 Research Article

Comprehensive Carbon Footprint Assessment Using EPA and DEFRA: A Case Study of Bursa Technical University

Somaia Shahin [1], **Samet Öztürk**[1*]

[1] *Bursa Technical University, Department of Environmental Engineering, 16310, Bursa, Türkiye*

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*Corresponding author: Samet Öztürk
E-mail:samet.ozturk@btu.edu.tr

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ABSTRACT

Bursa Technical University (BTU) is committed to achieving sustainability goals and has taken significant steps in this direction. This study was conducted in accordance with the emission factors of the Environmental Protection Agency (EPA) and the conversion factors of the Department of Environment, Food and Rural Affairs (DEFRA). The study was carried out in line with International Organization for Standardization (ISO) 14064 and ISO 14001 standards and in harmony with the Sustainable Development Goals (SDGs), drawing on the experiences of five Turkish universities. This paper provides detailed information on BTU's carbon footprint calculation methodology, the standards used, and its alignment with the SDGs. The application of two distinct emission factors, those of EPA and DEFRA, yielded divergent carbon footprint (CF) values for BTU. The EPA approach yielded a value of 2697 tCO2e while the DEFRA-based assessment resulted in a lower CF of 1526 ton of CO2 equivalent (tCO2e). It is noted that most of the carbon emissions in the university is due to electricity consumption followed by natural gas usage. A prioritized action plan could be reducing the electricity consumption with automated lighting and laboratory equipment, subsequently increasing energy efficiency in the buildings.

1. Introduction

The rapid depletion of natural resources has accelerated due to anthropogenic and industrial activities since the Earth's formation. Simultaneously, a rise in global temperatures and observable climate change have been evident since 1974 [1]. Accordingly, the 1992 Rio Summit said that the increase in greenhouse gas emissions has significantly contributed to global warming and climate change. Greenhouse gases trap a portion of the sun's energy, heating the Earth's atmosphere. This heat-catching phenomenon is identified as the greenhouse effect and is the primary driver of climate change [2]. Greenhouse gases disrupt the atmospheric heat balance, increasing the occurrence and strength of extreme weather events. These events include droughts, floods, storms, and extreme temperatures. Rising greenhouse gas emissions also contribute to

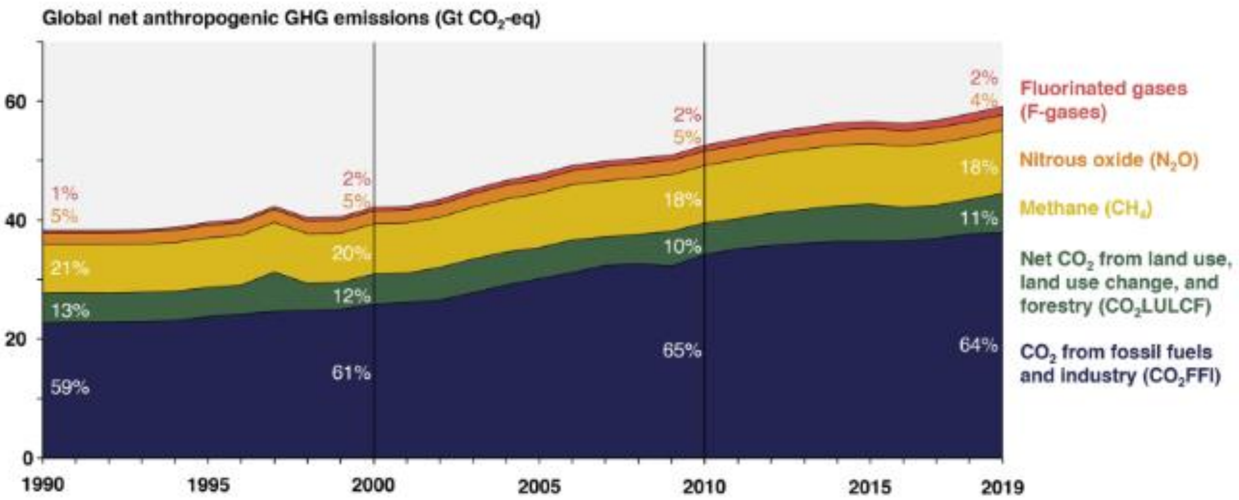


Figure 1: Global net anthropogenic GHG emissions [5]

sea level escalation, glacial melting, and ecosystem degradation [3]. In 2019, 64% of global greenhouse gas emissions were CO_2, 11% net CO_2, 18% N_2O, 4% F-gases, and 2% other gases (Figure 1) [4].

