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

EYLÜL ŞENÖZTOP

Thesis for the Master's Program in Industrial Engineering

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EYLÜL ŞENÖZTOP

THESIS ADVISOR: ASSOC. PROF. DR. FEHMİ GÖRKEM ÜÇTUĞ

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ETHICAL DECLARATION

I hereby declare that I am the sole author of this thesis and that I have conducted my work in accordance with academic rules and ethical behaviour at every stage from the planning of the thesis to its defence. I confirm that I have cited all ideas, information and findings that are not specific to my study, as required by the code of ethical behaviour, and that all statements not cited are my own.

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ABSTRACT

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Şenöztop, Eylül

Master’s Program in Industrial Engineering

Advisor: Assoc.Prof. Dr. Fehmi Görkem Üçtuğ

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With the increasing concern on carbon footprint in recent times, many businesses have started to calculate and take measures to reduce the carbon footprint of their products. Universities, which host several people and activities and therefore are energy-and-material-intensive locations, are suitable places for calculating the total carbon footprint within the framework of life cycle assesment. In this study, the total carbon footprint of İzmir University of Economics Campus was calculated by considering stationary and cleaning materials, geothermal, natural gas, water, electricitiy, waste, food and fuel for transportation and nontransportation. The life cycle inventory data was obtained from the University administration and was entered into the CCaLC2 program which utilizes Ecoinvent 2 database and CML2001 method. The annual carbon footprint of the campus was calculated as 3,630,803 kg CO_2eq. The biggest contribution with a share of 75.74% comes from electricity consumption. As the second stage of the project, five solution proposals were examined in order to reduce the total impact. A cost-benefit analysis was made for five proposals separately and an optimization study was carried out by modeling the system in order to choose the most effective budget-based method. For this analysis, a mixed integer programming mathematical model was developed using Cplex program and budget-based solution proposal combinations were obtained for various budgets. This study is considered to be valuable contribution to the existing literature in the sense that it provides a useful tool which combines life cycle assessment and budget optimization for the comparative analysis of environmental impact mitigation scenarios.

Keywords: budget allocation, carbon footprint, life cycle assesment, optimization, university campus

ÖZET

ÜNİVERSİTE KAMPÜSÜNÜN ENERJİ VERİMLİLİĞİNİ ARTIRMAK VE SERA GAZI EMİSYONLARINI AZALTMAK İÇİN BÜTÇE TAHSİSİ ENİYİLEME TEKNİĞİNİN KULLANILMASI

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Son günlerde önemi giderek artan karbon ayak izi kavramıyla birlikte birçok işletme, ürünlerinin karbon ayak izini azaltmak için hesaplamalar yapmaya ve önlemler almaya başladı. Birçok kişiyi ve etkinliği barındıran ve bu nedenle enerji ve malzeme açısından yoğun lokasyonlar olan üniversiteler, yaşam döngüsü değerlendirmesi çerçevesinde toplam karbon ayak izini hesaplamak için uygun yerlerdir. Bu çalışmada, İzmir Ekonomi Üniversitesi Yerleşkesinin toplam karbon ayak izi, kırtasiye ve temizlik malzemeleri, jeotermal, doğal gaz, su, elektrik, atık, gıda ve ulaşım ve ulaşım dışı yakıtlar dikkate alınarak hesaplanmıştır. Yaşam döngüsü envanteri verileri Üniversite yönetiminden alınmış ve Ecoinvent 2 veri tabanı ve CML2001 yöntemini kullanan CCaLC2 programına girilmiştir. Kampüsün yıllık karbon ayak izi 3.630.803 kg CO_2eq. olarak hesaplanmıştır. En büyük katkı %75,74 pay ile elektrik tüketiminden gelmektedir. Projenin ikinci aşaması olarak toplam etkiyi azaltmak için beş çözüm önerisi incelenmiştir. Beş çözüm için ayrı ayrı maliyet-fayda analizi yapılmış ve bütçe bazında en etkin yöntemin seçilmesi için optimizasyon çalışması yapılmıştır. Bu analiz için Cplex programı kullanılarak karışık tamsayı programlama esaslı matematiksel bir model geliştirilmiş ve çeşitli bütçeler için bütçe bazlı çözüm önerisi kombinasyonları elde edilmiştir. Bu çalışma, çevresel etki azaltma senaryolarının karşılaştırmalı analizi için yaşam döngüsü değerlendirmesi ile bütçe optimizasyonunu birleştiren yararlı bir araç sağlaması açısından mevcut literatüre değerli bir katkı olarak değerlendirilmektedir.

Anahtar Kelimeler: bütçe, karbonayakizi, yaşam döngüsü değerlendirmesi, optimizasyon

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CHAPTER 1: INTRODUCTION

Global warming is a phenomenon that has been observed on earth for a very long time, almost since the 1850s. The main reasons are human activities, fossil fuels and the increase of greenhouse gas in the earth's atmosphere (Anon., 2023). For this reason, 1.5°C more temperature increase awaits us, especially in the near future. This situation will affect many ecosystems and people, as well as cause great danger and risks for the climate (Pörtner et al., 2022). These climate risks such as temperature change, precipitation instability and desertification will create vulnerability for many countries and sectors (Anon., 2019). That is, to define and summarize this climate change in general, it is the change in climate models caused by greenhouse gas emissions caused by human activities. This gas contains mostly compounds such as carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O) (Fawzy et al., 2020) When all these terms and concepts are considered together, another term emerges, "carbon footprint". One of the most popular and important issues of recent years is the carbon footprint. In fact, most articles define it as a buzzword since the concept was introduced. This explains the fact that this concept has been on the agenda since its emergence. The concept of "footprint" was first used and coined by William Rees and Mathis Wackernagel. They explained this concept as the effects of people's production and consumption activities (East, 2008). According to the article of Durojaye et al., although there is no definitive agreement on the measurement or quantification of carbon footprint it is the gas emission associated with the production and consumption activities of people, and it is a definition that is especially important for climate change (Durojaye et al., 2019). It cannot be said that this is definitely the definition. Therefore, there are some methods for its measurement. For example, examining the greenhouse gas effects of CO_2 emissions is a common resource used in carbon footprint calculations (Pandey et al., 2010). Since there is no fixed definition, the scope actually emerges at this point, such as what should be included and what should not be. It is important to determine what should be included in the calculations and to form the boundaries correctly. There is another concept that needs to be emphasized here, which is life cycle assessment (LCA). LCA is a method that is accepted worldwide, adheres to standards and examines the environmental effects of products and processes in detail. It is a very comprehensive method and unlike the carbon footprint, it is determined within the framework of ISO 14040 and ISO 14044 standards. Only in this way is it possible to examine the environmental effects of a product system. Although not included in our project, economic and social impacts can also be examined (Uysal et al., 2022). Despite the fact that there is such a comprehensive method with its standards in the background, the term carbon footprint is more on the agenda. Because this concept has broader appeal, it is catchy and more common. While the carbon footprint is simpler and easier to calculate, things get more complicated when considering LCA and many calculations have to be included in the process. These calculations are the use and emissions of multiple sources from different processes, different places and times, as well as the environmental impact of these processes. This is where the power of LCA actually comes from; the perspective is so broad and environmental issues are being studied so widely (Bjørn et al., 2018). LCA which is the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle is considered to consist of 4 steps. First one is the goal and scope. This stage is for defining the objective and setting boundaries. Because irrelevant parts should not be here and calculated. Second step is the inventory analysis. It is the stage of compiling inputs such as raw materials and energy and outputs such as waste and other emissions for each process of the analysis. The third stage is impact analysis, which is argued to be the most important. It is the grouping of emission and resource effects by measuring loads in the inventory analysis. Climate change, eutrophication, acidification or stress on ecosystems can be one of these effects. The last stage is the interpretation stage. It is the stage where the results of both the inventory and impact analysis stages are questioned. At the same time, it is proof that the purpose of the study has been achieved to answer the questions (Hellweg, 2014) (Jacquemin et al., 2012).

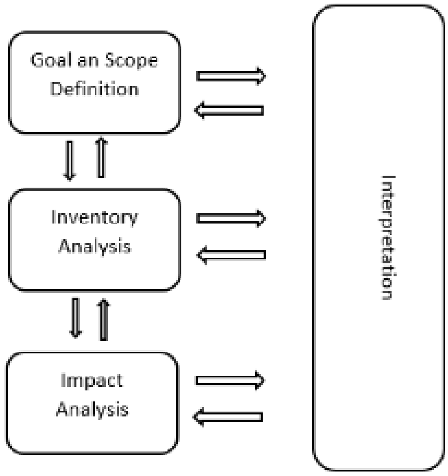

Figure 1. Life Cycle Assesment Framework

Each of these stages is not fixed and dependent on a specific procedure. For example, there are methods that can be followed during the collection of inventories. Suh and Huppes summarized these methods in their article as follows. First of all, there are two approaches to the calculation; process flow diagram and matrix inversion. By evaluating these methods, input-output analysis is carried out, the data is summarized and compared with the existing software, and finally, conclusions are drawn and future inferences are made by discussing whether they comply with the standards (Suh and Huppes, 2005) According to the Crawford et al. article, process analysis and input-output analysis are considered traditional during inventory collection, and these methods are also used in most life cycle analyzes. However, there is also a new method, which consists of using these two methods together in a hybrid way to reduce the limits to a lesser extent. Not only for narrowing the boundaries, for manipulating the input-output analysis process data alone this does not always provide an accurate model (Crawford, 2008). In addition to the different methods used, approaches have also changed over time. In their article, Steffen et al. also emphasized that collecting data in life cycle analysis requires labor and time, so they tried to prevent complexity and data density by using 5 approaches during the collection of these data. These are the parametric approach, modular approach, automation, aggregation/grouping, and screening. Among them, automation has been the best for simplification. They also underlined that these analyzes can now be carried out easier and faster with automatic data collection and artificial intelligence (Kiemel et al., 2022). There are some points to be considered in the impact analysis as well. Hauschild et al. gave details of this stage in their article. For example, the impact category should parallel the definition of scope, and inventories should be classified according to impact categories. Impact categories also characterized the impact profile of the product system. At the same time, there may be environmental impacts, as well as social and economic impacts (Hauschild, 2018). It is much easier to examine environmental effects because the effects can be seen in a quantitative way. However, social impact is much more difficult, both in terms of demonstrability and as it is not a quantitative measure. Nevertheless, in the article by Dreyer et al., impact categories representing workers' rights were examined (Dreyer et al., 2010).

A study with life cycle assessment will be much more efficient and realistic than an analysis with any emission coefficient due to the features and advantages mentioned above. For this reason, the annual carbon footprint calculation for the Izmir University of Economics Balçova Campus, which is such a populous location, is provided by the life cycle assessment. Afterwards, the solution proposals for reducing this calculated carbon footprint were considered from an economic and environmental point of view, and emission reductions that could be achieved with budget examples could be seen.

CHAPTER 2: LITERATURE REVIEW

2.1. Literature Review for LCA

Especially in these days, when studies on measuring and then reducing carbon footprint for various products and services are gaining momentum, several universities across the globe have also chosen to calculate their total impact. The fact that case studies are carried out especially in some universities is both instructive in calculating the carbon footprints of other universities and universities will be able to see their situation more clearly by making comparisons between each other. Especially in the study of Kiehle et al., the carbon footprint calculation of the University of Oulu was performed to set an example for other schools (Kiehle et al., 2023). The Carbon footprint of Chile The University of Talca (UT) has been examined annually on the basis of 3 types of objectives with its 5 campuses since 2012. These purposes are direct, indirect and other indirect emissions. For the first purpose, fuel consumption for heating and transportation, and for the second, electricity can be given as an example to the limits. DEFRA (Department for Environment, Food, and Rural Affairs—Gov. UK) data was used and the analysis was performed in accordance with ISO 14064 and the GHG Protocol. When the results are analyzed, it is as follows: The estimation of the CF in Scope 1 and Scope 2 were 2 0.03 tCO_2eq. and 0.25 tCO_2eq. per person per year, whereas scope 3 emissions were found to be 0.41 tCO_2eq. per person. The highest contribution to these results was seen as the transportation of the students included in scope 3 (Yañez et al., 2020). Another study was performed at Birla Institute of Technology in India. In this study, direct emissions such as electricity, heat or steam and other indirect emissions were examined in 3 scopes. To give an example of each, fuel is for scope 1, electricity is for scope 2 and waste, capital, chemicals, electronics, water, food are for scope 3. Although scope 3 is the widest, it was found that electricity consumption with a share of 50% has the highest impact. In modeling the emissions in the study, Umberto NXT Universal software is used with ISO 14064 standards and Ecoinvent v3.0 database. Apart from the dataset for Europe, methods such as survey and EMU, CPU *Estate management unit (EMU), #Centralized purchasing unit (CPU) were used to collect data. University campus, the famous Intergovernmental Panel on Climate Change (IPCC) was used for the carbon footprint assessment of BITS Pilani.

Global warming potential (GWP) assessed with a time horizon of one hundred years. Also other universities are evaluated for comparison in the study, one of them is the University of Leeds which has 30,761 undergraduates and 6938 postgraduates. The university also contains 7144 members of staff (Sangwan et al., 2018). In the article titled "Exploring the applications of carbon footprinting towards sustainability at a UK university: reporting and decision making", the main purpose of the study is to find solutions for campus greening efforts. Scopes are categorized as direct emissions, emissions from purchased electricity and indirect emissions. It was seen in the results that the highest effect was seen in scope 3 with 51%, therefore CF which derived with the GHG Protocol's guidance has been examined by giving importance to the 3rd scope. What is included in the scope 3 are; transport, capital goods, waste, energy. To measure the emissions of these goods and services, they must also take into account the entire life cycle. The most suitable methods for this are environmentally extended input output (EEIO) and process analysis (PA).One of the originality of the study is that it was also compared on a faculty basis, in this case, the highest effect was food and drink in one faculty and paper in another faculty. Making such a comparison will ensure that separate mitigation actions are taken for each faculty in the future (Townsend and Barrett, 2015). In the article by Clabeaux et al., the carbon footprint of Clemson University's campus was calculated using the life cycle assessment approach for comparison with other universities. Only the data for three quarters in line with the academic term were examined. Scope 1 covers direct GHG emissions experienced on campus, Scope 2 covers upstream emissions from electricity generation, Scope 3 covers indirect emissions. Upstream emissions were estimated under the use of open LCA 1.7 with Ecoinvent database version 3.3 or gleaned from literature. For calculation of effects of these GHG emissions, firstly HLCA approach used with the 100- year time horizon GWP based on the values defined in the IPCC Fifth Assessment Report (AR5) the total CF was expressed in CO_2eq. emissions. When the results were examined, it was seen that the highest greenhouse gas emission was observed due to electricity production with a share of 41%. The total values are as follows; 95,000 metric tons of CO_2eq., and 4.4 metric tons of CO_2eq. per student (Clabeaux et al., 2020). The study, which took place at Yale University, included all purchased goods and services, including electricity because indirect GHG emissions from procured goods and services are the greatest source of the university's emissions. Only categories such as food & beverages, miscellaneous, other unallowables, prepaid expenses, and subsidies were excluded from this analysis. Economic input-output-LCA (EIO-LCA) was used to estimate the GHG effect of items. All expenses incurred using this method were collected and classified. As a result of all analyses, it was seen that power generation and supply has the highest contributions to global warming potential (Thurston and Eckelman, 2011). In the paper titled "Investigating the Carbon Footprint of a University - The case of NTNU", the authors applied an Environmental Extended Input Output (EEIO) model to calculate the Carbon Footprint (CF) of the Norwegian University of Technology and Science (NTNU). The evaluations were carried out again within 3 scopes and as a result, a carbon footprint of 4.6 tons of CO_2eq. per student was found. Data of combustion of fuel and heating oil under scope 1, the purchase electricity and district heating within scope 2, and all other purchases of goods and services data were evaluated within scope 3. Standardized NACE industry classification was used to examine all the data in the 3rd scope, which means Statistical classification of economic activities in the European Communities and were evaluated separately on the basis of faculty (Larsen et al., 2013).

