated from an environmental, economic, and social perspective by implementing the integration of E-LCA, LCC, and S-LCA. To the best of the author's knowledge, this study presents for the first time an LCSA of a university in the literature, aiming to pave future studies on the holistic sustainability assessment of universities. It also helps to develop strategies to be a green campus for a university with an integrated perspective and to compare the analysis results alongside other universities around the world.

Description of Abdullah Gul University Sumer Campus

AGU is a recently established university located in the center of Kayseri, Turkey. It was formally founded in 2010 and admitted its first students in the 2013–2014 academic year. In 2019, the total number of undergraduate and graduate students were 1968, while 364 employees, including 219 academic staff and 145 administrative staff, were working at the AGU. The Sumer Campus of the university is located on an old, renovated textile industrial factory called the Sumerbank Textile Factory, which dates back to the year 1935. The development and establishment of the AGU Sumer campus on such a site have ensured to maintain the cultural heritage and historical values of the factory, while it has incorporated more unique elements in the design to promote sustainability. Within the AGU Sumer Campus, there are several buildings including the fitness center, external offices, security cabins, and the main campus buildings, which houses the classrooms, laboratories, and offices for the administrative staff and academic faculty with a total building area of 53,208 m^2. The campus area is illustrated in Fig. 1 with an approximate land area of 278,843 m^2 in which the green areas are two-thirds of the total campus area (Abdullah Gul University 2019).

The university campus in focus is the AGU Sumer Campus which was a renovation project converting the grounds of the abandoned textile industry to a higher education campus making it an important resource for the community. Renovation projects implement the creativity and uniqueness that goes into the restoration, operation, and servicing of old building models to avoid reconstruction while preserving the natural resources (Cascone and Sciuto 2018). For the case of AGU Sumer Campus, this was a stepping-stone to avoid further damage and demolishing of the old industrial area. The renovation applied in this project has converted an industrial site to a fully, functioning university campus with various services and facilities (Asiliskender and Baturayoglu Yoney 2016).

Materials and methods

Implementing a similar framework followed by the standards ISO 14040:14,044 on LCA, with some modifications made to the study, the developed methodology in this study targets the in-depth analysis of each specific phase of the LCSA study through its branches, namely E-LCA, LCC, and S-LCA. For the E-LCA aspect of the study, the indicators are focused on the Global Warming Potential (GWP) and the Cumulative Energy Demand (CED). These two indicators are based on the most concerning impacts in terms of environmental and building performances in the construction industry (Hossain and Poon 2018). The LCC part of the study is concerned with the cost considered during the usage phase of the LCA assessment. The cost indicators here were divided into two categories of direct and indirect cost, which are based on the inputs, and the outputs of the usage stage for the buildings and facilities within the campus. Lastly, the social study of S-LCA was determined by the people who are within the campus premises such as the consumer and workers who are comprised of the students, academic staff,

Fig. 1 The map view of Abdullah Gul University Sumer Campus

and administrative staff, and the ones outside and surrounding the campus such as the local community and the society. This varied group of social indicators was examined to get the responses on a wider social pattern of the society with direct relation to the AGU Sumer Campus. The methodology proposed for evaluating the LCSA of AGU Sumer Campus is summarized in Fig. 2.

Environmental life cycle assessment

The E-LCA is performed based on ISO 14040 and ISO 14044 which consists of four main stages; goal and scope definition, inventory analysis, impact assessment, and interpretation (ISO 2006a, b). E-LCA was applied to quantify the GWP and CED of the campus within the system boundaries. To quantify the E-LCA of the campus, the functional unit was chosen as kg CO_2 eq./person emission for determining the GWP (Clabeaux et al. 2020). On the other hand, the functional unit was chosen as Gigajoule (GJ)/person for the CED per person. With a gate-to-gate approach of the LCA analysis implemented in the study, four distinct categories make up the usage process, which puts the system boundaries for the environmental analysis. These categories are, namely energy, paper, water, transportation, and waste. Based on the application and usage stage of the life cycle of the AGU Sumer Campus, these four categories were identified as the indicators as shown in Fig. 3.

Life cycle inventory

The inventory data were collected from the administrative departments of the university (Table S1). This case study focused on data collected for the year 2019. As reported by Ridhosari and Rahman (2020), the possible sources of the university campus were identified and categorized in four specific scopes (energy, water, transportation, and waste) as shown in the system boundaries for E-LCA in Fig. 3. The energy covers the annual electricity and natural gas consumption for the operation of the buildings; water refers to annual water consumption for drinking, cleaning and irrigation; transportation covers the traveling of the academic and administrative staff; waste covers the solid wastes such as plastic, metal, paper, battery and wastewater generation in the campus. The collected inventory data were used in SimaPro 8.4.1 software for environmental impact assessment as inputs and outputs.

