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

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MOTIVATION

- Climate change is one of the most important problems of modern world because it affects multiple aspects of our lives, including

  - the environment
  - human health
  - economies
  - social systems

- It requires urgent attention and collective action to mitigate its impacts and build a sustainable future.

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WHY INVESTIGATE A CAMPUS – pt.1?

University campuses :

- require significant energy to power buildings, lighting, heating, cooling, and other facilities. The reliance on fossil fuels for energy can contribute to greenhouse gas emissions and climate change.

- consume large amounts of water for various purposes, including irrigation, sanitation, and research activities. Excessive water use can strain local water supplies and ecosystems, particularly in regions facing water scarcity.

- generate substantial amounts of waste from classrooms, laboratories, offices, and food services. Improper waste management can contribute to pollution, greenhouse gas emissions from landfills, and the depletion of natural resources.

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WHY INVESTIGATE A CAMPUS – pt.2?

- The transportation activities associated with a university campus, including commuting of students, faculty, and staff, can contribute to air pollution, traffic congestion, and greenhouse gas emissions.

- University campuses often require substantial land for buildings, infrastructure, and green spaces. The development and expansion of campuses can result in the loss of natural habitats and biodiversity.

- University laboratories and research facilities on university campuses often handle chemicals that can have environmental impacts if not managed properly. Chemical spills, improper disposal, and inadequate safety measures can lead to soil and water contamination, harming ecosystems and human health.

GOAL OF THE STUDY

- In this study, a combined methodology has been developed for impact mitigation in large organizations.

  - First, the global warming potential of a university campus over a one-year period was calculated with life cycle approach by taking several different mass and energy inputs as well as outputs such as waste into account.

  - Then, budget allocation optimization was performed by modelling the system as a knapsack problem, with the aim of coming up with the most cost-effective combination of impact mitigation strategies for different budgets.

NOVELTY

- The benefit of the optimization model was chosen as **the reduction in the GWP associated with the campus** and <u>not the amount of energy conserved.</u>

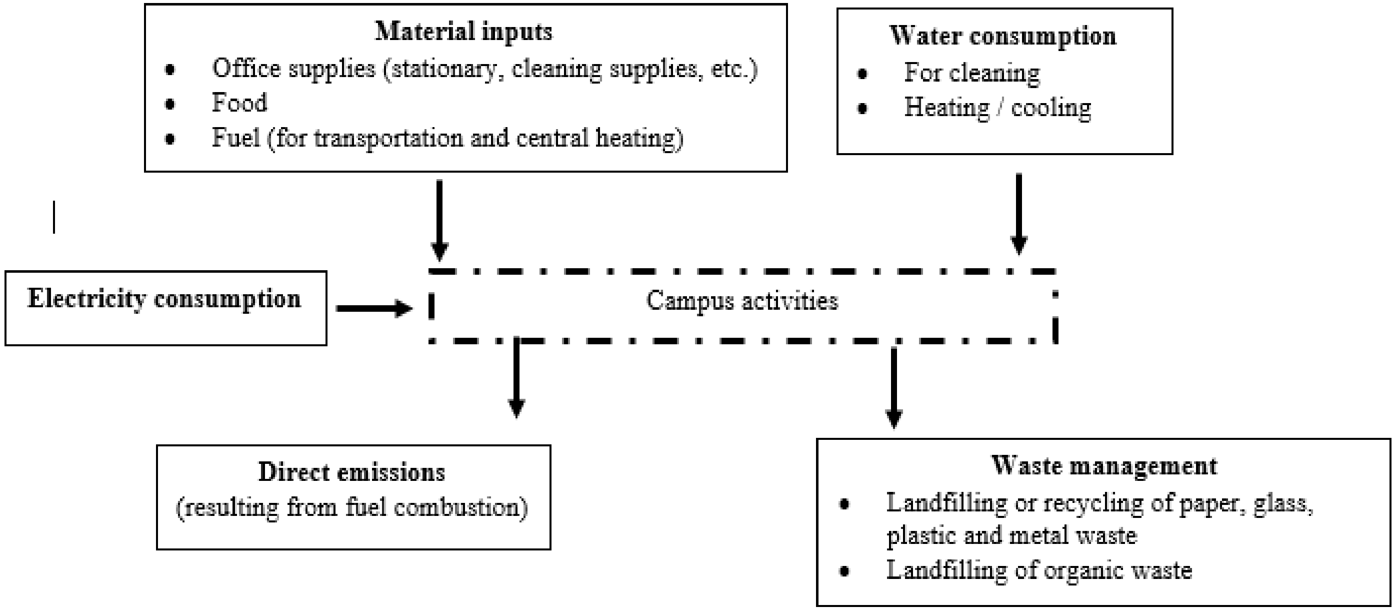
- A life cycle assessment methodology was used, meaning that **the impacts of the solution methods themselves were also taken into account** throughout their lifecycle.