A comparison of the studies summarized above can be found in Table 1 below:

Table 1. Comparison of the study of LCA in various universities across the World

Area of study	**Functional Unit**	**Environmental Impact**	**Approach/ Method**	**Hotspot**
Clemson University	three quarters in line with the academic	95 000 metric tons CO_2eq., and 4.4 metric tons CO_2eq. per student	streamlined LCA	electricity generation (41%)
University of Leeds	3 quarters of campus activity	For the year 2010/11, the UoL's CF was 161,819t CO_2eq.	process analysis (PA) Environmentally Extended Input Output Analysis	Since scope 1 and 2 data unavailable food and drink (82% of emissions)
Chile The University of Talca (UT)	Annually	Scope 1 - 0.03 tCO_2eq. Scope 2 - 0.25 tCO_2eq. Scope 3 - 0.41 tCO_2eq. per person per year	ISO 14064 and the Greenhouse Gas (GHG) protocol	Transportation of the students included in Scope 3
Birla Institute of Technology	Annually	Total of 16500 t CO_2eq. (metric tons of CO_2eq. of GHG emissions	Umberto NXT Universal software is used with ISO 14064 standards and Ecoinvent v3.0 database	Electricity with 50%
Yale University	Annual GHG emissions since 2003 Between 2003 – 2008 average	Total 325,000 MTCO_2eq.	Economic input-output-LCA (EIO-LCA)	Power plants % 62
Norwegian University of Technology and Science (NTNU)	Yearly	Carbon Footprint (CF) 92 kilotonnes of CO_2eq. CF per student 4.6 tonnes of CO_2eq. CF per employee 16.7 tonnes of CO_2eq.	Environmental Extended Input Output (EEIO)	Electricity with 13216 kg CO_2eq.

2.2. Literature Review for Knapsack Problem

The concept of optimization describes the process of finding the best possible solution to a problem. In mathematics, this process usually refers to maximizing or minimizing the value of a function under given constraints (Tezel Özturan, 2019). The solution methods will also vary according to the type of this objective function and constraints. For example, if f (x) and the constraints are linear, there is linear programming, If f (x) is a quadratic polynomial and the constraints are linear, it is quadratic programming, If f (x) and the constraints are nonlinear, there is nonlinear programming. Berberler claimed that Backpack (Knapsack) problems can be integer or 0-1 in terms of decision variables. Assuming that each of the items to be put in the backpack has a weight and value, and the backpack has a certain capacity, this capacity can be called a one-dimensional Knapsack problem only in terms of weight. However, if this model has more than one constraint, such as the weight and volume of the bag, this is an example of a multidimensional Knapsack (Berberler, 2009). There are variations of the knapsack problem, such as the fractional knapsack problem and the multiple knapsack problem, which introduce some degree of continuity or complexity into the problem, but they are still primarily discrete optimization problems rather than linear or nonlinear programming problems. Many studies for 0-1 Knapsack problems and their variations have been made since the 1950s. It is possible to diversify the method that has been used for such a long time in terms of species. For example, the varieties mentioned in the article by Cacchiani et al. are; Multiple Knapsack problems, Multidimensional (vector) Knapsack problems, Multidimensional geometric Knapsack problems, Quadratic Knapsack problems, Online Knapsack problems (Cacchiani et al., 2022). In Lust and Teghem's study, Knapsack and its multidimensional version were discussed in terms of multi-objective in order to find the appropriate solution set. Meanwhile, metaheuristic approaches such as pareto local search were also used (Lust and Teghem, 2012). Kellerer and Strusevich examined the Symmetric Quadratic Knapsack Problem and Half-Product Problem, which they saw as problems for Boolean nonlinear programming. In the article, firstly, the algorithm they wanted to develop for a scheduling problem in 2004 was mentioned, and then the last point of the work with the studies on it was explained (Kellerer and Strusevich, 2012). In their study, Christensen et al. examined the classic bin packing example, which is a type of Knapsack and whose purpose is to create the minimum number with binary variables, within the framework of online algorithms such as geometric bin packing, vector bin packing (Christensen et al., 2017). In the study of Laabadi et al., the Multidimensional Knapsack Problem (MKP) has been investigated in many ways. The aim is to maximize the total profit while complying with all the constraints as in the classical Knapsack. In addition, since it is a review for MKP, it is a guide for both researchers and practitioners (Laabadi et al., 2018). Container Loading Problems (CLP) are a set of well-known combinatorial optimization problems in the logistics industry and are solved based on the Knapsack problem. In the study of Silva et al., constraints such as Single Large Object Placement Problem (SLOPP), which is a specific problem, and multiple containers were examined and sensitivity analysis were performed. Thus, when the constraints such as transportation cost and the number of stops for each container are taken into account, it will be easier to examine the problems from a multidimensional perspective (da Silva et al., 2020). Another logistics application is cutting and packing. Meanwhile, the products placed in the container do not have to be completely straight. In real life, these materials often have irregular shapes. For this reason, it is possible to see examples in real life and there are already examples of this in the literature. For this problem, which is also accepted to be a knapsack problem, Leao et al. examined studies that include a metaheuristic approach (Leao et al., 2020).

There are examples of optimization studies in the literature for carbon footprint reduction and solution proposals that will provide environmental benefits. In the article titled "Life Cycle Optimization of Extremely Low Energy Dwellings" , an optimization method was developed for lower energy consumption by optimizing the energy use, environmental impact and financial costs of buildings throughout their life cycle. Since all analyses of the building were evaluated with benefit-cost, concepts such as multi-objective optimization, genetic algorithm and pareto were discussed. Insulation materials, installation systems and payback periods were examined for low energy purposes (Verbeeck and Hens, 2007). In the study by Üçtuğ and Yükseltan, a linear programming approach was used for the optimization of budget allocation and some solutions such as the use of photovoltaic panels, the use of double-layered glass instead of normal glass, the switching of goods to A energy level instead of C energy level, the change of light bulbs to reduce electricity usage were examined. A model was created for these suggestions using the Lingo program and evaluated for low, medium and high budgets. While facilities such as window glass and light bulbs give the best results for a low budget, it has been seen that the most benefit is obtained from photovoltaic panels as the budget increases (Üçtuğ and Yükseltan, 2012).

As seen in the literature, there are many studies on LCA and on Knapsack. These studies are both guiding on how analyzes can be carried out and instructive for understanding the concepts. It is possible to use both cases for specific cases and adapt them on a project basis. Because there are limits for every project and LCA is carried out according to these limits. It is also possible to offer solutions in line with the results obtained and to evaluate these solutions. Optimization is a method that can be adapted to all areas of life and developed to get the most efficient result. It can be used in every field as well as to choose the most correct solution.

Table 2. Comparison of Studies that used Knapsack Problem

ARTICLE	FIELD	GOAL	COST – BENEFIT	SOLVING METHOD
Towards Multiple Knapsack Problem Approach for Home Energy Management in Smart Grid	Home Energy Management	To maximize benefit and user comfort – minimize electricity bills	The weight of each object is the energy consumed by appliances in each time slot The value of the object in a specific time slot is the cost of power consumption of the appliance in that time slot	Solve multiple knapsack problems (MKP) using heuristic algorithms ant colony optimization (ACO) (Rahim, 2015)
Knapsack problem-based control approach for traffic signal management at urban intersections:	Traffic	to manage the green light duration autonomously following the queue length for each road lane	arrival time could be considered as weight and the number of vehicles as a value	Timed Synchronized Petri Net (TSPN) SUMO simulation (Elidrissi, 2020)

Increasing smooth traffic flows and reducing environmental impact				
Optimal selection of energy efficiency measures for energy sustainability of existing buildings	Sustainability of existing buildings	Maximizing the energy saving	Value - the amount of CO_2 (kg) that will be saved by using technology Weight - cost of technology	CPLEX 12.1 solver with MATLAB Greedy algorithms for heuristic (Tan, 2016)
Optimal allocation of carbon credits to emitting agents in a carbon economy	Carbon Emissions	Carbon credit allocation problem	Carbon credit has weight and cost	Greedy algorithm (Arava, 2010)
Power Allocation Optimization as the Multiple Knapsack Problem with Assignment Restriction	Power	Optimization of power allocation	Profit – value Size – weight	ZIMPL (Morimoto, 2017)

As can be seen in Table 2, there are studies using knapsack to reduce the carbon footprint. For this reason, if we list the most important differentiating aspects of our study in items;

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

For the reasons described above, this particular study is considered to be novel and to make a significant contribution to the existing literature.

CHAPTER 3: BACKGROUND AND MOTIVATION OF STUDY

There are many examples of LCA, they can be done or studied differently considering the 4 stages. Even if it is done exactly the same way, this study has a different originality as long as it is done for different places or for different processes. For example, in our study, it is planned to calculate the carbon footprint of İzmir University of Economics Balçova Campus with the life cycle analysis method and to examine the economic and environmental dimensions of the actions aimed at reducing the carbon footprint. However, there are many LCA studies that have been examined in the university campus so far. The study will take place in two stages, as the name of the project suggests. The first stage is the LCA study and analysis of the data using the CMI 2001 method and the CCaLC2 application, the second stage and the part that will ensure the originality of the study is an optimization in which maximum benefit can be achieved with a budget-oriented perspective. In other words, the carbon footprint will be examined as a benefit and it will be a very good budget allocation example.

In this study, we selected the Izmir University of Economics Balçova campus as a case study and made calculations for the resources used and examined the situation with the LCA approach. However, the aim here is not only to calculate or reduce the effects of IEU, but also to prepare a guiding resource for locations like campus that are found very common in the World. Since all calculations will be explained in detail in the methodology section, this study is actually adaptable to all desired situations. The first stage, the LCA, was examined in the widest scope (Scope 3) and the stages were determined. Since these stages are very understandable and simple, in addition to resources such as electricity and water, the total carbon footprint can be calculated by including each stage that is thought to have a great impact on the carbon footprint. The optimization example in the second stage of the study can actually be increased in terms of solution suggestions. For example, in our study, the most effect comes from electricity and a photovoltaic solution proposal is considered. It can be seen from here that the study does not have to be applied exactly when it is desired to be used in other large-scale buildings. In addition, since the budget will be a constraint that changes the situation, the cost of the solution proposals will be important as well as the environmental benefits.

Another purpose of this study is that when the LCA is concluded, the effects from the sources will be seen clearly and in a way, it is to raise awareness in the use of resources. For example, in our study, the effect from electricity is clearly seen. Although it is aimed to reduce these effects with the solution proposals developed, in fact, these solutions can be reduced by using less resources with awareness without the need for solutions. Even if there is no optimization study, as in our study, measures to reduce the impact will definitely be taken. Switching to an efficient lighting system for electricity reduction as a result of an LCA inspired by our project will be our gain.

CHAPTER 4: METHODOLOGY

4.1. Collection of DATA and LCA

Izmir University of Economics has been operating since April 14, 2001 and is located in Izmir Balçova. The annual number of students of Izmir University of Economics is 10,408 and 580 academicians and 224 administrative staff work 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 square meters.

Figure 2. Campus of İzmir University of Economics

Figure 3. Campus of İzmir University of Economics

It is important to determine the boundaries and stages in order to enter the data in the LCA process, which is the first stage of the study. First, what would be included in the system was determined and data was started to be collected accordingly.

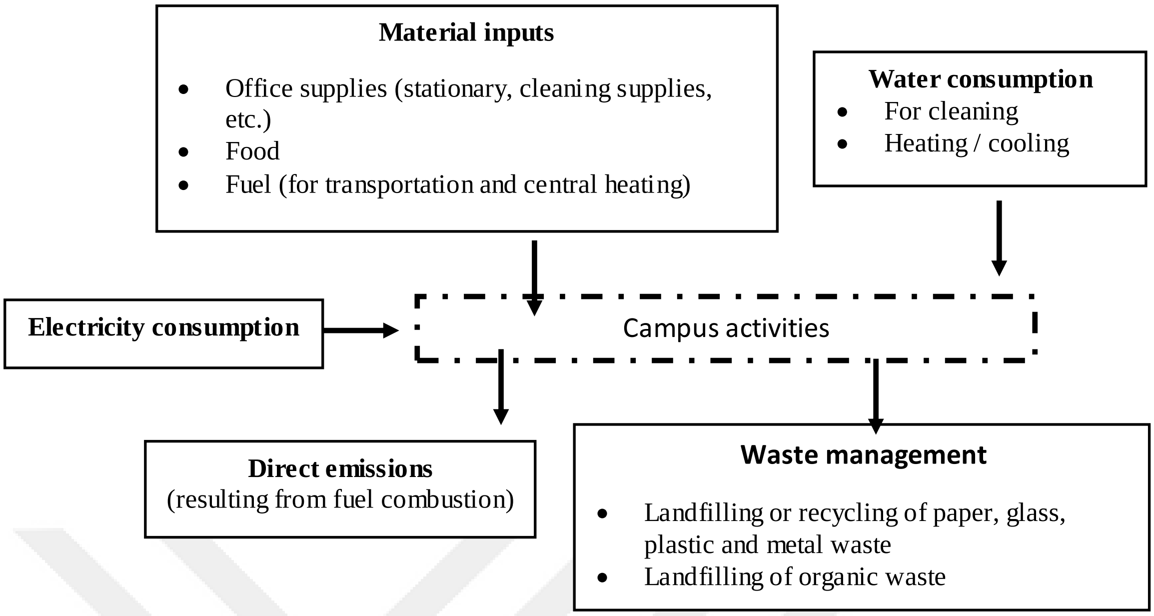

Figure 4. System Boundries for LCA Study

Data collection covers the entire year of 2022. Calculation of the carbon footprint was realized by using CCaLC2 software which utilizes the Ecoinvent2 database and CML2001 method. Within the scope of the study, 10 stages were determined and the data were processed into the CCaLC2 program so that the impact of each stage on the campus could be seen.

Figure 5. CCaLC2 modeling for all stages

Table 3. Inventory Table for LCA

Stage	Inputs	Amount	Ecoinvent dataset
	Sunflower Seed Oil	5293.44 kg	Vegetable oil (sunflower seed) , conventional, DE
	Ayran	4200 kg	User Defined (Üçtuğ et al., 2021)
Food	Honey	420 kg	honey, small glass jar UK - 43 g
	Reddish Shell Bean	120 kg	Red Kidney Beans(500g)
	Capia, Banana, Green Pepper	1542 kg	Pepper, IT
	Chocolate	190 kg	Chocolate, GH
	Breast of Veal	2226 kg	Beef Cattle, CA
	Dill	144 kg	User Defined (Anon., n.d.)
	Kashar Cheese	306 kg	Cheese Mild Cheddar, packed, UK
	Frozen Potato	1920 kg	Potato chips, frozen, conventional, DE
	Frozen Broccoli, Spinach, Pepper, Okra, Artichoke, Cauli…	9714 kg	Vegetables, conventional, frozen, DE
	Tomatoes	3780 kg	Tomatoes, conventional, UK
	Tomato Paste	1296 kg	User Defined (Üçtuğ et al., 2023)
	Frozen Chicken	286.1 kg	Chicken Meat, frozen, DK
	Meat Cubes	1251.6 kg	Lamb meat(lowland) organic, UK
	Frozen Cherry	6 kg	Vegetables, conventional, frozen, DE
	Cream	102 kg	Cream, conventional, DE
	Golden Apple	300 kg	Apples, golden, delicious, loose, Spain
	Starking Apple	3000 kg	Apples
	Dried Beans	288 kg	Haricot Beans (500 g)
	Hazelnut	12 kg	User Defined (Anon., 2023)
	Carrot	3228 kg	Carrot, batons (670g)
	Coconut	6 kg	User Defined (Anon., 2023)
	Fine Bulgur	504 kg	User Defined (Anon., 2023)
	Semolina	276 kg	User Defined (Anon., 2023)
	Thyme, Chili Pepper, Salt, Mint	1064.4 kg	Spices and Salt
	Zucchini	936 kg	Zucchini, IT
	Baking Powder	6 kg	Soda, powder, at plant
	Crumbs Bread	144 kg	Bread Crumbs
	Cocoa	51 kg	Cocoa Powder, GH
	Celery	240 kg	Root crops