Environmental impact assessment

IPCC 2013 GWP 100a (V1.03) method was used for environmental impact assessment of the AGU Sumer Campus

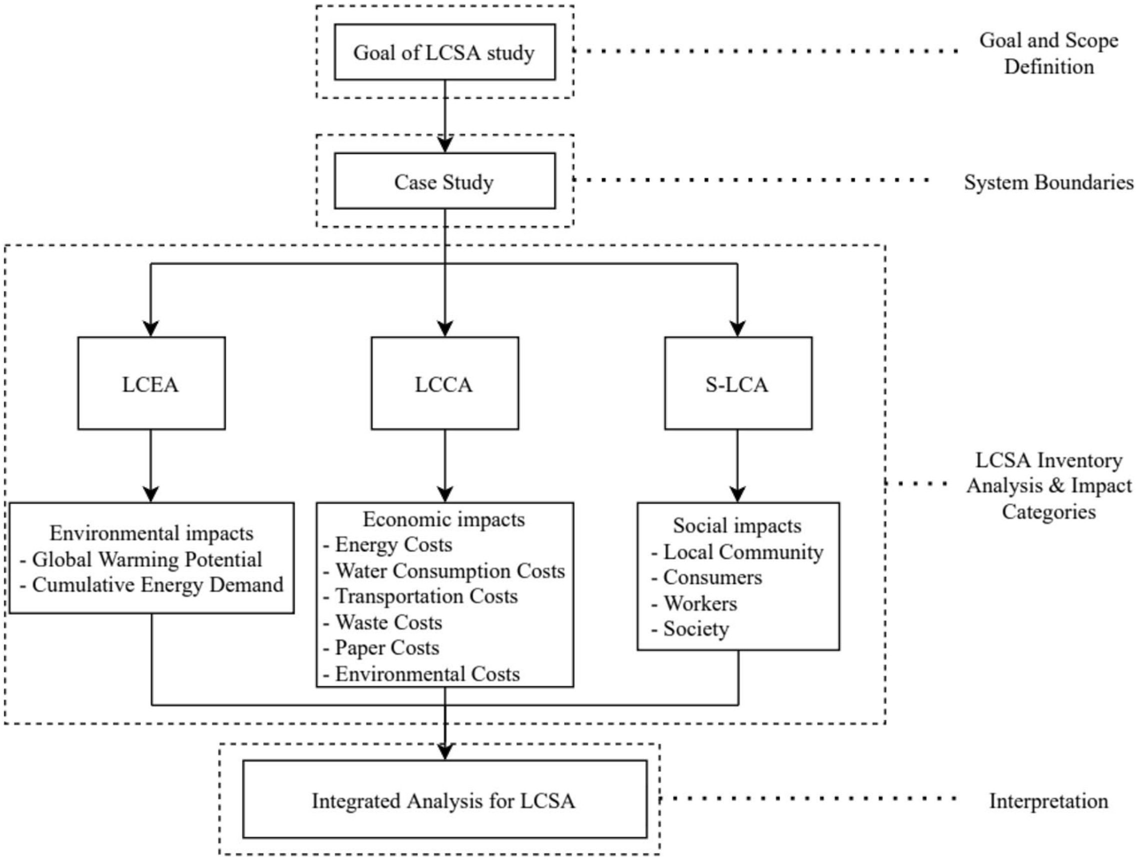

Fig. 2 The framework methodology used for life cycle sustainability assessment in this study

using SimaPro 8.4.1 software (Herrmann and Moltesen 2015). The method was developed by the Intergovernmental Panel on Climate Change (IPCC) in 2013. To quantify GWP and greenhouse gas emissions, the climate change factors of IPCC with 100 years horizon are used and expressed in kg CO_2 equivalent. Additionally, the CED V1.09 method was used for the quantification of the energy consumption of the campus. For environmental impact assessment, the Ecoinvent v3.1 database in Simapro was used with its well-documented data for a number of products and processes in this study (Ecoinvent v 3.1 2013; Frischknecht et al. 2005).