- Environmental impacts of the campus were calculated by considering **scope 3 type inputs** such as food or cleaning supplies in addition to **scope 1** (fuel for heating) and **scope 2** (electricity purchased) type inputs.

- Improvement strategies were not kept limited to the structural or operational features of the buildings – instead, **strategies that aim at improving the user behavior were also included.**

METHODOLOGY PT.1: LCA

- CCaLC software
- Ecoinvent 3.0 database
- CML 2001 method



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CASE STUDY

- The campus used for the case study is that of Izmir University of Economics (IUE), where this study was conducted. It is located in the Balçova district of Izmir.

- As of 2023, IUE has a total of 10,408 students, 580 academicians and 224 administrative staff working full time. There are 8 faculties, 3 vocational schools and 1 graduate education institute and 33 undergraduate, 24 vocational, 27 graduate and 7 doctorate programs. The total campus area is 38,000 m^2.

METHODOLOGY PT.2: BUDGET OPTIMIZATION

- Knapsack problem: The knapsack problem is a classic optimization problem in computer science and mathematics. It is named after the idea of packing a knapsack with items of different values and sizes. In the knapsack problem, the analyst is given a set of items, each with a certain value and weight. **The objective is to maximize the total value of the selected items while ensuring that the sum of their weights does not exceed the capacity of the knapsack**
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- v_i shows the value of each item "i", while w_i shows their weight. P indicates the total capacity of the backpack, and x_i is the binary decision variablead

$$max \sum_{i=1}^{n} v_i x_i$$

$$s.t \sum_{i=1}^{n} w_i x_i \leq \mathrm{P}$$

$$x_i \in \{0,1\}$$

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METHODOLOGY PT.2: BUDGET OPTIMIZATION

- Modified Knapsack problem: In this work, **the weight of each item is replaced by the cost of the improvement strategies (c_i), or solutions; the value (benefit) of each item is replaced by the GWP mitigation potential of each solution (B_i);** and the capacity of the backpack is replaced by the total budget available for impact mitigation solutions (TB).
- One deviation from the standard equation shown earlier is that **in our model not all the solution suggestions are binary**, i.e. one of them may be implemented at different rates. In the model below, the non-binary solution is shown with the index number 1 and y denotes the continuous decision variable.

