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Article

Developing the Ecological Footprint Assessment for a University Campus, the Component-Based Method

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Abstract: Global warming has become an increasing challenge due to the impact of human activities on the environment. In this regard, university campuses with various activities and departments have a great impact on the environment. Ecological Footprint Analysis (EFA) is a natural resource depletion assessment tool, with a high level of accuracy, that measures the impact of human activities on the environment. Considering the Ecological Footprint (EF) capabilities, this study developed a method to assess the environmental impacts of a university campus using component-based parameters. The goals of the study are to explore the effective components of EF and to propose some policy guidelines to diminish the human impacts on the environment on university campuses. Five components, including natural gas and electricity consumption, water and food usage, and waste production, were measured in a survey from 2013 to 2016 at the building scale. The mean EF of the campus was 16,484 global hectares (gha). Fossil fuel energy had the highest level of environmental impact with 70.73%, followed by waste production and food and water usage with 26.87%, 1.28%, and 1.12%, respectively. The results demonstrate that the EF Index (EFI) of the case study campus was -0.82 , which reveals an unsustainable performance. The EF results were illustrated on an Ecological Footprint Map (EFM), which shows the east and west parts of the camps were more unsustainable.

Keywords: sustainable development; Ecological Footprint Analysis (EFA); Biological Capacity (BC); environmental impacts; green university campuses; low carbon university campus



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1. Introduction

1.1. The Serious Impacts of Humans on the Environment

Current assessments indicate that approximately 83 million people are being added to the world's population every year [1]. Therefore, food consumption is increased fivefold and the related trade enlarged almost twenty times. Balancing the food supply with this growing market has resulted in the conversion of wetlands into farmlands, indiscriminate felling of forests, overexploitation of fishery resources, and degradation of natural life-dependent areas throughout the planet [2]. The human pressure on the environment in terms of natural resources depletion, greenhouse gas emissions, and waste production has been rising steadily [3]. Now the human ecological footprint is 60% higher than the world's ecosystems renewal capability. In 2020, the ecological footprint temporarily decreased due to the widespread effect of COVID-19 pandemic global lockdowns; however, it is still far beyond what our planet can replenish [4]. The human pressures on the environment have led to a serious problem for the planet, with one piece of evidence being global warming, a crucial environmental challenge [5]. The planet's mean surface temperature has risen about 1.18 degrees Celsius since the late 19th century, a change driven largely by carbon

dioxide and other greenhouse gas emissions into the atmosphere. In this regard, the highest warming temperatures have been recorded frequently in the past 40 years, with six critical warmest years since 2014 [6].

1.2. The Importance of Conducting the Ecological Footprint Assessment (EFA) at a University Campus

Based on various declarations such as the Talloires Declaration [7], Halifax Declaration [8], and Copernicus University Charter [9], one of the main environmental goals is the integration of education with environmental concepts, especially in higher educational institutions (HEIs). In recent years, Ecological Footprint (EF) as a decision-making [10] as well as an educational tool for sustainability [11] has been used to assess the environmental impact of higher educational organizations. Countries like the USA, China, and the United Kingdom have paid serious attention to integrating education with the environment and some research was conducted on the application of EF at university campuses [12–14]. Universities with thousands of students and staff and a variety of building types such as colleges, gyms, restaurants, outdoor sports centers, libraries, shops, conference halls, etc., have a fundamental impact on the environment. Understanding the ecological performance of a university campus is critical to address global warming.

1.3. The Novelty of the Proposed Method

This paper has developed the EF methodology. The first contribution of this research is the assessment of the UOK's EF (Ecological Footprint) that was conducted over four academic years (2013–2016), while most of the similar research was applied in one year. The second contribution is the assessment of the EF at both the campus and building levels, whereas other reviewed research was conducted only at the campus level. The assessment of the EF at the building scale leads to the comparison between the performance of the buildings and ranking them for further sustainability policy. The other contribution of the study refers to the visualizing of the results of the Ecological Footprint Analysis (EFA) and presenting them via Ecological Footprint Maps (EFMs).

2. Literature Review

2.1. Ecological Footprint Tool

A lot of tools and methods have been presented to assess ecological sustainability [15]. The footprint term is widely used to describe the sustainability level that is applied in various knowledge fields such as Carbon Footprint (CF) [16], Water Footprint (WF) [17], Material Footprint (MF) [18], and Urban Energy Density Footprint (UED_f) [19]. One of the most scientific methods for the assessment of environmental performance is the Ecological Footprint (EF) [20], which is broadly applied to measure the sustainability grade [21] of communities. EF is also an accounting tool for quantifying Herman Daly's (Nobel Prize winner for sustainable development) principles of sustainability, and it could provide the ability of natural resource consumption monitoring and present advice for the reduction of human pressure on the ecosystem [22].

Mathis Wackernagel and William Rees from the University of British Columbia defined the Ecological Footprint (EF) concept for the first time in the early 1990s [23]. EF has been applied frequently as an index to control the quality of the environment in educational institutions [24] and as a policy guide as well as a planning measure to achieve sustainability [25]. It is also a proper tool to address the UNICEF's motto of "education for sustainability" [26].

Since EF is calculated based on the appropriation of land and all the impacting components, expressed in global hectares (gha), it is also called the land footprint [27]. EF compares the amount of natural resource consumption with the available Biological Capacity (BC) to indicate how human beings are using natural resources. BC is determined by inverting the concept of EF [28,29] and can be interpreted as the maximum allowed resource consumption rate and waste discharge that can be sustained indefinitely in a

given region without gradually impairing the functional integrity and productivity of the relevant ecosystem [30].

EF is an accurate tool to measure the impact of all components resulted from human behaviors on a university campus. EF is calculated using two approaches, including the compound- and component-based models. In the compound approach (known as Wackernagel's approach) the human impact on each land type (fossil-energy land, arable land, pasture, forest, built-up land, and sea space) is considered for a given population [31]. In a component-based calculation, one starts with identifying all the individual items, i.e., goods and services, and accurate measuring of natural resources consumption as well as the produced waste by a given population in a given region. In the component-based model, the ecological footprint values are calculated using appropriate data belonging to the investigated region [32]. In this approach, one does not build up the total EF through an item-by-item methodology but starts from the overall consumption balance [33].