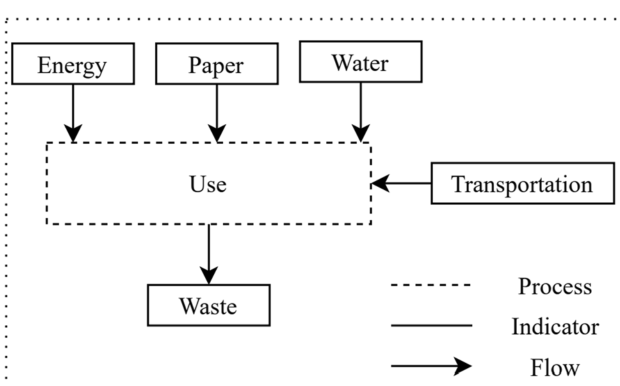

Fig. 3 The system boundaries of the environmental life cycle assessment

Life cycle costing

For the analysis of the economic sustainability of the campus, the LCC was used for a better understanding of life cycle evaluation from a financial perspective (Kaufman 1969). Although there is no specific standard for the LCC method, a few guidelines have been put forth in the literature (Reich 2005). To mention a particular guideline, the LCC assessment guideline created by Ciroth et al. (2009) was used in this study for the quantification of LCC as schematically indicated in Fig. 4 (Ciroth et al. 2009). Similar to LCEA, SimaPro 8.4.1 software was used for the LCC of the AGU Sumer campus. For LCC, the functional unit was used as USD per person (Fuller 2010).

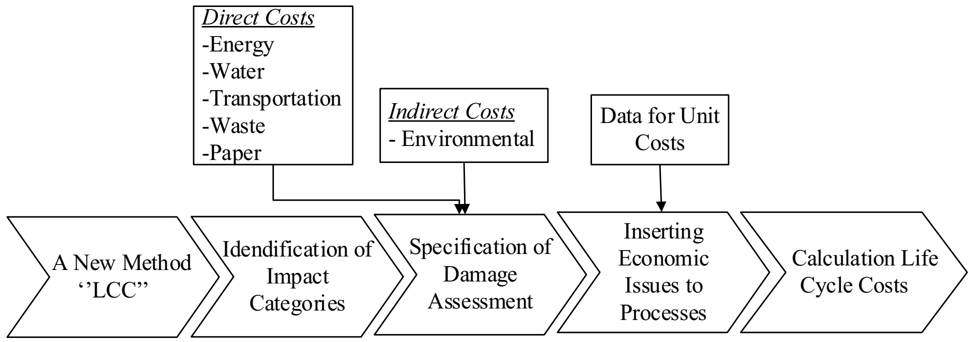

Fig. 4 The framework of the life cycle costing

Life cycle cost inventory

The inventory data for economic assessment of the campus were collected from the university administrative offices, official reports published by the university, and the literature (Table S2). The cost components of the campus were identified based on cradle-to-gate approach. The costs were categorized into two groups as direct and indirect costs within the scope of the study as shown in Fig. 5. The direct costs include energy, transportation, paper, water, and waste costs; meanwhile, indirect costs include only environmental costs which occur as the cost of the environmental impacts. The energy costs cover the costs of electricity and natural gas consumed for the operation of buildings in 2019. Transportation costs cover the travel costs of academic and administrative staff. Paper cost covers the total consumption costs of paper in the campus. Waste costs are the result of expenses from the waste management system of the campus.

Cost impact assessment

In this phase, the guideline published by Ciroth et al. (2009) was followed and used for the LCC (Ciroth et al. 2009). With the utilization of SimaPro software, the LCC method on the software was created as a first step; whereby in this step, characterization, damage assessment, normalization, and weighing properties were also determined. After that, each related unit cost was added for each material and process under the economic issues section of the SimaPro software. Finally, the total LCC of the campus was calculated within system boundaries.

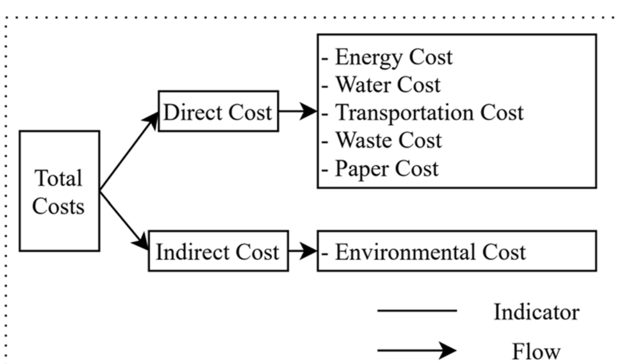

Fig. 5 The classification of the costs

Social life cycle assessment

As for the third pillar of sustainability, S-LCA is an effective tool to assess the social impacts of a product or process within its life cycle for all of its stakeholders (Macombe et al. 2018). The guideline published by UNEP/SETAC was followed for S-LCA in this study (Benoît-Norris et al. 2011; UNEP-SETAC 2009, 2013). For the S-LCA, as the inventory data were collected based on the UNEP/SETAC (2009) methodology in which the indicators are mainly of a descriptive format, the functional unit could not be specified to a particular dimension (Petti et al. 2018; UNEP-SETAC 2009).