$$max \sum_{i=2}^{5} x_i B_i + y B_1$$

$$s.t \sum_{i=2}^{5} x_i c_i + y c_1 \leq \text{TB}$$

$$x_i \in \{0,1\}, 0 \leq y \leq 1$$

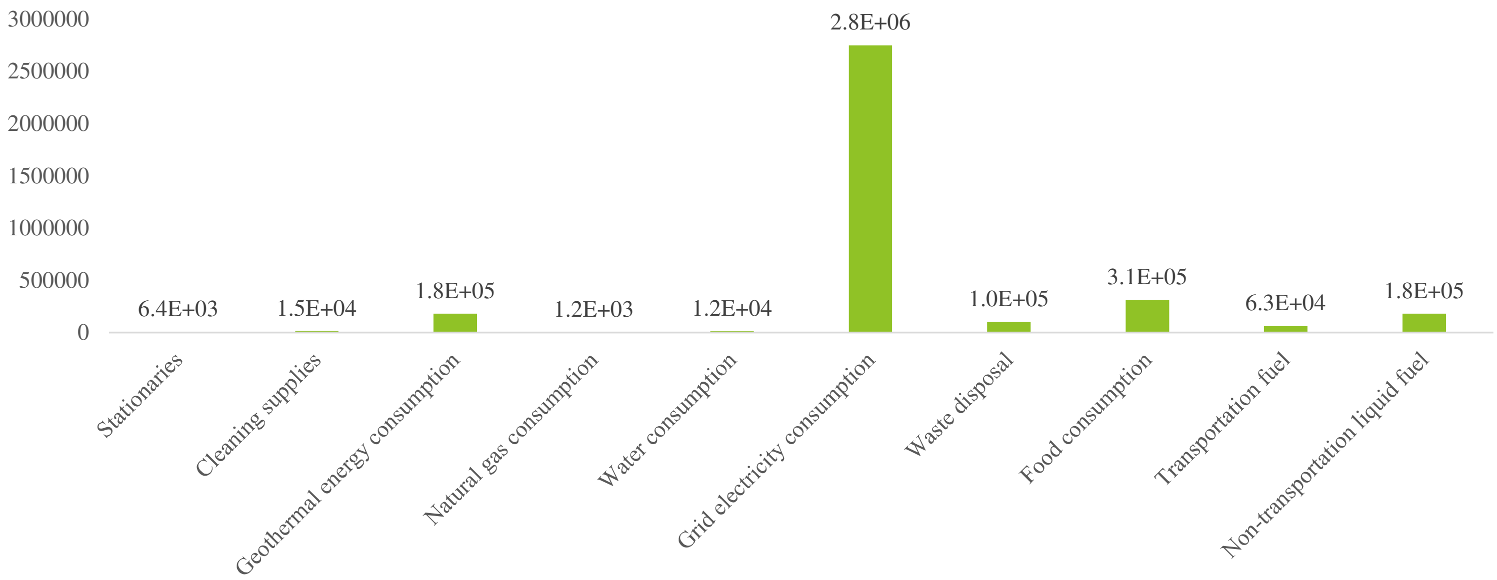
IMPACT MITIGATION STRATEGIES

- Installing photovoltaic solar panels on rooftops where available (S1)
- Installing a rainwater harvest system in the campus (S2)
- Replacing the rector’s office’s vehicle by an electric vehicle (S3)
- Having an only-vegetarian menu in the university cafeteria once a week (S4)
- Installing smart waste separation systems across the campus (S5)

BENEFIT-COST CALCULATIONS

- For each impact mitigation strategy, or solution, the costs ($) and benefits (kg$CO_2$eq.) were calculated over a 5-year period.
- Benefits define the impact reduction potential of implementing a particular strategy.

LCA RESULTS



Activity	Percentage contribution to GWP
Stationaries	0.18%
Cleaning supplies	0.42%
Geothermal energy consumption	5.01%
Natural gas consumption	0.03%
Water consumption	0.34%
Grid electricity consumption	75.74%
Waste disposal	2.86%
Food consumption	8.61%
Transportation fuel	1.75%
Non-transportation liquid fuel	5.05%

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BUDGET OPTIMIZATION RESULTS

Budget ($)	Values of the decision variables					Total reduction in GWP over a 5-year period ($kgCO_2eq.$)	% reduction in annual GWP
	y (S1)	x_2 (S2)	x_3 (S3)	x_4 (S4)	x_5 (S5)		
4,000	0.07	0	0	1	0	392862.5	2.2
10,000	0.17	0	0	1	0	612068.8	3.4
20,000	0.33	0	0	1	0	977412.5	5.4
40,000	0.67	0	0	1	0	1708100.0	9.4
60,000	1.00	0	0	1	0	2438787.5	13.4
80,000	1.00	1	0	1	0	2442399.8	13.5
120,000	1.00	0	0	1	1	2471282.8	13.6
160,000	1.00	1	0	1	1	2472369.8	13.6
200,000	1.00	1	0	1	1	2472369.8	13.6
204,000	1.00	1	1	1	1	2473130.8	13.6

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BUDGET OPTIMIZATION RESULTS

- **The most preferred solution with a binary decision variable is the vegetarian menu option (S4),** not because of its impact mitigation potential but **because it has no cost**. Thus, for all budgets the decision variable of that particular option turned out to be 1.

- **The least preferred solution is the electric vehicle option (S3),** which was only included in the solution set when the budget was increased to its maximum value ($204,000).

- **The critical budget values seem to be $40,000 and $60,000** where the percentage reduction **in the annual GWP of the campus rises from 5.4% to 9.4%, and then 9.4% to 13.4%,** respectively.

- Any **further increase in the budget beyond $60,000 has no significant effect** as far as impact reduction is concerned.

BUDGET OPTIMIZATION RESULTS

- If we perform a basic economic analysis by converting the avoided GWP into monetary quantities using the monetary valuation approach and taking the monetary valuation coefficient of climate change as 0.104 €/kgCO2eq., we would obtain the economic benefit of a $60,000 investment as approximately $284,000 over a five-year period, by neglecting the time value of money.
- When one also considers the external benefits of impact mitigation actions, such as improved credit score and improved stakeholder perception, the particular solutions developed in this work are almost certain to return a net economic benefit to the university.

