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TECHNICAL PAPER

Assessing the electricity energy efficiency of university campus exterior lighting system and proposing energy-saving strategies for carbon emission reduction

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Abstract
This paper presents efficiencies research and energy-saving strategies for carbon emission reduction of the exterior lighting system of Avşar Campus of Kahramanmaraş Sütçü İmam University, Turkey. Once the campus’s average energy consumption for the previous five years was calculated, it was found to be 18,802 Megawatt hour/year (MWh/year), with 6,203 carbon dioxide (CO₂) tons/year emissions. Also, the annual electrical energy consumption for exterior lighting was calculated as 670,395 MWh/year, with annual emissions of 221,170 CO₂ tons/year. Inefficient lamp choices in exterior lighting systems and longer than necessary operating times have been identified as the causes of these high values. That’s because High-Pressure Sodium (HPS) lamps with an installed power of 109,050 Kilowatt (kW), which have a low efficiency but a high energy consumption, provide for 70% of exterior lighting. Thus, seven unique energy-saving strategies have been designed with the aim of decreasing total energy consumption and achieving more cost savings as well as less harmful emissions released into the atmosphere. All of the strategies were designed under the following three headings: dimming method, optimization of lamps’ operation times, and retrofitting lamps with new and technological ones. The study’s novelty lies in the creation of seven unique energy-saving strategies for the first time in light of the three headings highlighted, as well as their adjustment to a sophisticated campus with such high energy consumption. Once all of the proposed strategies are compared to the current system, it has been discovered that strategy-7 saves 81.656% energy consumption (547,418 MWh/year), 180,599 CO₂ tons/year saving, and € 49,268 (£/year) cost-saving. Such a low energy consumption is vital for a rapidly growing and expanding campus in terms of carbon emissions, cost savings, and environmental quality.

Keywords Electricity energy efficiency · Energy-saving strategies · Exterior lighting · Carbon emission reduction · Campus sustainability

1 Introduction
Humans need the energy to survive. This demand grows in parallel with the world’s population and technological advancements. Of course, we have a finite amount of fossil-based energy; it emits harmful gases into the atmosphere and will eventually run out (Kerem et al. 2014; Saygin and Kerem, 2017; Kerem and Gürbak, 2020). We have eco-friendly renewable energy sources such as wind (Kerem and Saygin, 2019) and solar (Kerem et al. 2020), however, a large part of them are still waiting to be utilized. This expectation is, without a doubt, mostly influenced by economic concerns.

Efficient energy consumption is crucial for appropriate energy management. It is important to prevent unconscious usage by increasing energy efficiency at all stages from energy production to final consumption (Atis and Ekren, 2016). Especially over the last decades, ever-increasing energy consumption has further accelerated man-made global warming, harming people and ecosystems. For this reason, many countries have taken steps and developed strategies to reduce greenhouse gas (e.g. CO₂) emissions, including those from lighting sources (Ardavani et al.,
In addition, energy-efficient improvements have been made mandatory at all levels of public administration, since an increase in energy consumption of approximately 40% on a global scale is projected until 2030 (Carli et al., 2018).

Exterior lighting is one of the massive energy consumption sectors. It makes roads safe and reduces accidents (Görgülü and Kocabey, 2020), increases the safety in homes, workplaces, and city centers (Ozadowicz and Grela, 2017), contributes to the city’s beauty, provides a vibrant nightlife, and rejuvenates (Chena et al., 2020). However, it consumes a substantial amount of energy (Shahzad et al., 2018) and it continues to rise at a rate of around 6% each year, globally (Jagerbrand, 2020). Due to its inefficiency structure, street and road lights currently account for 2.3% global energy consumption (Ogando-Martínez et al., 2018). Furthermore, the amount of consumed energy by street lighting accounts for 30–40% of the total energy consumption of the city (Kaleem et al. 2016; Ozadowicz and Grela, 2017). Public lighting accounts for 2.3% of global electricity usage, 80% of municipal electricity usage, and 60% of municipal energy bills (Orzáez and Díaz, 2013). National electricity usage for lighting in industrialized countries ranges from 5 to 15% of total electrical energy consumption (Aries and Newsham, 2008). Also, artificial lighting at night in exterior environment has other negative indirect effects such as contributing to the emission of CO₂, increasing global climate change, and also, light pollution and undesired ecological effects on ecosystems and biodiversity (Jagerbrand, 2021). Thus, it’s significant to have effectively exterior lighting system to make more energy savings. With advanced exterior lighting methods, millions of tons of fossil fuel can be saved, reducing CO₂ (Zotos et al., 2012).

Lighting systems enable efficient usage of energy in relation to the applied control strategies. Smart lighting systems include complicated wireless sensor networks, dimmers, and meters managed by advanced control applications to achieve a specific goal. Since they have improved performance, efficiency, and sustainability, these systems have been adopted as the next-generation standard for lighting systems (Farahat et al., 2014).

Luminaires used for lighting can be included Incandescent (INC), Compact Fluorescent (CFL) lamp, Metal Halide (MH) lamp, High-Pressure Sodium (HPS) lamp, and Light Emitting Diode (LED) (Pereira et al., 2015; Wallace and Botha, 2016). However, the European Eco-Design Directive (2009/125/EC) recommended Light Emitting Diode (LED) luminaires by banning mercury vapor lamps (Hermoso-Orzáez et al., 2017). LED has low energy consumption (Ardavani et al., 2020), long life, less need for maintenance (Burgos-Payán et al., 2012), low investment and maintenance cost (Beccali et al., 2019), environmentally friendly structure thanks to includes no mercury or lead (Hermoso-Orzáez et al., 2017), digitally controlled, efficient electronic device. The usage of LEDs instead of aging conventional lamps resulted in a 74% reduction in energy consumption in Leipzig, Germany (Farahat et al., 2015). Literature on energy-saving exterior lighting studies is given in Table 1.

In this paper, efficiency research and energy-saving strategies for the exterior lighting system of Avşar Campus of Kahramanmaraş Sütçü İmam University, Turkey was investigated. Buildings, roadways, pedestrian ways, gardens, and parking lots have all been studied as part of the exterior lighting system research. The average energy usage of the campus over the previous five years was found as 18,802 MWh/year, with emissions of 6,203 CO₂ tons/year. Additionally, the yearly electrical energy usage for exterior lighting was calculated as 670,395 MWh/year, leading to annual 221,170 CO₂ tons emissions. Unfortunately, it still continues to consume a great deal of energy and release harmful gases into the atmosphere. Inefficient lamp choices in exterior lighting systems and longer than necessary operating times have been identified as the sources of these high values. That’s because Large-Pressure Sodium (HPS) lights with an installed power of 109,050 kW, which have a low efficiency but a high energy consumption, provide approximately 70% of exterior lighting. Thus, seven distinct energy-saving strategies have been developed with the aim of decreasing total energy consumption to achieve greater cost savings and fewer harmful emissions released into the atmosphere. All of the strategies were designed under the following three headings: dimming method, optimization of lamps’ operation times, and retrofitting lamps with new and technological ones. In all seven proposed distinct strategies, less energy consumption and less CO₂ emissions were observed compared to the current system. In addition, it has been discovered that Strategy-7 saves 81.656% energy consumption (547,418 MWh/year), 180,599 CO₂ ton/year saving, and €49,268 cost-saving. In terms of carbon emissions, cost-savings, and environmental quality, such low energy consumption is vital for a rapidly growing and expanding campus.

The main aim of this research study is to reduce the inefficient and excessive energy consumption of exterior lighting systems on the university campus. In this way, CO₂ emissions that pollute the environment will be reduced and cost-savings will be achieved.

The key contributions of this research study are:

1. To my experience, it is the first time the literature that seven unique energy strategies have been designed to reduce overall energy consumption by making the university campus exterior lighting system more efficient, resulting in less harmful emissions to the atmosphere.
A control algorithm was developed to ensure the adaptability of the lights, improve the user experience, and maintain the lighting system's efficiency. It was carried out a research on the effects of urban morphological characteristics on nocturnal exterior lighting. Some sites were studied to analyze the existing luminous flux lighting installations with automatic control systems. For the pre-evaluation of an exterior lighting renovation with LED technology, experimental studies on energy efficiency and smart control systems have been performed. The role of transgenic bioluminescent plants in urban and suburban lighting environments has been investigated for minimizing light pollution, reducing electricity energy consumption and etc. The adjustment of lighting parameters from photopic values to mesopic values and the evaluation of the change in energy needs accordingly have been investigated in exterior lighting installation strategy. Maintenance factor was determined by using simulation and optimization techniques in outdoor lighting. The system architecture is designed according to the vision of the Internet of Things (IoT). The role of transgenic bioluminescent plants in urban and suburban lighting environments has been investigated for minimizing light pollution, reducing electricity energy consumption and etc. The adjustment of lighting parameters from photopic values to mesopic values and the evaluation of the change in energy needs accordingly have been investigated in exterior lighting installation strategy. Maintenance factor was determined by using simulation and optimization techniques in outdoor lighting installations. Lighting simulation was carried out using Radiance and optimization carried out using PSO/HJ algorithm.