Life cycle social inventory

For the S-LCA is concerned, the data were collected through online surveys conducted on the four stakeholder categories which are local community, consumer, worker, and society. The local community refers to people who live in the surrounding of the campus area; the consumer refers to students, academic and administrative personnel in AGU, the worker refers to academic and administrative personnel in AGU and society refers to people who live in Kayseri.

The impact categories implemented for the S-LCA are adapted from UNEP/SETAC (2009) which branches to several subcategories within the parameters of stakeholders within the university campus (Petti et al. 2018). For the social assessment, 12 subcategories and 27 indicators were selected from the UNEP/SETAC guideline as summarized in Table 1 (UNEP-SETAC 2009, 2013).

An online survey was conducted, which consists of ''yes'' or ''no'' type descriptive questions for each stakeholder in social assessment (Table S3–S6). Yes/no responses were quantified by assigning the percentages of yes responses for each question in the survey. For instance, the number of

Table 1 Selected stakeholders, subcategories and indicators for the social life cycle assessment study

Stakeholder	Subcategory	Indicator
Local community	Cultural heritage	Strength of policies in place to protect cultural heritage
		Presence/Strength of organizational program to include cultural heritage expression in product
	Access to material resources	Has the organization developed project-related infrastructure with mutual community access and benefit
	Safe and healthy living conditions	Management effort to minimize the use of hazardous substances
Consumer	Health and safety	Presence of Management measures to assess consumer health and safety
		Quality of labels of health and safety requirements
	Feedback mechanism	Presence of a mechanism for customers to provide feedback
		Practices related to customer satisfaction, including results of surveys measuring customer satisfaction
	Privacy	Strength of the internal management system to protect consumer privacy, in general
	Transparency	Non-compliance with regulations regarding transparency
		Consumer complaints regarding transparency
		Publication of a sustainability report
		Quality and comprehensiveness of the information available in the sustainability report or other documents regarding the social and environmental performance of the v
		Certification/label the organization obtained for the product/site
		Company rating in sustainability indices (Dow Jones Sustainability Index, FTSE4Good, ESI, HSBC, FTSE4Good, ESI, HSBC, etc.)
Worker	Equal opportunities/ discrimination	Presence of formal policies on equal opportunities
	Health and safety	Presence of a formal policy concerning health and safety
		Adequate general occupational safety measures are taken
		Preventive measures and emergency protocols exist regarding accidents and injuries
		Preventive measures and emergency protocols exist regarding pesticide and chemical exposure
		Education, training, counseling, prevention and risk control programs in place to assist workforce members, their families, or community members regarding serious diseases
Society	Public commitment to sustainability issues	Presence of publicly available documents as promises or agreements on sustainability issues
		Implementation/signing of principles or other codes of conduct (Sullivan Principles, Caux Round Table, UN principles, etc.)
	Contribution to economic development	Contribution of the product/service/organization to economic progress (revenue, gain, paid wages, R + D costs in relation to revenue, etc.)
	Technology development	Involvement in technology transfer program or projects
		Partnerships in research and development
		Investments in technology development/ technology transfer

workers answering yes to the question on the presence of formal policies for equal opportunities in the survey. This number represents the fraction of the sampled population of workers satisfied with formal policies on equal opportunities in the university. Then, this fraction can be converted into percentages, and the percentages were classified in accordance with Table 2 as mentioned in Sect. 3.3.2 (Foolmaun and Ramjeeawon 2013). The survey was conducted on identified four stakeholders, and both the students and workers were considered as 'consumer.' The number of responses for the survey is as follows: 276 students, 100 workers (academic and administrative staff), 79 people who live close to the campus, and 118 people who live in Kayseri.

