USING BUDGET ALLOCATION OPTIMIZATION TECHNIQUE (KNAPSACK METHOD) TO IMPROVE THE ENERGY EFFICIENCY AND REDUCE THE GREENHOUSE GAS EMISSIONS OF A UNIVERSITY CAMPUS

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Overview

Climate change, whose effects have been discussed for many years, has begun to affect our daily lives economically and socially, especially with the introduction of the European Union Green Deal. Hence, the accurate determination of the carbon footprint of environments such as university campuses that serve a high number of people and therefore have a widespread impact, and also examining the consequences of actions aimed at reducing the carbon footprint will be of great importance. In this project, the carbon footprint of İzmir University of Economics Balçova Campus has been calculated with a Scope 3 approach [1] and the economic and environmental dimensions of the actions aimed at reducing the carbon footprint have been analyzed. It is envisioned that the results obtained in this work will create a road map, especially for universities both in Turkey and abroad, towards measuring and reducing their environmental impacts; and will set an example for a possible "National Green Campus" standardization in the future.

Methods

The following system boundaries were used for the calculation of the carbon footprint.

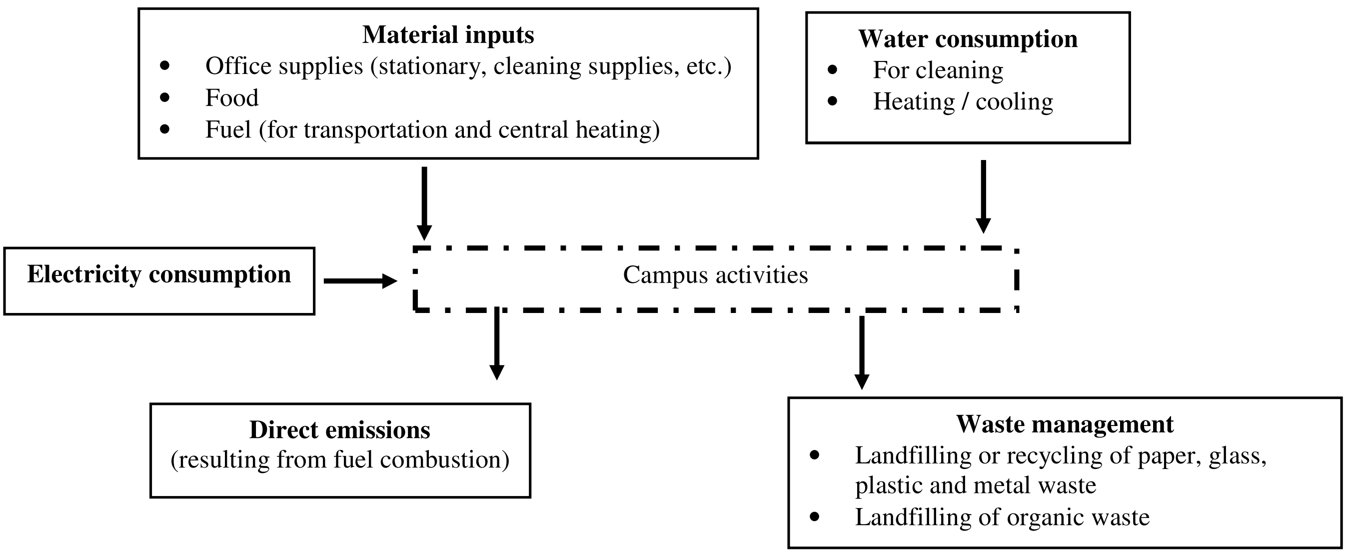


Figure 1. System boundaries for the calculation of the carbon footprint of the campus

Data collection covers the entire year of 2022. Calculation of the carbon footprint was realized by using CCaLC2 software which utilizes Ecoinvent2 database and CML2001 method.

After the calculation of the impact scores was realized, the following strategies were developed in order to reduce these impacts:

S1: Installing photovoltaic (PV) panels in the campus where available
S2: Installing a rainwater harvest system
S3: Replacing the internal combustion engine-powered passenger vehicles by electric vehicles
S4: Installing multiple reverse vending machines that award the user for proper recycling across the campus
S5: Serving an only vegetarian menu in the university cafeteria once a week throughout the entire year

For each of the strategies mentioned above, data from the literature was used to calculate the lifetime cost (initial price plus operation cost) and the greenhouse gas emission (GHGE) reduction potential as the cost and the benefit of that strategy, respectively. Afterwards, knapsack method [2] was utilized with various budget values in order to observe how the optimum mix of the strategies listed above would change with respect to the budget. The knapsack problem derives its name from a scenario where one is constrained in the number of items that can be placed inside a fixed-size knapsack. Given a set of items with specific weights and values, the aim is to get as much value into the knapsack as possible given the weight constraint of the knapsack. This way, the user of our model would be able to determine the most effective set of strategies that could be used for GHGE mitigation. Knapsack algorithm was coded on IBM ILOG OPL CPLEX STUDIO software.