### Table 1: Literature on energy-saving exterior lighting studies

| Lighting type | Implementation area | Content | Reference |
|---------------|---------------------|---------|-----------|
| Exterior      | University campus   | To increase efficiency and operational reliability in exterior lighting systems, LED applications of smart control systems and the smart grid concept have been studied in Russian Federation. | Filimonova et al. (2017) |
| Exterior      | Street lighting     | They examined the efficacy and energy savings of MH and ceramic discharge lamps. It was shown that energy-saving technologies could be used to dim ceramic MH lamps without compromising their life span or quality of light. | Orzáez and Díaz (2013) |
| Exterior      | Urban and suburban lighting | The role of transgenic bioluminescent plants in urban and suburban lighting environments has been investigated for minimizing light pollution, reducing electricity energy consumption and etc. | Ardavani et al. (2020) |
| Exterior      | University campus   | ZigBee-based exterior lighting control system has been designed for street lamps for reducing energy consumption. | Siddiqui et al. (2012) |
| Exterior      | Street lighting     | They designed energy efficient, smartly managed and remotely dimmable exterior lighting system. And, it has been observed 37% energy savings in one month. | Zotos et al. (2012) |
| Exterior      | Building at university campus | They designed an efficient smart exterior lighting control system that can use daylight and electrical energy more efficiently and reduce CO₂ emissions. | Atis and Ekren (2016) |
| Exterior      | Pedestrian path     | They investigated the development of photoluminescent composites for energy efficiency and smart exterior lighting applications. For this aim, they used spectroradiometric techniques to measure the interaction between various compounds and different light sources. | Fabiani et al. (2021) |
| Exterior      | Road                | They studied to analyze the existing luminous flux lighting installations with automatic control systems and to eliminate some of their deficiencies. The estimated efficiency of the new control system is 60% compared to existing lighting systems. | Pavlov et al. (2017) |
| Exterior      | Road                | They aimed to operate the exterior lighting system with renewable energy and to use the appropriate lamp for the illumination of the roads with low traffic. They calculated annual energy production as 371.7 kWh and consumption as 222.8 kWh. Also, suggested that remaining 148.9 kWh could be sold. | Bouroussis et al. (2006) |
| Exterior      | Street lighting     | A case study was carried out on energy saving and efficient using for street lighting in South of Spain. By replacing 250 W mercury vapor lamps with 59 W LED lamps, a 74% reduction in power was achieved and light pollution was reduced. | Burgos-Payán et al. (2012) |
| Exterior      | Street lighting     | A case study was carried out on the impact of traffic intensity detector parameters on dynamic street lighting energy consumption in Krakow, Poland. LED light sources were used in this research study. | Wojnicki and Kotulska (2018) |
| Exterior      | Street lighting     | Using the Sustainable Process Index (SPI) methodology, the ecological effects of widely available lighting technologies for exterior lighting such as High Pressure Sodium (HPS), Compact Fluorescent (CF) and LED have been investigated. | Shahzad et al. (2018) |
| Exterior      | General             | A control algorithm was developed to ensure the adaptability of the lights, improve the user experience, reduce energy consumption and take into account all variables in the environment Tampere, Finland. The system architecture is designed according to the vision of the Internet of Things (IoT). | Farahat et al. (2014) |
| Exterior      | Some sites          | It was carried out a research on the effects of urban morphological characteristics on nocturnal exterior lighting environment in cities. | Pan and Du (2021) |
| Exterior      | University campus   | It has been investigated to switch off some lights, dimming the lamps, and replacing the lamps with efficient ones using some scenarios for exterior lighting efficiency. They have been achieved 762 MWh/year energy saving, 251 ton CO₂ saving and 60% energy saving with Scenario-4. | Görgülü and Kocabay (2020) |
| Exterior      | Parking lot         | A multi-assessment criteria procedure for exterior lighting has been presented, in which lighting conditions, light pollution, and lighting energy efficiency were all evaluated. | Pracki and Skarzynski (2020) |
| Exterior      | Street lighting     | The adjustment of lighting parameters from photopic values to mesopic values and the evaluation of the change in energy needs accordingly have been investigated in exterior lighting installation strategy. | Galvez et al. (2021) |
| Exterior      | General             | A new smart solar powered LED (30 W) exterior lighting system has been designed, manufactured and tested. They have succeeded in designing a new lighting system that securing more than 40% of working hours compared to traditional systems. | Kiwan et al. (2018) |
| Exterior      | Street lighting     | The economic effect of intelligent dynamic control in urban exterior lighting has been investigated. A new approach is proposed using real-time sensor data, based on artificial intelligence techniques and graphical transforms. | Wojnicki et al. (2016) |
| Exterior      | Seaside beach and boardwalk | For the pre-evaluation of an exterior lighting renovation with led technology, experimental studies on power quality and energy efficiency have been studied and amortization analysis has been made. | Hermoso-Orzáez et al. (2017) |
| Exterior      | Street lighting     | Maintenance factor was determined by using simulation and optimization techniques in outdoor lighting installations. Lighting simulation was carried out using Radiance and optimization carried out using PSO/HJ algorithm. | Ogando-Martínez et al. (2018) |
as well as more cost savings. So, this unique study is expected to contribute to the literature.

2. In all seven proposed distinct strategies, less energy consumption and less CO$_2$ emissions were observed compared to the current system. Thus, it has been demonstrated that both cost-savings and the amount of harmful gas emitted into the atmosphere can be reduced significantly.

1. With Strategy-7, 81.656% energy savings (547,418 MWh/year), 180,599 tons/year CO$_2$ savings, and € 49,268 (€/year) cost-savings compared to the current system have been achieved.

2. Service and maintenance savings have been achieved by replacing inefficient luminaires with new, technological, and low-maintenance LED lamps.

3. It has been shown that the remaining budget from reduced electricity consumption expenditures can be used in scientific research projects and technological infrastructures.

4. This study can be a role model, motivating, and encouraging research study on energy saving in exterior lighting systems for other universities and local governments.

The rest of the paper continues as follows. The general electricity consumption of the university and the exterior lighting consumption values of the campus have been mentioned in Sect. 2. The research methodology and proposed strategies are presented in Sect. 3. The result and discussion of proposed strategies are presented in Sect. 4. The conclusions and recommendations are given in Sect. 5.

## 2 Overview and motivation

Kahramanmaraş Sütçü İmam University was founded in 1992, and is located in Kahramanmaraş city in the Mediterranean region of Turkey. The geographical location of Kahramanmaraş Sütçü İmam University is shown in Fig. 1 (MENR, 2021).

This university contains 12 faculties, 3 institutes, 3 colleges, 8 vocational schools, 5 departments associated with the rectorate, 25 application, and research centers, and 1 health practice and research hospital, and it continues to developing and expanding every year. Some specifics of the university campus are given in Table 2.

### Table 1 (continued)

| Lighting type       | Implementation area | Content                                                                 | Reference          |
|---------------------|---------------------|-------------------------------------------------------------------------|--------------------|
| Exterior            | Street lighting     | A multi-criteria decision making tool was designed for energy efficiency optimization of public street lighting systems. | Carli et al. (2018). |

Fig. 1 The geographical location of Kahramanmaraş Sütçü İmam University

Avşar Campus is the central campus and it includes the Rectorate building, Engineering and Architecture Faculty, Medicine Faculty, Dentistry Faculty, Education Faculty, Arts and Sciences Faculty, Fine Arts Faculty, Economics and Administrative Sciences Faculty, Theology Faculty, Forestry Faculty, Agriculture Faculty, School of Foreign Languages, School of Physical Education and Sports, Institute of Science, Institute of Social Sciences, Institute of Health Sciences and Health Practice and Research Hospital.

Avşar Campus has a modern and energetic appearance with external lighting and landscaping. There are lecture theaters, smart classrooms, conference halls, laboratories equipped with the latest technology, sports facilities, internet lounges, libraries, and student cafeterias. In addition, there is 1 soccer pitch, 1 amphitheater, 3 astroturf, 4 basketball courts, 6 tennis courts, 4 volleyball courts, a 1,500-seat indoor sports hall, a 5,000-seat stadium, and a semi-olympic swimming pool.

With its many active and modern facilities, the Avşar Campus consumes a large amount of electrical energy. Current energy consumptions for January 2021, February 2021, March 2021, and April 2021 are 1,243 MWh, 1,180 MWh, 1,224 MWh and 956,537 MWh, respectively. The equivalent carbon emissions to these consumptions are calculated as 410 tons, 389 tons, 404 tons and 316 tons for January 2021, February 2021, March 2021 and April 2021, respectively. An emission factor of 329.91 equivalent gCO$_2$/kWh was used to calculate CO$_2$ emissions (Beccali et al., 2015).