Social impact assessment

In the S-LCA impact assessment stage, the social impacts of the campus on each stakeholder category were quantified with the calculation of subcategory results. The scoring system was used as a methodology to assess the social

Table 2 The scoring system for the evaluation of social performance

Subcategory	Percentage	Marks
Cultural heritage, Access to material resources, Safe and healthy living conditions, Health and safety, Feedback mechanism, Privacy, Transparency, Equal opportunities/discrimination, Public commitment to sustainability issues, Contribution to economic development, Technology development	0–20	0
	21–40	1
	41–60	2
	61–80	3
	81–100	4
Transparency	0–20	4
	21–40	3
	41–60	2
	61–80	1
	81–100	0

performance of the campus for this study. The scoring system is a characterization method to analyze quantitative or semi-quantitative social indicators. In the literature, there are several used scoring methods by (Bork et al. 2015; Foolmaun and Ramjeeawon 2013; Spillemaeckers et al. 2001). In this study, social inventory gathered from online survey was evaluated as semi-quantitative which is yes/no corresponding. After the survey responses for each indicator were quantified (Foolmaun and Ramjeeawon 2013), the scores to subcategories were assigned from 0 to 4 in accordance following classification: 0–20%, 21–40%, 41–60%, 61–80%, and 81–100%, respectively (Foolmaun and Ramjeeawon 2013). Then, each indicator was assigned a score with respect to percentage classification as given in Table 2. The total score for a subcategory was divided by the number of indicators for that sub-category to obtain a final score of that subcategory (Foolmaun and Ramjeeawon 2013). It is assumed that all subcategories and indicators have equal weight.

Results and discussion

This section puts forth the results obtained from the analysis of the LCSA for the AGU Sumer Campus. The integrated assessment of campus seeks to engage all aspects of the sustainability triple bottom line. The integrated methodology proposed enabled the environmental, economic and social assessment of the AGU Sumer Campus. It is important to obtain an overall sustainable performance of the campus to identify the impacts of the university campus for each dimension of the sustainability. The results of E-LCA, LCC, and S-LCA were discussed for the environmental, economic, and social aspects in the following subsections.

Environmental life cycle assessment results

The selected environmental impacts of the campus by considering the gate-to-gate approach were calculated with IPCC 2013 GWP 100a and CED methods, and the results are indicated in Table 3. The GWP of the campus was found as 2.92 tCO_2 eq./person and the CED as 15.4 GJ/person. From these two different methods, the majority of the contribution is from the energy category of the system boundaries (Fig. 6). The environmental impacts due to transportation,

Table 3 The results of the environmental impacts of the university campus per person

Impact categoryunit	Water consumption	Waste	Transportation	Energy	Paper	Total
Non-renewable, fossil MJ/person, (%)	8.49E-01 (0.0006)	1.98E+01 (0.14)	8.86E+02 (6.28)	1.32E+04 (93.386)	2.95E+01 (0.21)	1.41E+04 (100)
Non-renewable, nuclear MJ/person, (%)	1.57E-02 (0.0383)	1.75E+00 (4.283)	4.48E+00 (10.95)	3.06E+01 (74.739)	4.09E+00 (10.01)	4.09E+01 (100)
Non-renewable, biomass MJ/person, (%)	1.34E-07 (0.0001)	2.86E-03 (2.14)	2.86E-03 (21.32)	9.74E-02 (72.658)	5.22E-03 (3.90)	1.34E-01 (100)
Renewable, biomass MJ/person, (%)	4.78E-04 (0.0006)	4.37E-01 (0.56724)	3.73E+01 (48.36)	2.06E+01 (26.66)	1.88E+01 (24.41)	7.71E+01 (100)
Renewable, water MJ/person, (%)	6.01E-03 (0.0005)	3.24E-01 (0.0273)	1.77E+00 (0.15)	1.18E+03 (99.672)	1.63E+00 (0.13)	1.19E+03 (100)
IPCC GWP 100a kg CO_2 eq./person, (%)	7.46E-03 (0.0003)	8.82E-01 (0.0302)	3.06E+01 (1.05)	2.89E+03 (98.82)	2.41E+00 (0.082)	2.92E+03 (100)

