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INVESTIGATION OF CARBON DIOXIDE EMISSIONS RELEASED FROM POWER PLANTS DUE TO ELECTRIC ENERGY CONSUMPTION DURING THE COOLING PERIOD OF RESIDENTIAL BUILDINGS

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ABSTRACT

This study calculated the amount of carbon dioxide released during electricity production in power plants, focusing on using electrical energy in buildings during the cooling period. The emissions were analysed based on different fuels used in power plants, including semi-anthracite, bituminous and lignite coal, methane, propane, and butane. To determine the electrical energy consumption of buildings during the cooling period, cooling degree day (CDD) values and the building envelope heat transfer coefficient were utilised. The calculations for cooling degree days were based on long-term averages, including average temperature, average high temperature, maximum temperature, and TS 825 temperature values from 1929 to 2023. The average temperature for provinces in the first climate zone has been calculated based on the following values: cooling degree day value of 936 for Şanlıurfa, average high-temperature value of 2136 for Batman, maximum temperature value of 5592 for Adana, and the temperature values provided in TS 825 from 1929 to 2023, based on a value of 543. The building envelope heat transfer coefficient values were sourced from TS 825. The amount of carbon dioxide released during electricity production in power plants has been calculated as 0.369 kg/kWh for semi-anthracite with the highest value and 0.210 kg/kWh for methane with the lowest value. As a result, the highest carbon dioxide (CO2) emissions were calculated for semi-anthracite, ranging from 11.008 to 70.332 kg/m^2, while the lowest emissions were for methane, ranging from 6.265 to 40.021 kg/m^2.

Keywords: Building Electricity Consumption, Cooling Degree-days, Power Plants, Carbon Dioxide Emissions

1. INTRODUCTION

Electricity and heat generation accounts for nearly two-thirds of the global increase in total CO_2 emissions in recent years. In power plants that produce both electricity and heat, thermodynamic parameters, including combustion reactions, are critically influenced by the type and composition of the fuel as well as the design of the plant [1]. Today, more than 50% of the world's power plants rely on fossil fuels, contributing to environmental pollution and global warming through greenhouse gas emissions [2].

Today, thermal power plants that operate on coal and other hydrocarbons produce combustion gases containing harmful components that negatively impact the lives of humans, animals, and plants. The most significant harmful component is carbon oxides, with carbon dioxide being the most prevalent gas released from the combustion of fuels used on an industrial scale [3].

Electrical devices consume a lot of energy and are designed to provide thermal comfort and reduce household temperatures during the summer months. Their usage is closely linked to weather variables, particularly air temperature [4]. The largest energy consumer in a building is the cooling system, which accounts for 49% of electrical energy use [5].

The relationship between electrical energy consumption and outdoor temperature, along with the heating and cooling of building envelopes, is crucial for energy applications. This connection has been widely examined in the literature, primarily using heating degree days (HDD) and cooling degree days (CDD) [6]. The degree-day method, which relies on outdoor temperature data, is commonly applied in various contexts, from individual buildings to city-wide assessments, effectively estimating cooling and heating loads across diverse climates and regions [7]. When we examined the literature, Farhan and Parwana examined climate variation trends using data from the World Development Indicators, WAPDA, and the Climate Knowledge Portal. Using the ARDL model, they identified significant connections between climate factors and national energy demand. Their findings highlighted the substantial impact of climate on energy needs and recommended that the government develop strategies to transform challenges into opportunities for long-term economic and social improvements [8]. Eisapour et al. evaluated a novel solar thermal and photovoltaic thermal system combined with insulated concrete forms and reverse osmosis designed to meet a building's heating demands using actual energy bills. The study will analyse four scenarios integrating the reverse osmosis system with solar energy and thermal storage, comparing them to a baseline system without these features. Additionally, a sensitivity analysis will assess the impact of the area of solar modules on the overall performance of the system [9].