### Table 2 Some specifics of the university campus

| Coordinates | University name | Campus name | City | Country                  |
|-------------|----------------|-------------|------|--------------------------|
| 37° 35' 08.7” N – 36° 49' 07.7” E | Kahramanmaraş | Avşar Campus | Sütçü İmam University | Kahramanmaraş Turkey |
Electricity consumption and CO₂ emission values of University campus for 2021 is given Fig. 2.

It includes all electricity consumption, such as interior lighting, external lighting, air conditioning, electrical appliances in labs, workshops, and hospitals, and so on, among the energy consumption visual work described in Fig. 2. In this study, it is aimed to investigate exterior lighting consumption values, which is one of the electrical energy consumption items, and to reduce with effective strategies. This decrease will also lead to a reduction in carbon emissions, which is vital for environmental quality. View of university campus is given in Fig. 3.

2.1 The university’s overall electricity consumptions

This section focuses on the total electrical energy consumption of the University campus from 2015 to 2021. It has been determined as 15,535 MWh, 18,187 MWh, 18,607 MWh, 18,647 MWh, 19,655 MWh and 18,914 MWh for 2015, 2016, 2017, 2018, 2019 and 2020, respectively. Total energy consumption continued to increase between 2015 and 2019. However, in 2020, there was a 741 MWh decrease compared to the previous year. The reason for this decrease can be explained as the cessation of formal education due to the Covid-19 pandemic. For 2021, the electric energy consumption still continues and it has been calculated as 4,604 MWh so far.

Furthermore, the CO₂ emissions of the campus in 2015–2021 were also examined. It has been calculated as 5,125 tons, 6,000 tons, 6,139 tons, 6,152 tons, 6,484 tons and 6,240 tons of CO₂ for 2015, 2016, 2017, 2018, 2019 and 2020, respectively. For 2021, it has been calculated as 1,519 tons so far and still continues. Electricity consumption and CO₂ emission amounts of university campus for 2015–2021 are given in Fig. 4.

When the electricity consumptions for 2015–2021 are analyzed, it was determined that the highest consumptions were generally in June, July, August, and September. The cause of these raises has been determined as the cooling/air conditioning systems which consumed a huge amount of energy in facilities. Also, the hospital building was confirmed to be the most energy-consuming facility on campus. Electricity consumption amounts of university campus for 2015–2021 (MWh) are given in Fig. 5.

2.2 The university’s exterior lighting consumptions

The campus’s current exterior lighting system is controlled by an astronomical timer. In other words, the operating time of the system varies depending on the sunrise and sunset times according to the months. The average daily operating hours of the exterior lighting system are 14 h 08 m, 13 h 11 m, 12 h 04 m, 10 h 50 m, 10 h 18 m, 9 h 16 m, 9 h 30 m, 10 h 23 m, 11 h 34 m, 12 h 45 m, 13 h 50 m and 14 h 25 m for January, February, March, April, May, June, July, August, September, October, November, and December, respectively. The longest operating hours are in December, in the winter, and the shortest in June, in the summer. The
operating hours of the exterior lighting system of university campus are given in Table 3.

HPS, MH, LED, and CFL lamps were determined as the types of lamps utilized for exterior lighting on campus. There are 1,082 lamps in total, with a total installed lamp power of 155,071 kW. Total installed power values are calculated as 109,050 kW, 24,675 kW, 13,299 kW and 8,047 kW for HPS, MH, LED and CFL, respectively. HPS has the most total installed power as 109,050 kW, while CFL has the lowest as 8,047 kW. The distribution graph of total installed power (kW) based on lamp types is given in Fig. 6.

The energy consumption of the current exterior lighting system varies according to climatic changes, that is, based on used daylight times. While there are longer exterior lighting periods in winter seasons with less daylight, shorter

The total energy consumption of exterior lighting is calculated as 670,395.194 kWh/year, annually. According to the lamp types, it has been determined as 471,439.51 kWh/year, 106,673.73 kWh/year, 57,493.57 kWh/year, and 34,788.39 kWh/year for HPS, MH, LED and CFL, respectively. The current exterior lighting situation of the university campus is given in Table 4.

The energy consumption of the current exterior lighting system varies according to climatic changes, that is, based on used daylight times. While there are longer exterior lighting periods in winter seasons with less daylight, shorter

### Table 3 Operating hours of the exterior lighting system of the university campus

| Months  | Number of days | Sunrise time (average) | Sunset time (average) | Daily working hours (average) |
|---------|----------------|------------------------|-----------------------|-------------------------------|
| January | 31             | 07:46                  | 17:38                 | 14 h 08 m                     |
| February| 28             | 07:22                  | 18:11                 | 13 h 11 m                     |
| March   | 31             | 06:43                  | 18:39                 | 12 h 04 m                     |
| April   | 30             | 05:58                  | 19:08                 | 10 h 50 m                     |
| May     | 31             | 05:53                  | 19:35                 | 10 h 18 m                     |
| June    | 30             | 05:11                  | 19:55                 | 9 h 16 m                      |
| July    | 31             | 05:23                  | 19:53                 | 9 h 30 m                      |
| August  | 31             | 05:48                  | 19:25                 | 10 h 23 m                     |
| September| 30           | 06:14                  | 18:40                 | 11 h 34 m                     |
| October | 31             | 06:40                  | 17:55                 | 12 h 45 m                     |
| November| 30             | 07:12                  | 17:22                 | 13 h 50 m                     |
| December| 31             | 07:40                  | 17:15                 | 14 h 25 m                     |

### Table 4 The current exterior lighting situation of the university campus

| Lamp type | Lamp power (W) | Lamp count | Total installed power (kW) | Total energy consumption (kWh/year) |
|-----------|----------------|------------|----------------------------|------------------------------------|
| CFL       | 23             | 89         | 2,047                      | 8,849,488                          |
| LED       | 150            | 2          | 0,300                      | 1,296,945                          |
| MH        | 160            | 30         | 4,800                      | 20,751,120                         |
| TOTAL     | 1,082          | 155,071    | 670,395.194               | 2628,640                            |

### Abbreviation:
- CFL: Compact Fluorescent Lamp
- LED: Light Emitting Diode
- HPS: High Pressure Sodium lamp
- MH: Metal-halide lamp

### Table 5 Changing of energy consumption and CO₂ emissions of current exterior lighting

| Months  | Energy consumption (MWh) | CO₂ emission (tCO₂) |
|---------|--------------------------|---------------------|
| January | 67,782                   | 22,362              |
| February| 57,242                   | 18,885              |
| March   | 58,007                   | 19,137              |
| April   | 50,398                   | 16,627              |
| May     | 49,514                   | 16,335              |
| June    | 43,110                   | 14,222              |
| July    | 45,668                   | 15,066              |
| August  | 49,915                   | 16,467              |
| September| 53,810                | 17,752              |
| October | 61,292                   | 20,221              |
| November| 64,354                   | 21,231              |
| December| 69,304                   | 22,864              |
| TOTAL   | 670,395                  | 221,170             |
exterior lighting periods are experienced in summer seasons when daylight is abundant. The highest energy consumption for exterior lighting is in December at 69,304 MWh, while the lowest energy consumption is in June at 43,110 MWh. The quantity of CO$_2$ released into the atmosphere is directly proportional to the quantity of energy consumed, and it is highest in December at 22,864 tons and lowest in June at 14,222 tons. Changes in energy consumption and CO$_2$ emissions of current exterior lighting are given in Table 5.

3 Methodology

The methodology consists of three subheadings such as current challenges on the existing exterior lighting system, solution approaches for the existing exterior lighting system, and energy-saving strategies for the existing exterior lighting system.

3.1 Current challenges on the existing exterior lighting system

The main aim of this methodology’s creation is to reduce CO$_2$ emissions by increasing the effectiveness of the campus’s exterior lighting system. It is determined that the followings are the primary reasons influencing the decrease in campus’s exterior lighting efficiency:

- operation of the lamps without any dimming process,
- using an astronomical timer,
- inefficient lamp choices.

3.2 Solution approaches for the existing exterior lighting system

Exterior lighting works such as street lighting, can be classified into three groups for energy efficiency and consumption reduction. The first one refers to the optimization of street lighting system design such as the height of lighting units and overhang of lighting poles etc. The second one refers to choosing the technological ones of the lamps and luminaires. The third one refers to the automatic control of lamps and luminaires under project conditions, that is, taking time and road conditions into account (Carli et al., 2018). In addition, there are three main methods to control lamps in exterior lighting control systems: lamp control based on illumination level (photocell), lamp control with motion sensors, and lamp control using modular clocks (Atis and Ekren, 2016).