Kiwifruit	84 kg	Kiwi, NZ
White Cabbage	600 kg	Cabbage(white) conventional, DE
Red Cabbage	1812 kg	Cabbages
Aubergine	30 kg	Aubergine, IN
Chickpea	468 kg	Chickpeas (500g)
Potato	4644 kg	Potatoes conventional, DE
Milk UHT	6276 L	Milk, whole, UHT (1 litre)
Peach Juice	120 kg	Fruit juice, DE
Bulghur	1230 kg	User Defined (Anon., 2023)
Ketchup	273.48 kg	User Defined (Anon., 2022)
Red Lentil	864 kg	Red Split Lentils (500 g)
Sausage	144 kg	Cured meat, sausages
Yoghurt	15120 kg	Yogurt, conventional, DE
Pasta varieties	2250 kg	Pasta, organic, DE
Pasta Spaghetti	468 kg	Pasta, Spaghetti (2 kg)
Mushroom	624 kg	Mushroom, packed, market value (750g)
Margarine	282 kg	Margarine
Lettuce	3486 kg	Lettuce, fuel heated, CH
Maize Starch	300 kg	Maize Starch at plamt
Mash	336 kg	Prepared meals mash potato(425g)
Garden Orach	306 kg	User Defined (Anon., 2022)
Garlic	10.8 kg	Garlic, UK
Oranges	2148 kg	Oranges
Biscuitte	206.4 kg	Biscuitte and Crackers
Leek	780 kg	Leek, NL
Rice	3156 kg	Rice
Roll Bread and Pastry	2822.4 kg	Bread Rolls, conventional, DE
Cucumber	708 kg	Cucumber
Onions	3084 kg	Onions
Butter	108 kg	Butter
Lemon and lemon sauce	1800 kg	Lemon juice (concentrated), IT
Olive oil	420 L	Olive oil (1 litre)
Eggs medium (30*1)	828 kg	Eggs organic medium
Fresh Yeast	24 kg	Yeast paste from whey at fermentation
Green Lentils	288 kg	Green lentils canned in water (410 g)
Flour	3138 kg	Wheat Flour conventional, DE
Granulated Sugar	1980 kg	Sugar from cane granulated

	Sesame	79.2 kg	User Defined (Anon., 2023)
	Pickles	62 kg	User Defined (Anon., 2023)
	Black Olive	144 kg	User Defined (Espadas-Aldana et al., 2019)
	Sujuk	134.4 kg	Sausage smoked conventional, DE
	Black – eyed Bean	96 kg	User Defined (Anon., 2022)
	Garden Rocket	30 kg	User Defined (Anon., n.d.)
	Peanut	18 kg	User Defined (Anon., 2023)
	Powder Dessert	424.8 kg	sugar from sugar beet at the sugar refinery + modified starch
	Dried apricots	2.4 kg	User Defined (Anon., 2023)
	Parsley		User Defined (Anon., 2023)
	Mayonnaise	225 kg	User Defined (Anon., 2023)
	White Cheese –	162 kg	Cheese conventional, DE
	Toast Cheese	1202 kg	
	Pomegranate Syrup	453.6 kg	User Defined (Anon., 2023)
	Chicken Tenderloin Breast	1980 kg	Chicken Breast Fillets Market Value
	Rice Flour	18 kg	User Defined (Anon., 2022)
	Chicken Tenderloin	624 kg	Chicken Meat Organic Butcher ,DE
	Vinegar	825 kg	User Defined (Anon., 2023)
	Soy Sauce	96 kg	User Defined (Anon., n.d.)
	Pastry Oil	24 kg	Vegetable oil organic DE
	Battery	49.7 kg	User Defined (Hamade et al., 2020)
	CD + DVD	168 kg	User Defined (Egeland-Jensen, 2021)
	Corrugated	103 kg	User Defined (Anon., n.d.)
Stationary	Paper (A4, A3, Flipchart..)	4270 kg	Paper: Inkjet, A4, extra white (90 gsm, 500 sheets)
	Pilot Pen	13.5 kg	User Defined (Kähkönen, 2020)
	Sheet Protector	260 kg	Polyethylene(PE) 100% recycled HDPE or LDPE
	Folder	213 kg	PVC calendered Sheet
	Scissors	4 kg	User Defined (Ulrich, 2020)
	Sellotape	38.6 kg	User Defined (Moes, 2017)

	Staple	9.8 kg	User Defined (Spencer, n.d.)
	Staples	7.74 kg	Steel Product Manufacturing, average metal working
	Eraser	0.99 kg	Synthetic Rubber Production
	Wood Pencil	0.96 kg	User Defined (Anon., 2014)
Cleaning	Toilet Paper, Paper Towel	27800 kg	Cellulose Fibre, Inclusive Blowing in, at plant
	Bin Bag	198 kg	Polypropylene (pp) fibre
	Soap	2700 kg	Soap, at plant
Geothermal	Geothermal	1.09×10^7 MJ	User Defined – Geothermal Energy in Turkey (Atilgan and Azapagic, 2016)
Natural Gas	Natural Gas	1.92×10^4 MJ	Natural Gas (Burned)
Water	Water	3.86×10^7 kg	Tap water, at user, Europe
Electricity	Electricity	1.90×10^7 MJ	User Defined (Atilgan and Azapagic, 2016)
Waste	Domestic Waste	70790.8 kg	Landfill, municipal waste,3

Transportation Fuel	Diesel	16778 kg	Diesel, at regional storage, Europe
	Gasoline	642 kg	Gasoline
Non-transportation Fuel	Diesel	1275 kg	Diesel, at regional storage, Europe
	Fuel Oil	50000 kg	Heavy Fuel Oil, at regional storage, Europe

The first of these categories is stationary materials used on campus. The data were obtained from the purchasing unit and entered directly for the existing materials in the database, and for the non-existent ones, they were found from the literature or tried to be provided by calculating the mass data of their raw materials. Paper consumption is undoubtedly the highest item here as far as mass-based inputs are concerned. The second category is the materials used for cleaning purposes in the campus. The data here was also provided by the school's purchasing department. The majority of them here are cellulose, which is in the structure of materials such as toilet paper and towel paper. Although there are important factors in these two categories, their effects do not constitute even 1% of the total damage. Detailed list is available in the inventory table.

Another category is geothermal. Since this energy is data specific to the region where the campus is located, it is not an item that will be valid in all studies. Since the Izmir University of Economics campus is located in Balçova, which has important geothermal resources, geothermal energy in Turkey, which is found in the literature, has been added to the CCaLC2 database. Details to be seen in Appendix 1 The total amount of geothermal used for 1 year was found to be 1.09×10^7 MJ which equals to 3,028,372 kWh from the sources at the school. The fourth category is natural gas, although most of the heating is provided by geothermal, natural gas is used in the culinary arts department. According to the data provided by the school (Appendix B), 5320 kWh, that is, approximately 19,152 MJ of energy, is used in a year. Natural gas (burned) character factorization in the CCaLC2 database and this amount were entered into the system and the total carbon footprint was found as a result of the calculations. The fifth category is water consumption, the data is obtained from the Izsu invoices of the university in m^3 as can be seen in the Appendix C. 38,641 m^3 of water was entered into the system in kg, at the same time, a total carbon footprint calculation was provided by using 3.19×10^{-4} kg CO_2eq. for tap water, Europe. The sixth category is the electricity used in the campus. One-year consumption data obtained from the campus has been entered into the system (Appendix D). As a characterization factor, electricity consumption data in Turkey, which was obtained from the literature, was added (Atilgan and Azapagic, 2016). As a result, the total carbon footprint value of the electricity used in the campus has been calculated as 2.75×10^6 kg CO_2eq. The seventh category is waste. Studies are already being carried out for waste separation within the scope of zero waste on the campus of Izmir University of Economics. Wastes are collected by being sorted into recyclable, domestic waste, medical waste, motor oil, vegetable oil. An agreement is reached with companies for all waste groups except domestic waste and delivered to these companies for recycling or disposal. Therefore, the only type of waste for which it is responsible in terms of carbon footprint is domestic waste. For this reason, data belonging to domestic waste were processed into CCaLC2 database as landfill- municipal waste and calculation of annual carbon footprint amount was provided.

Table 4. Distribution of Waste Amount in İzmir University of Economics

Mixed (Paper,Glass,Plastic,Metal)	52,706.9 kg
Non-Recycled (Domestic Waste)	70,790.8 kg
Medical Waste	966.9 kg
Engine Oil	591 kg
Vegetable Oil	250 kg
Total Waste Amount	125,305.6 kg

Categories eight and ninth are for fuel, but since data are provided for transport and non-transport, their contribution to the LCA cycle is also examined separately. To start with the transportation, annual diesel and gasoline usage amounts were obtained from the University administration. Then, the total carbon footprint was found by multiplying the emission factors and the amounts separately (https://ghgprotocol.org/, n.d.) while the emission amounts in kg were found by using the fuel densities.

To summarize all these calculations, for example, annual usage data for gasoline is given as L by the university. Afterwards, the emission factors for the fuel used were found in gal from the literature. Therefore, since 1 gal is 3.8 L, necessary conversions were made and the carbon footprint was found by multiplying by the emission factor. Meanwhile, the amount of fuel was found in kg by making use of the density of the fuel, and it was added to both the inventory table and the CCaLC2 raw materials stage.

= 855.88 / 3.8 = 225.23 gal

= 225.23 × 8.6 = 1,936.978 kg CO_2eq.

Table 5. Calculations of total CO_2 amount for transportation fuel

	Gasoline	Diesel
Amount of consumption	855.88 L = 225.23 gal	19738.42 L = 5,194.32 gal
Emission factor	8.6 kg CO_2eq./ gal	10.1 kg CO_2eq./ gal
kg CO_2eq.	1,936.978	52,462.64
Total CO_2	54,399.62	
Average density	0.75 kg/L	0.85 kg/L
Average amount (kg)	642	16,777

For all the data provided for the ninth category, non-transport fuel, the carbon footprint calculation is as in the Table 5. Since the fuel used is directly supplied in kg, values are entered into the system without the need for any additional calculations.

Table 6. Calculations of total CO_2 amount for non-transportation fuel

	Fuel Oil	Diesel
Amount of consumption	50,000 kg	1,500 L = 394.74 gal
Emission factor	11.8 kg CO_2eq./ gal	10.1 kg CO_2eq./ gal
kg CO_2eq.	155,574	3,986.84
Total CO_2	159,561	
Average density	not necessary	0.85 kg/L
Average amount (kg)	50,000	1275

The last category is the carbon footprint from food. For this purpose, data on all annual usage on kg basis were obtained from the catering company responsible for the school's cafeteria. In addition to the items in the CCaLC2 database, there were many items found in the literature in foods. It is the stage with the highest data entry among all the stages in the study.

4.2. Knapsack Problem

As the second part of the project, after the data entry is performed in accordance the LCA method and the impact results are obtained, an optimization study was carried out to reduce these impacts. The most suitable method to be used for this is the Knapsack algorithm. The Knapsack is based on obtaining the optimum efficiency from the available data and is one of the most discussed problems in the operations research literature. If Knapsack is explained with a simple example that is close to real life; a thief can put items up to a certain weight in his Knapsack. At home, things have weights and values, the thief should leave the house in the most optimal way and fill his bag accordingly. As can be seen in the table, each of the items in the house has a weight and the backpack has a capacity. For this reason, it should be filled in such a way that it does not exceed the capacity of the bag, so that the highest values are taken at the same time and the process is completed in the most efficient way.

Table 7. Example for Knapsack consept

Item	**Weight**	**Price**
1	4 kg	2 ₺
2	2 kg	3 ₺
3	3 kg	6 ₺
4	2 kg	2 ₺

To summarize and generalize the method briefly; n items, whose values and weights are known, should be optimally packed into a finite-capacity backpack. As can be seen in the modeling, v_i shows the value of each item "i", while c_i shows their weight. B indicates the total capacity of the backpack (Karsu, 2018).

$max \sum_{i=1}^{n} vi\, xi$

$s.t \sum_{i=1}^{n} cixi \leq B$

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

In our project, the weight of each item is replaced by the cost of the solution strategies whereas the value of each item is replaced by the emission mitigation potential of each strategy. Our solution suggestions can be compared to the items in the backpack problem, the benefit it will provide to the value of the item, and the cost to be spent on the solution proposal to the weight. Because since the budget allocation will be examined, the constraint here will actually be the costs of the solutions. Unlike in our project, all solution proposals will not be considered binary. As will be explained in the solutions section, a continuous variable will be defined for the photovoltaic and will be included in the system in this way. In other words, the model and logic in our project will be as follows, b can be thought of as the notation for benefit and W can be thought of as costs.

$max \sum_{i=1}^{n} bi\, xi + y\ 0.1299$

$s.t \sum_{i=1}^{n} Wixi + (y\,\frac{0.32}{3.6}) \leq Budget$

$xi \in \{0,1\}, y > 0$

4.3. Development of Solutions

We have come up with 5 solutions designed to reduce the carbon footprint of the campus after all analyses have been carried out. First one is photovoltaic panel utilization, as a result of the data obtained from the school, this is one of the most obvious improvements, since the use of electricity is very high. The second one is building a rainwater harvest system installation. The water cycle is also important to us since we are in an environment where many people use in common, such as the campus. It is one of the improvements that seem very logical, especially since it is aimed to use this water in the siphon system. Another solution is the utilization of electric vehicles. The use of electric vehicles will be very beneficial for us, especially considering the passenger vehicle- because we have only one used within the borders of the campus annually. Another solution is waste separation, which is one of the easiest and common method when it comes to sustainability. We take this one step further and aim to establish a smart waste deposit system so that it will attract people's attention and the parsing process will be more successful. The final solution is vegetarian menu option. In the campus cafeteria, meals are served in a normal menu. There are studies showing that the carbon footprint is reduced with a vegetarian menu (Üçtuğ et al., 2021). Therefore, this method, which does not require any cost as the cost of replacing meat-based foods by vegetable-based foods of the same calorific content will actually be negative, will be very useful to us. However, switching to mostly-vegetarian menu will likely face cultural resistance as the staff and students alike will expect to eat at least one meat-based dish every day. For this reason, it was decided that vegetarian menu shall be served only once a week.

4.3.1. Photovoltaic panel utilization

Photovoltaic systems emerged as a high-tech product after the 1950s, and these systems can work anywhere where there is sufficient sunlight (Güçlüer, 2011). In its simplest definition, the system that generates electricity from the sun with solar panels is called photovoltaic panel. The sun rays falling on the solar cells transform directly into direct current. It is usually positioned on the roofs, at the top of the structures, so that the photons can reach the panel clearly. Some materials are used on the panels to convert solar energy into electrical energy. Systems designed with these semiconductor materials use the sun's rays. The resulting voltage creates an electric current (Anon., n.d.). One of the reasons why this solution comes to mind for the project is the difference between electricity and photovoltaic. It can even be seen from the CCaLC2 database that there is an emission reduction of 0.1299 kg CO_2eq./MJ when the photovoltaic solution is selected instead of Turkish grid electricity. When expressed as a percentage, an impact reduction of 90.2% is achieved. Another reason is that Izmir University of Economics is located in Izmir. As can be seen from the solar map of Turkey below, it is one of the provinces that receive the most sunshine in Turkey which means that it is one of the most suitable places to install a photovoltaic system (Anon., 2020).

Figure 6. Solar radiation durations by city in Turkey (Source: (Anon., 2020))

For this method, primarily market research was conducted and panels applicable to the campus were examined. The recommended current price for the panel with 400 W power and 1984×1007×40 mm dimensions is 4,750 TL (Anon., n.d.). After the price research, it is necessary to find the amount of energy we can use in the area to be established, so we found the annual radiation value for İzmir University of Economics in İzmir Balçova as 1,496 kWh/m^2-year (Anon., n.d.).

Table 8. Sun Exposure Time and Radiation Value for İzmir

City	Sun Exposure Time (hour-year)(hour-year)	Radiation Value (kWh/m^2-year)
İzmir	2,986	1,496

A = unit panel price per m^2= 2,400 TL/m^2

B = annual energy production per unit area = 1,496 kWh/ m^2 year

C = system life = 5 years

D = energy production from unit area throughout system life (5 years) (kWh/ m2)

This campus, located in İzmir- Balçova, is in question to be relocated, so all the investments to be made will be calculated so that the campus life is 5 years.

$B \times C = D = 1{,}496\ kWh/\ m^2\ year \times 5 = 7{,}480\ kWh/\ m^2$ **(1)**

$$\frac{A}{D} = \frac{2400\,\frac{TL}{m2}}{7480\,\frac{kWh}{m2}}$$

E = A/D = price per energy to be gained (TL/kWh) = 0.32 TL/ kWh **(2)**

According to all these calculations, in this case, energy production and cost became directly proportional to each other. For example, as a result of the investment of 3,200 TL to be made in the panels, the energy to be produced in 5 years will be 10000 kWh.