Zhang et al. examined the effects of climate on residential electricity usage in a Chinese region that outpaced Australia in 2018. They employed temperature response models to analyse how heating and cooling degree days influence energy consumption in urban and rural settings. Their results indicated that increased heating and cooling requirements boost electricity usage, while growing rural income and urban development intensify the need for temperature control, despite a negative impact from urban income. The research also underscores the significance of accounting for precipitation and population shifts variations when estimating energy demand [10]. Fikru and Gauter analysed the impact of weather variation on energy use using five-minute interval data from two homes: a conventional house and a net-zero solar house. Results show that the solar house is less sensitive to weather changes. A one-unit increase in heating degree minutes raises energy use by 9% in the conventional house and 5% in the solar house; cooling degree minutes increase use by 5% and 4%, respectively. Non-temperature factors like solar radiation and humidity also affect energy consumption, with lower sensitivity in the solar house. The sensitivity to weather varies by season and time of day [11]. Following recent government guidelines, Marten and Newbold developed an integrated assessment model to estimate the social costs of CO2, CH4, and N2O from 2010 to 2050. Using global warming potentials, they compared the estimates for non-CO2 gases with those from the social cost of CO_2. The findings indicate significant estimation errors with these potentials for single and multi-gas policies, suggesting that direct estimates are preferable. However, when direct estimates are unavailable, reductions calculated with global warming potentials generally yield lower errors than default zero estimates, providing a lower bound for abatement benefits [12]. Craig and Feng examined how electricity generation sources and consumption affect carbon emissions in the U.S., focusing on climatic variability and energy efficiency (EE). They found that 97.2% of carbon emissions variability was linked to coal generation and residential use. Cooling degree days were the main climatic drivers, correlating positively with electricity consumption. Most reductions from EE programs were negatively related to consumption, with many states seeing decreased savings despite rising usage. The study suggests using communication theory to enhance EE program effectiveness [13]. Zheng et al. quantified the impact of climate change on total electricity consumption (TEC) and residential electricity consumption (REC) in Guangzhou, China.

Using the Mann-Kendall test to assess climate trends and best subset regression for consumption modelling, they calculated changes in electricity consumption from 2016 to 2095 under various socio-economic and climate scenarios. The results indicated a significant warming trend of 0.15–0.47 °C per decade until the end of the 21st century, leading to increased cooling demands. TEC was more sensitive to warming than REC, with a 1 °C rise in temperature resulting in a 2.7% increase in TEC and a 0.9% increase in REC. Additionally, consumption projections varied significantly under different greenhouse gas emission scenarios, with TEC expected to rise by 3.2%–10.4% by the 2080s compared to the baseline [14]. Xu et al. used archived General Circulation Model (GCM) projections, downscaling them for building cooling and heating simulations up to 2040, 2070, and 2100. They found that if cooling technology remains unchanged, electricity use for cooling in some California areas could rise by 50% under the worst-case IPCC carbon emission scenario (A1F1) and by about 25% under the more likely scenario (A2). While some building types are more sensitive to climate change, the overall energy consumption for heating and cooling is expected to increase only slightly [15]. Shakouri estimated the loop gain using a bottom-up regional model to calculate electricity consumption for cooling in residential and commercial sectors across 12 global regions. Each region's CO_2 emissions are linked to its fossil fuel power plants. By analysing global emission trends and temperature anomalies, a linear ARMAX model computes the loop gain. Results suggest that emissions from cooling electricity could significantly increase by the century's end, with the loop gain indicating that emissions may initially decline but are expected to rise again mid-century, even if fossil fuel generation is reduced [16]. Ditl and Sulc advocate using rigorous chemical engineering calculations to assess fuel combustion instead of traditional methods. They provide an MS Excel program as supplementary material that calculates specific CO_2 production by considering factors such as energy losses, adiabatic flame temperature, calorific value, and overall energy efficiency. Results are presented for coal, hydrocarbons, and renewable fuels, with calculated outcomes compared to existing literature. A key advantage of their approach is its applicability to any fuel with known composition and various combustion-based energy processes [1]. KC and Ruth identified notable variations in the temperature-electricity relationship based on building characteristics and usage patterns. They found that weekday effects significantly impacted electricity consumption. In summer, an increase in cooling degree days (CDD) raised daily electricity use, while winter heating degree days (HDD) also contributed to higher consumption. The study utilized two models to project electricity demand for 2030, indicating increased demand during summer and spring. Under both low and high-emission scenarios, electricity demand is expected to rise, potentially straining the U.S. electric grid and increasing energy costs by 2030 [6].