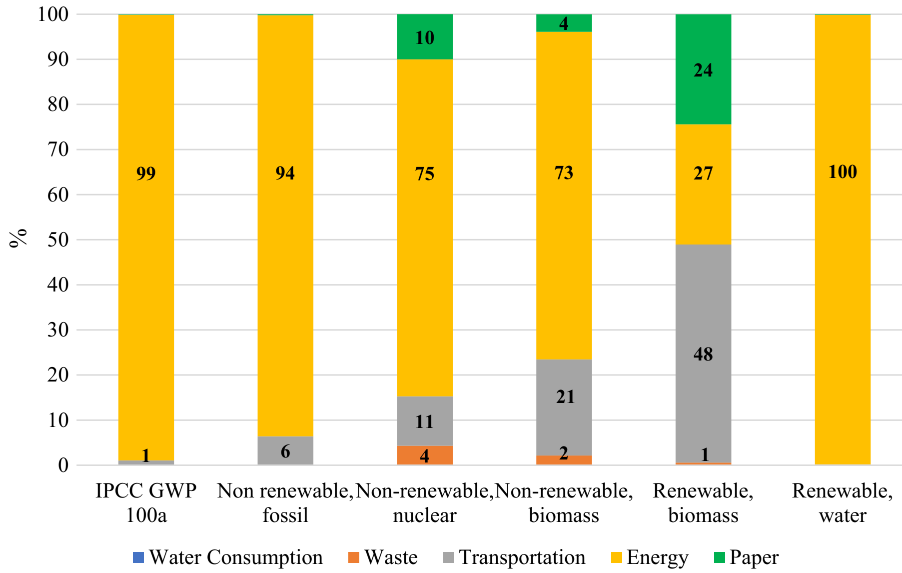

Fig. 6 The environmental impacts of the university campus

water, paper, and waste are relatively low when compared with energy.

The majority of the emissions (98.8%) are accounted for by the energy consumption of the system boundaries in this study. GWP being one of the indicators of this study was developed for simultaneously studying the impacts of global warming of various greenhouse gases in terms of CO_2 equivalent by their radiative efficiency and for how long they are present in the atmosphere (Environmental Protection Agency 2016). Of the two contributors for a high energy-related environmental impact, the natural gas consumed by the campus is involved with a relatively higher emission rate at approximately 76.9% than the electricity consumption at 23.1%. The electricity sector in Turkey generates a majority of its electricity through the consumption of coal (Bakay and Ağbulut 2021). The electricity generation from fossil-based sources such as hard coal, lignite, and natural gas is highly unsustainable when compared to other renewable sources such as hydropower, solar, and wind. The high share of fossil-based sources in the Turkish national electricity mix and increasing demand due to population growth lead to global warming and other environmental problems. Thus, the initiative to support more supply of clean energies is an environmentally friendly option. On the other hand, Turkey is one of the greatest consumers of natural gas mainly used for heating requirements (Erdoğan et al. 2019). To reduce natural gas consumption by 10–50%, sustainable heating alternatives such as biomass and geothermal heat can be implemented. The collected heat energy from the sun could be modified to provide heating capabilities throughout the campus (Slorach and Stamford 2021).

On the other hand, the CED determines the total direct and indirect energy consumption by the campus during its usage stage of the life cycle (Frischknecht et al. 2015). As another environmental indicator, the CED is used to quantify the total energy consumption of the campus in terms of renewable and non-renewable energy sources in this study. Both of these indicators are studied to present the result per person in order to understand the environmental impact subjected by the person within the system boundaries.

The waste management system implemented in the university is appropriate with waste-sorting practices as there are several disposable stations situated all around the campus with specific bins allocated for a specific material disposed of namely paper, metal, organic, glass, and plastic in the sense of having and maintaining a sustainable waste disposal methods (Wiganingrum et al. 2018). In addition, a gray wastewater management system used on the campus, which treats the wastewater, discharged from the campus' restrooms to be used for the automatic water-planting systems around the campus.

The comparison of the results in Table 4 shows the resulted value of AGU Sumer Campus' emission with respect to the relative emission resulting from other universities in similar studies. As a result, it can be observed that the campus has a significantly lower emission value when compared to other universities as it is a recently established university with very few years of operation and yet still growing. With the values resulting here, it is of utmost importance to ensure sustainable measures to reduce the emission levels to conserve any future harmful environmental impacts from occurring globally.

Life cycle costing results

In the usage phase of a life cycle, the expenses are recurring based on the rate of consumption and demand of the materials and services. Table 5 presents the breakdown

Table 4 The comparative results of university emissions

University	Year of study	Number of students	Total emissions (tCO_2 eq.)	Emission (tCO_2 eq.)	References
Abdullah Gul University	2019	1968	6,810	2.92 (/person)	–
Clemson University	2014–2017	21,857	95,418	4.40 (/student)	Clabeaux et al., (2020)
University of Leeds	2010–2011	30,761	161,819	4.60 (/student)	Townsend and Barrett(2015)
University of Madrid	2015	31,722	98,338	3.10 (/student)	Vásquez et al. (2015)
University of Pennsylvania	2016	24,816	325,090	13.1 (/student)	Almufadi and Irfan (2016); Tisch (2017)
University of Leicester	2015–2016	20,150	26,732	1.32 (/student)	(Anand 2017)
University of Cambridge	2018–2019	23,247	483,834	20.8 (/student)	University of Cambridge (2019)