Figure 2: Aerial views of Bursa Technical University campuses

Bursa Technical University (BTU) operates its educational and research activities on two campuses: Mimar Sinan and Yıldırım Bayezid. Both campuses are located at the city center and close by to public transportation and metro stations. The Mimar Sinan campus has four faculties, a graduate education institute, four research centers and business and laboratory management units. The Yıldırım Bayezid Campus has two faculties and a foreign language preparatory school. As of 2024, BTU has 11,205 students, 569 academic staff, and 350 administrative staff [6]. Figure 2 shows the aerial views of the campuses of Bursa Technical University

BTU stands out as an educational institution with a campus that covers approximately 30% green space. These green areas play a significant role in student well-being and air quality, in addition to adding aesthetic value. However, BTU has many opportunities to further its sustainability journey. In this context, the university is committed to working in areas such as energy efficiency, waste management, water conservation, and sustainable education. BTU is determined to work with all stakeholders to achieve these goals and make the campus even more sustainable. By doing so, BTU believes it can contribute to building a more livable world for future generations.

There are several studies which estimated carbon footprints of university campuses in the literature. Erzincan Binali Yıldırım University (EBYU)'s primary carbon footprint was estimated as 2753,20 tCO2e for 2019 while it was calculated as 2383,74 tCO2e for 2020[7]. In comparison to 2019, there was a 13,42% decrease in the carbon footprint at EBYU in 2020. EBYU's primary carbon footprint was calculated as 2314,53 tCO2e for 2019 and 1826,53 tCO2e for 2020 using DEFRA conversion factors. Relative to 2019, there was a 21,08% reduction in carbon footprint [7]. Manisa Celal Bayar University's carbon footprint was calculated to be 8.953,91 tons of CO2 using the IPCC Model Tier 1 approach [8]. It was determined that 87,85% of carbon emissions originated from electricity consumption, while the least amount originated from gasoline consumption at 0,09% [8]. Carbon footprint for Çankırı Karatekin University was estimated for its campus in 2017 as 5.633,13 tCO2e/year using data obtained from greenhouse gas emission sources classified into categories 1, 2, and 3. The calculation revealed an average annual greenhouse gas emission of 4,54 tCO2e/person and a daily average carbon emission of 15,44 tCO2e/day [9]. The total CO2e emissions from Burdur Mehmet Akif Ersoy University Bucak Health College due to sum of all scope levels – Scope 1, 2 and 3 was found to be 217,50 tCO2e/year [10]. The calculations revealed that the most significant impact on carbon emissions comes from combustion of natural gas for heating system, followed by electricity consumption, emissions from diesel, gasoline, and LPG-powered vehicles [10]. CF calculated for the total carbon emissions from natural gas consumption at Osmaniye Korkut Ata University's Karacaoğlan campus to be 2659 tCO2e in 2021 [11]. GIt was noted for Osmaniye Korkut Ata University that in the periods of 2020 and 2021, there was a transition from face-to-face education to online education, therefore, the pool and cafeteria were closed. Consequently, natural gas consumption in common areas and for heating purposes was significantly reduced [11]. Hünerli et al. utilized IPCC Tier 1 and DEFRA methods to estimate carbon footprint of Muğla Sıtkı Koçman University campus for 2020 and 2021. They have found that the emissions indicate a rising trend [12].

Most of the reviewed papers applied a single method for several consecutive years [8-12]. Even though two papers calculated carbon footprint by using both methods, in those papers, Scope 3 was not included in the analyses [7, 12]. However, no paper, to the authors' knowledge have compared the carbon footprint results with different methods considering all Scope levels for carbon footprint estimation. The novelty of this paper is being the most comprehensive carbon footprint evaluation considering different emission factors, namely EPA and DEFRA for Bursa Technical University campus. This is a novel approach in the context of Turkish universities.