If we can define y as energy savings in MJ and W_5 as cost investment for photovoltaic panels this equation can be made;

y = energy saving in MJ for the system = W_5 /E × 3.6 = W_5 /0.32 × 3.6 **(3)**

F = characterization factors difference of electricity and photovoltaic solution (from CCaLC2 Data)

= 1.44×10^{-1} kg CO_2eq./ MJ - 1.41×10^{-2} kg CO_2eq./ MJ = 0.1299 kg CO_2eq./ MJ

G = total usable roof area = 625.72 m^2

W_{max} = max budget for the system = G × A **(4)**

= 625.72 m^2 × 2,400 TL / m^2 = 1,501,728 TL

y_{max} = max energy saving in MJ = Wmax/ E × 3.6

(5)

= (1,501,728 TL / 0.32 TL/ kWh) × 3.6 = 16,894,440 MJ

H = emission reduction(total benefit) for photovoltaic system = F × y_{max} **(6)**

4.3.2. Electric Vehicle Utilization

Many countries and governments have started incentive policies regarding the use of electric vehicles and support the production and adoption of this use. The reason for this is that by reducing the fuel use of electric vehicles, it reduces greenhouse gas emissions and alleviates the effects that cause climate change (Sierzchula et al., 2014).

If the use of these vehicles becomes widespread, it will help to reduce many problems such as environmental pollution, global warming and oil dependency (Liao et al., 2017). The contribution of these vehicles is such that with the increase in the number of vehicles until 2030, the carbon footprint will decrease by 1.6% (Üçtuğ, 2022). As these vehicles are so prominent all over the world and their effects are significant, it is impossible not to include them among the solution proposals for carbon footprint reduction. There are no shuttle vehicles that operate within the campus of Izmir University of Economics, since the campus does not cover a very large area. Due to the proximity of the buildings to each other, students can easily walk from one to another. However, there is a passenger vehicle that is used every day, which is the rector's vehicle. For the project, it has been assumed that this vehicle will be replaced by an electric vehicle. Some assumptions have been made about the distance traveled for annual use. Coming to school in total working days during the year and the average distance between home and campus is 20 km. As a result of these assumptions and the values found in the literature, emission reduction in fuel use and damage to the environment due to electricity use have been calculated. Thus, all factors were considered and calculated in order to reveal the total benefit.

4.3.2.1. Benefit

J = annual working day
K = number of departure-return by car in a year
L = average distance between home and school

M = total kilometers traveled per year = J ×K × L **(7)**
= 240 (annual working day) × 2 (departure and return) × 20 km (average distance between home and work) = 9600 km
N = fuel burned by the vehicle at 100 km in liter
AUDI A6 Gasoline Consumption / 100 km = 4.7 L (Anon., 2014-2023)
O = annual fuel consumption of the vehicle in kg = M × N /100 × I **(8)**
Annual AUDI A6 Gasoline Consumption = 451.2 L = 0.45 m^3 = 369.984 kg
I = density of fuel in kg/m^3 = 820 kg/ m^3
P = emission factor of fuel (Diesel) = 8.6 kg CO_2eq. / gal
R = annual emission reduction for fuel in kg CO_2eq.= P × O **(9)**

= 8.6 kg CO_2eq. / gal × 1 gal/ 3.785 L × 1000L / m^3 × 1 m^3 / 820 kg × 369.984 kg = 1025.18 kg CO_2eq.

S = electricity consumption per km

T = annual total electricity consumption = S × M **(10)**

U = characterization factor of electricity in CCaLC2= 0.144 kg CO_2eq.

V = carbon footprint from electricity in MJ = T × U × 3.6 **(11)**

W = the annual emission reduction this system provides = R-V **(12)**

X = the total emission reduction this system provides (total benefit) = W × C **(13)**

X = Total Benefit =[R - (S × M × 3.6 J × U)] × 5

X = Total Benefit =[1025.18 kg CO_2eq. - (1680 kWh × 3.6 J × 0.144 kg CO_2eq.)] × 5 = 761 kg CO_2eq.

4.3.2.2. Cost

S = electric vehicles consume an average of 17.5 kWh per 100 km (Anon., 2021-2023)

a = electricity unit price per kWh = 1.74 TL / kWh

b = total electricity cost = M × S × a × C **(14)**

= 96 × 17.5 × 1.74 × 5 = 14,616 TL

While selecting the new vehicle, care was taken to ensure that it was the same brand as the old vehicle. This model has been chosen since it is seen that the AUDI e-tron model will be the most affordable when the range price comparison is made among all Audi vehicles.

Y = sales price of used car

Z = price of new car = AUDI e - tron = 2,802,249 TL (Anon., n.d.)

c = total cost of electrical vehicle system = Z + b - Y **(15)**

= Price of new car + 5 years of electricity cost - Sales price of used car

= 2,802,249 + 14,416 – 1,000,000 = 1,817,000 TL

4.3.3. Rainwater Harvest System Installation

The rainwater harvesting method is to collect and store the rainwater runoff from a surface for later use for various purposes. There are many reasons for doing this, for one rainwater is relatively clean and a free source of water. In addition, water control can be achieved completely in this way. This is a great opportunity, especially for regions with water constraints. Another primary reason is that it contributes to water saving. In addition, it will help prevent events such as flooding that can be caused by excessive rain. With this method, collected water can be used as the main water source as well as as an alternative to well and municipal water. This system has many benefits and is very simple to install. It can be applied to a new construction as well as to an existing structure very easily. In addition, since the structure of the system is flexible, it will be very suitable for expansion, restructuring and repositioning (Anon., n.d.). In this method, the following can be given as examples of how water is collected; collecting run-off from roofs and roads, collecting from local catchments, and capturing seasonal flood water from local streams (Sharma, 2022). For a simple rainwater harvesting system, collecting run-off can be said to be the first step for the system. The water collected with the help of pipes and gutters installed in large areas such as roofs is filtered into a tank located below or above the ground, and is stored. At the same time, it is pumped out for whatever purpose it will be used with the help of the pumps in the main tank. There are also systems with more complex structures (Anon., 2022).

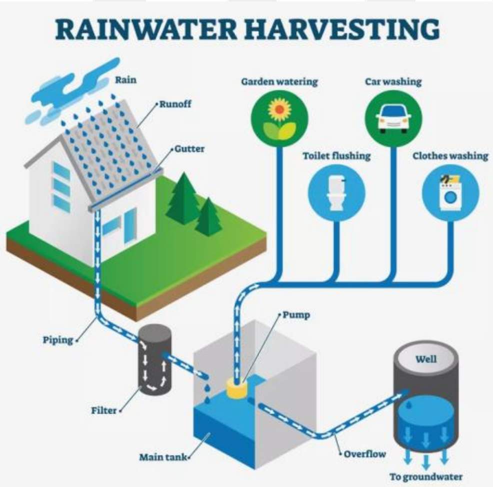

Figure 7. Rainwater Harvesting System (Source: Anon., 2022)

4.3.3.1. Benefit

As a first step, the relevant formula was used to find the amount of water that this investment will save us.

Rainwater yield = Rain Collection Area × Rainfall × Roof Coefficient × Filter Efficiency Coefficient (Anon., 2007-2023)

d = rain collecting area in m^2: It is the roof area of the blocks
e = rainfall in m: It is the total annual rainfall determined by the General Directorate of Meteorology
f = roof coefficient: It is the coefficient specified as 0.8 in DIN1989 by German standards. It means that all the rain falling on the roof cannot be recycled.
g = filter efficiency coefficient: It is the coefficient specified by German standards in DIN1989 (0.9). It is the efficiency coefficient of the first filter passed to separate the rain water obtained from the roof from the visible solids. It is a coefficient given by calculating that some amount of water cannot pass through here.
According to TUIK data, there is information that the annual average precipitation for the province of Izmir is around 700 mm, according to the 1938-2021 measurement values (Anon., 2020).

There is an article that we used as a reference for data such as roof area, tank size and materials used in the tank. Yan et al. conducted an LCA study to find the environmental impact of a tank used in a rainwater method. Starting from here, we also accepted the roof area of 1500 m^2, enough space for this is available on the campus of Izmir University of Economics. The reason for using a different area from the photovoltaic solution is that the entire area welded from various materials on the roof cannot be reserved for the panel. However, we do not have such a restriction for rainwater harvesting (Yan et al., 2018).

$$h = \text{annual rainwater yield in } m^3 = d \times e \times f \times g \quad \textbf{(16)}$$

$$= 1500\ m^2 \times 0.7\ m \times 0.8 \times 0.9 = 750\ m^3$$

Since this system is designed for 5 years, we will save 3750 m^3 of water in total. This means that we will save on the carbon footprint caused by 3,750,000 kg of tap water. However, there is also a harm that the materials to be used in the meantime will cause to the environment. For this, a data analysis was made in the CCaLC2 program regarding the materials used and a value of 263 kg CO_2eq. was found.

Total carbon footprint for stage:	263	kg CO2 eq. / f.u.
Total water usage for stage:	0.00	m³ water / f.u.
Total water footprint (stress-weighted) for stage:	0.00	m³ water eq. / f.u.

Raw material	Amount (kg/f.u.)	CO2 eq. (kg/kg raw material)	CO2 eq. (kg/f.u.)	Water usage (m³/kg raw material)	Water usage (m³/f.u.)	Water footprint (stress-weighted) (m³ eq./f.u.)	Database section	Production stage
Aluminium (rolled, virgin)	1,37	10,5	14,3	0.00	0.00	0.00	CCaLC/Materi...	rain harvest sy...
aluminium oxide, at plant	0,380	1,24	0,470	0.00	0.00	0.00	Ecoinvent/Ma...	rain harvest sy...
Aluminium sheet	12,5	3,23	40,4	0.00	0.00	0.00	CCaLC/Materi...	rain harvest sy...
brass, at plant	0,140	2,46	0,344	0.00	0.00	0.00	Ecoinvent/Ma...	rain harvest sy...
carbon black, at plant	0,084	2,37	0,199	0.00	0.00	0.00	Ecoinvent/Ma...	rain harvest sy...
cardboard	10,0	0,540	5,40	0.00	0.00	0.00	UserDefined/...	rain harvest sy...
cellulose fibre, inclusive blowi...	0,090	0,368	0,033	0.00	0.00	0.00	Ecoinvent/Ma...	rain harvest sy...
ceramic tiles, at regional stora...	0,350	0,782	0,274	0.00	0.00	0.00	Ecoinvent/Ma...	rain harvest sy...
copper production, primary, EU	0,130	1,91	0,248	0.00	0.00	0.00	Ecoinvent/Ma...	rain harvest sy...
epoxy resin, liquid, at plant	0,010	6,73	0,067	0.00	0.00	0.00	Ecoinvent/Ma...	rain harvest sy...
flat glass, coated, at plant	0,160	1,09	0,175	0.00	0.00	0.00	Ecoinvent/Ma...	rain harvest sy...
metal product manufacturing, ...	0,470	1,87	0,879	0.00	0.00	0.00	Ecoinvent/Ma...	rain harvest sy...
natural rubber based sealing, ...	0,058	1,95	0,113	0.00	0.00	0.00	Ecoinvent/Ma...	rain harvest sy...
paper production, wood cont...	0,370	1,61	0,595	0.00	0.00	0.00	Ecoinvent/Ma...	rain harvest sy...
Polyamide (PA) 6 (Nylon 6)	3,00E-3	9,13	0,027	0.00	0.00	0.00	CCaLC/Materi...	rain harvest sy...
Polycarbonate	0,125	4,13	0,516	0.00	0.00	0.00	CCaLC/Materi...	rain harvest sy...
Polyethylene (PE), 100% recy...	42,0	0,910	38,2	0.00	0.00	0.00	CCaLC/Materi...	rain harvest sy...
Polyethylene terephthalate (P...	1,32	2,05	2,70	0.00	0.00	0.00	CCaLC/Materi...	rain harvest sy...
Polypropylene (PP) fibre	0,178	2,80	0,498	0.00	0.00	0.00	CCaLC/Materi...	rain harvest sy...
Polyurethane (PUR, PIR) rigid...	1,00E-3	4,17	4,17E-3	0.00	0.00	0.00	CCaLC/Materi...	rain harvest sy...
Polyvinylchloride (PVC) pellet...	1,02	0,190	0,194	0.00	0.00	0.00	CCaLC/Materi...	rain harvest sy...
printed wiring board, mounted...	0,550	266	146	0.00	0.00	0.00	Ecoinvent/Ma...	rain harvest sy...
ptfe	6,00E-3	9,60	0,058	0.00	0.00	0.00	UserDefined/...	rain harvest sy...
silicone product, at plant	0,099	2,71	0,268	0.00	0.00	0.00	Ecoinvent/Ma...	rain harvest sy...
silver, at regional storage	0,050	101	5,05	0.00	0.00	0.00	Ecoinvent/Ma...	rain harvest sy...
Stainless steel - hot rolled coil	1,62	3,23	5,23	0.00	0.00	0.00	CCaLC/Materi...	rain harvest sy...
zinc, primary, at regional stora...	1,00E-3	3,38	3,38E-3	0.00	0.00	0.00	Ecoinvent/Ma...	rain harvest sy...

Figure 8. CCaLC2 Calculation for Rainwater Harvesting System

Finally, the total benefit will be calculated as follows;

w = water savings over the life of the system in m^3 = h × C **(17)**

j = water savings over the life of the system in kg = 1000 × w **(18)**

k = characterization factor of tap water in CCaLC2 = 3.19×10^{-4} kg CO_2eq.

l = emission reduction of the system for water = j × k **(19)**

m = damage caused by the system to be installed to the environment from CCaLC2 calculation

n = total emission reduction (total benefit) of rainwater harvest system = l - m **(20)**

= j × k - m = water savings over the life of the system in kg × characterization factor of tap water in CCaLC2 - damage caused by the system to be installed to the environment from CCaLC2 calculation

3.19×10^{-4} kg CO_2eq. (from tap water) × 3,750 000 kg - 263 kg CO_2eq. = 1087 kg CO_2eq.

4.3.3.2. Cost

In order to reflect the reality of cost data and to prove the feasibility of the study, the actual price for 25 m^3 was taken from SFR Dış Ticaret A.Ş company in Turkey. The reason for accepting 25 m^3 is because of the article that we first inspired. Secondly,

the exact determination of the tank volume will be ensured by monitoring the precipitation amount in the mentioned location moment by moment. Meanwhile, we will also need data such as the amount of water consumed in the campus, how much water will enter the tank and how much water will come out. If the amount of water that will accumulate in the tank at any point is more than 25 m^3, it should be determined as the maximum value that will exceed the volume of the tank. In the same way, if the calculations say that the maximum amount of accumulation is less than 25 m^3 and the maximum amount is 20 m^3, for example, this should be accepted. In this study, since there is no value such as instantaneous precipitation and instantaneous consumption in the data, a generally accepted value is accepted. For this reason, the rainwater harvesting method is defined as binary in our model. As a result the change of tank volume is not integrated into this model, but future studies may take this into account. However, in this study, we will examine separately for 20 m^3 - 25 m^3 - 30 m^3 to see how the tank volume will affect the model and for sensitivity analysis.
o = cost of the rain harvest water system

The price for a 25 m^3 tank is taken as 15,000 Euro, the cost was determined as 300,000 TL by accepting the exchange rate as fixed and 20 TL. For the other two capacities, the 0.6 rule was accepted and prices were determined separately.

$COST_A = COST_B \times (\frac{CapacityA}{CapacityB})^{0.6}$ (Tribe and Alpine, 1986)

Table 9. Benefit- Cost Information for Capacity

Capacity	Benefit	Cost
20 m^3	-210 kg CO_2eq.	262,407 TL
25 m^3	-263 kg CO_2eq.	300,000 TL
30 m^3	-316 kg CO_2eq.	334,680 TL

4.3.4. Smart Waste Deposit System Installation

In fact, the deposit system is a technology that has existed for a long time. A deposit return scheme (DRS) for packaging is a system where consumers pay an additional amount for the packaging itself and receive a refund when they take it back. This can be done by means of a machine or manually. These machines are a more expensive option, but they have great advantages, they can use sensors and sort by brand, material type and color. The detailed description of the machine will be provided later. However, this system also has many positive effects even when applied manually. It is seen in the analyses made that this system results in an increase in the percentage of recycling without exception in all cases where it is applied. For example, in the table below, the dates when this system started to be used for 8 countries are given and the data showing how effective it was from 2006 to 2017 are added. In most countries there has been an increase, but two countries show a decreasing trend. The declining recycling rate in Estonia is due to the high percentage of this waste being incinerated for energy, while in Croatia this trend is the result of poor implementation of waste legislation as well as insufficient accurate reporting on packaging placed on the market (Anon., 2020).