Table 5 The life cycle costs of the university campus for the year 2019

Cost categories	Unit cost (USD/person)	Total cost (USD)
Direct Costs		
Energy		
Electricity	1.40E + 02	3.26E + 05
Natural Gas	3.12E + 01	7.27E + 04
Water	5.30E + 00	1.24E + 04
Transportation		
Vehicles	1.15E + 01	2.68E + 04
Fuel	1.01E + 01	2.34E + 04
Waste	3.90E-01	8.98E + 02
Paper	1.20E + 00	2.81E + 03
Indirect costs		
Environmental	1.90E-01	4.41E + 04
Total cost	**2.00E + 02**	**4.66E + 05**

Table 6 The social life cycle assessment results for each stakeholder and subcategory

Stakeholder	Subcategory	Score
Local Community	Cultural heritage	3
	Access to material resources	0
	Safe and healthy living conditions	1
Consumer	Health and safety	2
	Feedback mechanism	2
	Privacy	0
	Transparency	2
Worker	Equal opportunities/discrimination	1
	Health and safety	1
Society	Public commitment to sustainability issues	1
	Contribution to economic development	2
	Technology development	1

of the results of LCC based on the categories identified in Sect. 3.2. The energy cost from the analysis conducted is the largest contributor (86%) to the total cost demand for the year 2019. This demonstrates that the imported electricity and natural gas from the state energy generation companies are relatively among the highest recurring cost. With the electricity demand of the campus at approximately 2.67 GWh in 2019 and the cost of electricity at the rate of 0.12 USD/kWh, the cost of electricity in Turkey is on par with that of the USA (Ajayi et al. 2017). Since the campus is growing and recently established, the total cost implications of the year 2019 per person have set a comparatively low amount at 200 USD/person. The environmental cost being a part of the indirect cost constitutes the emissions from the energy consumed by the campus and further gives a quantified cost dimension for the environmental impacts. The emission amount obtained from the environmental result as shown in Table 4 is converted at the rate of 0.151USD/kg CO_2 eq. (Klaassen et al. 2020).

In order to minimize the energy consumption as well as the emissions by 5–10%, the imposing of a carbon tax could be a method of minimizing the overall cost. The carbon tax basically places a tax rate on the CO_2 emission by buildings. Since campuses are mainly comprised of a collection of various buildings and similar structures, this tax form would maintain a reduced emission level while maintaining the economic growth for the campus (Huang et al. 2018).

Social life cycle assessment results

The main goal of performing S-LCA was to evaluate the social performance of the campus on identified four stakeholders. The results of S-LCA with the scoring method are indicated in Table 6. The inventory results confirmed that the campus contributes significantly to protect cultural heritage and its transfer to future generations. However, the campus showed weak social performance under access to material resources in the local community. The survey results revealed that people who live around the campus could not benefit from or access the projects sufficiently. In addition, the results also showed that the local community did not aware of safe and healthy living conditions on campus.

The results of the online survey administered to students and workers indicated that the subcategory of 'privacy' received the lowest score among the four subcategories. The main reason for this is the lack of an internal management system to protect consumer privacy. Besides, other subcategories, health, and safety, feedback mechanism, and transparency have similar and average social performance for consumers. The responses of consumers for the survey revealed that management of health and safety for consumers is not sufficient. It is also found that consumer satisfaction of feedback mechanism is lower for students and workers. Moreover, transparency had an average score due to some consumer complaints regarding transparency. The survey results also show that although the campus has green building certification and zero waste certification, most of the students and workers are not informed about them.

In addition, the campus performed weak social performance under subcategories of 'Equal opportunities/discrimination' and 'Health and safety' due to the weakness of formal policies on equal opportunities and preventive measure of health and safety for workers. Thus, the university should ensure well and sufficient health and safety for its workers by considering all risks and threats on the campus. Moreover, the formal policies on equal opportunities/discrimination should be well-prepared and applied to prevent possible inequalities and discrimination among the workers. The results revealed that the society is not well informed in three subcategories, which are 'Public commitment to sustainability issues,' 'Contribution to economic development' and 'Technology development.' Although the university gives priority to sustainability issues in both educational and research areas, the survey results show that the society does not aware of these efforts of the university on sustainability issues. Additionally, the university gives significant weight to technology development and transfer with the projects conducted with the governmental and non-governmental organizations. Although there is not enough space in this study to evaluate comprehensively the main reasons leading to this inadequate performance, there are two cardinal reasons for the poor mark. The first is that the university does not make these issues the central part of its marketing strategy, unlike its counterparts in the world such as Harvard, Oxford, and Stanford universities and in Turkey, such as the Middle East Technical University (METU), Bosphorus, and Erciyes universities. The second is the age of the AGU. The university was set up in 2013, and this situation has prevented the university to develop robust capacity and mechanisms to integrate itself into the city sufficiently—city administration and civil society in Kayseri.