2. Materials and Methods

2.1. Material

In this study, BTU's carbon footprint was determined using the EPA and DEFRA emission factors for carbon footprint calculations between August 2022 and July 2023. The EPA and DEFRA methods are employed in this study due to their distinct advantages. Firstly, they are standardized approaches grounded in internationally recognized frameworks, ensuring reliability and consistency. Secondly, these methods encompass a wide range of sectors, including energy, transportation, industrial processes, and waste management, all of which are integral to the operations and activities of a university. Lastly, their databases are readily accessible, and the associated emission factors are comprehensively documented, enhancing clarity and ease of use. These methods also have notable disadvantages. A common limitation of both is their reliance on region-specific emission factors. For instance, emission factors for electricity grids are tailored to specific countries or states, which can restrict their applicability in other regions. Additionally, in certain sectors, there may be gaps in available emission factors or reliance on generalized or averaged data. This can lead to inaccuracies and potential miscalculations in carbon emissions estimations, particularly in cases requiring granular or localized analysis. Several standards are followed to conduct carbon footprint analysis in this study. ISO 14064-1 is a standard that identifies the fundamentals for publishing greenhouse gas (GHG) emissions [13] while ISO 14067 standard states principles, requirements, and guidelines for evaluating and informing the carbon footprint (CFP) of a product [14]. GHG Protocol provide guidelines for users to calculate GHG emissions from specific bases or businesses [15]. The Intergovernmental Panel on Climate Change (IPCC) is a United Nations organization that measures the knowledge regarding climate change. The IPCC prepares inclusive GHG inventories to estimate carbon footprints of businesses or products [16].

2.2. BTU Campus Consumption Data

In this study, Scope 1, Scope 2, and Scope 3 CO2 Emissions at Bursa Technical University (BTU) were calculated for the period from August 2022 to July 2023. BTU contributes to greenhouse gas emissions through natural gas and diesel consumption due to the operation of laboratories, the use of motor vehicles and operations' machinery on its campuses. These emissions constitute an organization's Scope 1.

However, the environmental impact of BTU's activities is not limited to the emissions that occur in its own facilities. Scope 2 emissions consist of emissions from electricity consumption inside the organization. Moreover, activities that occur outside BTU's control, such as the production and transportation of purchased materials, and the use of products and services sold, also lead to greenhouse gas emissions constitute BTU's Scope 3.

In general, a significant portion of university campus consumption-based emissions come from sources such as heating and cooling systems, air conditioners, ambient lighting, office equipment, and elevators [8].

Another factor affecting consumption of electricity is the climate. The increase in air conditioning use due to rising temperatures in the summer months leads to an increase in electricity consumption and therefore carbon emissions. In winter, on the other hand, the widespread use of natural gas heating systems reduces the need for electricity to meet heating needs but leads to an increase in natural gas emissions.

In this study, consumption data are gathered to conduct a comprehensive analysis of the university's greenhouse gas emissions to calculate its carbon footprint (Table 1).

Table 1: BTU consumption data for August 2022-July 2023

Scope 1		Scope 2	Scope 3				
Natural Gas (m^3)	Diesel (l)	Electricity (kWh)	Water (m^3)	GES (kWh)	Paper and board (t)	Passenger-Car (km)	Mixed Plastics (t)
352.414	19.416,10	3.498.921	99.293	10.800	4,70	156.379	2,66

2.3. Methodology

This study adopted methodologies widely used in the European Union (EU) and the United States (US) for calculating Bursa Technical University's Carbon Footprint (CF). In this context, EPA and DEFRA emission factors were used. The calculations provided BTU's annual carbon emissions in CO2 equivalents.

EPA (Environmental Protection Agency) is a self-governing federal organization in the United States responsible for environmental security. The EPA's Greenhouse Gas Emissions Factors Hub is intended to offer organizations with a recurrently revised and user-friendly set of default emission factors for greenhouse gas reporting for businesses [4].

Department of Environment, Food and Rural Affairs (DEFRA) is a United Kingdom (UK) administrative organization which is responsible for policy and legislation in subjects for example the ecosystem, variety of biological creatures. It works with various organizations to implement these policies [16]. The DEFRA emission factor is a value that represents the correlation between the quantity of contaminant yielded and the quantity of natural resource handled or burned. This factor is used in greenhouse gas emissions calculations and environmental impact assessments. DEFRA is responsible for determining and updating emission factors used in the UK [17].