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The existing exterior lighting system on our campus has an astronomical timer that turns on at sunset and turns off at sunrise. However, it is not possible to mention that this is an efficient lighting system. Lamps that operate even when it’s still bright outside or before it turns dark are common. Since the current exterior lighting system consumes extremely high energy, it causes massive economic losses and CO$_2$ emissions. Thus, in light of the above-mentioned items, ways to reduce CO$_2$ emissions by making the electrical energy...
consumed in the exterior lighting system of the university campus more efficient have been investigated. The study started with the feasibility analysis of the exterior lighting system of the entire campus. That is, projects and fieldwork were carried out to determine the exterior lighting consumption and the types of lamps used on the campus. Buildings, gardens, roadways, pedestrian ways, sports facilities, and all other facilities were all scrutinized separately. The installed powers were calculated separately by determining the lamp types, lamp powers, and lamp counts of each place. The total operating hours and total energy consumptions were then computed by taking into consideration the sunrise and sunset hours periods. Also, CO$_2$ emissions are calculated and noted for consumption values. The quantities of energy consumption and CO$_2$ emissions have been analyzed and found to be quite high, prompting the design of strategies to reduce both. Then, energy consumption, energy-saving, CO$_2$ consumption, and CO$_2$ saving values for each strategy are calculated separately. Flowchart of research methodology is given in Fig. 7.

3.3 Energy-saving strategies for the exist exterior lighting system

To overcome these adverse situations which are mentioned in Sect. 3.1, the seven unique strategies have been designed in light of Sect. 3.2. Energy-saving strategies for university campus exterior lighting system are given in Fig. 8.

### 3.3.1 Strategy-1

In this strategy, the dimming method has been applied to all lamps in the current system to reduce the energy consumption in the exterior lighting system. Lamps were dimmed to a certain rate but not completely turned off. Education and activity time frames on campus were carefully investigated before the process of strategies design. To avoid causing any security problems, sensitive and careful work was carried out, and the authorities were consulted. It has resulted in Table 6:

| Lamp type | Lamp power (W) | Lamp count | Total installed power (kW) | Until 00:00 (with 20% dimming) | Then 00:00 (with 60% dimming) | Total energy consumption (MWh/year) | Energy saving (MWh/year) |
|-----------|----------------|------------|----------------------------|---------------------------------|---------------------------------|-----------------------------------|--------------------------|
| CFL       | 125            | 48         | 6,000                      | 9,399                           | 5,676                           | 16,075                            | 10,864                   |
|           | 23             | 89         | 2,047                      | 3,206                           | 1,937                           | 5,143                             | 3,706                    |
| LED       | 150            | 2          | 0,300                      | 0,470                           | 0,284                           | 0,754                             | 053                      |
|           | 100            | 45         | 4,500                      | 7,049                           | 4,257                           | 11,306                            | 8,148                    |
|           | 75             | 78         | 5,850                      | 9,164                           | 5,534                           | 14,699                            | 10,592                   |
|           | 36             | 17         | 0,612                      | 0,959                           | 0,579                           | 1,538                             | 1,108                   |
|           | 35             | 6          | 0,210                      | 0,329                           | 0,199                           | 0,528                             | 0,380                    |
|           | 18             | 68         | 1,224                      | 1,917                           | 1,158                           | 3,075                             | 2,216                    |
|           | 9              | 53         | 0,477                      | 0,747                           | 0,451                           | 1,198                             | 0,864                    |
| HPS       | 1,000          | 20         | 20,000                     | 31,329                          | 18,921                          | 50,249                            | 36,214                   |
|           | 400            | 27         | 10,800                     | 16,917                          | 10,217                          | 27,135                            | 19,555                   |
|           | 250            | 247        | 61,750                     | 96,727                          | 58,418                          | 155,145                           | 111,809                  |
|           | 150            | 110        | 16,500                     | 25,846                          | 15,610                          | 41,456                            | 29,876                   |
| MH        | 160            | 30         | 4,800                      | 7,519                           | 4,541                           | 12,060                            | 8,691                    |
|           | 150            | 29         | 4,350                      | 6,814                           | 4,115                           | 10,929                            | 7,876                    |
|           | 125            | 73         | 9,125                      | 14,294                          | 8,633                           | 22,926                            | 16,522                   |
|           | 80             | 50         | 4,000                      | 6,266                           | 3,784                           | 10,050                            | 7,243                    |
|           | 50             | 48         | 2,400                      | 3,759                           | 2,271                           | 6,030                             | 4,346                    |
| TOTAL     | 1,082          | 155,071    | 242,907                    | 389,612                         | 280,783                         |                                    |                          |

Fig. 8 Energy-saving strategies for university campus exterior lighting system
been determined that education activities can continue until 23:00, and other social and sports activities can continue until 23:30, rarely. However, it was determined that human mobility on campus did not exceed 00:00 and that mobility ended after this hour (the hospital on campus is considered as an exception). Thus, this strategy has been examined in two different categories as “until 00:00 period” and “then 00:00 period”. In the current system, the annual average exterior lighting time is calculated as 1958.03 h for “until 00:00 period”, while it is as 2365.12 h for “then 00:00 period”. While 20% dimming was applied to the system in the “until 00:00 period”, 60% dimming was in the “then 00:00 period”. Energy consumptions of “until 00:00 period” and “then 00:00 period” are calculated as 242,907 MWh/year and 146,704 MWh/year, respectively.

While total consumption was reduced to 389,612 MWh/year in this strategy, an energy saving of 280,783 MWh/year was achieved. In other words, 41.883% energy saving has been observed compared to the current system. In addition, the CO₂ emission was reduced to 128,537 tons CO₂/year, while the CO₂ saving was achieved as 92,633 tons CO₂/year. Results of strategy-1 are given in Table 6.

### 3.3.2 Strategy-2

In this strategy, it is aimed to save energy, economy, and CO₂ emissions by turning off some of the lamps completely. Electronic timer switches were added in all lamps without causing any damage to the current system or demanding extra study. The desired lamps could be completely turned off in this way. However, no place (e.g. building, garden, roadways, pedestrian ways etc.) was left completely unlit for pedestrian and driver safety. This study was meticulously prepared, and campus tours were conducted.

This strategy has been examined in two different categories: “until 00:00 period” and “then 00:00 period”. In the “until 00:00 period”, all of the lamps continued to operate as in the current system, taking into account the mobility in the campus, that is, no lamps were turned off. In the “then 00:00 period”, turn-off operations were performed based on location and at certain rates. For instance, the junctions are only 20% turned off for security and location control. Considering the possibility of emergency cases in hospital and dentistry buildings, both were turned off at a rate of 60%. Pedestrian ways and roadways were both turned off at 70%, parking lots at 80%, gardens, library, and other buildings at 90%. Turn-off rates of strategy-2 are given in Table 7.

### Table 7 Turn-off rates of strategy-2

| Places                                    | Turn off rate (%) |
|-------------------------------------------|-------------------|
| Buildings (Faculties, research centers and etc.) | 90                |
| Library                                   | 90                |
| Hospital                                  | 60                |
| Dentistry faculty                         | 60                |
| Junctions                                 | 20                |
| Pedestrian ways                           | 70                |
| Roadways                                  | 70                |
| Gardens                                   | 90                |
| Parking lots                              | 80                |