Results

Figure 2 below presents the results of the carbon footprint calculations whereas Figure 3 provides the results of the knapsack method analysis. Data presented in Figure 3 correspond to the maximum available budget at which all five strategies could be implemented simultaneously.

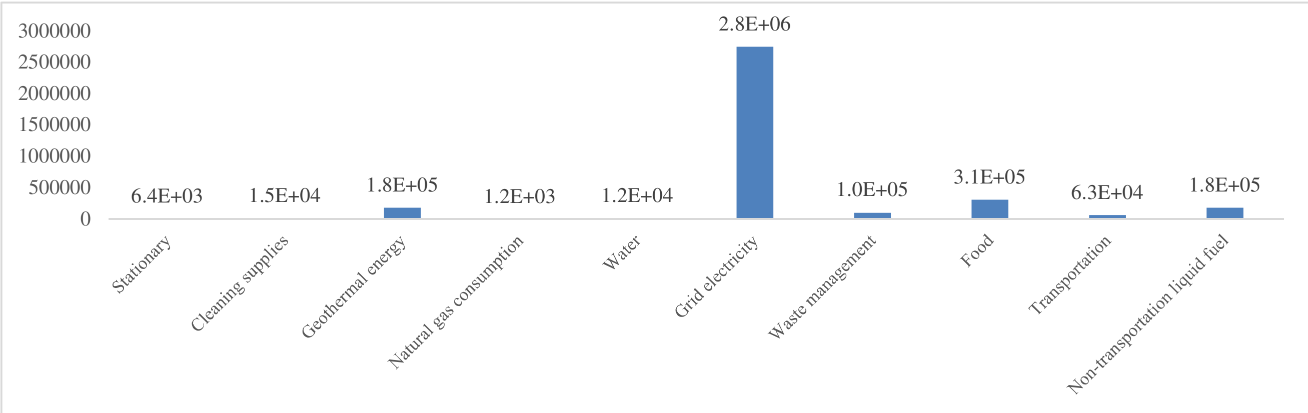
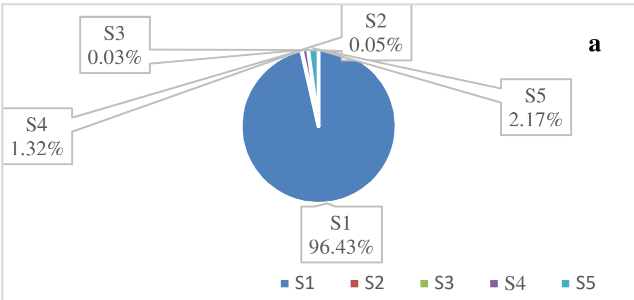


Figure 2. Carbon footprint distribution of the campus (kg CO_2eq.)



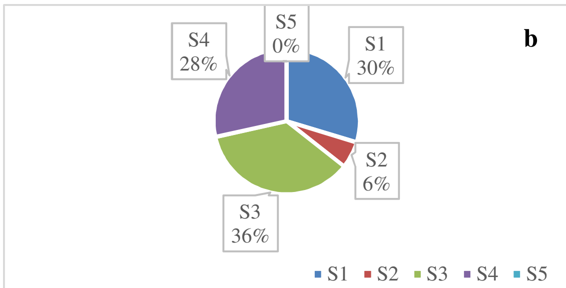


Figure 3a. Contribution of different strategies to the overall GHGE mitigation
Figure 3b. Share of different strategies in the total budget

Conclusions

According to Figure 2, the biggest contributor to the campus' GHG emissions is electricity consumption with a share of 76%, followed by food consumption, non-transportation liquid fuel use and geothermal energy use. Figure 3a shows that the most beneficial strategy as far as benefit-to-cost-ratio is concerned is S1. While the model includes S5 in all its solution sets, it is simply due to the fact that switching to a vegetarian menu from an omnivorous menu actually decreases the cost of that particular meal. Thus, in the model this particular strategy was assigned a cost of zero, as can be seen in Figure 3b. The strategy that was picked the last turned out to be S3, with the lowest benefit-to-cost-ratio.

It must be noted that the main novelty of this study is the utilization of knapsack method for GHGE mitigation in university campuses, and the particular strategies developed to reduce the impacts do not necessarily have apply to other systems.

References

[1] ISO 14064-1:2018, Greenhouse gases — Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals.
[2] Cacchiani V, Iori M, Locatelli A, Martello S. Knapsack problems — An overview of recent advances. Part I: Singleknapsack problems, *Computers and Operations Research* 143 (2022) 105692.