2.2. The Background of the Ecological Footprint Assessment for University Campuses

In recent years, Higher Education Institutions (HEIs) have been encouraged worldwide to boost their role to be an active part of the sustainable society, therefore, several research studies have been conducted to assess the sustainability level of HEIs [34–37]. As key actors in society, HEIs may educate thousands of students and staff for challenges connected to sustainable development. The fundamental purposes of EF accounting in HEIs can be summarized in 3 steps: (1) to have a clear intuition about the HEI's ecological impact, (2) to serve as a base for further policy planning, (3) to raise ecological awareness through education in the society [38].

EFA has been applied for several university campuses around the world and the specifications of this research are reviewed and summarized in Table 1. It shows both the total and the per capita footprint, the research period, the percentage impact of each component, the component with the highest environmental impact (%), and the Ecological Footprint Index (EFI) of each university. However, few studies have calculated the EFI. More information on the EFI is presented in Section 4.4.

One of the major defects in the reviewed research is related to the short period of the assessment time (an academic year) of the calculated EF. To assess the EF of university campuses accurately, selecting a longer period is fundamental. The impact of humans on the environment may alter over the years because of temporary activities at campuses such as the number of national or international conferences or building constructions. For example, if the EF measurement is conducted in a year in which a university organized several international conferences (impact of guests) or during the same year engaged with new building construction, definitely the EF in that year is radically higher than normal. Therefore, analyzing the EF during one academic year is not reliable.

Furthermore, the assessment of the EF at a campus scale, as conducted in the reviewed literature, does not provide detailed information. Understanding which part of a university such as colleges, cafeterias, libraries, sports centers, etc. behaves unsustainably is essential to outline sustainable policy plans. Among 14 reviewed university campuses in terms of EF assessment, none of them has conducted EFA at the building scale. In the majority of the university campuses (at six campuses, including this study), fossil fuel energy has the highest environmental impact, followed by mobility (at four campuses), waste (at two campuses), and food (at two campuses). Only on a campus, the built-up land had the highest environmental impact (Table 1). The per capita EF varies between 0.16 gha (Tianjin University, China) and 8.66 gha (Ohio State University, the USA). The EFI was only calculated for Tianjin University (0.61). The EFI was only calculated for Tianjin University (0.61). We also calculated the EFI for the UOK campus.

Table 1. Summarizing the EFA results of different universities.

University (Country)	Newcastle (Australia)	Redlands (USA)	Holme Lacy (UK)	Kwantlen (Canada)	Ohio State (USA)	SRM (India)	Northeastern (China)	Toronto at Missis-sauga (Canada)	Otago (New Zealand)	East Anglia (UK)	Illinois (USA)	Algarve (Portugal)	Leuven (Belgium)	Tianjin (China)	UOK (Iran)
Reference	Flint [39]	Venetoulis [40]	Dawe et al. [41]	Burgess and Lai [42]	Janis [43]	Thattai [44]	Li et al. [45]	Conway et al. [46]	Bell et al. [47]	Wright et al. [13]	Klein-Banai and Theis [14]	Nunes et al. [48]	Lambrechts and Van Liedekerke [38]	Liu et al. [12]	This study (2021)
Year	1998–1999	1998–1999	2001–2002	2005–2006	2006–2007	2006–2007	2003–2004	2005–2006	2008–2009	2007–2008	2008–2009	2013–2014	2010–2011	2014–2015	2013–2016
Study Period	One academic year	One academic year	One academic year	One academic year	One academic year	One academic year	One academic year	One academic year	One academic year	One academic year	One academic year	One academic year	One academic year	One academic year	Four academic years
Population	19,200	2727	524	10,376	77,120	10,000	23,345	8100	—	18,000	36,640	4950	7611	30,000	9982
Area (ha)	135	57	240	62	710.5	30	110	90	—	129.5	97	20	2.22	200	101
Total EF (gha)	3592	2300	296	3039	650,665	30,606	24,787	8744	217	13,160.59	97,601	5049–9999	2663.70	4659	16,484
Total EF/Area	27	40	1.23	49	916	1020	225	97	—	102	1006	252–500	1200	23.30	163.21
EF per capita	0.19	0.84	0.56	0.29	8.66	3.06	1.06	1.08	—	0.73	2.66	1.02–2.02	0.35	0.16	1.69
Energy (%)	—	50.26	55.20	28.91	21.81	1.72	68.28	69.40	22	28.96	72.66	51–89.6	17.83	7.8	70.73
Food (%)	5.97	—	72.80	9.64	—	98.02	21.91	9.14	7.13	—	2.60	3.3–5.9	4.77	48.28	1.28
Mobility (%)	42.66	32.57	69.20	52.96	74.14	0.25	0.08	16.07	38	10.28	12.60	41–41.9	44.22	—	—
Built-up land (%)	43.73	—	20.40	1.10	—	—	—	1.14	6.38	1.01	—	0.07–0.14	—	—	—
Waste (%)	—	12.50	74.90	—	4.06	—	5.77	4.03	26.38	59.50	11.83	0.14–0.25	0.05	16.56	26.87
Water (%)	—	4.67	3.60	0.16	—	4.2	1.98	0.23	0.11	0.25	0.14	2.1–3.7	0.01	27.37	1.12
Goods & Services (%)	3.97	—	—	7.24	—	—	1.99	—	—	—	—	0.29–0.49	23.69	—	—
Infrastructure (%)	3.67	—	—	—	—	—	—	—	—	—	—	—	9.43	—	—
Component with the highest impact (% of EF)	Built-up land (43.73)	Energy (50.26)	Waste (74.90)	Mobility (52.96)	Mobility (74.14)	Food (98.02)	Energy (68.28)	Energy (69.40)	Mobility (38)	Waste (59.50)	Energy (72.66)	Energy (51–89.6)	Mobility (44.22)	Food (48.28)	Energy (70.73)
EFI	—	—	—	—	—	—	—	—	—	—	—	—	—	0.61	–0.82

3. Case Study

The case study, the University of Kurdistan (UOK), is located in the south of Sanandaj city, Kurdistan province, Iran. The UOK is located at a latitude of $35^{\circ}16'$ North and a longitude of $46^{\circ}59'$ East. It is one of the largest universities in the West of the country. The UOK campus has a total area of 101 ha (hectare) and includes seven faculties, three dormitory building blocks, two restaurants and cafeterias, several office buildings, a central building of classes (Gollan Building), several amphitheaters, several labs, outdoor/indoor sports centers, and two central libraries. The mean population (students and staff) during the four years of research was about 9982 people. In Figure 1 two faculties at the UOK are shown (left: the Faculty of The Literature and Languages; right: the Faculty of Engineering) as an example.