Table 10. Recycling Rate according to Countries for Deposit System

Country	Implementation year	Return of PET bottles	Recycling rate change 2006-2017
Sweden	1984	84,9% (2016)	+11%
Finland	1996	92% (2016)	+67%
Denmark	2002	90% (2016)	+90%
Germany	2003	98% (2015)	+26%
Estonia	2005	87% (2017)	-21%
The Netherlands	2005	95% (2016)	+55%
Croatia	2006	87% (2016)	-18%
Litvania	2016	92% (2017)	+178%

Circular economy studies such as recycling, reuse and reducing use play an important role in adopting the zero waste concept. One of the projects emerging in this context is the machine deposit system. This system, which is completely a product of technology, is based on the conversion of waste into money or gift slips. First of all, customers pay a certain deposit when they buy a product that can be recycled, and it is returned to the machine after use. The post-refund system will provide a receipt for this deposit or equivalent to the money. The benefit of this system is undeniable because it not only contributes to the 3R principle, namely recycle, reuse and reduce, but also enables them to be produced less at the beginning of the producing process. On the other hand, since it prevents these wastes from mixing with the water ecosystem, it also prevents the negative situations that will occur here. The most important feature of this system is that it encourages people to use it by reducing human labor and giving money. This system also raises the awareness of climate change and the change in consumption habits will be the most important condition for achieving the goal of a sustainable future (Anon., 2021).

Figure 9. Machine for Deposit System (Source: Anon., 2021)

4.3.4.1 Benefit

Our university has paper, glass, plastic and metal boxes for recycling. However, waste distribution information is not available as a result of the data obtained from the school.

It is only known that the total waste of the university is 52706.9 kg. Therefore, based on the study of Tiew et al., we assume that of this amount, which is accepted as 30% of the total waste, 15.9% is paper, 0.7% is glass, 12.2% is plastic, 1.2% is metal waste by mass (Tiew et al., 2011). For example, we can find the amount of paper waste from the calculation of 15.9/30 × 52,707 = 27,935 kg. This is the amount of waste thrown into our recycling bin. There is also the amount of household waste that should be disposed of for recycling, and our solution will be effective at this point. Because the smart wasfte deposit system we will establish will benefit the environment by ensuring that the wastes that are discarded in the wrong place are disposed of in the right place. According to the article by Bozdoğan et al., 70% of university students apply recycling correctly, while 30% of them throw their garbage indiscriminately. In this case, if we go over the paper example again, the calculation of 27,935 kg × 3/7 will give us the amount of waste that should be recycled, but thrown into households (Bozdogan et al., 2016). The system to be established provides rewards when you ensure that these wastes are separated correctly, thus encouraging people to dispose of waste correctly. However, there will still be those who do not use the system. According to a report by PWC, it has been observed that this system works up to 50% accurately, especially in PET bottles, which will generate the most profit. Therefore, we accept the success rate of the system as 50% (PricewaterhouseCoopers et al., 2016).

The system was established, the students took care to dispose of the waste more accurately and the system achieved 50% success. However, there is another point to be considered here, which is how much of this waste that is properly separated can be recycled. These rates were accepted as 60% for paper (Sahin, 2016), 100% for metal (Anon., 2019) and glass (Anon., 2014), and 28% for plastic (Bakırcı, 2021), respectively. In fact, when we take all plastics as a basis, this rate drops to 9% on average. However, plastic waste for the school campus will mostly be waste such as plastic bottles. Therefore, the recycling percentage was taken as equivalent to PET recycle rate. All necessary calculations were made and data entry was provided in the CCaLC2 program. Amount to contribute after data entry is 5,994 CO_2eq. However, since this value is considered with annual waste data, the life of the project should be multiplied by 5 years. As a result the total contribution can be considered as 29,970 CO_2eq.

Table 11. Recycling Amount Calculation for CCaLC2

	Paper	Glass (kg)	Plastic (kg)	Metal (kg)
Amount in recyclable waste	27,935 kg	1,230	21,434	2,108
Recyclable amount in household waste	11,972 kg	527	9,186	903
With the success rate of the method %50	5,986 kg	264	4,593	452
Considering the Recycling Efficiency	3,592 kg	264	1,286	452
CCaLC2	1,436 packages	264	1,286	452

Total carbon footprint for stage:	5994	kg CO_2 eq. / f.u.
Total water usage for stage:	0.00	m^3 water / f.u.
Total water footprint (stress-weighted) for stage:	0.00	m^3 water eq. / f.u.

Raw material	Amount (kg/f.u.)	CO_2 eq. (kg/kg raw material)	CO_2 eq. (kg/f.u.)	Water usage (m^3/kg raw material)	Water usage (m^3/f.u.)	Water footprint (stress-weighted) (m^3 eq./f.u.)	Database section	Production stage
Glass-bottle (virgin)	264	0,912	240	0.00	0.00	0.00	CCaLC/Materi...	Stage 1
metal product manufacturing, ...	452	1,87	845	0.00	0.00	0.00	Ecoinvent/Ma...	Stage 1
Paper: Value A4 (75gsm, 500...	1436	1,49	2144	0.00	0.00	0.00	CCaLC/Materi...	Stage 1
PET resin (bottle grade)	1286	2,15	2765	0.00	0.00	0.00	CCaLC/Materi...	Stage 1
Total:	3438	Total:	5994	Total:	0.00	0.00		

Figure 10. CCaLC2 Calculation for Smart Waste Deposit System

a1 = total recyclable waste in kg

b1 = rate of paper waste

c1 = rate of glass waste

d1 = rate of plastic waste

e1 = rate of metal waste

f1 = amount of paper waste in kg = a1 × b1 **(21)**

g1 = amount of glass waste in kg = a1 × c1 **(22)**

h1 = amount of plastic waste in kg = a1 × d1 **(23)**

$i1$ = amount of metal waste in kg = $a1 \times e1$ **(24)**

$j1$ = rate of people separating waste carefully

$k1$ = recycle paper amount in domestic waste = $f1 \times j1$ **(25)**

$l1$ = recycle paper amount in domestic waste = $g1 \times j1$ **(26)**

$m1$ = recycle paper amount in domestic waste = $h1 \times j1$ **(27)**

$n1$ = recycle paper amount in domestic waste = $i1 \times j1$ **(28)**

$o1$= success rate

$p1$ = paper amount with succes rate = $k1 \times o1$ **(29)**

$r1$ = glass amount with succes rate = $l1 \times o1$ **(30)**

$s1$ = plastic amount with succes rate = $m1 \times o1$ **(31)**

$t1$ = metal amount with succes rate = $n1 \times o1$ **(32)**

$u1$ = recycle rate of paper

$u2$ = recycle rate of glass

$u3$ = recycle rate of plastic

$u4$ = recycle rate of metal

$v1$ = paper amount with recycling efficiency = $p1 \times u1$ **(33)**

$w1$ = glass amount with recycling efficiency = $r1 \times u2$ **(34)**

$x1$ = plastic amount with recycling efficiency = $s1 \times u3$ **(35)**

$y1$ = metal amount with recycling efficiency = $t1 \times u4$ **(36)**

$z1$= annual emission reduction (total benefit) of deposit system from CCaLC2 with v1,w1,x1,y1

$a2$ = emission reduction (total benefit) of deposit system from CCaLC2 with v1,w1,x1,y = $z1 \times C$ **(37)**

4.3.4.2 Cost

It was learned from a consultant firm that 4 systems would be sufficient for a campus the size of Izmir University of Economics and that one machine would cost 18,000

Euros. Here again, if the exchange rate is accepted as 20 TL, the cost of the system will be 1,440,000 TL. For this price, it has been negotiated with AcoRecycling company. AcoRecycling, a Turkey-based enterprise specializing in manufacturing high-tech and game-changing environmental solutions, offers a G-1 Smart Reverse Vending Machine (Anon., 2021).

a3 = cost of the smart waste deposit system installation

4.3.5. Vegetarian Menu Option

Although vegan and vegetarian nutrition, which has been frequently encountered in recent years, is actually applied as a health and life philosophy by most people, it also makes a great contribution to carbon footprint reduction. In the study of Üçtuğ et al., normal, vegetarian and vegan menu were compared in terms of carbon footprint. As can be seen visually from the chart below, the highest carbon footprint comes from the normal menu (Üçtuğ et al., 2021). When meat is removed from this order, the carbon footprint is further reduced, and when all animal products are removed, it decreases most. For this reason, it can be said that a vegan menu will provide the least carbon footprint. However, a vegetarian menu will be taken as a basis for the project to be more realistic and applicable.

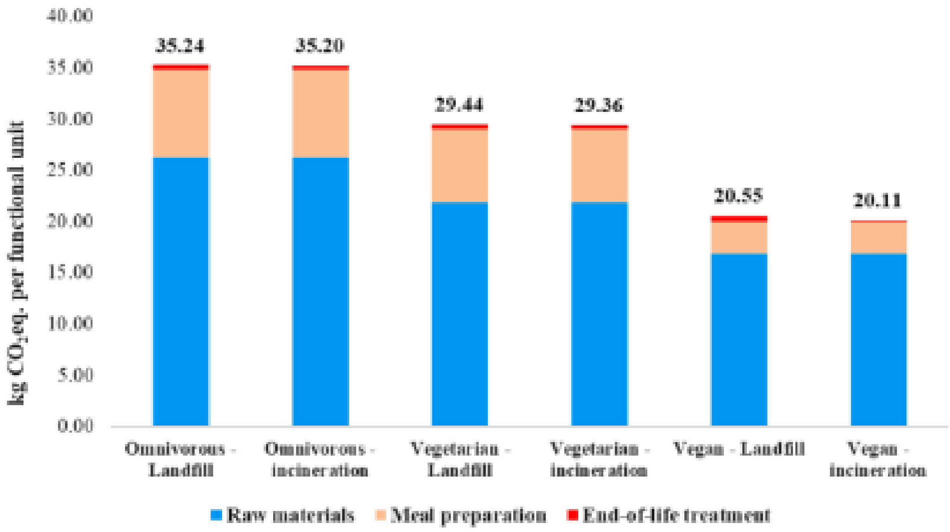

Figure 11. Omnivorous, Vegetarian, Vegan Menu Comparison (Source: Üçtuğ,2021)

4.3.5.1.Benefit

In this solution method, the normal menu will be converted to a vegetarian menu once a week, and in fact, the heavy contribution of meat dishes to the carbon footprint will be reduced and it will be more beneficial to the environment. For this, we benefited from the article of Üçtuğ et al., in which they examined normal, vegetarian and vegan nutrition. In this article, menus for all nutrition types were created and the carbon footprint of each was analyzed by the LCA method. As a result, omnivorous, vegetarian and vegan menu were found to have carbon footprints of 35.22, 27.8 and 18.5 kg CO_2eq., respectively. In this case, if we are going to switch to the vegetarian menu, it will provide us with a reduction of 1 - 27.8/ 35.22 = 0.21 = 21%. We know the 312,705.51 kg CO_2eq. of the carbon footprint from the food in the LCA in our study. In this case, the total footprint multiplied by the ratio will give our gain. Since we will arrange this situation once a week, we will have to multiply this value by 0.2.

p = total carbon footprint value of food from CCaLC2

q = ratio of normal menu to vegetarian menu

r = frequency status (for once a week 0.2)

s = total benefit for vegetarian menu option = p × q × r × C **(38)**

= 312,705.51 × 0.2 × 0.789 × 5 = 246,725 kg CO_2eq.

4.3.5.2.Cost

When we remove meat from the menus, we gain a serious advantage in terms of cost as well as carbon footprint. For example, when we think of the main dish as meatballs and rice, it can cost 35.98 TL per person, while this cost can decrease to 10.45 TL when dried beans and rice are used. There is a profit of 25.53 TL per person. While food is served for 600 people, the daily income is 15,318 TL, but when we design this system for 5 years, a profit of 3,063,600 TL can be obtained. But we will model the cost as 0 because we are making a budget analysis in our study, since we are based on investments.

(1) energy production from unit area throughout campus life (5 years) (kWh/m^2)

(2) price per energy to be gained (TL/kWh)

(3) energy saving in MJ for the system

(4) max budget for the system

(5) max energy saving in MJ

(6) emission reduction (total benefit) for photovoltaic system

(7) total kilometers traveled per year

(8) annual fuel consumption of the vehicle in kg

(9) annual emission reduction for fuel in kg CO_2eq.

(10) annual total electricity consumption

(11) carbon total electricity consumption

(12) the annual emission reduction this system provides

(13) the total emission reduction this system provides (total benefit)

(14) total electricity cost

(15) total cost of electrical vehicle

(16) annual rainwater yield in m^3

(17) water savings over the life of the system m^3

(18) water savings over the life of the system in kg

(19) emission reduction of the system for water

(20) total emission reduction (total benefit) of rainwater harvest system

(21)(22)(23)(24) amount of ... waste in kg

(25)(26)(27)(28) recycle … amount in domestic waste

(29)(30)(31)(32) … amount with succes rate

(33)(34)(35)(36) … amount with recycling efficiency

(37) emission reduction (total benefit) of deposit system from CCaLC2

(38) emission reduction (total benefit) of vegetarian menu

4.4. Optimization Part

In the optimization study developed for five solution proposals, the decision variable and constraints are clearly explained mathematically. Maximizing the environmental benefit is the objective function of the study, and the amount of budgets are constraint. It can be said that this modeling is actually a mixed integer programming example inspired by the knapsack problem.

1 → rainwater harvest system installation

2 → electric vehicle utilization

3 → smart waste deposit system installation

4 → vegetarian menu

5 → photovoltaic panel utilization

Decision Variables

x_i = if the option is chosen or not (binary)

i = 1..4

y = energy saving for photovoltaic system in MJ

Parameters

b_i = benefit of options

W_i = investment for options

Objective Function

Max $Z = \sum x_i \times b_i + y \times 0.1299$

Open form → Max $Z = 1087 \times x_1 + 761 \times x_2 + 29970 \times x_3 + 246725 \times x_4 + 0.1299 \times y$

Constraints

$\sum W_i x_i + (y \times 0.32/3.6) <= \text{Budget}$

$y <= y_{max}$

Open Form →

$300{,}000\ x_1 + 1{,}817{,}000\ x_2 + 1{,}433{,}000\ x_3 + 0\ x_4 + (y \times 0.32/3.6) <= 5.1M$

y <= 16,894,440 MJ

4.4.1. OPL Modeling

dvar boolean x_1;

dvar boolean x_2;

dvar boolean x_3;

dvar boolean x_4;

dvar float+ y;

maximize 1,087*x1 + 761*x2 +29,970*x3 +246,725*x4 + 0.1299* y;

subject to{

```
y<= 16 894 440;
300 000* x1 + 1 817 000 * x2 + 1 440 000* x3 + 0* x4 + ( y*0.32/3.6) <= 100000;
}
```

CHAPTER 5: RESULTS AND DISCUSSION

5.1. LCA Results

As stated in the methodology stage, after all data were processed into the CCaLC2 program, carbon footprint calculation was performed for all stages. The results are as seen in the Table 11 in kg CO_2eq.It has been seen that the inputs are listed as electricity, food, non-transport fuel, geothermal, waste, fuel for transportation, cleaning, water, stationary and natural gas categories, respectively. In this case, the use of electricity makes the biggest contribution to the carbon footprint in our study.

Table 12. Total CF for each stage

	kg CO_2eq.
Stationary	6419
Cleaning supplies	15412
Geothermal energy	182000
Natural gas consumption	1193
Water	12311
Grid electricity	2750000
Waste management	104000
Food	312758
Transportation	63432
Non-transportation liquid fuel	183278

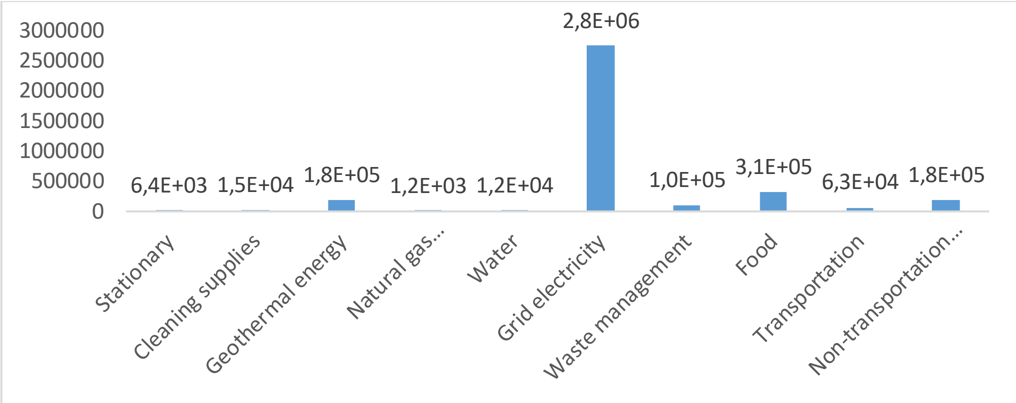

Figure 12. CF Distribution for each stage

If it is examined as a percentage, the place of electricity in the whole model can be seen quite clearly. As a result of the study, it has been seen that 75.74% of the carbon footprint emitted by the Izmir University of Economics campus comes from electricity, 8.61% from food, 5.05% from non-transport fuel, 5.01% from geothermal, 2.86% from waste, 1.75% from transportation. 0.42% comes from cleaning materials, 0.34% from the water used, 0.18 from stationery materials and the last 0.03% from natural gas consumption.