Overall, it is clear from the results that the campus needs high improvements in some subcategories, which are 'Access to material resources,' 'Safe and healthy living conditions,' 'Privacy,' 'Equal opportunities/discrimination,' 'Health and safety,' 'Public commitment to sustainability issues' and 'Technology development' (scored as 0 or 1) and a moderate improvement in other subcategories that include 'Cultural heritage,' 'Health and safety,' 'Feedback Mechanism,' 'Transparency' and 'Contribution to economic development' (scored as 2 or 3). Thus, decision-makers should improve the social performance of the campus by making the S-LCA results of this study the prominent part of the university policies and should set a strong mechanism to test and improve the S-LCA of the universities regularly. This study will help to guide the decision-makers and managers in the universities to achieve more sustainable campuses. As a suggestion, the universities should set their academic and campus standards by aligning them with the international quality management systems, which can help to enhance the organization's overall performance and provide primary sustainable development initiatives (International Organization for Standardization, 2015). Thus, the quality management systems can contribute to the sustainability of university campuses systematically.

Conclusion

The holistic sustainable assessment of a campus is a methodology that is not studied widely and proves to be noteworthy toward idealizing a completely sustainable campus in terms of the triple bottom approach. Several studies deal with the environmental performance of the campuses; however, in the literature, there is a deficiency of studies conducted for the economic and social performances of the campuses with respect to SDGs put forth by the UN. Even in the literature, there is a lacking sustainable assessment of campuses that integrates the environmental, economic, and social aspects under study. The AGU Sumer Campus had resulted in having the GWP amount of 2.92 tCO_2 eq./person and the CED amount of 15.4 Gigajoule (GJ)/person. The GWP and CED helped in the better understanding of the environmental impact dealing with the emissions of greenhouse gases which entrap heat leading to increased temperatures globally and the direct and indirect energy consumed in the usage of the facilities and building operations of the campus. While the study is conducted for the gate-to-gate phase focusing on the usage stage, the electricity and natural gas by 98.8% show significant impact on the environment. The proposition of equipping the campus with its own electricity generation systems and heating application systems is one of the ways to minimize the effects in this matter. Despite the limited scope of the study, future studies could be considered to have a wider range of life cycle impact methods to give a further in-depth analysis of the environmental impacts of campuses. The majority of the cost by approximate 86% is demanded by the energy consumed within the campus. Underlining once again, the implementation of the campus' own energy generation facilities could reduce the cost and improve the economic growth of the campus. For the social aspect, the campus lacks notable recognition in areas such as 'Access to material resources,' 'Safe and healthy living conditions,' 'Privacy,' 'Equal opportunities/discrimination,' 'Health and safety,' 'Public commitment to sustainability issues,' 'Technology development,' 'Cultural heritage,' 'Health and safety,' 'Feedback Mechanism,' 'Transparency' and 'Contribution to economic development.' The study has been conducted within an in-depth sustainable assessment of AGU Sumer Campus to recognize and put forth all its outstanding features for helping to model and establish a sustainable campus as it could be growing to be a campus of total realistic sustainable practices. This knowledge will help educate the decision-makers and designers about the effect of their day-to-day practices and affect improvements in campus operations. Campuses should critically evaluate the SDGs, assessing their influence on the university community and assessing the impacts of accordance or not. In this approach, there is a discussion on university sustainability, which is, on the one hand, the responsible use of resources to ensure the University's longevity and advancement as an institution, and, on the other hand, the influence university engagement has or would have on the sustainability of society.

LCSA provides holistic evaluation by considering environmental, economic, and social aspects; the methodology still faces some challenges about the integration of results. In the literature, there is no ideal method for integration of LCSA results, and the complexity of these methods is the main barrier for decision-makers to apply them to evaluate sustainability. In this study, the scope of the LCSA was limited to a university campus, for instance, urban and architectural features were excluded from the system boundaries due to the non-availability of data and the long time needed to collect inventory data. In the literature, the studies on S-LCA and LCSA are limited; this study paves the way for further studies, while it makes a significant contribution to the novel area of S-LCA and LCSA.

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Declarations

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