### Table 8 Results of strategy-2

| Lamp type | Lamp power (W) | Until 00:00 | Then 00:00 | Energy consumption (MWh/year) | Energy saving (MWh/year) |
|-----------|----------------|-------------|------------|-------------------------------|--------------------------|
|           | Lamp count     | Total installed power (kW) | Lamp count     | Total installed power (kW)         |                          |
| CFL       | 125            | 48          | 6,000      | 5                             | 0,625                     | 13,226                   | 12,713                  |
|           | 23             | 89          | 2,047      | 9                             | 0,207                     | 4,498                    | 4,352                   |
| LED       | 150            | 2           | 0,300      | 1                             | 0,150                     | 0,942                    | 0,355                   |
|           | 100            | 45          | 4,500      | 5                             | 0,500                     | 9,994                    | 9,460                   |
|           | 75             | 78          | 5,850      | 9                             | 0,675                     | 13,051                   | 12,239                  |
|           | 36             | 17          | 0,612      | 2                             | 0,072                     | 1,369                    | 1,277                   |
|           | 35             | 6           | 0,210      | 1                             | 0,035                     | 0,494                    | 0,414                   |
|           | 18             | 68          | 1,224      | 16                            | 0,288                     | 3,078                    | 2,214                   |
|           | 9              | 53          | 0,477      | 6                             | 0,054                     | 1,062                    | 1,000                   |
|           | 3              | 42          | 0,126      | 5                             | 0,015                     | 0,282                    | 0,263                   |
| HPS       | 1,000          | 20          | 20,000     | 7                             | 7,000                     | 55,716                   | 30,747                  |
|           | 400            | 27          | 10,800     | 5                             | 2,000                     | 25,877                   | 20,813                  |
|           | 250            | 247         | 61,750     | 65                            | 16,250                    | 159,342                  | 107,613                 |
|           | 150            | 110         | 16,500     | 20                            | 3,000                     | 39,403                   | 31,929                  |
| MH        | 160            | 30          | 4,800      | 6                             | 0,960                     | 11,669                   | 9,082                   |
|           | 150            | 29          | 4,350      | 7                             | 1,050                     | 11,001                   | 7,805                   |
|           | 125            | 73          | 9,125      | 17                            | 2,125                     | 22,893                   | 16,556                  |
|           | 80             | 50          | 4,000      | 5                             | 0,400                     | 8,778                    | 8,514                   |
|           | 50             | 48          | 2,400      | 15                            | 0,750                     | 6,473                    | 3,902                   |
| TOTAL     | 1,082          | 155,071     | 206        | 36,156                        | 389,147                   | 281,248                  |
In the “until 00:00 period” there is no turned off the lamp, which means all the lamps are turned on. The total number of lamps and total installed power values are 1,082 and 155,071 kW, respectively. In the “then 00:00 period”, the number of turned on lamps and the total installed power value were reduced to 206 and 36,156 kW, respectively, by applying the turn-off rates shown in Table 7. For this strategy, the total energy consumption was calculated as 389,147 MWh/year, while an annual energy saving of 281,248 MWh/year was achieved. A 41.953% energy saving was observed compared to the current system. In addition, the CO₂ emission was reduced to 128,384 tons CO₂/year, while the CO₂

| Lamp count | Present lighting system | Fresh lighting system |
|------------|-------------------------|----------------------|
| Lamp type  | Lamp power (W) | Total installed power (kW) | Lamp type | Lamp power (W) | Total installed power (kW) |
| 48 | CFL | 125 | 6,000 | LED | 60 | 2,880 |
| 89 | 23 | 2,047 | 14 | 1,246 |
| 2 | LED | 150 | 0,300 | LED | 150 | 0,300 |
| 45 | 100 | 4,500 | 36 | 0,612 |
| 78 | 75 | 5,850 | 75 | 5,850 |
| 17 | 36 | 6,012 | 36 | 0,612 |
| 6 | 35 | 0,210 | 35 | 0,210 |
| 68 | 18 | 1,224 | 18 | 1,224 |
| 53 | 9 | 0,477 | 9 | 0,477 |
| 42 | 3 | 0,126 | 3 | 0,126 |
| 20 | HPS | 1,000 | 20,000 | LED | 300 | 6,000 |
| 27 | 400 | 10,800 | 120 | 3,240 |
| 247 | 250 | 61,750 | 100 | 24,700 |
| 110 | 150 | 16,500 | 80 | 8,800 |
| 30 | MH | 160 | 4,800 | LED | 90 | 2,700 |
| 29 | 150 | 4,350 | 80 | 2,320 |
| 73 | 125 | 9,125 | 40 | 2,920 |
| 50 | 80 | 4,000 | 18 | 0,900 |
| 48 | 50 | 2,400 | 9 | 0,432 |

| Lamp count | Present lighting system | Fresh lighting system |
|------------|-------------------------|----------------------|
| Lamp type  | Lamp power (W) | Energy consumption (MWh/year) | Lamp type | Lamp power (W) | Energy consumption (MWh/year) | Energy saving (MWh/year) |
| 48 | CFL | 125 | 25,939 | LED | 60 | 12,451 | 13,488 |
| 89 | 23 | 8,849 | 14 | 5,387 | 3,463 |
| 2 | LED | 150 | 1,297 | LED | 150 | 1,297 | - |
| 45 | 100 | 19,454 | 100 | 19,454 | - |
| 78 | 75 | 25,290 | 75 | 25,290 | - |
| 17 | 36 | 2,646 | 36 | 2,646 | - |
| 6 | 35 | 0,908 | 35 | 0,908 | - |
| 68 | 18 | 5,292 | 18 | 5,292 | - |
| 53 | 9 | 2,062 | 9 | 2,062 | - |
| 42 | 3 | 0,545 | 3 | 0,545 | - |
| 20 | HPS | 1,000 | 86,463 | LED | 300 | 25,939 | 60,524 |
| 27 | 400 | 46,690 | 120 | 14,007 | 32,683 |
| 247 | 250 | 266,955 | 100 | 106,782 | 160,173 |
| 110 | 150 | 71,332 | 80 | 38,044 | 33,288 |
| 30 | MH | 160 | 20,751 | LED | 90 | 11,673 | 9,079 |
| 29 | 150 | 18,806 | 80 | 10,030 | 8,776 |
| 73 | 125 | 39,449 | 40 | 12,624 | 26,825 |
| 50 | 80 | 17,293 | 18 | 3,891 | 13,402 |
| 48 | 50 | 10,376 | 9 | 1,868 | 8,508 |

| Lamp count | Present lighting system | Fresh lighting system |
|------------|-------------------------|----------------------|
| Lamp type  | Lamp power (W) | Energy consumption (MWh/year) | Lamp type | Lamp power (W) | Energy consumption (MWh/year) |
| 48 | CFL | 125 | 670,395 | LED | 300 | 370,209 |

Table 9 Retrofitting the existing lamps with LED lamps

Table 10 Results of strategy-3
saving was achieved as 92,786 tons CO$_2$/year. Results of strategy-2 are given in Table 8.

### 3.3.3 Strategy-3

In this strategy, low efficiency and old technology lamps such as CFL, HPS, and MH in the current system have been retrofitted with new, technological, efficient, and long-lasting LED lamps. No change has been made in the total number of lamps and operating times. 771 old technology lamps were retrofitted with LED lamps. The total number of used lamps remained unchanged at 1,082.

125 W and 23 W CFL lamps are retrofitted by 60 W and 14 W LED lamps, respectively. 1,000 W, 400 W, 250 W, and 150 W HPS lamps are retrofitted by 300 W, 120 W, 100 W, and 80 W LED lamps respectively. 160 W, 150 W, 125 W, 80 W, and 50 W MH lamps are retrofitted by 90 W, 80 W, 40 W, 18 W, and 9 W LED lamps respectively. Thus, the total installed power in the current system has been reduced from 155,071 kW to 69,437 kW with this strategy. Retrofitting existing lamps with LED lamps is given in Table 9.

With the installation of more efficient LED lamps, both the total installed power and energy consumption in the current system have been decreased from 670,395 MWh/year to 300,187 MWh/year, annually. With this strategy, a 55.222% energy saving, in other words, 370,209 MWh/year energy saving has been achieved compared to the current system.

### 3.3.4 Strategy-4

This strategy was designed by combining strategy-1 and strategy-2 to reduce the total energy consumption in the current system. Both strategies have been applied to the current system simultaneously. In “until 00:00 period”, unlike the current system, only 20% dimming was performed. In the “then 00:00 period”, both 60% dimming and some of the lamps were switched off completely. The number of lamps has been reduced from 1,082 to 206 during this period. Annual energy consumption was calculated as 242,907 MWh/year for the “until 00:00 period”, and 34,205 MWh/year for the “then 00:00 period”. It was observed a 14% decrease of energy consumption between the two periods. With this strategy, the total energy consumption was calculated as 277,113 MWh/year and energy saving as 393,283 MWh/year. Also, 58.664% energy saving was achieved compared to the existing system. Furthermore, the CO$_2$ emission was reduced to 91,422 tons CO$_2$/year, while the CO$_2$ saving was achieved as 129,748 tons CO$_2$/year. Results of strategy-4 are given in Table 11.