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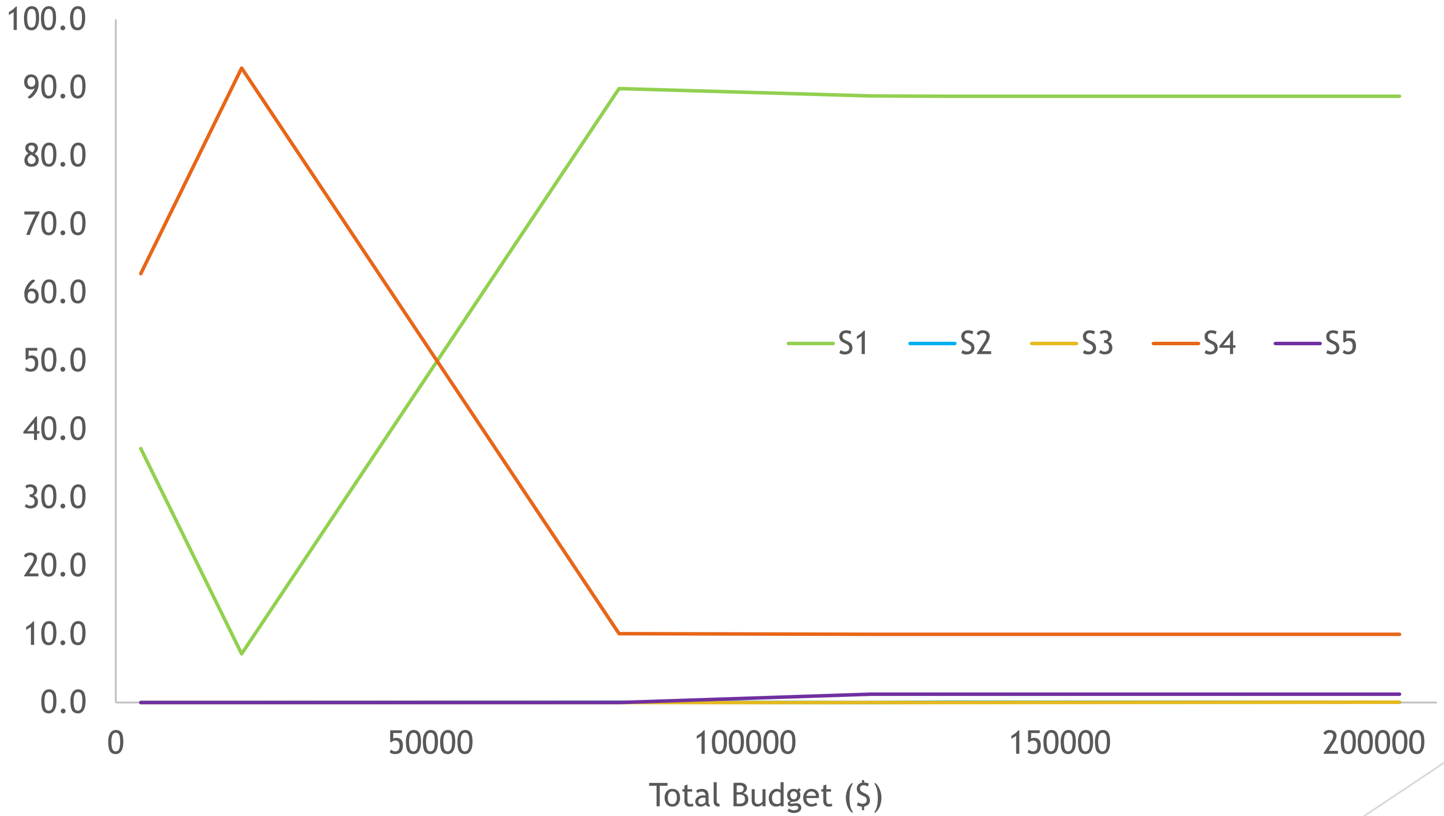
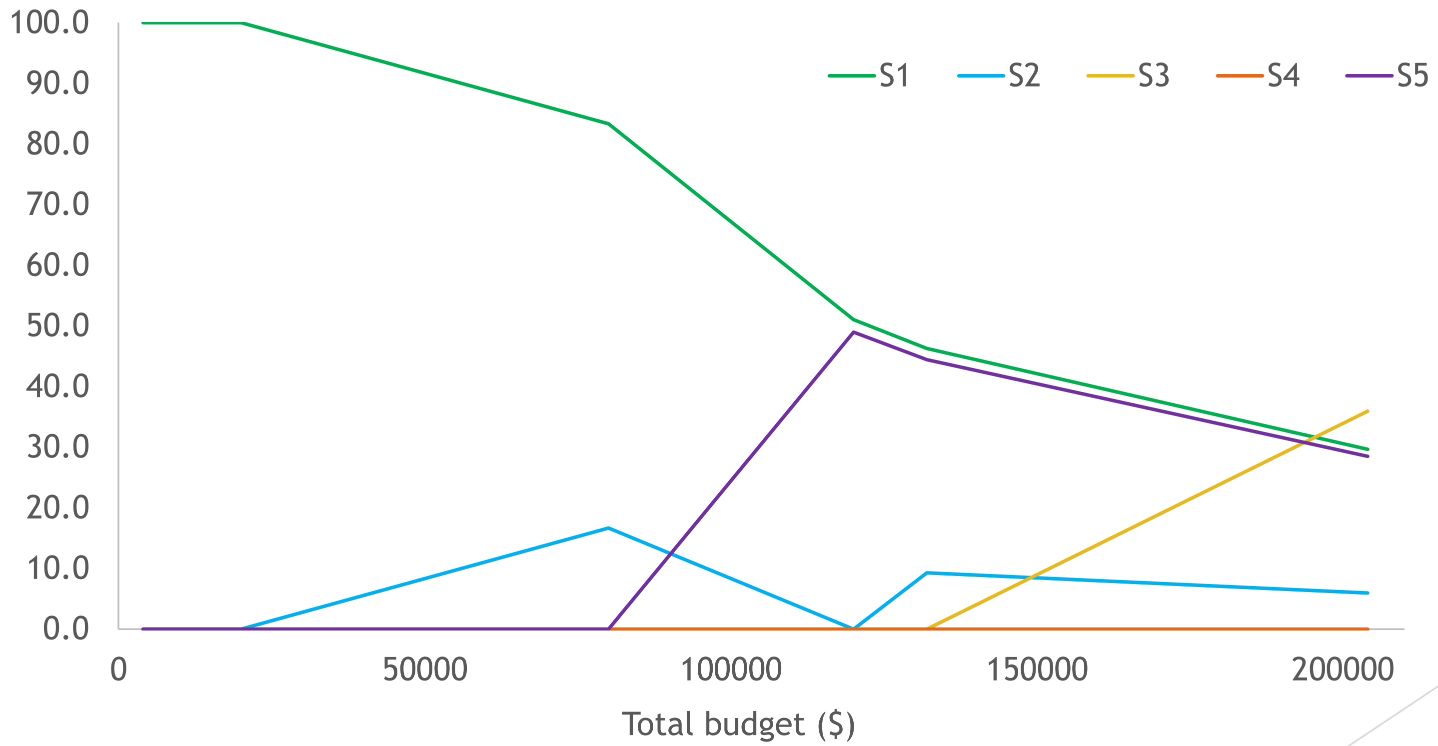
Percentage shares of the solutions within the total GWP avoided as a function of budget