The carbon footprint is presented as a value in CO2 equivalents. The CO2 value is determined using mathematical calculations and methods. In this study, emission factors are determined using core performance indicators and are also used by organizations that voluntarily report on various environmental issues. The calculations of the carbon footprint estimation were done using the following steps.

1. Go to the activity-specific page to calculate emissions: In the Excel report, this is the step of opening the page for the activity for which we want to calculate emissions.

2. Read the guide: This is the step of reviewing the emission calculation guide for the activity on the page to learn how to apply the desired method.

3. Collect activity data: This is the step of collecting data related to the activity for which we are calculating emissions. For example, this includes data such as the amount of electricity used or the distance traveled.

4. Multiply the activity data by the corresponding conversion factor: This is the step of multiplying the collected or estimated activity data by the emission factor determined for the relevant activity. This process allows us to calculate an estimate of the greenhouse gas emissions from the activity in question, as shown in Equation 1.

$$\text{GHG emissions} = \text{Activity data} \times \text{Emission conversion factor} \quad (1)$$

2.3.1. EPA Emission Factors

A greenhouse gas inventory report is a comprehensive written document that provides the methodologies and data used to prepare a set of standard reporting tables and estimates covering categories and years. The 2006 IPCC Guidelines provide an internationally accepted standard for the preparation of greenhouse gas inventories. These guidelines ensure the comparability and consistency of inventories prepared by different countries by providing standardized reporting tables and methodologies.

The 2006 Guidelines also include worksheets to facilitate the implementation of the basic (or Tier 1) estimation methodology transparently. These sheets allow countries to calculate their greenhouse gas emissions from basic data and prepare reports in accordance with international standards.

The IPCC method uses the emission factors (EFs) provided by the EPA to calculate greenhouse gas emissions. A similar multiplication operation is used in the DEFRA method. However, the emission factors given by EPA differs depends on the electricity grid in the USA, therefore the emission factor from electricity consumption is taken as the closest one with the Turkish electricity grid [18].

Since the EPA's emission factors are specific to the United States, the units used are also English units. Therefore, when making calculations with our data, the units have been converted. Table 2 shows the emission factors used in this study.

2.3.2. DEFRA Emission Factors

This section includes emission calculation guides and conversion factors for various activities suggested by DEFRA. By carefully reviewing the guide and conversion factor for each activity for which emissions are calculated, multiplying the activity data by the relevant conversion factor will result in an estimate of the greenhouse gas emissions from the activity in question. The equivalents of the emission factors used in the DEFRA method are given in different units. Table 3 shows the emission factor suggested by DEFRA.

Table 2: Emission factors provided by EPA

Scopes	Usage Type	Unit	Emission Factor (kg CO2e)
	Natural Gas	scf	35,32
Scope 1	Diesel	Gallon	10,21
Scope 2	Electricity	MWh	550,00
	Water Supply	m^3	0,18
	Water Usage	m^3	0,20
Scope 3	Paper/Cardboard	Metric Ton	0,03
	Electricity GES	kWh	0,02
	Travel	Vehicle-mile	0,31

Table 3: Emission Factors by DEFRA

Scopes	Usage Type	Unit	Emission Factor (kg CO2e)
	Natural Gas	m^3	2,04
Scope 1	Diesel	L	2,51
Scope 2	Electricity	kWh	0,21
	Water Supply	m^3	0,18
	Water Usage	m^3	0,20
Scope 3	Paper/Cardboard	ton	0, 02
	Electricity (GES)	kWh	0,02
	Travel	Passenger-Km	0,10

3. Results and Discussion

3.1. Results from EPA and DEFRA emission factors

In this study, a comprehensive carbon footprint calculation is applied for Bursa Technical University campuses using the EPA and DEFRA emission factors to estimate carbon footprint. This calculation, which determines CO_2 emissions for the period between 2022 August and July 2023, provides a framework for developing concrete strategies to achieve emission reduction goals in the future.