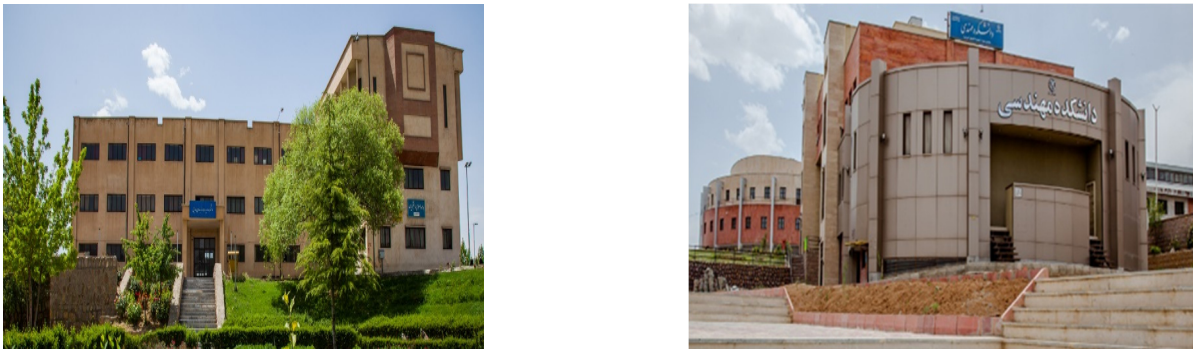


Figure 1. The Faculty of Engineering (**Right**) and the Faculty of Literature and Languages (**Left**), UOK campus.

4. Research Method

Since the type of EF approach is primarily selected based on the size of a case study and the available data resolution [11], the detailed data of the resource consumption and waste production is a key factor. The component approach is more flexible when the goal of the EF assessment is to measure the impact of activities in a smaller area (at campus scale) [46]. Accordingly, in this research, the component-based model was applied to assess the EF of the UOK campus. In the methodology, five components, including natural gas (m^3) and electricity consumption (kWh), water (m^3) and food usage (Ton), and waste production (Ton), have been analyzed in the period of four years, 2013–2016. The applied methodology is outlined in Figure 2.

4.1. Data Collection and Cleaning

The necessary data were attained directly from the Central Office and the Central Services Office of the University of Kurdistan at the building scale. Some parts of the data were attained via survey and interview with the relevant managers. The collected data were categorized into four classes, including fossil energy (natural gas and electricity consumption), water and food usage, and waste production for four academic years (2013–2016). If mobility is excluded from EFA, the EF value of different universities converges toward more similar values [48]. This strategy makes the comparison between campuses more accurate, so the contribution of mobility is not calculated in this research. Mobility is better to be considered separately to assess the EF in higher educational institutions [49].

4.1.1. Energy Consumption

The data of fossil energy, including electricity and natural gas consumption, was attained from the Central Services Office of the university. To raise the accuracy of the calculation, we have also extracted detailed data from the monthly bills of the local meters at the building level.

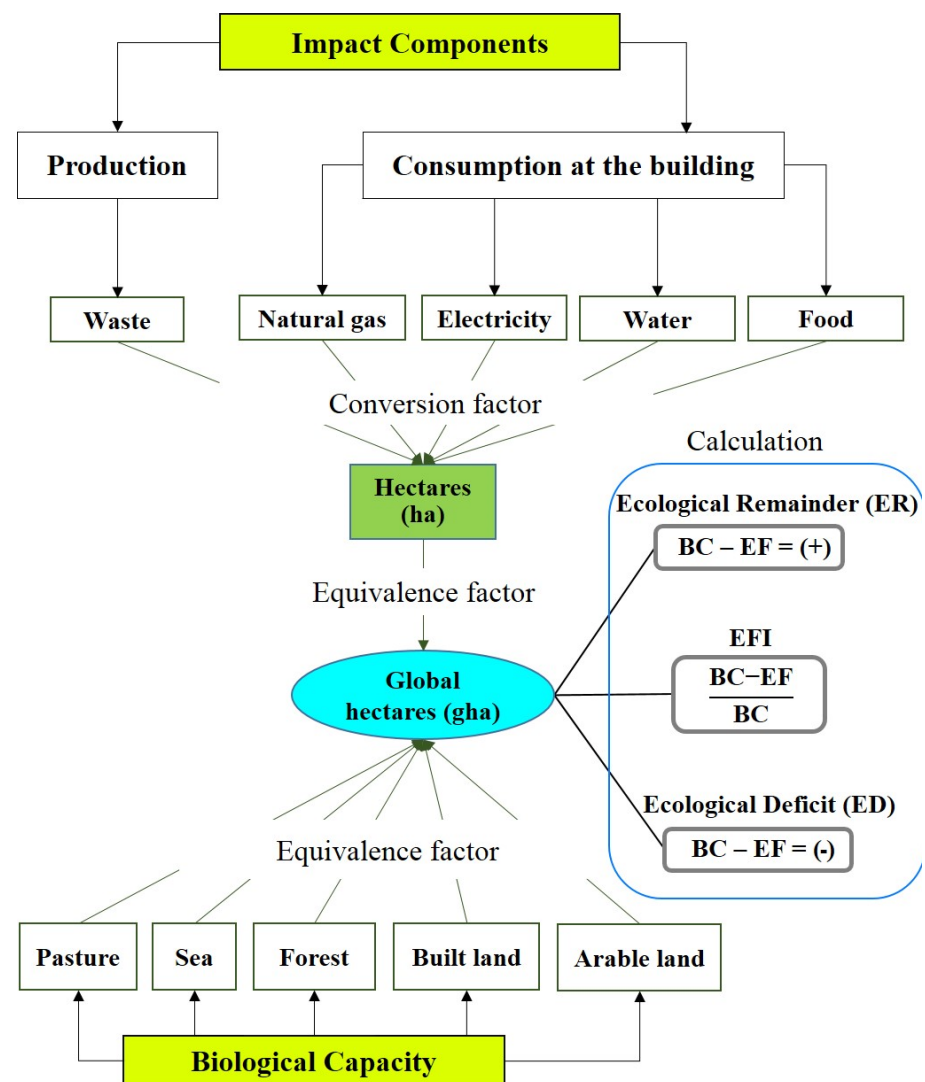


Figure 2. Flowchart of the developed model for the UOK.