| Lamp type | Lamp power (W) | Lamp count | Total installed power (kW) | Energy consumption (MWh/year) | Lamp type | Lamp power (W) | Lamp count | Total installed power (kW) | Energy consumption (MWh/year) | Lamp type | Lamp power (W) | Lamp count | Total installed power (kW) | Energy consumption (MWh/year) |
|-----------|----------------|------------|-----------------------------|------------------------------|-----------|----------------|------------|-----------------------------|------------------------------|-----------|----------------|------------|-----------------------------|------------------------------|
| CFL       | 125            | 48         | 6,000                       | 9,399                        | LED       | 150           | 2          | 0,300                       | 0,470                        | HPS       | 1,000          | 20         | 20,000                     | 31,329                      |
|           | 23             | 89         | 2,047                       | 3,206                        |           | 150           | 2          | 0,300                       | 0,470                        |           | 27             | 10,800                  | 16,917                     |
|           |                |            |                             |                              |           | 100           | 45         | 4,500                       | 7,049                        |           | 247            | 61,750                 | 96,727                    |
|           |                |            |                             |                              |           | 75            | 78         | 5,850                       | 9,164                        |           | 110            | 16,500                 | 25,846                    |
|           |                |            |                             |                              |           | 36            | 17         | 0,612                       | 0,959                        |           | 27             | 61,750                 | 96,727                    |
|           |                |            |                             |                              |           | 35            | 6          | 0,210                       | 0,329                        |           | 247            | 61,750                 | 96,727                    |
|           |                |            |                             |                              |           | 18            | 68         | 1,224                       | 1,917                        |           | 110            | 16,500                 | 25,846                    |
|           |                |            |                             |                              |           | 9             | 53         | 0,477                       | 0,747                        |           | 27             | 10,800                  | 16,917                    |
|           |                |            |                             |                              |           | 3             | 42         | 0,126                       | 0,197                        |           | 47             | 55                       | 4,350                     |
| HPS       | 1,000          | 20         | 20,000                      | 31,329                       |           | 250           | 247        | 61,750                      | 96,727                       |           | 150            | 16,500                 | 25,846                    |
|           | 400            | 27         | 10,800                      | 16,917                       |           | 150           | 110        | 16,500                      | 25,846                       |           | 20             | 3,000                   | 2,838                     |
| MH        | 160            | 30         | 4,800                       | 7,519                        |           | 150           | 29         | 4,350                       | 6,814                        |           | 247            | 61,750                 | 96,727                    |
|           | 125            | 73         | 9,125                       | 14,294                       |           | 125           | 73         | 9,125                       | 14,294                       |           | 30             | 4,800                   | 7,519                     |
|           | 80             | 50         | 4,000                       | 6,266                        |           | 80            | 50         | 4,000                       | 6,266                        |           | 47             | 55                       | 4,350                     |
|           | 50             | 48         | 2,400                       | 3,759                        |           | TOTAL        | 1,082      | 155,071                     | 242,907                      |           | 206            | 36,156                 | 34,205                    |

Table 11: Results of strategy-4

In addition, the CO$_2$ emission was reduced to 99,035 tons CO$_2$/year, while the CO$_2$ saving was achieved as 122,136 tons CO$_2$/year. Results of strategy-3 are given in Table 10.
3.3.5 Strategy-5

This strategy was designed by combining strategy-1 and strategy-3 to reduce the total energy consumption in the current system. In “until 00:00 period”, all lamps were retrofitted by efficient and long-lasting LED lamps and 20% dimming was applied to all lamps. In “then 00:00 period”, 60% dimming was applied to all LED retrofitted lamps. The number of lamps were not changed during these operations. The energy consumption was as 108,768 MWh/year during

| Lamp type | Lamp power (W) | Lamp count | Until 00:00 | Then 00:00 | Total energy consumption (MWh/year) | Energy saving (MWh/year) |
|-----------|----------------|------------|-------------|------------|-----------------------------------|------------------------|
| CFL       | 60 (LED)       | 48         | 4,511       | 2,725      | 7,236                             | 18,703                 |
|           | 14 (LED)       | 89         | 1,952       | 1,179      | 3,131                             | 5,719                  |
| LED       | 150 (LED)      | 2          | 0,470       | 0,284      | 0,754                             | 0,543                  |
|           | 100 (LED)      | 45         | 7,049       | 4,257      | 11,306                            | 8,148                  |
|           | 75 (LED)       | 78         | 9,164       | 5,534      | 14,698                            | 10,592                 |
|           | 36 (LED)       | 17         | 0,959       | 0,579      | 1,538                             | 1,108                  |
|           | 35 (LED)       | 6          | 0,329       | 0,199      | 0,528                             | 0,380                  |
|           | 18 (LED)       | 68         | 1,917       | 1,158      | 3,075                             | 2,216                  |
|           | 9 (LED)        | 53         | 0,747       | 0,451      | 1,198                             | 0,864                  |
|           | 3 (LED)        | 42         | 0,197       | 0,119      | 0,317                             | 0,228                  |
| HPS       | 300 (LED)      | 20         | 9,399       | 5,676      | 15,075                            | 71,388                 |
|           | 120 (LED)      | 27         | 5,075       | 3,065      | 8,140                             | 38,550                 |
|           | 100 (LED)      | 247        | 38,691      | 23,367     | 62,058                            | 204,896                |
|           | 80 (LED)       | 110        | 13,785      | 8,325      | 22,110                            | 49,222                 |
| MH        | 90 (LED)       | 30         | 4,229       | 2,554      | 6,784                             | 13,967                 |
|           | 80 (LED)       | 29         | 3,634       | 2,195      | 5,829                             | 12,977                 |
|           | 40 (LED)       | 73         | 4,574       | 2,762      | 7,336                             | 32,112                 |
|           | 18 (LED)       | 50         | 1,410       | 0,851      | 2,261                             | 15,031                 |
|           | 9 (LED)        | 48         | 0,677       | 0,409      | 1,085                             | 9,290                  |
| TOTAL     |                |            | 1,082       | 108,768    | 65,691                            | 174,459                | 495,937               |

Table 13 Results of strategy-6

| Lamp type | Lamp power (W) | Lamp count | Until 00:00 | Total installed power (kW) | Then 00:00 | Total installed power (kW) | Energy consumption (MWh/year) | Energy saving (MWh/year) |
|-----------|----------------|------------|-------------|---------------------------|------------|---------------------------|-----------------------------|------------------------|
| CFL       | 60 (LED)       | 48         | 2,880       | 5                         | 0,300      | 6,349                     | 19,590                      |
|           | 14 (LED)       | 89         | 1,246       | 9                         | 0,126      | 2,738                     | 6,112                       |
| LED       | 150 (LED)      | 2          | 0,300       | 1                         | 0,150      | 0,942                     | 0,355                       |
|           | 100 (LED)      | 45         | 4,500       | 5                         | 0,500      | 9,994                     | 9,460                       |
|           | 75 (LED)       | 78         | 5,850       | 9                         | 0,675      | 13,051                    | 12,239                      |
|           | 36 (LED)       | 17         | 0,612       | 2                         | 0,072      | 1,369                     | 1,277                       |
|           | 35 (LED)       | 6          | 0,210       | 1                         | 0,035      | 0,494                     | 0,414                       |
|           | 18 (LED)       | 68         | 1,224       | 16                        | 0,288      | 3,078                     | 2,214                       |
|           | 9 (LED)        | 53         | 0,477       | 6                         | 0,054      | 1,062                     | 1,000                       |
|           | 3 (LED)        | 42         | 0,126       | 5                         | 0,015      | 0,282                     | 0,263                       |
| HPS       | 300 (LED)      | 20         | 6,000       | 7                         | 2,100      | 16,715                    | 69,748                      |
|           | 120 (LED)      | 27         | 3,240       | 5                         | 0,600      | 7,763                     | 38,927                      |
|           | 100 (LED)      | 247        | 24,700      | 65                        | 6,500      | 63,737                    | 203,218                     |
|           | 80 (LED)       | 110        | 8,800       | 20                        | 1,600      | 21,015                    | 50,317                      |
| MH        | 90 (LED)       | 30         | 2,700       | 6                         | 0,540      | 6,564                     | 14,187                      |
|           | 80 (LED)       | 29         | 2,320       | 7                         | 0,560      | 5,867                     | 12,939                      |
|           | 40 (LED)       | 73         | 2,920       | 17                        | 0,680      | 7,326                     | 32,123                      |
|           | 18 (LED)       | 50         | 0,900       | 5                         | 0,090      | 1,975                     | 15,318                      |
|           | 9 (LED)        | 48         | 0,432       | 15                        | 0,135      | 1,165                     | 9,210                       |
| TOTAL     |                |            | 1,082       | 69,437                    | 206        | 15,020                    | 171,484                     | 498,911                |
the “until 00:00 period”, and, it was reduced to as 65,691 MWh/year during the “then 00:00 period”. In this strategy, total energy consumption was calculated as 174,459 MWh/year, while energy-saving was obtained as 495,937 MWh/year. Compared to the current system, a 73.977% energy saving has been achieved. In addition, the CO₂ emission was reduced to 57,556 tons CO₂/year, while the CO₂ saving was achieved as 163,614 tons CO₂/year. Results of strategy-5 are given in Table 12.

### 3.3.6 Strategy-6

This strategy was designed by combining strategy-2 and strategy-3 to reduce the total energy consumption in the current system. In “until 00:00 period”, all lamps were retrofitted by efficient and long-lasting LED lamps. The number of lamps used in this period was as 1,082 and the total installed power was as 69,437 kW. In the “then 00:00 period”, some of the lamps retrofitted by LED were completely turned off. The number of lamps has been reduced to 206 and the total installed power to 15,020 kW. Energy consumption was calculated as 171,484 MWh/year, while energy-saving was calculated as 498,911 MWh/year. Compared to the existing system, 74.420% energy saving has been achieved. In addition, the CO₂ emission was reduced to 56,574 tons CO₂/year, while the CO₂ saving was achieved as 164,596 tons CO₂/year. Results of strategy-6 are given in Table 13.