Table 13. Percent distribution of total CF

Stationary	0.18%
Cleaning supplies	0.42%
Geothermal energy	5.01%
Natural gas consumption	0.03%
Water	0.34%
Grid electricity	75.74%
Waste management	2.86%
Food	8.61%
Transportation	1.75%
Non-transportation liquid fuel	5.05%

Results and percentages have been shared for each category separately, but if it needs to be evaluated as a total, the total carbon footprint of Izmir University of Economics is 3,630,803 kg CO_2eq. Considering the total student, academic and administrative staff, there are 11224 people on campus. For this reason, considering the CF per person, it can be said that there is 323.49 kg CO_2eq. Another possible interpretation is to find the carbon footprint per square meter. Since the campus area is known as 38,000 m^2, 95.55 kg CO_2eq. is formed per m^2.

When comparing with other results in the literature in order to evaluate the point we are at, we see that 0.41 ton CO_2eq. per person per year, when one of the universities evaluating human-based assessment, Chile The University of Talca, evaluated it for scope 3. These data are very suitable for comparison because scope 3 was examined in our study. If we have to think with the same unit, it is seen that the footprint spent at our university is less, since it will be 0.32 ton CO_2eq. for İzmir University of Economics. Considering square meters, for example, the carbon footprint per m^2 at BITS Pilani university is 0.083 tons of CO_2eq. If it is considered in the same unit, it is seen that the carbon footprint of 0.095 tons of CO_2eq. is more than BITS. The main reason for this difference is campus area of IUE.

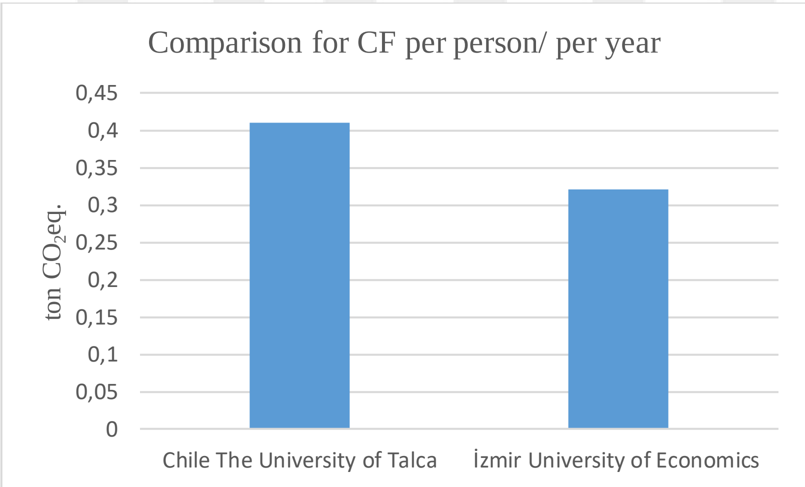

Figure 13. Comparison for CF per person

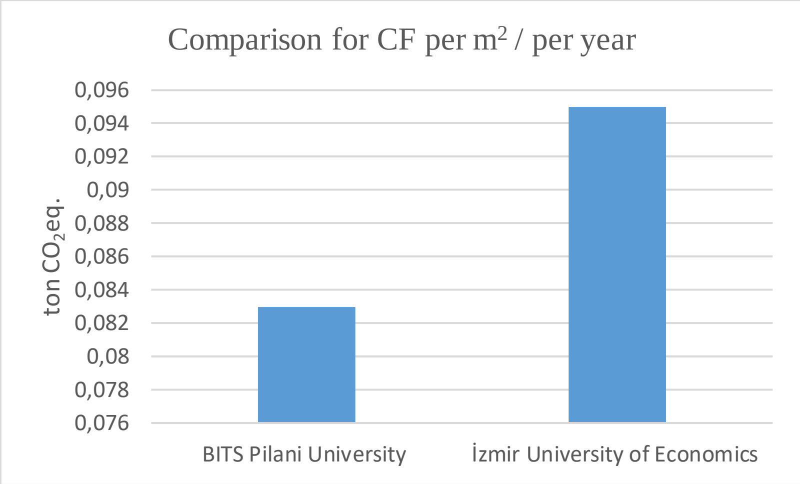

Figure 14. Comparison for FC per m^2

5.2. Knapsack Problem Results

After determining the environmental benefits and costs related to the developed solutions and creating the model, the results were obtained from the IBM ILOG CPLEX program. The model was repeatedly tried with different constraints depending on different budgets. In order to determine the borders and budgets correctly, the budget ranges were kept low and the model was run with a budget of close to 20. Comments are as in the Table 14. Afterwards, 6 budgets, which were the most appropriate to evaluate, were examined in detail. The graphs of these budgets were also interpreted.

Table 14. CPLEX Results

BUDGET (TRY)	X_1	X_2	X_3	X_4	y PV	Z Objective Function (kg CO_2eq.)	REMARKS
100,000	0	0	0	1	1.125×10^6	392,862.5	
250,000	0	0	0	1	2.8125×10^6	612,068.75	
500,000	0	0	0	1	5.625×10^6	977,412.5	
1,000,000	0	0	0	1	1.125×10^7	1,708,100	
1,400,000	0	0	0	1	1.575×10^7	2,292,650	
1,500,000	0	0	0	1	1.6894×10^7	2,438,787.5	The model reached the max value for y
1,810,000	1	0	0	1	1.6894×10^7	2,442,399.756	Exact boundary point for the second solution
2,000,000	1	0	0	1	1.6894×10^7	2,442,399.756	Exactly the same as the 1.81 M, but a more formal budget
2,900,000	1	0	0	1	1.6894×10^7	2,442,399.756	No difference in results from 2 M to 2.9 M
2,922,000	0	0	1	1	1.6673×10^7	2,442,452.75	Model chooses Deposit system over RWH system when I there is enough budget for a waste system but it reduces PV
2,950,000	0	0	1	1	1.6894×10^7	2,471,282.756	Exact point where PV does not decrease
3,000,000	0	0	1	1	1.6894×10^7	2,471,282.756	Exactly the same as the 2.95 M, but a more formal budget
3,300,000	1	0	1	1	1.6894×10^7	2,472,369.756	Starting from 3.3 M, the model starts selecting x_1 and x_3 together
4,000,000	1	0	1	1	1.6894×10^7	2,472,369.756	Results are same as 3.3 M
5,000,000	1	0	1	1	1.6894×10^7	2,472,369.756	Results are same as 3.3 M
5,059,000	1	1	1	1	1.6894×10^7	2,473,130.756	From 5.1 M the model can select all solutions
5,100,000	1	1	1	1	1.6894×10^7	2,473,130.756	
10,000,000	1	1	1	1	1.6894×10^7	2,473,130.756	The results are exactly the same as 5.1 M

X_1 = *rainwater harvest sytem installation*

X_2 = *electrical vehicle*

X_3 = *smart waste deposit system installation*

X_4 =*vegetarian menu option*

y = photovoltaic panel option

Z = objective function

As can be seen in the discussion, the budgets were examined in detail and the most suitable budgets were selected. The initial budget includes only the supply system and the photovoltaic solution. With the second budget, it can be seen that the benefit from photovoltaic increases linearly as the budget is increased. Since the highest benefit is obtained from this solution, the model will always continue to choose it primarily until it reaches the maximum budget and benefit. In the third budget, it has now provided the maximum efficiency from photovoltaic and started to move on to other solution proposals. It is seen that the first solution proposal chosen here is the RWH system due to its cost advantage, but if sufficient budget is given, this choice leaves its place to the smart waste deposit system due to its environmental benefits which is evident in the 4th budget. When the budget reaches 3.3 M by adding a small budget on it, the system now selects 4 solution proposals. If we want to provide all solution proposals of the system, the maximum budget that can be invested for this project is 5.1 M.

Table 15. Results for selected budgets

BUDGET (TRY)	**X_1**	**X_2**	**X_3**	**X_4**	**y**	**Z**
100,000	0	0	0	1	1.125×10^6	392862.5
500,000	0	0	0	1	5.625×10^6	977412.5
2,000,000	1	0	0	1	1.6894×10^7	2442400
3,000,000	0	0	1	1	1.6894×10^7	2471283
3,300,000	1	0	1	1	1.6894×10^7	2472370
5,100,000	1	1	1	1	1.6894×10^7	2473131

However, at this point, when the results from the model are examined, it is seen that it will be meaningless to make this investment since the investment to be made after 3M will affect our objective function to a small extent. As can be seen in the graphs below, the 3rd budget is the most logical, because in the first graph, the benefit tends to stabilize after the 3rd budget proposal, and in the second graph, the budget where the budget and the benefit are closest to each other is 2 M.

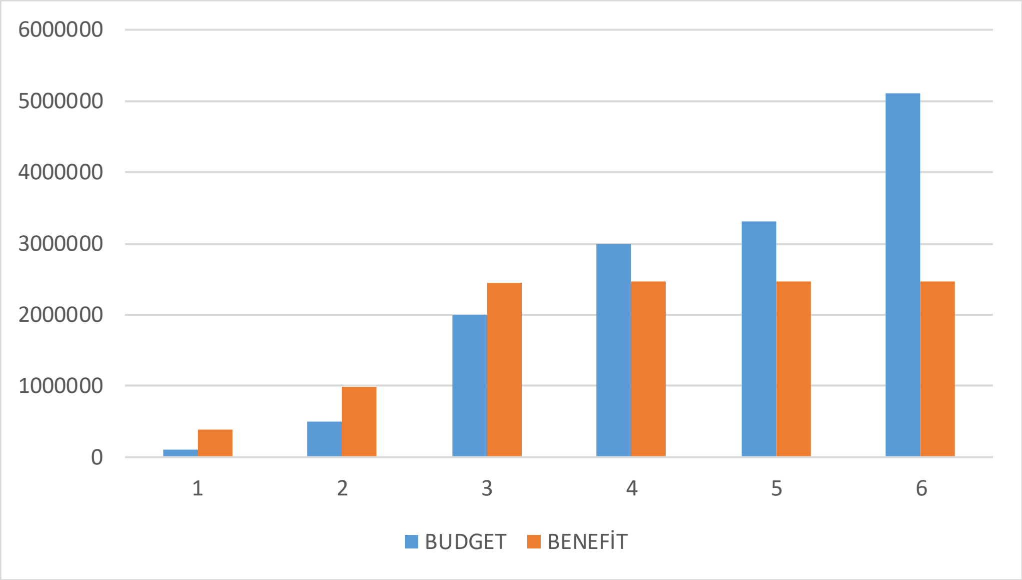

Figure 15. Bar chart for Budget- Benefit

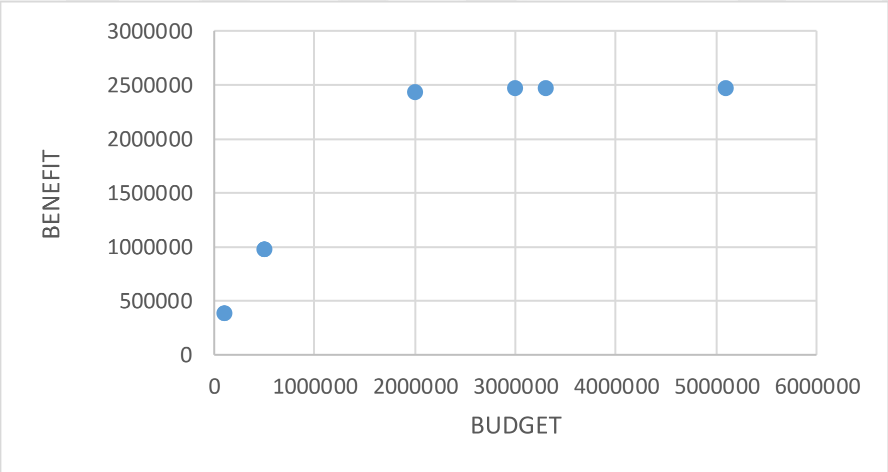

Figure 16. Dot chart for Budget- Benefit

If these budget distributions are examined more visually, they can be evaluated separately with pie charts.

Table 16. Results for a Budget of 100,000 TL

BUDGET	**X1**	**X2**	**X3**	**X4**	**y**	**Z**
100,000	0	0	0	1	1.13×10^6	392862.5
Objective Function	0	0	0	246725	1.46×10^6	392862.5
Budget	0	0	0	0	1.00×10^5	100000

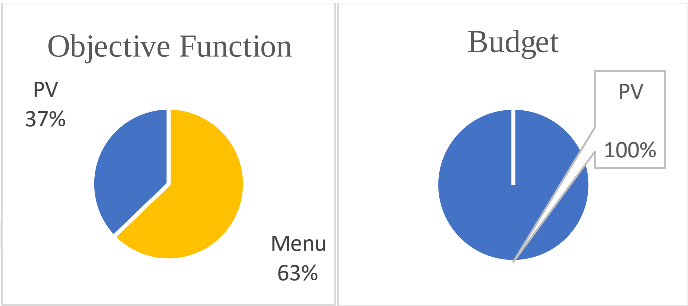

Figure 17. Pie Charts of Objective Function and Budget for 100,000 TL

For the first budget, when the benefit and budget graphs are examined, it is seen that 63% of this benefit comes from vegetarian menu option, while 37% comes from the photovoltaic. Moreover, since this system does not have any cost, the entire budget can be used for photovoltaic.

Table 17. Results for a Budget of 500,000 TL

BUDGET	**X_1**	**X_2**	**X_3**	**X_4**	**y**	**Z**
500,000	0	0	0	1	5.63×10^6	977412.5
Objective Function	0	0	0	246725	7.31×10^5	977412.5
Budget	0	0	0	0	5×10^5	500000

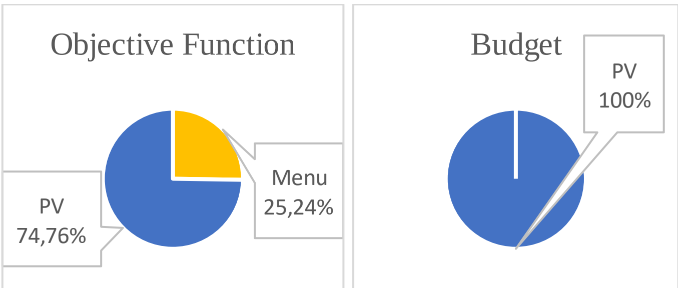

Figure 18. Pie Charts of Objective Function and Budget for 500,000 TL

Likewise, the second budget includes only vegetarian menu and photovoltaic solutions. As mentioned before, as the budget increases, the benefit provided for photovoltaics increases linearly. However, since the vegetarian menu option appears in every budget scenario, it can be said that the total benefit increases as a percentage as the budget increases. For example, in the first graph, 74.76% of the total benefit was photovoltaic, while the total budget was spent only on this.

Table 18. Results for a Budget of 2,000,000 TL

BUDGET	X_1	X_2	X_3	X_4	y	Z
2,000,000	1	0	0	1	1.69×10^7	2442400
Objective Function	1087	0	0	246725	2.19×10^6	2442343
Budget	300000	0	0	0	1.50×10^6	1801689

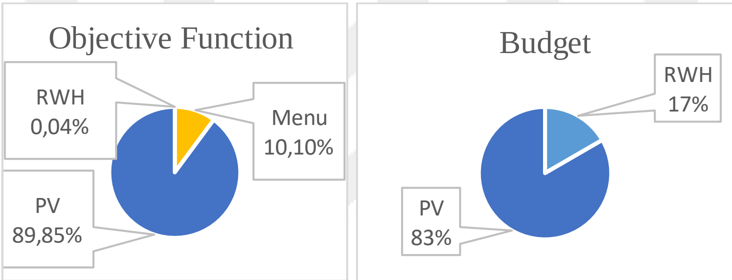

Figure 19. Pie Charts of Objective Function and Budget for 2,000,000 TL

The third budget was one of the most ideal values as it was the closest to each other in terms of environmental benefit and budget. It can be seen that 3 solution suggestions are used at once. Again, the highest benefit comes from photovoltaics with 89.85%. While photovoltaics account for 83% of the budget, 17% is spent on rainwater harvest system installation. Although almost 20% of the budget is used for RWH, its effect as a benefit is not even 1%.