4.1.2. Water Usage

The data of the water usage was also obtained from the Central Services Office of the university and its granularity is the same as the energy data.

4.1.3. Food Usage

The amount of food usage at the UOK campus was provided by the central services. We have also used 560 invoices in a year collected from the university restaurants. A survey and interview were also conducted to calculate the amount of food usage. Food variables were divided into the following categories: rice, meat, fish, dairy, vegetables, and oil.

4.1.4. Waste Production

The waste production data were obtained via interviews with university waste disposal officials. Since waste is collected daily at the university, we have estimated the amount of the waste during a day according to the allowed load on trucks. Then, the annual waste weight in tons was estimated. The recorded reports of the Central Services Office were applied in the estimations. Apparently, on some days there was no waste, particularly during the holidays.

4.1.5. Biological Capacity

As explained, Biological Capacity (BC) has a fundamental role in ecological sustainability. To calculate the BC for the UOK campus, first, the necessary data such as the area of forests, agricultural lands, etc. were obtained from the Forest, Range and Watershed Management Organization (FRWMO) of Kurdistan province [50], and then this information was double-checked using the data obtained from the Agriculture Jihad Organization (AJO) [51]. Based on the validated data, the BC for the province was calculated (1,397,698 gha) and then the BC per capita was determined, which was 0.93. The province BC extrapolated for the UOK campus was based on its mean population. The BC per capita for Kurdistan province was calculated and the results are presented in Table 2.

Table 2. Kurdistan province's per capita BC in 2016.

Land Type	Area (ha)	Equivalent Factor	Annual Production (Ton)	Yield Factor	Biocapacity (BC)
Arable	807,745.33	2.8	1,778,494	0.45	1,027,198.97
Pasture	1,414,000	0.5	541	0.0004	270.50
Forest	374,084	1.1	97	0.0003	106.70
Sea	122,247	0.2	8290	14.75	360,538.70
Built-up land	7605.34	2.8		0.45	9582.73
Total BC of Kurdistan province (gha)					1,397,698
Population of Kurdistan Province					1,493,645
BC per capita (gha)					0.93

4.2. Ecological Footprint Calculation for UOK Campus

Total EF (gha) was determined via a weighted sum of the total natural resources consumption components and waste production divided by p_i (ha/ton/year), where c_i (amount/year) is the amount of the consumed resources or waste production in a year, ef_i (global ha/ha) is a constant coefficient, and p_i (ha/ton/year) is the land productivity (Equation (1)) [48]. In Table 3 the constant coefficients used in the calculation of ecological footprint are compiled from [48,52].

$$\text{Total EF (gha)} = \sum_i \frac{c_i \cdot ef_i}{p_i} \quad (1)$$

Table 3. Constant coefficients used in the calculation of ecological footprint.

Consumption Component	Land Productivity (p_i)	Equivalent Factor (ef_i)
Electricity consumption	0.56	1.37
Natural gas consumption	2.11×10^{-3}	1.37
Water usage	0.2	1.37
Waste production	1.65×10^{-6}	0.48
Rice usage	2.264	0.5
Meat usage	0.19	0.5
Fish usage	0.033	0.2
Dairy usage	0.276	0.5
Vegetables usage	22.5	0.5
Oil usage	1.485	0.5

A region's BC (gha) for any land use type is calculated as follows (Equation (2)) [53].

$$\text{BC (gha)} = A \cdot \text{YF} \cdot \text{EqF} \quad (2)$$

where A is the available area for a given land use type (ha), YF is the yield factor that is different for anywhere (Equation (3)) [53], and EqF is the equivalent factor.

$$\text{Yield Factor (YF)} = \frac{\text{Annual production (Ton)}}{\text{Area (ha)}} \quad (3)$$

As most human settlements are located in the most fertile areas of the world [54], arable land and built area are equal in the amount of EqF. The equivalent factors for various land types are presented in Table 4 [55].

Table 4. Equivalent factors for various land types.

Equivalent Factor	Land Type
2.8	Arable land
0.5	Pasture
1.1	Forest
0.2	Sea
2.8	Built area

4.3. Ecological Deficit and Ecological Reminder

The Ecological Deficit (ED) indicates that the ecological resilience capacity is insufficient, whereas the Ecological Remainder (ER) indicates that the ecological capacity is surplus, i.e., more than the resource consumption and the amount of waste neutralization. This concept is illustrated in Figure 3.

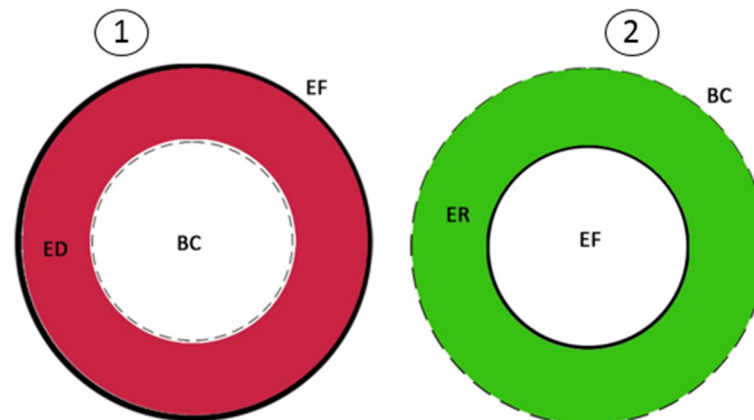


Figure 3. Ecological deficit (1) and ecological remainder (2).

ED: when EF is larger than BC (Figure 3, on the left).

ER: when EF is smaller than BC (Figure 3, on the right).