### 3.3.7 Strategy-7

This strategy was designed from the combination of all proposed strategies, that is, strategy-1, strategy-2 and strategy-3. All lamps used in this strategy were LED lamps. In the “until 00:00 period”, 20% of the lamps were dimming applied, no lamp was not turned off completely. The number of actively used lamps was 1,082 and the total installed power is 69,437 kW. In the “then 00:00 period”, the number of lamps was reduced to 206 and 60% of these lamps were dimming. Thus, the total installed power has been reduced to 15,020 kW. Energy consumptions were calculated as 108,768 MWh/year and 14,210 MWh/year for “until 00:00 period” and “then 00:00 period”, respectively. The total energy consumption for both time periods was 122,978 MWh/year and the energy-saving was 547,418 MWh/year. An 81.656% energy saving was achieved compared to the current system. In addition, the CO₂ emission was reduced to 40,572 tons CO₂/year, while the CO₂ saving was achieved as 180,599 tons CO₂/year. Results of strategy-7 are given in Table 14.

### 4 Result and Discussion

In this section, all proposed strategies are evaluated. The main aim of this study is to reduce the energy consumption of exterior lighting of the university campus and to

### Table 14 Results of strategy-7

| Lamp type | Lamp power (W) | Until 00:00 | Then 00:00 | Total energy consumption (MWh/year) |
|-----------|---------------|-------------|------------|-----------------------------------|
| CFL       | 60 (LED)      | 48          | 5          | 4,511                             |
|           | 14 (LED)      | 89          | 9          | 1,952                             |
| LED       | 150 (LED)     | 2           | 1          | 0,675                             |
|           | 100 (LED)     | 45          | 5          | 0,473                             |
|           | 75 (LED)      | 78          | 9          | 0,639                             |
|           | 36 (LED)      | 17          | 2          | 0,086                             |
|           | 35 (LED)      | 6           | 1          | 0,055                             |
|           | 18 (LED)      | 68          | 16         | 1,294                             |
|           | 9 (LED)       | 53          | 6          | 0,518                             |
|           | 3 (LED)       | 42          | 5          | 0,379                             |
| HPS       | 300 (LED)     | 20          | 7          | 1,987                             |
|           | 120 (LED)     | 27          | 5          | 6,568                             |
|           | 100 (LED)     | 247         | 65         | 6,289                             |
|           | 80 (LED)      | 110         | 20         | 1,514                             |
| MH        | 90 (LED)      | 30          | 6          | 0,514                             |
|           | 80 (LED)      | 29          | 7          | 0,530                             |
|           | 40 (LED)      | 73          | 17         | 0,643                             |
|           | 18 (LED)      | 50          | 5          | 0,085                             |
|           | 9 (LED)       | 48          | 15         | 0,128                             |
| TOTAL     | 1,082         | 69,437      | 15,020     | 122,978                           |

This table shows the results of strategy-7 for different lamp types with their power, total installed power, energy consumption, and energy saving. The results are given in MWh/year.
investigate methods that make this current system more efficient. For this purpose, seven distinct strategies have been designed to provide energy efficiency, make cost savings, and decrease CO\textsubscript{2} emissions.

In the first strategy, the dimming method was applied to the existing 1082 lamps. It was divided into two categories in terms of application time: “until 00:00 period” and “then 00:00 period”. Due to human mobility on campus, 20% dimming was applied at “until 00:00 period”, and 60% dimming was applied at “then 00:00 period” thanks to human mobility almost completely ended. Thus, the amount of consumed energy in both time periods has been reduced. When the performance results of this strategy were examined (see Table 15), it was seen that 41.883% energy saving was achieved. The total amount of consumed energy was reduced from 670,395 MWh/year to 389,147 MWh/year. The CO\textsubscript{2} emission was reduced from 221,170 tons to 128,384 tons CO\textsubscript{2}/year, resulting in 92,786 tons CO\textsubscript{2}/year saving. In addition, when this strategy is examined in terms of equity investment, economic saving, and payback period (see Table 16), it is seen that equity investment is € 75,740, cost-saving € 35,395 (€/year) and the payback period is 2.1 years (about 26 months).

In the second strategy, considering the human activity on the campus, none of the lamps were turned off in the “until 00:00 period”, all of them continued to operate as in the current system. In the “then 00:00 period”, lamp off operations were performed based on location and at specific rates. The number of active lamps has been reduced from 1,082 to 206 during this period. Thus, the amount of consumed energy has been reduced. When the performance results of this strategy were examined (see Table 15), it was seen that 41.953% energy saving was achieved. The total amount of consumed energy was reduced from 670,395 MWh/year to 300,187 MWh/year, with this strategy. The CO\textsubscript{2} emission was reduced from 221,170 tons to 99,035 tons CO\textsubscript{2}/year, resulting in 122,136 tons CO\textsubscript{2}/year saving. In addition, when this strategy is examined in terms of equity investment, cost-saving, and payback period (see Table 16), it is determined that equity investment is € 60,876, economic saving € 33,319 (€/year), and the payback period is 1.8 years (about 22 months).

The fourth strategy, which was developed by combining strategy-1 and strategy-2, aimed to reduce total energy consumption. Both strategies have been applied to the current system simultaneously (discussed in Sect. 3.3.4). When the performance results of this strategy were analyzed (see Table 15), it was discovered that it saved 58.664% of energy. This rate indicates that it is more effective than the previous three strategies (strategy-1, strategy-2, and strategy-3). The total energy consumption was reduced from 670,395 MWh/year to 277,113 MWh/year, with this strategy. The CO\textsubscript{2} emission was reduced from 221,170 tons to 91,422 tons CO\textsubscript{2}/year and 129,748 tons CO\textsubscript{2}/year saving was obtained. In addition, when this strategy is examined in terms of equity investment, cost-saving, and payback period (see Table 16), it is determined that the equity investment is € 75,740, cost-saving € 35,395 (€/year) and the payback period is 2.1 years (about 26 months).

The fifth strategy was designed by combining strategy-1 and strategy-3 and aimed to reduce total energy consumption. Both strategies were applied to the current system simultaneously (discussed in Sect. 3.3.5). When the performance results of this strategy were analyzed (see Table 15), it was discovered that it saved 73.977% of energy. This rate indicates that it is more effective than the previous four strategies (strategy-1, strategy-2, strategy-3, strategy-4, strategy-5, strategy-6, strategy-7).

| Table 15 Sum of all strategies for energy consumption-saving and CO\textsubscript{2} emission-saving |
|---------------------------------|-----------------|-----------------|-------------------|-------------------|
| Cases                          | Energy consumption (MWh/year) | Energy saving (MWh/year) | Energy saving (%) | CO\textsubscript{2} emission (tCO\textsubscript{2}/year) | CO\textsubscript{2} saving (tCO\textsubscript{2}/year) |
| Existing state                 | 670,395          | -                | -                | 221,170            | -                |
| Strategy-1                     | 389,147          | 280,783          | 41.883           | 128,537            | 92,633           |
| Strategy-2                     | 389,147          | 281,248          | 41.953           | 128,384            | 92,786           |
| Strategy-3                     | 300,187          | 370,209          | 55.222           | 99,035             | 122,136          |
| Strategy-4                     | 277,113          | 393,283          | 58.664           | 91,422             | 129,748          |
| Strategy-5                     | 174,459          | 495,937          | 73.977           | 57,556             | 163,614          |
| Strategy-6                     | 171,484          | 498,911          | 74.420           | 56,574             | 164,596          |
| Strategy-7                     | 122,978          | 547,418          | 81.656           | 40,572             | 180,599          |
when this strategy is examined in terms of equity investment, cost-saving, and payback period (see Table 16), it is determined that the equity investment is € 136,616, cost saving € 49,268 (€/year) and the payback period is 2.7 years (about 34 months). Energy consumptions and savings for all strategies are given in Fig. 9.

To summarize the achievements of all strategies, strategy-7 was the least energy-consuming with 122,978 MWh/year and the highest energy saving achievement with 547,418 MWh/year (81.656% energy saving). This strategy achieved the least CO$_2$ emission with 40,572 tons CO$_2$/year and the highest CO$_2$ saving with 180,599 tons CO$_2$/year. In addition, this strategy has been the most successful cost-saving strategy with € 49,268 (€/year). Furthermore, following the current inefficient system, strategy-1 consumed the most energy with 389,612 MWh/year and saved the least energy with 280,783 MWh/year (41.883% saving). Also, this strategy, following the current system, has had the highest CO$_2$ emission to the atmosphere with 128,537 tons CO$_2$/year and the least CO$_2$ saving with 92,633 tons CO$_2$/year. In addition, this strategy was the lowest cost-saving strategy with € 25,271 (€/year).