- For Scope 1 emissions, direct emissions from natural gas and diesel consumption in the university's operations are considered. Electricity is the most consumed type of energy on campus. Scope 2 emissions represent emissions by electricity consumption which is calculated by summing up the electricity usage values of every area within the university. This value is analyzed more comprehensively by considering the emission conversion factor, the electricity production source (indirect), and electricity losses from the grid. Scope 3 emissions are indirect emissions which include emissions from 15 categories such as purchase goods and services, fuel and energy related activities, processing and sold of use products and business travel [15]. Scope 3 for BTU's carbon emission is estimated considering following activities due to the data limitation:

- Travel: Business travel, commuting, and student travel all contribute to Scope 3 emissions.

- Waste: The disposal of waste, including paper, cardboard, and food scraps, generates Scope 3 emissions.

- Water: The extraction, treatment, and distribution of water also contribute to Scope 3 emissions.

- Renewable energy: The solar panels which use electricity and its waste contributes to Scope 3 emissions.

Table 4 presents the total CO2 equivalent emissions from Scope 3. The university has achieved nearly 80% recycling rate for paper and cardboard and efforts are ongoing to further improve this rate. Scope 3 emissions are also affected by water usage. Table 4 shows the water consumption and associated CO2 equivalent emissions. The EPA does not currently provide an estimation method specifically for Solar Energy Generation Systems (SEGS) and water consumption. As a result, the methodology outlined here is using DEFRA's emission factors for only SEGS and water consumption.

The results indicate that BTU's total CO2 equivalent emissions amount to 2697,06 tons as shown in Table 4. Scope 2 emissions contribute the most with 1924,41 tons of CO2, followed by 724,43 tons of CO2 from Scope 1 direct emissions. Within Scope 3, the most significant emissions were attributed to travel, totaling 30,40 tons of CO2. Emissions from renewable sources were observed to be very low, amounting to only 0,193 tons of CO2.

Table 4: The total of FC using EPA emission factors

Scope	Emission	Quantity	Unit	Result of CF (Ton CO2e)
Scope 1	Natural Gas	352.414	m^3	672,06
	Diesel	19.416	m^3	52,37
	CF Total			724,43
Scope 2	Electricity	3.498.921	kWh	1924,41
Scope 3	Water (Municipal/Usage)	99.293	m^3	17,58
	Electricity SEGS	1.080	kWh	0,19
	Travel	156.379	Passenger-Km	30,40
	Paper/Cardboard	4,70	Ton	0,14
	CF Total			48,69
CF Grand Total				2.697,06

By using DEFRA's emission factors Scope 1 emissions at Bursa Technical University (BTU) arise from the combustion of oil and gas-based fuels, such as natural gas and diesel, in heating and equipment machinery. The greenhouse gases released because of the combustion of these fuels are listed in Table 5 in CO2 equivalents. It should be noted that the EPA emission factors yielded higher CO2 emissions from diesel and natural gas consumptions comparing with the results from DEFRA method. Scope 3 emissions are indirect emissions that result from a company's activities but occur at sources that are not owned or controlled by the company. These emissions can be a significant portion of a company's total carbon footprint.

This study calculated emissions from all forms of transportation, including air, ground, and sea travel. The results show that travel emissions are the largest source of Scope 3 emissions for BTU. As a predominantly paper-based institution, Bursa Technical University (BTU) primarily generates waste in the form of paper and cardboard. DEFRA emission factors for paper and cardboard were utilized to quantify the associated emissions as outlined in Table 5. BTU's water usage is categorized into municipal water and grey water. The university's water consumption levels are considered moderate. Table 5 shows water-related CO2 emissions that account for energy consumption and source. The university has installed solar panels on its campus, which are generating electricity and helping to reduce emissions. However, even for generating electricity from solar panels carry CO2 emissions which are presented in Table 5. BTU's carbon footprint for the period of August 2022 and July 2023 has been calculated as 1525,92 tons of CO2 using the DEFRA method. Water use is identified as the highest emission source in Scope 3, contributing 17,55 tons of CO2 equivalent emissions. Scope 1 has the highest overall contribution with 767,66 tons of CO2 emissions, while the lowest is Scope 3 with emissions amount to 30,98 tons of CO2. Indirect emissions from electricity are shown as 724,54 tons of CO2.

3.2. Discussion

In this study, it is noted that comparing the IPCC method with the DEFRA method, the IPCC method provides a higher total CO2 emission value. This discrepancy is due to the emission factors used in different methods. As shown in Figure 3, for the same amount of natural gas, the IPCC method covers 7% while the DEFRA method covers 6% with the same data. This difference is because each country has different approaches and values for evaluating CO2 emissions.