Table 19. Results for a Budget of 3,000,000 TL

BUDGET	X_1	X_2	X_3	X_4	y	Z
3,000,000	0	0	1	1	1.69×10^7	2471283
Objective Function	0	0	29970	246725	2.19×10^6	2471226
Budget	0	0	1440000	0	1.50×10^6	2941689

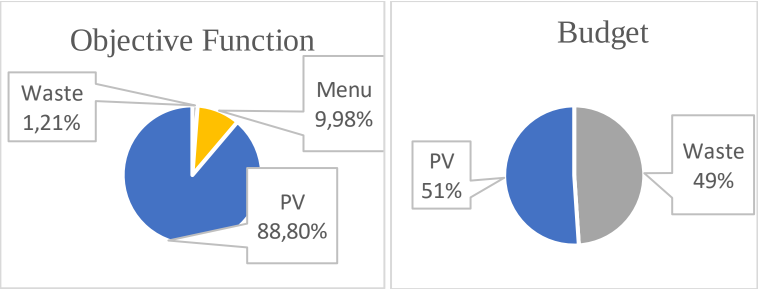

Figure 20. Pie Charts of Objective Function and Budget for 3,000,000 TL

In the fourth budget, there are 3 solution proposals, but in a different combination. Since the budget was increased here, the model chose the smart waste deposit system installation, which has more environmental benefits, instead of RWH. The graph confirms this, because 1.21% of the total benefit is the smart waste deposit system. In the budget graph, there is almost equality, because 51% of the budget is photovoltaic, while 49% is the deposit system.

Table 20. Results for a Budget of 3,300,000 TL

BUDGET	X_1	X_2	X_3	X_4	**y**	**Z**
3,300,000	1	0	1	1	1.69×10^7	2472370
Objective Function	1087	0	29970	246725	2.19×10^6	2472313
Budget	300000	0	1440000	0	1.50×10^6	3241689

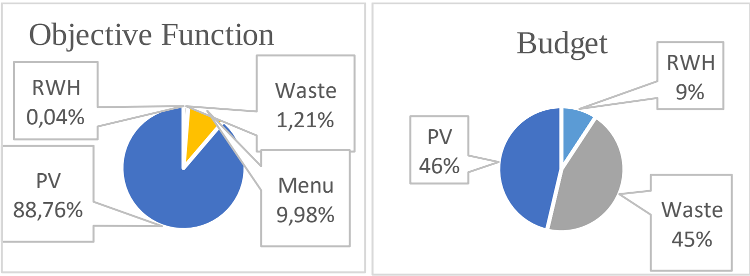

Figure 21. Pie Charts of Objective Function and Budget for 3,300,000 TL

When 3.3M, which is the fifth budget and very close to the fourth budget, is spent, four of the five solution proposals can be achieved. Again, most of the environmental benefit appears to be photovoltaic with 88.76%. Even the closest value to this solution is the vegetarian menu option with 9.98%, followed by the waste system with 1.21% and the rainwater harvest system installation with 0.04%. If the budget graph is to be examined, 46% of the total investment is photovoltaic, 45% is the deposit system and

9% is the RWH system.

Table 21. Results for a Budget of 5,100,000 TL

BUDGET	X_1	X_2	X_3	X_4	y	Z
5,100,000	1	1	1	1	1.69×10^7	2,473,131
Objective Function	1,087	761	29,970	246725	2.19×10^6	2,473,074
Budget	300,000	1,817,000	1,440,000	0	1.50×10^6	5,058,689

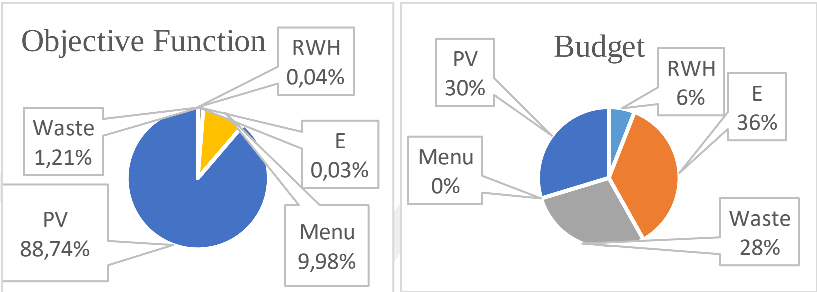

Figure 22. Pie Charts of Objective Function and Budget for 5,100,000 TL

The minimum budget at which all solution proposals can be utilized together is 5.1 M. When the benefit graph is examined, it is seen that 88.74% of the total benefit is photovoltaic panel utilization, 9.98% is vegetarian menu option, 1.21% is the deposit system, 0.04% RWH, 0.03% is the electric vehicle utilization, which is the last preferred solution. In terms of budget, the highest budget will have to be allocated for electric vehicles. The distribution of the entire budget is as follows; electric vehicle utilization 36%, photovoltaic panel utilization 30%, deposit system 28%, rainwater harvest system installation 6%.

When we compare the total impact of the budget as a percentage, we can see that no matter how much we increase the budget, the maximum contribution we can provide with the current solution proposals is 13.62%. That means that if the budget that can provide all the solution proposals is selected, the reduction of the carbon footprint will increase to 13%. If we examine it separately, it can be said that when we use the first budget of 100,000 TL, the total emission reduction system will choose an amount for vegetarian menu option and photovoltaic panel utilization, and a total of 392862.5 kg CO_2eq. will be reduced by 2.16%. This ratio will be approximately 6% as the income we will gain from photovoltaic panel utilization will increase with the second budget.

With the third budget, 2M, this rate will be 13.45%, as we will both reach the maximum amount for photovoltaic panel utilization and use the rainwater harvest system installation. When we allocate 3M, 3.3M and 5M budgets, this ratio will be at most 68.11%.

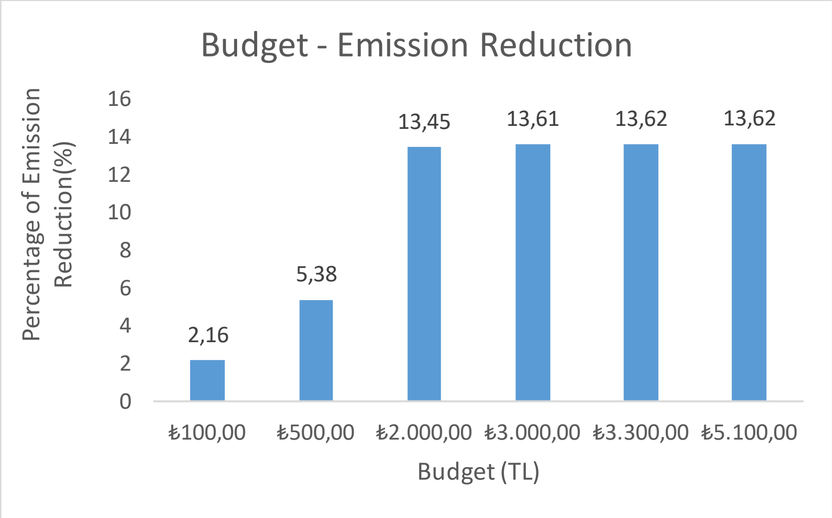

Figure 23. Comparison of Budget – Emission Reduction

5.3. Sensitivity Analysis

As mentioned before, for the rainwater harvesting system, 25 m^3 was taken as a basis in our project and the benefit and price provided in the whole modeling were calculated for this value. However, price and benefit values were found for 20 m3 and 30 m^3 values as part of the project. This was done to determine how the tank volume required for rainwater harvest system installation affects the project. The reason why we are doing this especially in the rainwater harvest model is that this is our most uncertain value. Again, in some budget values, all values for 20-25-30 m^3 were changed and recalculated. There has been no change in the budget values, where this solution is not selected anyway. The budgets where the actual total benefit changes is that this solution proposal is also used. For example, in the calculation made in the solution proposal with a budget of 2 M, the objective function is 2,442,452.756 kg CO_2eq. for 20 m^3, 2,442,399.756 kg CO_2eq. for 25 m^3, and 2,442,346.756 kg CO_2eq. for 30 m^3. Although the differences are very small, the highest value was seen for 20 m^3. It is seen that the result is like this for all the budgets considered.

Table 22. Sensitivity Analysis Results for the Rainwater Harvest System

BUDGET	m^3	X_1	X_2	X_3	X_4	y	Z
1,810,000	20	1	0	0	1	$1.6894x10^7$	2,442,452.756
	25	1	0	0	1	$1.6894x10^7$	2,442,399.756
	30	0	0	0	1	$1.6894x10^7$	2,441,312.756
2,000,000	20	1	0	0	1	$1.6894x10^7$	2,442,452.756
	25	1	0	0	1	$1.6894x10^7$	2,442,399.756
	30	1	0	0	1	$1.6894x10^7$	2,442,346.756
3,300,000	20	1	0	1	1	$1.6894x10^7$	2,472,422.756
	25	1	0	1	1	$1.6894x10^7$	2,472,369.756
	30	1	0	1	1	$1.6894x10^7$	2,472,316.756
5,000,000	20	1	0	1	1	$1.6894x10^7$	2,472,422.756
	25	1	0	1	1	$1.6894x10^7$	2,472,369.756
	30	1	0	1	1	$1.6894x10^7$	2,472,316.756
5,100,000	20	1	1	1	1	$1.6894x10^7$	2,473,183.756
	25	1	1	1	1	$1.6894x10^7$	2,473,130.756
	30	1	1	1	1	$1.6894x10^7$	2,473,077.756
10,000,000	20	1	1	1	1	$1.6894x10^7$	2,473,183.756
	25	1	1	1	1	$1.6894x10^7$	2,473,130.756
	30	1	1	1	1	$1.6894x10^7$	2,473,077.756

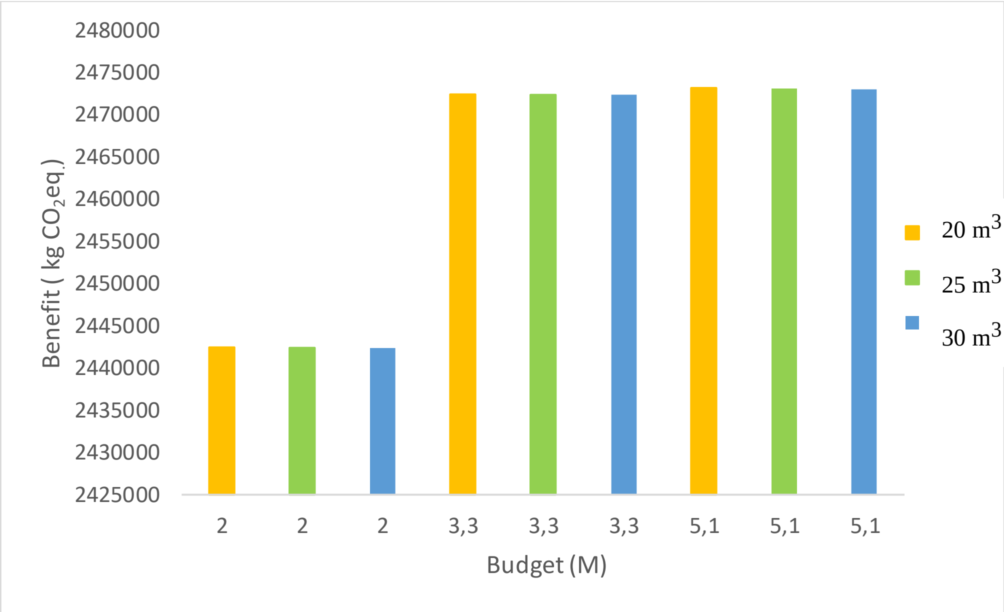

Figure 24. Bar Chart of Budget- Benefit- Tank Volume

This analysis was made for the rain harvest system, which has the most uncertain value in the project. However, as can be seen in the graphs as a result of the examination, this uncertainty did not cause a high sensitivity. Rainwater harvest system installation was specifically studied for the three budgets used: 2M, 3.3M, and 5.1 M. Three budgets, three different tank volumes, with 20 m^3 representations in orange, 25 m^3 in green, and 30 m^3 in blue, are also examined in the graph. The difference is negligible and if it is to be calculated as a percentage, each value is merely 0.02% different than the previous. So it can be commented that the total environmental benefit in the project will not be sensitive to the tank volume of the rainwater harvest system. In this case, the region where the project is located in the table below is the high uncertainty and low sensitivity region. There is no problem, but if the sensitivity was too high, that is, if the system was sensitive to the tank volume, many calculations would be made for the project from the beginning and new studies would have to be done to determine the tank volume.

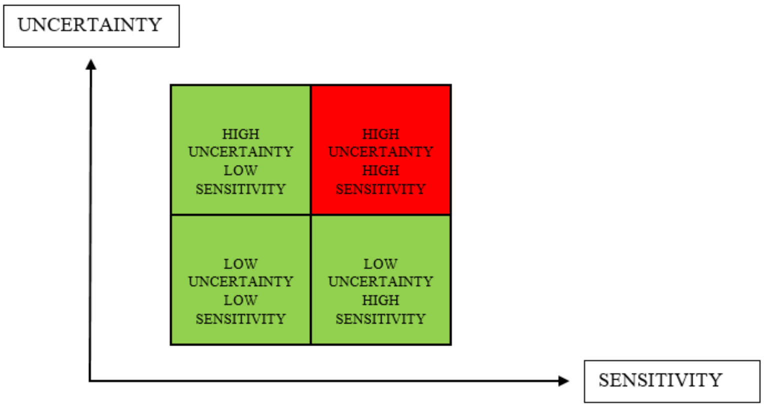

Figure 25. Relationship for Uncertainity and Sensitivity

5.4. Limitations of the Study

One may argue that a higher number of impact mitigation strategies, or solutions, could have been included in the analysis. While this is true, search on the previous literature whose results are summarized earlier shows that in many studies typically 5 to 10 solutions are suggested to improve the energy efficiency, and in return, reduce the environmental impact of the buildings. Last but definitely not least, it should be mentioned that from a methodology point of view, a higher number of solutions may render knapsack problem approach ineffective. The computational complexity of the knapsack problem is strongly influenced by the number of items. The problem belongs to the class of nondeterministic polynomial-complete problems, which means that finding an optimal solution for large instances becomes increasingly difficult and time-consuming as the number of items increases. As the number of items grows, the search space expands exponentially, making it infeasible to explore all possible combinations. When faced with a large number of items in the knapsack problem, it becomes necessary to employ optimization techniques and heuristics to find good approximate solutions within a reasonable amount of time. Some common approaches include Greedy Algorithms, Dynamic Programming, or Metaheuristic Algorithms. Additionally, specialized algorithms and optimization frameworks can be employed to handle specific instances of the knapsack problem, such as branch and bound algorithms or integer programming formulations. Heuristic algorithms like genetic algorithms, simulated annealing, and particle swarm optimization can be used to find solutions for larger instances of the knapsack problem. These algorithms can explore a wide search space and provide good solutions within a reasonable amount of time.

As an advanced stage of this project, it will be possible to find 100 solutions and how these solutions can be selected in line with the budgets that can be provided with a genetic algorithm. Genetic algorithms are heuristic optimization techniques inspired by the process of natural selection. They can effectively explore the solution space and provide good solutions in a reasonable amount of time, even for complex optimization problems like the knapsack problem. In the literature, there are studies that have solved the knapsack problem with a genetic algorithm. For example, Rezoug et al. used this method for multidimensional knapsack (Abdellah Rezoug, 2018) Also in the article of Djannaty et al. hybrid genetic algorithm is used for multidimensional type. (Farhad Djannaty, 2008) If the application of the genetic algorithm in the knapsack problem is phased, the sequence will be as follows; (Hristakeva, 2004)

Representation of Solutions: Each solution (individual) in the genetic algorithm can be represented as a binary string of length equal to the number of items. Each bit represents whether an item is included (1) or excluded (0) from the knapsack.

Initialization: Generate a population of random solutions (individuals), where each individual is a binary string representing the inclusion/exclusion of items.
Fitness Function: Define a fitness function that evaluates how good a solution is. In the context of the knapsack problem, the fitness function should calculate the total value of items in the knapsack while considering the weight constraint. If the total weight exceeds the knapsack capacity, the fitness should be penalized.

Selection: Select individuals from the current population to become parents for the next generation. Individuals with higher fitness values are more likely to be selected.

Crossover: Apply crossover (recombination) to pairs of selected parents to create new offspring. This involves exchanging parts of their binary strings to produce new individuals.