Percentage shares of the solutions within the total budget as a function of budget



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What happens at the maximum budget?

Solution method	Share in the GWP avoided (%)	Share in the total budget (%)
S1	88.74	29.66
S2	0.04	5.93
S3	0.03	35.93
S4	9.98	0.00
S5	1.21	28.48

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What do the results mean?

- The most cost-effective solutions appear to be S1 (PV installation) and S4 (vegetarian menu option), and the least cost-effective solution turned out to be S3 (electric vehicle).

- It should be kept in mind that under different circumstances the distributions would have been entirely different. Thus, one should not jump to the conclusion that photovoltaic panel utilization is always a more effective GWP mitigation strategy compared to electric vehicle utilization.

- As indicated in the earlier sections of this paper, the numerical data presented in the Results section has no generally representative value; as all the benefit, cost, and budget values are specific to Türkiye, IEU, and the solution methods chosen.
- The authors would like to reiterate that it is the combined LCA-budget allocation optimization methodology that is the main output of this work, and the results are merely those of a particular case study.

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CONCLUSIONS

- The study's significant **contribution is the development of a method and model for impact mitigation** using optimization and LCA methodology.
- The approach can be applied to **resource-and-energy-intensive systems like universities, hospitals, and public buildings,** potentially leading to regulatory implications and incentive mechanisms.
- Future improvements include **considering additional environmental impacts beyond GWP, and exploring optimization techniques such as Greedy Algorithms, Dynamic Programming, or Metaheuristic Algorithms** to handle the complexity of the knapsack problem.

THANK YOU FOR LISTENING!

ANY QUESTIONS?

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