Table 5: Total of CF by the DEFRA emission factors

Scopes	Emission	Quantity	Unit	Result of CF (Ton CO2e)
Scope 1	Natural Gas	352.414	m^3	718,92
	Diesel	19.416	m^3	48,73
	CF Total			767,66
Scope 2	Electricity	3.498.921	kWh	724,54
Scope 3	Water (Municipal/Usage)	99.293	m^3	17,55
	Electricity SEGS	1.080	kWh	0,19
	Travel	156.379	Passenger-Km	15,98
	Paper/Cardboard	4,70	Ton	0,09
	CF Total			30,68
CF Grand Total				1.525,92

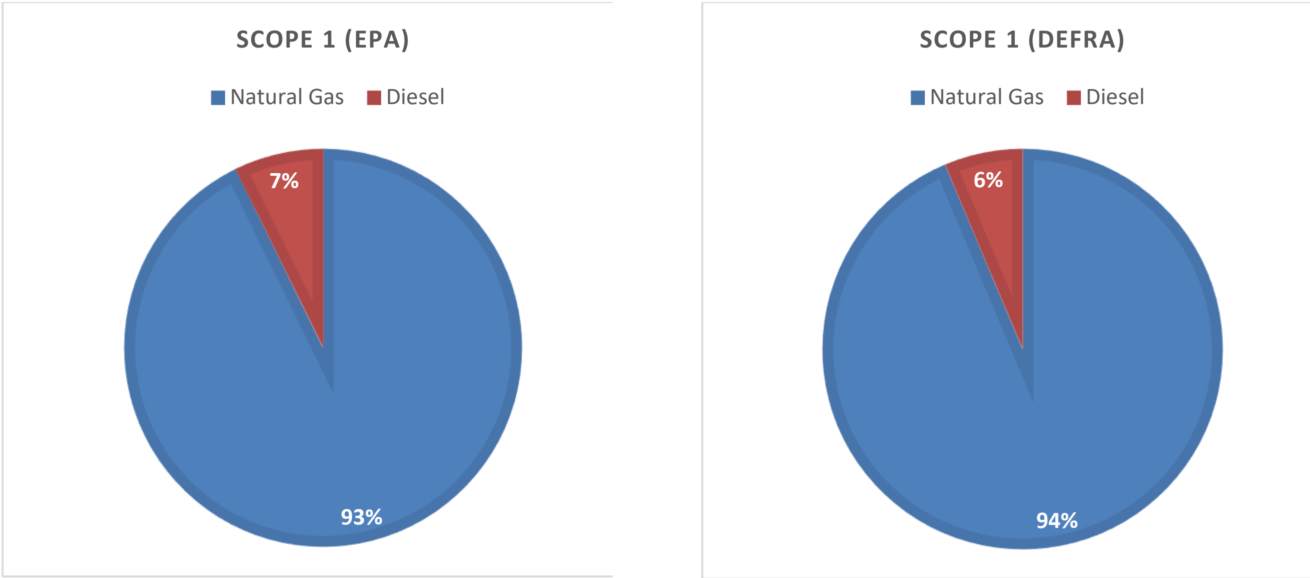


Figure 3: Shares of emissions in Scope 1

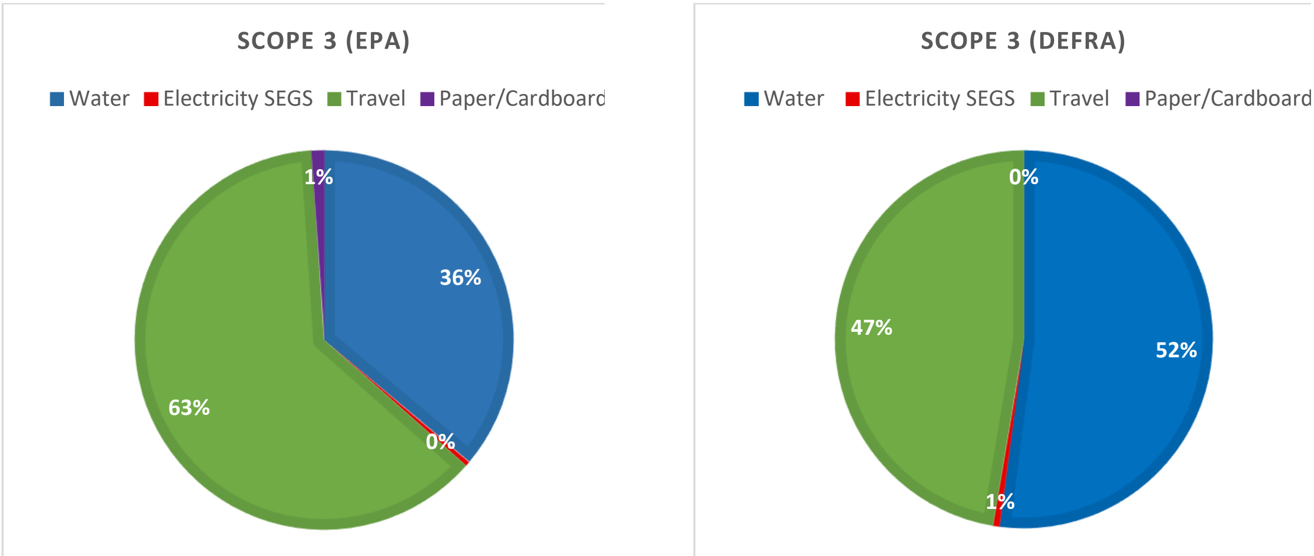
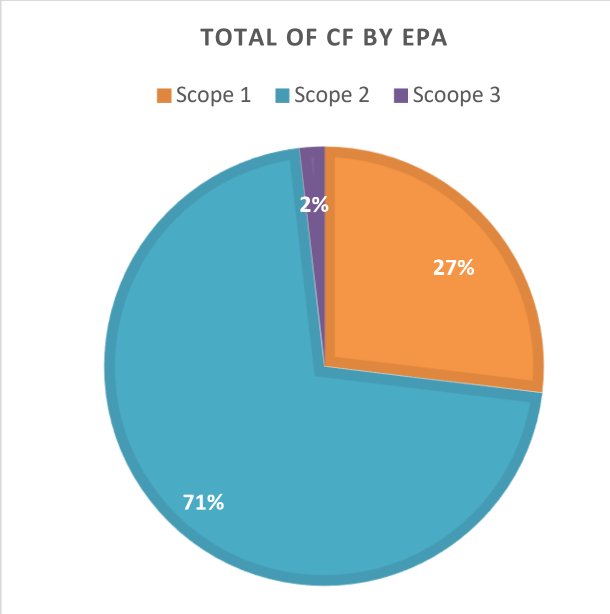


Figure 4: Shares of emissions in Scope 3

For Scope 3 emission calculations, this study used data from water, solar panels, travel, and paper/cardboard. In this context, the equivalence between the EPA and DEFRA emission factors is quite high. Both methodologies yield similar results, confirming the consistency and accuracy of the approach.

Figure 5 illustrates the distribution of emissions across the three scopes according to the DEFRA and IPCC methodologies. In the DEFRA method, Scope 1 and Scope 2 emissions have a larger share compared to the IPCC method. This difference arises from the variations in emission conversion factors. Specifically, the conversion factor used for electricity consumption is higher in the IPCC method, resulting in higher electricity-related emissions calculated by that method. Additionally, it was found that Scope 1 emissions accounted for the largest share under the DEFRA method, comprising 50% of the total. At the same time, Scope 2 emissions (electricity consumption) made up 71%.