BC and EF are used to determine whether a region is located in an ecological remainder or ecological deficit situation. They are calculated as follows (Equation (4)) [12]:

$$R - D = BC - EF \begin{cases} ER > 0, & \text{Sustainable environment} \\ ED < 0, & \text{Unsustainable environment} \end{cases} \quad (4)$$

ER and ED show the given regions with footprints larger and smaller than their capacity (BC), respectively. To show how much they are smaller than the threshold, in other words, to depict how much they are sustainable, the authors of this research have used another concept, i.e., Ecological Footprint Index (EFI), which determines the level of sustainability. EFI presents more information compared with ER or ED.

4.4. The Ecological Footprint Index Concept

The Ecological Footprint Index (EFI) is the percentage difference between the ecological resilience capacity and the ecological footprint and shows the level of sustainability

of a given region. Equation (5) [12] is applied to calculate the EFI. The interpretation of EFI and its relationship with the sustainability level are shown in Table 5 [12]. In terms of sustainability, there are four levels of a society's performance. Each level is interpreted using a numerical code from 1 to 4. The UOK's EFI assessment is presented in Section 5.4.

$$EFI = \frac{BC - EF}{BC} \quad (5)$$

Table 5. Ecological footprint index.

Level	EFI	Sustainability Level
1	$0.5 < EFI > 1$	Strong sustainability
2	$0 < EFI \leq 0.5$	Weak sustainability
3	$-1 < EFI \leq 0$	Unsustainable
4	$EFI \leq -1$	Strong unsustainability
Level	EFI	Sustainability level

5. Results

5.1. The Assessment of Ecological Footprint at UOK Campus

The EF per capita of the UOK campus over four years (2013–2016) has been determined and is presented in Table 6. Since the annual amount of waste production and food usage roughly is the same at the university, we have generalized the calculation of one year to the others for these components.

Figure 4 shows that the performance of the UOK campus in terms of EF per capita from 2013 to 2016 is not sustainable. In the first academic year (2013), the EF per capita was 1.05 gha, while the mean EF per capita was 1.69 gha. The highest EF per capita was observed in 2015 (2.11 gha), whereas the EF per capita in 2014 was 1.84 gha. In 2016, it was 1.74 gha. The percentage annual EF difference with the mean EF is presented in Figure 4. The results show that it is not logical to rely on data for one year for EF assessment as well as interpretation of the sustainability of a society. The EF of 2013 was much lower than that for the other years. The main reason relates to several construction projects such as the Central Services Office, Faculty of Art and Architecture, and renovation of Faculty of Humanities and Social Sciences, which were started in 2014 and continued until 2016.

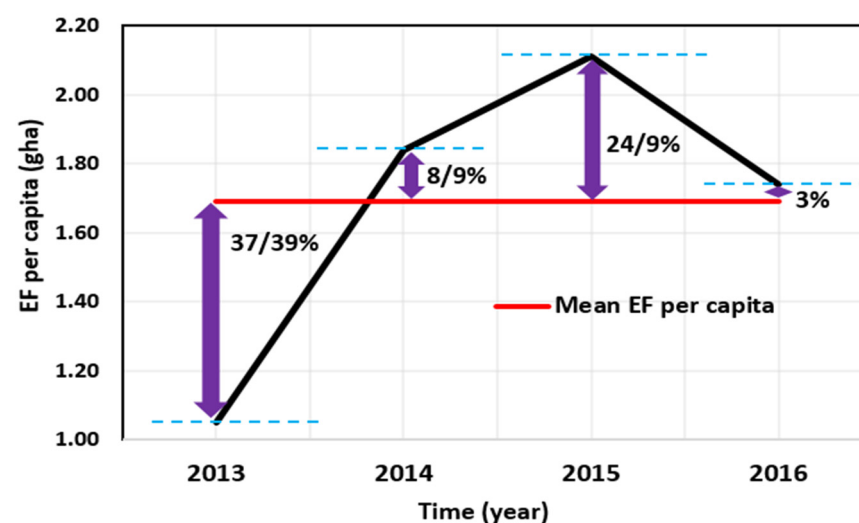


Figure 4. Ecological footprint per capita of the UOK campus.

Table 6. Ecological footprint (per capita) of UOK campus.

Component EF		Electricity Consumption	Natural Gas Consumption	Water Usage	Food Usage	Waste Production	Total
Year: 2013	EF (gha)	3430	4158	180	204	4297	12,270
Population: 11,633	EF per capita	0.29	0.36	0.02	0.02	0.37	1.05
Year: 2014	EF (gha)	3775	8805	182	204	4297	17,264
Population: 9378	EF per capita	0.40	0.94	0.02	0.02	0.46	1.84
Year: 2015	EF (gha)	4910	10,116	199	204	4297	19,726
Population: 9331	EF per capita	0.53	1.08	0.02	0.02	0.46	2.11
Year: 2016	EF (gha)	5043	6969	162	204	4297	16,676
Population: 9585	EF per capita	0.53	0.73	0.02	0.02	0.45	1.74
Mean Population: 9982	EF (gha)	4290	7512	181	204	4297	16,484
	EF per capita	0.44	0.78	0.02	0.02	0.43	1.69

Figure 5 presents a detailed breakdown of the mean EF of the UOK campus throughout the study. About 70.73% of the total ecological footprint belonged to fossil fuel energy consumption, followed by waste production (26.87%), food usage (1.28%), and water usage (1.12%) respectively.

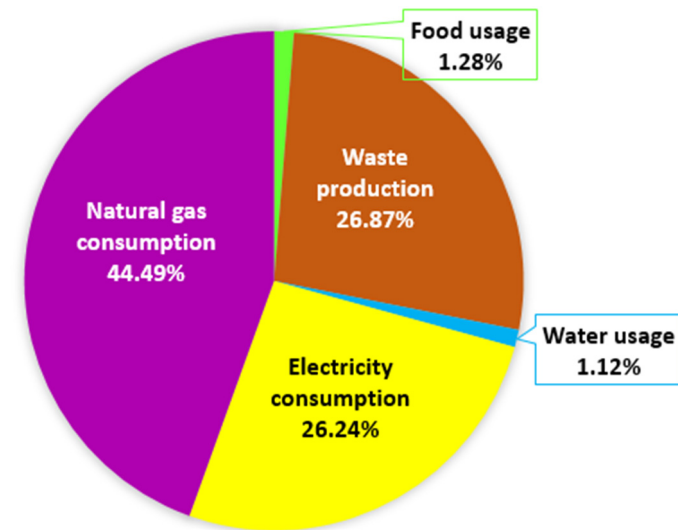


Figure 5. Percentage of the mean ecological footprint of each component.