When the literature is examined, it is seen that energy-saving exterior lighting studies are widely used for different areas such as street lighting, pedestrian path, road, parking lots, and university campuses.

| Cases     | Equity investment (€) | Economic saving (€/year) | Payback period (year) |
|-----------|-----------------------|-------------------------|-----------------------|
| Strategy-1 | 54,100                | 25,271                  | 2.141                 |
| Strategy-2 | 21,640                | 25,312                  | 0.855                 |
| Strategy-3 | 60,876                | 33,319                  | 1.827                 |
| Strategy-4 | 75,740                | 35,395                  | 2.140                 |
| Strategy-5 | 114,976               | 44,634                  | 2.576                 |
| Strategy-6 | 82,516                | 44,902                  | 1.838                 |
| Strategy-7 | 136,616               | 49,268                  | 2.773                 |

and strategy-4). The total energy consumption was reduced from 670,395 MWh/year to 174,459 MWh/year, with this strategy. The CO$_2$ emission was reduced from 221,170 tons to 57,556 tons CO$_2$/year and 163,614 tons CO$_2$/year saving was obtained. In addition, when this strategy is examined in terms of equity investment, cost-saving, and payback period (see Table 16), it is determined that the equity investment is € 114,976, cost-saving € 44,634 (€/year) and the payback period is 2.5 years (about 31 months).

The sixth strategy, which was developed by combining strategy-2 and strategy-3, aimed to reduce total energy consumption. Both strategies were applied to the current system simultaneously (discussed in Sect. 3.3.6). When the performance results of this strategy were analyzed (see Table 15), it was discovered that it saved 74.420% of energy. This rate indicates that it is more effective than the previous five strategies (strategy-1, strategy-2, strategy-3, strategy-4, and strategy-5). The total energy consumption was reduced from 670,395 MWh/year to 171,484 MWh/year, with this strategy. The CO$_2$ emission was reduced from 221,170 tons to 56,574 tons CO$_2$/year and 164,596 tons CO$_2$/year saving was obtained. In addition, when this strategy is examined in terms of equity investment, cost-saving, and payback period (see Table 16), it is determined that the equity investment is € 82,516, cost-saving € 44,902 (€/year) and the payback period is 1.8 years (about 22 months).

The seventh strategy was designed by combining strategy-1, strategy-2 and strategy-3 and aimed to reduce total energy consumption. All three strategies have been applied to the current system simultaneously (discussed in Sect. 3.3.7). When the performance results of this strategy were analyzed (see Table 15), it was discovered that it saved 81.656% of energy. This rate indicates that it is more effective than the previous six strategies (strategy-1, strategy-2, strategy-3, strategy-4, strategy-5, and strategy-6). The total energy consumption was reduced from 670,395 MWh/year to 122,978 MWh/year, with this strategy. The CO$_2$ emission was reduced from 221,170 tons to 40,572 tons CO$_2$/year and 180,599 tons CO$_2$/year saving was obtained. In addition,
In street lighting studies, Orzáez and Diaz (2013) examined the efficiency and energy-saving of MH and ceramic discharge lamps. They demonstrated that energy-saving technology can be used to dim the ceramic MH lamps while preserving life and light quality. Zotos et al. (2012) observed 37% energy savings in one month by designing an energy-efficient, intelligently managed, and remotely dimmable exterior lighting system. Galvez et al. (2021) investigated adjusting lighting parameters from photopic to mesopic and evaluating the change in energy requirements in an exterior lighting installation strategy. In a pedestrian path study, Fabani et al. (2021) investigated the development of photoluminescent composites for energy efficiency and smart exterior lighting applications, using spectrophotometric techniques to measure the interaction between various compounds and different light sources. In road studies, Pavlov et al. (2017) investigated existing luminous flux lighting installations with automatic control systems in order to identify and correct some of their deficiencies. When compared to conventional lighting systems, the new control system is expected to be 60% more efficient. Bouroussis et al. (2006) aimed to use renewable power to generate the exterior lighting system and employ appropriate lamps to illuminate low-traffic roads. They determined that yearly energy production would be 371.7 kWh and consumption would be 222.8 kWh, with the remaining 148.9 kWh being sold. In a parking lot study, Pracki and Skarzynski (2020) studied multi-assessment criteria approach for exterior lighting in which lighting conditions, light pollution, and lighting energy efficiency were all assessed. In university campus studies, Filimonova et al. (2017) researched the LED applications of smart control systems and the smart grid concept in the Russian Federation to boost efficiency and operational dependability in exterior lighting systems. Siddiqui et al. (2012) designed a ZigBee-based exterior lighting control system for street lamps in order to save electricity. Atis and Ekren (2016) designed an energy-efficient smart exterior lighting control system that maximizes the use of sunshine and electrical energy while reducing CO₂ emissions. Görgülü and Kocabey (2020) investigated switching off some lamps, dimming lamps, and replacing lamps with efficient lamps using some scenarios for outdoor lighting efficiency. They designed four different scenarios and achieved the most success with Scenario-4, which provided 762 MWh/year energy savings, 251 tons of CO₂ reduction, and 60% energy savings.

According to my experience, only one study that is partially comparable to my study has been discovered in the literature. In that study, four different scenarios were designed and the highest 60% energy-saving (with 762 MWh/year energy-saving and 251 tons of CO₂ reduction) were achieved (Görgülü and Kocabey, 2020). However, in my study, seven unique energy-saving strategies were designed, resulting in 81.656% energy-saving (with 547,418 MWh/year energy-saving and 180,599 CO₂ tons/year saving). It can be seen that the research findings differed considerably in terms of savings. Thus, it is expected that this unique research will contribute to the literature.

5 Conclusions and Recommendations

Energy-saving strategies for the exterior lighting system of Kahramanmaraş Sütçü Imam University’s Aşar Campus were implemented in this study. Since this is a rapidly growing and expanding central campus, energy demand is increasing steadily. In this case, energy efficiency is vital in terms of cost-saving and CO₂ emissions to the atmosphere. This study proposes seven separate solutions, all with the aim to identify the energy-saving model with the lowest energy consumption and CO₂ emissions. The outcomes of all of the proposed strategies are listed below:

According to energy consumption analysis;

- Strategy-7 achieved the highest energy saving rate with 81.656% and the highest energy saving with 547,418 MWh/year, while the lowest energy saving rate was strategy-1 with 41.883%.
- While strategy-7 reached the minimum energy consumption with 122,978 MWh/year, strategy-1 reached the highest energy consumption with 389,612 MWh/year.

According to CO₂ emission analysis;

- Strategy-7 achieved the highest CO₂ savings with 180,599 tons of CO₂/year, while strategy-1 reached the least savings with 92,633 tons of CO₂/year.
- While strategy-7 released the least CO₂ emission with 40,572 tons of CO₂/year, strategy-1 released the highest emission of 128,537 tons of CO₂/year.

According to economic analysis;

- Strategy-7 achieved the most economical saving strategy with € 49,268 (€/year), while strategy-1 reached the least economical saving with € 25,271 (€/year).
- Strategy-7 was the most expensive strategy with € 136,616 equity investment. Since it includes the costs of dimming control units, electronic timer switches, and LED lamps, it’s only reasonable that this strategy is the most costly. Equity investments were calculated as € 54,100, € 21,640, € 60,876, € 75,740, € 114,976 and €
Incandescent While strategy-7 has the longest payback period with 2.7 years (about 34 months), strategy-2 has the shortest payback period with 0.8 years (about 10 months).

Furthermore, Kahramanmaras province has a total annual sunshine time of 2,924 h and annual global radiation of 1,611 kWh/m²-year. The amount of energy that can be produced per unit area using solar monocrystalline silicon has been calculated as 27,000 kWh/m²-year (DOĞAKA, 2017). More energy savings and more cost-saving can be achieved by installing a solar power plant on the campus considering the solar potential of the city.

Thanks to the decreased energy consumption expenses, the residual budget can be used to invest in the eco-friendly and sustainable campus transformation to obtain more energy-saving and to reduce carbon footprint.

In future works, the dimming rates of the lamps can be determined using Image Processing (IP) and Artificial Intelligence (AI) algorithms for more energy-saving.

**Nomenclature.**

| AI       | Artificial Intelligence |
|----------|------------------------|
| CF       | Compact Fluorescent    |
| EV       | Electric Vehicle       |
| HPS      | High-Pressure Sodium   |
| IP       | Image Processing       |
| INC      | Incandescent           |
| IoT      | Internet of Things     |
| LED      | Light Emitting Diode   |
| MH       | Metal Halide lamp      |
| SPI      | Sustainable Process Index |

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