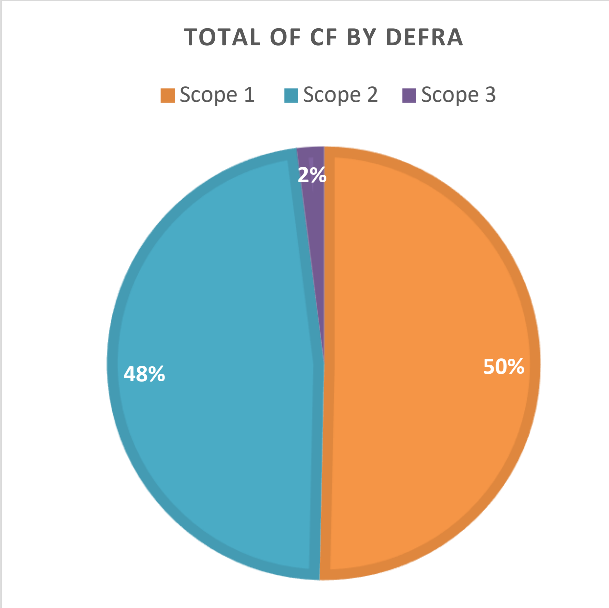


Figure 5: The distribution of total CO2 emissions

The primary cause of climate change is the greenhouse gases emitted into the atmosphere due to human activities, particularly carbon dioxide (CO_2). Reducing carbon emissions is crucial to mitigating the effects of climate change [7]. Using two different approaches, carbon footprint of one-year period for Bursa Technical University found as 2.697 tons of CO_2 equivalent emissions with the EPA emission factors whereas it is estimated as 1.526 tons of CO_2 equivalent emissions with the DEFRA emission factors. The difference in the results could be attributed to the difference between the emission factors of electricity consumption of EPA and DEFRA. In both approaches, the largest share of greenhouse gas emissions comes from electricity consumption. On the other hand, the value for Scope 3 emissions is not very robust due to the lack of comprehensive data. Direct CO_2 emissions yield different results depending on the method used. As this is the first time calculating BTU's carbon footprint, the results should be reviewed more comprehensively and inclusively to support future emissions calculations and projections.

The results from this study compares well with the other studies in the literature in terms of ton CO2-eq per student values. Carbon footprint estimations swing between 0,12 to 0,60 ton CO2-eq per student in the studies that was published for Turkish universities in the literature [7-12] whereas, in this study, the result shows 0,26 tons of CO2-eq per student for Bursa Technical University. It must be noted that this comparison has been applied for only the sum of Scope 1 and 2 estimations since most of the earlier studies did not consider Scope 3.

4. Conclusions and Recommendations

This study analyzes the carbon footprint of Bursa Technical University operations using two different emission factors, namely EPA and DEFRA. The study finds out that the results from both methods are in the alignment, EPA approach yielding the greater value. Since, the emission factor of DEFRA is 0,207 kg/CO2eq which is lower than the emission factor of Turkish electricity grid, the results from the EPA approach could be considered more reliable. Furthermore, as per the shares of Scopes in the total emission value, Scope 2 constitutes a high rate due to the university's reliance on electricity usage. Finally, Scope 3 emissions could be extended with more data while in this study it is limited by the data available.

To reduce the carbon footprint of a university, various measures might be implemented. Followings are several recommendations.

- Electricity Use: Automated lighting and laboratory equipment systems can be vital in the relevant to reduce electricity consumption. Moreover, redundant use of electrical systems must be reviewed and eliminated.

- Energy Efficiency: Improving insulation in buildings can reduce heating and cooling needs, thereby decreasing energy consumption. This not only demonstrates an environmentally friendly approach but also saves on energy costs.

- Vehicle Usage: Although the university is in an area easily accessible by public transportation, high fuel consumption has been observed. One approach to reduce this is to install bicycle or electric scooter stations next to metro stations near each campus.

- Plastic Use: The significant impact of plastic on greenhouse gas emissions often stems from single-use consumption habits. Raising environmental awareness in the community is an effective way to reduce plastic use. For example, since plastic cups and bottles constitute 70% of daily solid waste at our university, we recommend switching to glass and reusable alternatives. Additionally, efforts should be made to reduce hazardous waste in laboratory operations.

- Digital Paper Usage: Replacing traditional paper with digital documents is an environmentally friendly alternative that enhances efficiency, reduces storage and archiving costs, and facilitates document access. Thus, digital paper usage plays a crucial role in both environmental sustainability and operational efficiency.

A prioritized action plan could be reducing the electricity consumption with automated lighting and laboratory equipment, followed by increasing energy efficiency in the buildings. Furthermore, vehicle usage might be limited by utilizing micro mobility or public transportation.

Article Information

Authors' Contrtibution:
Samet Ozturk: Conceptualization, Data Acquisition, Design, Analysis, Writing, Supervision, Critical review.
Somaia Shahin: Literature review, Resources, Data Acquisition, Analysis, Writing.

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