The result of electricity and water EF at the building scale over four years, 2013–2016, is presented in Figure 6. It can be observed where and when the electricity and water at the UOK campus had the most and least amount of EF per capita. This analysis does not include the natural gas consumption because the breakdown data of gas consumption at the building scale was not available.

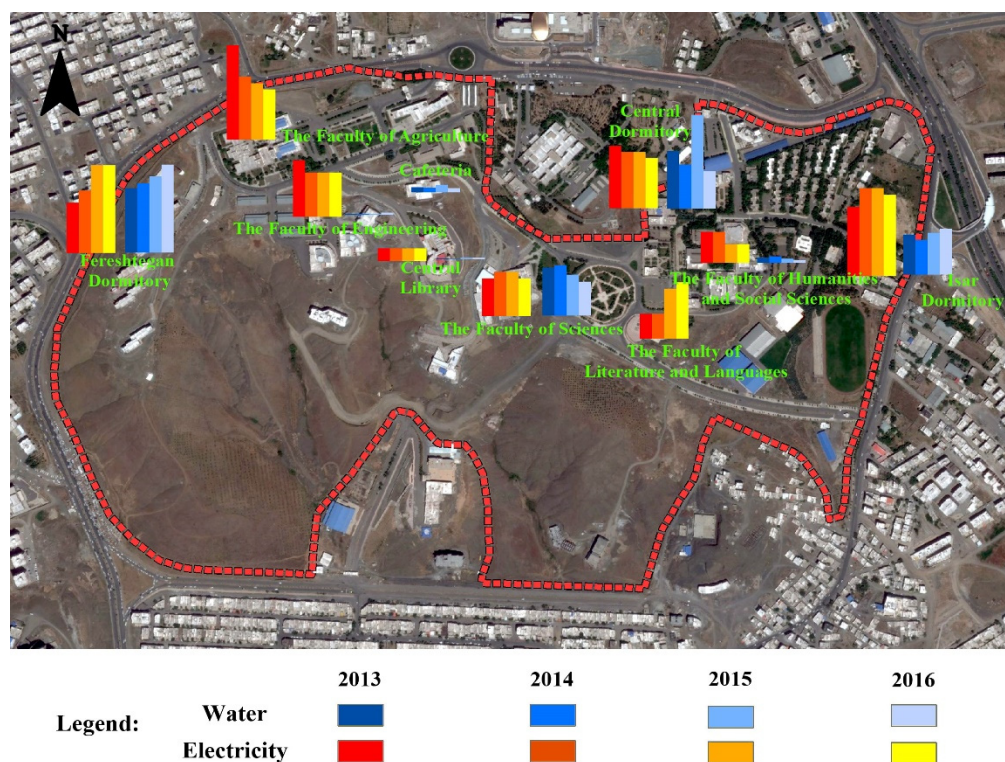


Figure 6. Annual (2013–2016) ecological footprint breakdown of water and electricity.

The Ecological Footprint Assessment for Food Usage

The food component consisted of meat, fish, rice, vegetable, dairy, and oil usage. The mean (2013–2016) EF of food usage at the UOK was 204 gha (Table 6). Figure 7 shows the six categories of food usage. The highest EF belonged to meat usage (94.13 gha), whereas the lowest EF belonged to oil usage (2.1 gha).

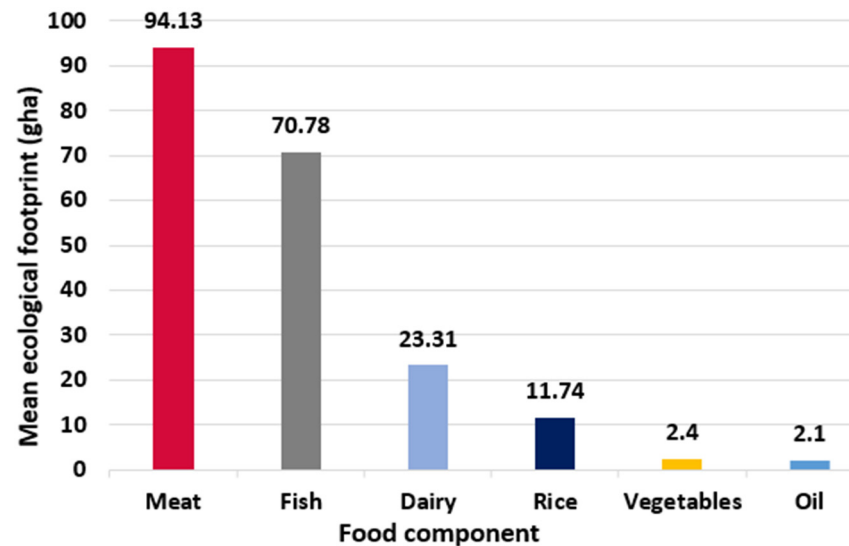


Figure 7. Mean (2013–2016) ecological footprint of food usage at UOK.

5.2. Mapping the Ecological Footprint Assessment at the UOK Campus

In addition to the campus-scale EF calculation, this index was assessed for each building as well. Figure 8 shows the Ecological Footprint Map (EFM) of the UOK campus, in which the west and east parts of the campus have the highest level of environmental impacts. Therefore, the first step to decrease the EF at the UOK should be commenced with the buildings that are located in the west and east parts of the university campus (i.e., the Isar Dormitory, the Fereshtegan Dormitory, the Central Dormitory and the Faculty of Agriculture and the Faculty of Natural Resources).