Mutation: Introduce a small probability of mutation for each bit in the offspring's binary string. Mutation helps maintain diversity in the population and can prevent the algorithm from getting stuck in local optima.

Replacement: Replace the old population with the new population of offspring. This can be done using various replacement strategies, such as generational replacement or elitist replacement.

Termination: Repeat the selection, crossover, mutation, and replacement steps for a certain number of generations or until a stopping criterion is met

Solution Extraction: Once the algorithm terminates, extract the best solution (individual) found during the optimization process. Decode the binary string to determine which items are included in the knapsack.

Parameter Tuning: Experiment with different parameters of the genetic algorithm, such as population size, crossover and mutation rates, and termination conditions, to find the right balance between exploration and exploitation.

5.4.1. Genetic Algorithm Modeling

```
import random
# Knapsack problem parameters
num_items = 100
# Generate random numbers
items = [("Item{}".format(i + 1), random.randint(100000, 2000000), random.randint(1000, 200000)) for i in range(num_items)]
max_weight = 500000

# Genetic algorithm parameters
population_size = 50
generations = 100
mutation_rate = 0.1

def fitness(individual):
    total_weight = sum(item[1] for item, bit in zip(items, individual) if bit)
```

```
    total_value = sum(item[2] for item, bit in zip(items, individual) if bit)
    return total_value if total_weight <= max_weight else 0
def crossover(parent1, parent2):
    crossover_point = random.randint(1, len(parent1) - 1)
    child1 = parent1[:crossover_point] + parent2[crossover_point:]
    child2 = parent2[:crossover_point] + parent1[crossover_point:]
    return child1, child2
def mutate(individual):
    total_weight = sum(item[1] for item, bit in zip(items, individual) if bit)
    remaining_weight = max_weight - total_weight
    for i in range(len(individual)):
        if random.random() <= mutation_rate and remaining_weight > 0:
            if individual[i]:
                individual[i] = False
                remaining_weight += items[i][1]
            else:
                if items[i][1] <= remaining_weight:
                    individual[i] = True
                    remaining_weight -= items[i][1]
    while total_weight > max_weight:
        max_weight_item = max((item for item, bit in zip(items, individual) if bit),
key=lambda x: x[1])
        index = items.index(max_weight_item)
        individual[index] = False
        total_weight -= max_weight_item[1]
    return individual
def create_random_individual():
    return [random.choice([True, False]) for _ in range(len(items))]
def genetic_algorithm():
    population = [create_random_individual() for _ in range(population_size)]
    for generation in range(generations):
        population = sorted(population, key=lambda x: -fitness(x))
        new_population = population[:population_size // 2]
        while len(new_population) < population_size:
```

```
            parent1, parent2 = random.choices(population[:population_size // 2], k=2)
            child1, child2 = crossover(parent1, parent2)
            child1 = mutate(child1)
            child2 = mutate(child2)
            new_population.extend([child1, child2])
        population = new_population
    best_individual = max(population, key=fitness)
    return best_individual
if __name__ == "__main__":
    solution = genetic_algorithm()
    total_weight = sum(item[1] for item, bit in zip(items, solution) if bit)
    total_value = sum(item[2] for item, bit in zip(items, solution) if bit)
    print("Knapsack Problem Solution:")
    for item, bit in zip(items, solution):
        if bit:
            print(f"{item[0]} - Weight: {item[1]}, Value: {item[2]}")
    print(f"Total Weight: {total_weight}")
    print(f"Total Value: {total_value}")
```

In this python language modeling, 100 randomly assigned solution proposals with different costs and benefits were selected by genetic algorithm and solution sets were obtained. Although random numbers are assigned, these numbers can be calculated one by one and written into the program in a fixed way. The aim here is how the model will make its choices depending on the budget when we increase the solutions, and as can be seen, the model gives good results.

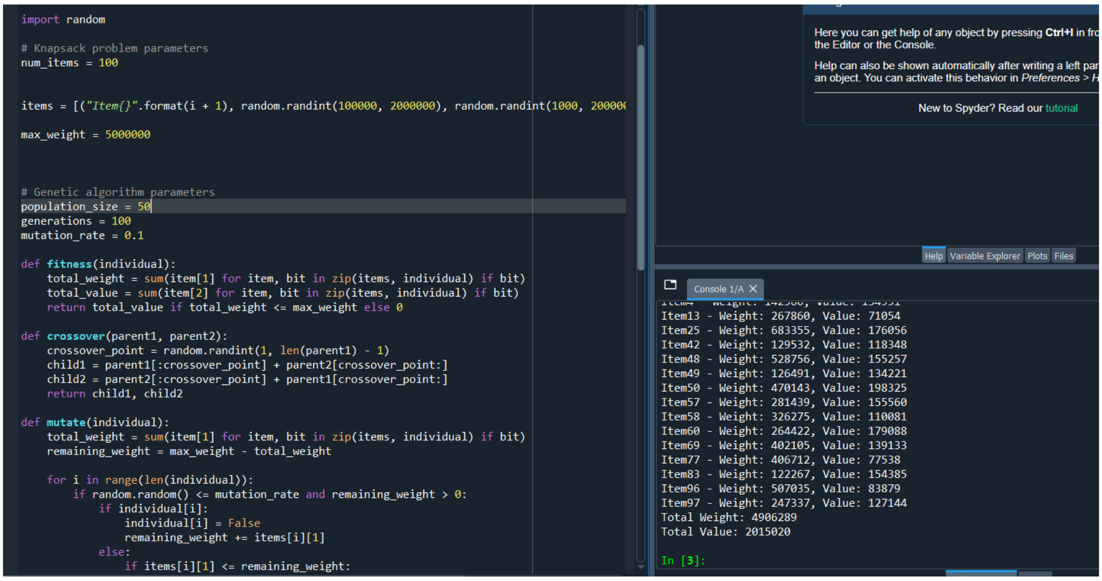

Figure 26. Print Screen of Python Modeling

The previous 5 solution suggestions were also tested with this code prepared within the framework of the genetic algorithm used for 100 solution suggestions with random cost and benefit values. However, when used in modeling, a solution proposal that is taken as a continuous variable is this time taken as binary. Therefore, when solved with OPL, the results that can be obtained in parts are now based on whether the solution proposal is selected or not. From the point where it reached the maximum values, the same values were obtained with both solution methods.

Table 23. Comparison of OPL and GA Results

BUDGET (TRY)	**X_1**	**X_2**	**X_3**	**X_4**	**y**	**Z**
OPL						
100,000	0	0	0	1	1.125×10^6	392862.5
500,000	0	0	0	1	5.625×10^6	977412.5
2,000,000	1	0	0	1	1.6894×10^7	2442400
3,000,000	0	0	1	1	1.6894×10^7	2471283
3,300,000	1	0	1	1	1.6894×10^7	2472370
5,100,000	1	1	1	1	1.6894×10^7	2473131
Genetic Algorithm						
100,000	0	0	0	1	0	246725
500,000	0	0	0	1	0	247812
2,000,000	1	0	0	1	1	2442400
3,000,000	0	0	1	1	1	2471283
3,300,000	1	0	1	1	1	2472370
5,100,000	1	1	1	1	1	2473131

CHAPTER 6: CONCLUSION

The project was completed in two phases as mentioned in most parts of the study. The first step is to determine the carbon footprint emerging on the Izmir University of Economics campus by life cycle analysis. The second stage is the optimization study with the budgets and solutions determined in line with the results. For life cycle analysis, all consumption data obtained from the school were processed into the CCaLC2 program. Meanwhile, CCaLC2 database was used directly for the required carbon footprint value or these values were entered into the program after they were found from the literature. After the results were obtained, five solution proposals were developed for the optimization model: photovoltaic panel utilization, rainwater harvest system installation, electric vehicle utilization, smart waste deposit system installation, vegetarian nutrition system. The environmentfal benefits and costs of each of these solution methods were calculated. Some cost values are taken from companies in order to be more realistic. There is no specific budget to be provided for the study, so the results of the different budgets are evaluated separately. The main purpose here is to see which solution proposals in the system can be selected when different budgets are provided. Thus, it is also a guide for the investor because it has been clearly seen how much environmental benefit will be provided for which budget. After all the data were determined, the model was created and the results of the model were obtained by using the IBM CPLEX program. It was also seen how the solution proposals affected the work as a result of the results obtained from different budgets.

The most significant result of this study and its contribution to the literature is the method and model developed. This model is the application of Knapsack and budget allocation to a real system with the results obtained with LCA. However, the numerical values obtained do not actually have any validity beyond the specific case of IEU Balçova Campus. The actual outcome of this study is the developed model, and not the numerical values. Numerical values are only important for the case study, these are not generalizations, they are only a study for understanding the event and exemplifying the developed model. With the help of the developed model, the approach in this study can be applied to all kinds of systems with intensive resource and energy consumption, especially universities, hospitals, or municipal public buildings. Furthermore, the implementation of such studies can be tied to a regulation and the law-makers may even consider introducing such an incentive mechanism.

There are also aspects that can be improved for the study, for example, although the analysis was made with the logic of life cycle assessment, only the carbon footprint was calculated amongst the environmental impacts. The main reason for this is that most of the inputs required for the process in the database and literature do not have values except for carbon footprints. This is a natural consequence of Turkey's lack of a national database and this is actually a conclusion from this study. When these data are provided, the study can be developed by using these data as a continuation of the study. Another improvement point in the study is the absence of an instantaneous water consumption vs. storage analysis for the rainwater harvest system installation, as also mentioned in section 4.3.3. Calculation of rainwater harvest with real data could have been more meaningful, but instead it was modeled by using generic equations from the literature. This is because instantaneous consumption data is not available. The measurement of instantaneous consumption data is very important. Thus, existence of technological infrastructure that can instantaneously measure the consumption of energy and water in a facility would enable us to determine the most effective set of solutions in order to improve the efficiency of the uses of those resources. As a solution to this, smart building management systems can be used in buildings used by such a large number of people. As such systems adopt the principle of saving energy as well as providing a more comfortable life, they can fully adapt to environmental conditions. For this, the system is already active with real-time tracking (Eini et al., 2021) Another inference made with this examination is that this can be questioned for all solutions, because they were actually developed according to the available data. For example, in some moments, 100% energy can be obtained from photovoltaic panels. In other words, since there are no instantaneous values, there is no certainty about how effective the solutions found are. The existence of systems that can measure instantaneous energy consumption is very important in such large buildings.

Last but not least, other solution proposals could have come to the fore besides these five solution proposals. The reason why no more solution proposals are brought forward is that the purpose here is not to discuss the effectiveness of the solution proposals. Because these solution proposals can work in Izmir University of

Economics, but may not be applied to buildings in other climate conditions and other usage conditions. The aim here is not to see the effectiveness of the solution proposals, but to develop an approach to determine which one is the most optimal after the benefits and costs of these solution proposals are revealed. Therefore, not going beyond five solutions is not a shortcoming of this study, but we think that these solutions are sufficient for this particular case study. With this competency, however, advanced stages, meaning further solution proposals, can still be achieved using a genetic algorithm for the knapsack problem. An example regarding this has been written using the Python programming language.

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APPENDICES

Appendix A- Yearly Data for Geothermal Consumption

YEAR	MONTH	CONSUMPTION AMOUNT (m3)	CONSUMPTION AMOUNT (kWh)	EXPLANATION
2021	SEPTEMBER	590.00	23,300.00	D BLOCK HEATING
2021	OCTOBER	950.00	36,200.00	D BLOCK HEATING
2021	OCTOBER	1,904.00	34,300.00	A BLOCK HEATING
2021	NOVEMBER	1,614.00	92,700.00	D BLOCK HEATING
2021	NOVEMBER	11,256.00	294,322.00	A BLOCK HEATING
2021	DECEMBER	2,388.00	134,600.00	D BLOCK HEATING
2021	DECEMBER	19,133.00	214,150.00	A BLOCK HEATING
2022	JANUARY	3,882.00	193,600.00	D BLOCK HEATING
2022	JANUARY	33,108.00	830,400.00	A BLOCK HEATING
2022	FEBRUARY	2,495.00	119,200.00	D BLOCK HEATING
2022	FEBRUARY	33,987.00	583,400.00	A BLOCK HEATING
2022	MARCH	2,728.00	135,900.00	D BLOCK HEATING
2022	APRIL	841.00	44,700.00	D BLOCK HEATING
2022	APRIL	23,015.00	169,000.00	A BLOCK HEATING
2022	MAY	896.00	31,700.00	D BLOCK HEATING
2022	MAY	810.00	2,000.00	A BLOCK HEATING
2022	JUNE	1,149.00	41,100.00	D BLOCK HEATING
2022	JULY	904.00	28,400.00	D BLOCK HEATING
2022	AUGUST	645.00	19,400.00	D BLOCK HEATING

Appendix B- Yearly Data for Natural Gas

YEAR	MONTH	CONSUMPTION AMOUNT (m^3)	CONSUMPTION AMOUNT (kWh)	EXPLANATION
2021	SEPTEMBER			NO CONSUMPTION
2021	OCTOBER	36.6	403.393	CULINARY ARTS
2021	NOVEMBER	74.56	811.831	CULINARY ARTS
2021	DECEMBER	78.535	850.367	CULINARY ARTS
2022	JANUARY	26.403	290.055	CULINARY ARTS
2022	FEBRUARY			NO CONSUMPTION
2022	MARCH	72.077	782.984	CULINARY ARTS
2022	APRIL	69.483	761.634	CULINARY ARTS
2022	MAY	54.245	591.12	CULINARY ARTS

2022	JUNE	48.51	521.271	CULINARY ARTS
2022	JULY	26.99	287.353	CULINARY ARTS
2022	AUGUST	1.927	20.526	CULINARY ARTS

Appendix C- Yearly Data for Water Consumption

YEAR	MONTH	CONSUMPTION AMOUNT (m^3)	EXPLANATION
2021	SEPTEMBER	2,124.00	CAMPUS
2021	SEPTEMBER	31.00	MEDICINE CONSTRUCTION AREA
2021	OCTOBER	2,882.00	CAMPUS
2021	OCTOBER	4.00	MEDICINE CONSTRUCTION AREA
2021	NOVEMBER	4,160.00	CAMPUS
2021	NOVEMBER	3.00	MEDICINE CONSTRUCTION AREA
2021	DECEMBER	2,750.00	CAMPUS
2021	DECEMBER	3.00	MEDICINE CONSTRUCTION AREA
2022	JANUARY	4,249.00	CAMPUS
2022	JANUARY	3.00	MEDICINE CONSTRUCTION AREA
2022	FEBRUARY	1,891.00	CAMPUS
2022	FEBRUARY	4.00	MEDICINE CONSTRUCTION AREA
2022	MARCH	3,451.00	CAMPUS
2022	MARCH	12.00	MEDICINE CONSTRUCTION AREA
2022	APRIL	3,681.00	CAMPUS
2022	APRIL	25.00	MEDICINE CONSTRUCTION AREA
2022	APRIL	1.00	MANSION OF İZMİR
2022	MAY	3,554.00	CAMPUS
2022	JUNE	4,086.00	CAMPUS
2022	JUNE	43.00	MEDICINE CONSTRUCTION AREA
2022	JUNE	10.00	MANSION OF İZMİR
2022	JULY	2,661.00	CAMPUS
2022	JULY	26.00	MEDICINE CONSTRUCTION AREA
2022	JULY	15.00	MANSION OF İZMİR
2022	AUGUST	2,933.00	CAMPUS
2022	AUGUST	22.00	MEDICINE CONSTRUCTION AREA
2022	AUGUST	17.00	MANSION OF İZMİR

Appendix D- Yearly Data for Electricity

YEAR	MONTH	ENERGY CONSUMPTION kWh	SUPPLIERS
2021	SEPTEMBER	368,239.20	AKSA ELEKTRİK
2021	OCTOBER	285,566.85	AKSA ELEKTRİK
2021	NOVEMBER	370,012.50	AKSA ELEKTRİK
2021	DECEMBER	448,851.90	AKSA ELEKTRİK
2022	JANUARY	479,446.50	AKSA ELEKTRİK
2022	FEBRUARY	316,240.80	AKSA ELEKTRİK
2022	MARCH	433,140.51	AKSA ELEKTRİK
2022	APRIL	301,009.05	KOLEN ELEKTRİK
2022	MAY	408,172.95	KOLEN ELEKTRİK
2022	JUNE	672,222.15	KOLEN ELEKTRİK
2022	JULY	571,737.45	KOLEN ELEKTRİK
2022	AUGUST	629,048.85	KOLEN ELEKTRİK