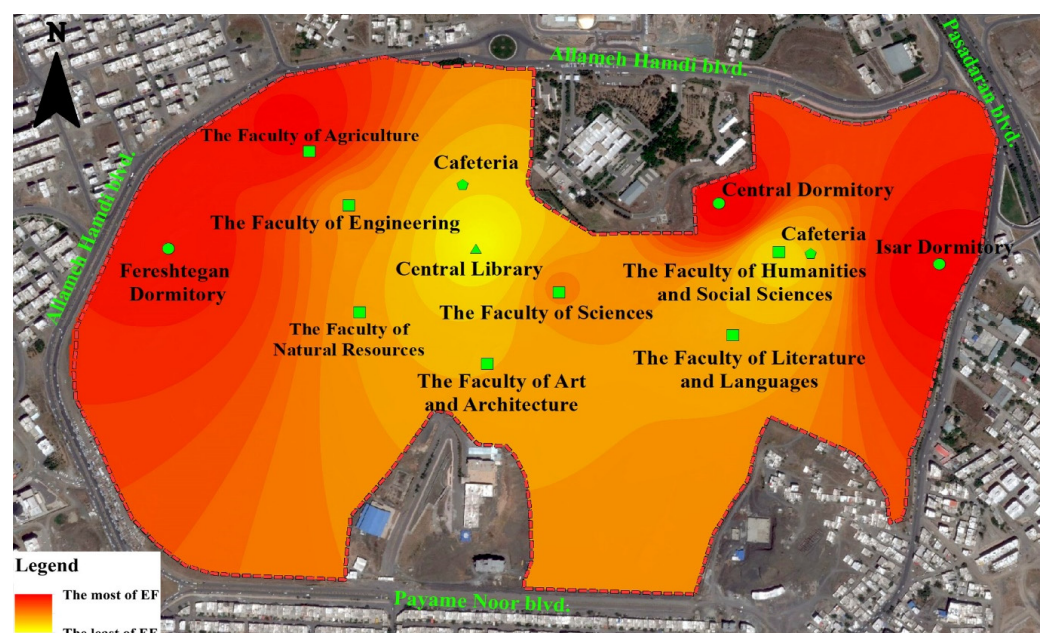


Figure 8. Ecological footprint map of the UOK campus.

5.3. The Ecological Deficit and the Ecological Remainder at the UOK Campus

The BC per capita (gha) and EF per capita (gha) have been determined for the UOK campus over the study period (2013–2016) and the results are presented in Table 7. The mean BC per capita in the UOK was 0.93 gha, while the mean EF per capita was 1.69 gha. This indicates that the performance of the UOK in terms of a comparison of BC with EF is not desirable because the amount of BC per capita is smaller than the EF per capita. In other words, the amount of R-D was negative (ED). This means that the environmental resources cannot provide a balance between resources consumption or waste production and ecological replenishment at the UOK campus.

Table 7. Ecological deficit (ED) and ecological remainder (ER) at the UOK campus in 2013–2016.

Year	Standard BC per Capita (gha)	EF per Capita (gha)	R-D	ED or ER
2013	0.93	1.05	−0.12	ED
2014	0.93	1.84	−0.91	ED
2015	0.93	2.11	−1.18	ED
2016	0.93	1.74	−0.81	ED
Mean	0.93	1.69	−0.76	ED

5.4. Ecological Footprint Index (EFI), the Sustainability Indicator of the UOK Campus

The sustainability level of the UOK campus was calculated using an Ecological Footprint Index (EFI) and the results are presented in Table 8. The negative EFI shows the dire situation of the campus. Comparing the EFI results of the UOK campus with the sustainability level presented in Table 5 indicates that a sustainable level at the UOK was not obtained at all, in contrast, a strong unsustainability level in 2015 (−1.27) was observed. The best performance was −0.13 in 2013. These results have been attained without considering other components like transportation, paper usage, etc. If these components were considered the results would be worse.

Table 8. Sustainability level of the UOK campus.

Year	BC per Capita (gha)	EF per Capita (gha)	EFI	Sustainability Level
2013	0.93	1.05	−0.13	Unsustainable
2014	0.93	1.84	−0.98	Unsustainable
2015	0.93	2.11	−1.27	Strong unsustainability
2016	0.93	1.74	−0.87	Unsustainable
Mean	0.93	1.69	−0.82	Unsustainable

6. Discussion

The EF, as well as the sustainability level (EFI) of the UOK campus, have been determined over four years. The mean EF based on five components, including natural gas and electricity consumption, water and food usage, and waste production were 7512, 4290, 181, 204, and 4297 gha, respectively. Natural gas consumption with 44.49% had the highest portion and water usage with 1.12% had the lowest portion of the total EF at the UOK throughout 2013–2016. According to the results, fossil fuel energy consumption (electricity and gas) had the highest level of environmental impact, followed by waste, food, and water (Figure 5). This research revealed that energy consumption had a major ecological footprint at the UOK campus.

The EF of the UOK campus over four academic years was analyzed and the results such as mean EF per capita (1.69 gha per capita) during this period were compared with other studies. At the UOK, the total EF (16,484 gha) is high in comparison with the EF of most other universities. In some cases, it was five times higher (Figure 9).

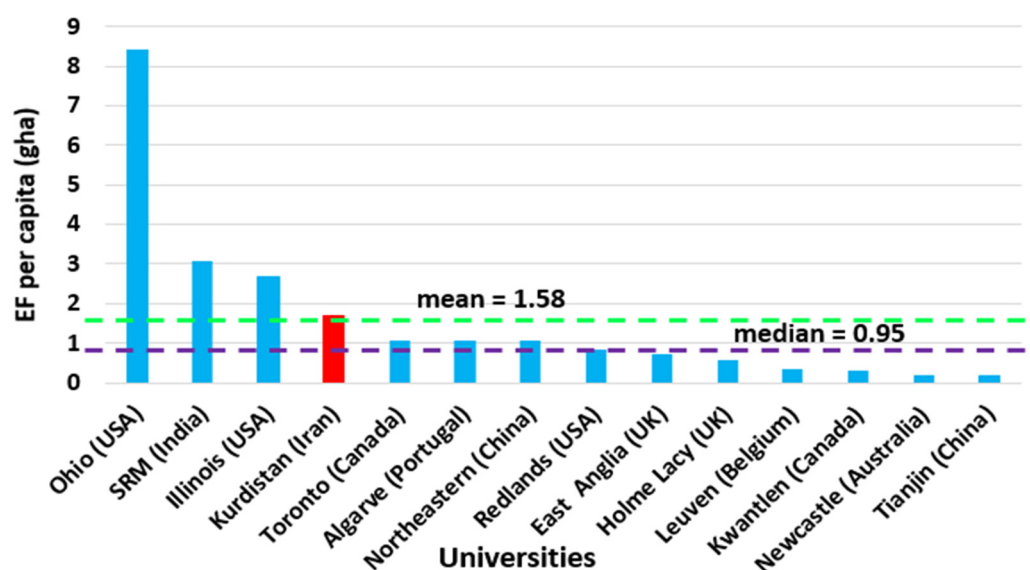


Figure 9. Comparing the ecological footprint (per capita) of the UOK with other universities.

The EF of fossil fuel energy at the UOK is significantly high (70.73%), whereas at some universities like Tianjin (7.8% of total EF), Leuven (17.83% of total EF), and Kwantlen (28.91% of total EF) it is lower than 30% (Table 1). This indicates that the UOK officials must apply effective plans to decline fossil energy consumption. At Redlands University, Northeastern University, the University of Toronto, Illinois University, the University of Algarve, and the Kurdistan University the energy consumption is the most important component in terms of the total percentage of EF. In other words, at six universities (40% all studied universities) the energy has the largest impact on the environment. Among these universities, the highest and the lowest per capita EF belonged to Ohio State University with 8.66 gha per capita and Tianjin with 0.16 gha per capita respectively. The UOK's per capita EF was 1.69 gha so that it was larger than the mean EF (1.58 gha per capita) of the fifteen studied universities. In addition, the UOK is the fourth highest university in terms of per capita EF after Ohio State (8.66 gha per capita), Sri Ramaswamy Memorial (SRM) (3.06gha per capita), and Illinois (2.66 gha per capita).

The proportion of the total water EF at the UOK (1.12% of total EF) is low, which is comparable with the performance of the University of East Anglia (0.25% of total EF) and the University of Leuven (0.01 of total EF). However, water EF should be considered as a vital component because freshwater scarcity is one of the fundamental environmental challenges in the world, particularly in semiarid countries such as Iran. It is so important to include water footprint as one of the components of the footprint family [56].

Furthermore, among these fifteen reviewed universities, the EFI was only calculated at Tianjin University and the UOK. The amount of mean EFI at the UOK (−0.82) is considerably lower than at Tianjin University (0.61). It shows that the performance of the University of Kurdistan is radically unsustainable.

In Table 9, we have suggested several recommendations to decline the EFI of the UOK. These recommendations can be extrapolated into other universities in the world. These recommendations may be implemented by officials, faculty members, staff, or students.

Table 9. Recommendations (action, strategy) to decrease the ecological footprint of the UOK.

Component	Recommendations
Energy and water	Changing the fuel type from fossil to renewables in stepwise steps (strategy), applying solar PV panels (20% of total electricity usage until 2030, 50% of total electricity usage until 2040 and 100% of total electricity usage before 2050), solar thermal (50% of total hot water usage till 2030 and 100% before 2040) (action)
	Applying thermal insulation, especially in dormitories (action)
	Using high-efficiency central heating systems such as district heating (strategy)
	Installation of double-glazing thermal break windows and doors (action)
	Implementation of Energy Benchmarking policy in the buildings (strategy)
	Water recycling, using purified greywater of Freshtegan Dormitory for irrigation (strategy)
Food and Waste	To implement a solar distillation system in the Faculty of Sciences, the Faculty of Agriculture, and the Faculty of Natural Resources (action)
	Diet changing and optimizing, for example, reducing the amount of red meat usage in the Keshawarzi restaurant (strategy)
The institutional culture of sustainability	Waste recycling, paper recycling (action)
	Adding a voluntary class called “Environmental Studies” in university curriculum (strategy)
	Enhancing the knowledge of primary and secondary schools by collaborating between the UOK and the Education Department of Sanandaj city (strategy)
	Recommending an “Environmental Coordinator” at the UOK to encourage a behaviour change (action)

7. Conclusions

Global warming and other negative impacts of humans on the environment are the main challenges of the world. Consequently, the concept of sustainable development has been frequently investigated to address these challenges. In recent years, the Ecological Footprint Assessment (EFA) tool has played a significant role in evaluating sustainable development performance, especially in academic institutes. Applying EFA helps the planners to explore which part of a community and to what extent has a higher impact on the environment. This information forms the foundation of future sustainable action plans to diminish the environmental impacts.

Accordingly, this paper focused on the assessment of EF at the UOK campus to explore how the campus performs sustainability development. In the research, the index of EF was studied from 2013 to 2016 based on Gottlieb, Vigoda-Gadot, Haim, and Kissinger’s recommendation to further develop the approach [26]. Comparing with the reviewed studies that evaluated the EF at the campus scale, the authors of this study have assessed the EF of the UOK at the building scale as well as the campus scale.

The methodology for the assessment of the EF was developed in terms of the longer period of the study, data cleaning, visualization, and conducting the assessment simultaneously at both community and individual building levels. Furthermore, the authors developed the EF method by illustrating the Ecological Footprint Map (EFM) for the UOK campus. The map showed that the west and east parts of the campus have the highest level of environmental impacts. The developed method can be replicated in all urban communities as well as universities.

The results show the mean ecological footprint (per capita) of the UOK campus and the EFI were 1.69 gha and -0.82 throughout the study period. It indicates that the UOK ecological performance is unsustainable. A detailed breakdown of the mean EF of the campus was presented throughout the study. Fossil fuel energy consumption, which had the highest total EF (70.73%), should be considered in future sustainability plans of the campus to decrease the UOK’s EF, followed by waste production (26.87%). According to the EF assessment of food usage, meat (94.13 gha) and oil (2.1 gha) usage had the highest and lowest EF respectively.

Among the fifteen reviewed universities, the UOK with an EF per capita of 1.69 was the fourth highest. Furthermore, the UOK had the highest EF (16,484 gha) after Ohio State University, Illinois University, SRM University, and Northeastern University.

Based on the EFA, a range of strategies and actions are suggested to diminish the impact of fossil fuel energy, reduce the water footprint, and decrease the impact of food components on the campus environment.

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