Hong et al. studied the impact of socio-economic, building, macro-climatic, and micro-climatic factors on office building energy consumption. They found that micro-climate regulation contributed the least 9.64% to energy use, but improving it is easier and less costly than major renovations. Their analysis revealed that integrating green spaces and water bodies was more effective for reducing carbon emissions than alone. While green spaces had a threshold effect, water bodies did not, making water-body construction more beneficial for minimising energy usage and emissions [17]. Zhang et al. studied the impact of income growth on urban residential electricity consumption in the Yangtze River Delta, using unbalanced panel data from 23 cities between 2004 and 2015. Their model examined heating-degree days, cooling-degree days, and their interactions. They found that heating and cooling demands and income growth significantly boosted residential energy use. However, increasing disposable income diminished the positive effects of these demands, as residents shifted from electricity to natural gas for heating and adopted more energy-efficient appliances. The research emphasized the sensitivity of urban energy consumption to changes in permanent populations. It proposed the hypothesis of a negative moderating effect of income growth on temperature responses, offering adaptive strategies and policy implications for climate change [18].

Kheiri et al. introduced the split-degree day method, significantly improving the accuracy of building energy use estimations compared to traditional degree day methods. Analysing data from 801 U.S. locations, they found that this new method better accounts for weather parameters, resulting in over 5% improved accuracy in total annual energy predictions, 8% for heating, 0.3% for cooling, and 33% for fan energy use. The split-degree day method incorporates more detailed weather information, enhancing predictions even when base temperatures deviate from optimal levels. This approach offers a more precise alternative for applications like building energy estimation and climate classification [19]. Kim et al. assessed the impacts of internal and external loads on building temperatures by analysing the core-to-perimeter zone ratio based on average floor area. Using various analytical methods, the researchers identified significant differences in internal and external temperatures across six building types, with variations up to 6°C for internal and 4°C for external ones.

Generally, as the average floor area increased, internal and external temperatures decreased, indicating that internal loads had a greater influence. This effect was particularly notable for lodging, medical, and retail buildings, where newer structures had lower temperatures. However, this trend was less clear for facilities for seniors and children, likely due to differing designs and occupant preferences. While the study focused on South Korea, it highlighted the need for refined base temperatures for building types, vintages, and floor areas, especially in large urban areas [7]. Li et al. introduced a low-carbon learning and scheduling method for power systems that integrates a carbon capture system and carbon emission flow theory. They developed carbon emission flow models at both the equipment and system levels. A bi-level optimal scheduling model was created for day-ahead planning and load demand response, solved using a deep deterministic policy gradient algorithm within a deep reinforcement learning framework. Simulations of real grid structures demonstrated that this approach enhanced operational efficiency, with deep reinforcement learning offering benefits in convergence and solution accuracy [20].

Can et al. performed an exergy and economic analysis of the Esenyurt Thermic Power Plant in Türkiye using operational data. They applied the first and second laws of thermodynamics, assessing fuel utilization efficiency, power output, and process heat rate in a steady-state open thermodynamic framework. The analysis showed a second law efficiency of 89.5%, deemed acceptable in academic literature. Furthermore, the plant's payback period was 3.5 years, indicating a favorable economic return for well-designed facilities [21]. Filonchyk and Peterson used both terrestrial and satellite data to examine emissions from coal-fired power plants and the effectiveness of government policies in reducing these emissions. They found that from 1990 to 2020, sulphur dioxide emissions decreased by 93.4%, nitrogen oxides by 84.8%, and carbon dioxide by 37% between 2007 and 2020. Despite the decline, some plants have not yet installed necessary environmental controls. The study highlighted major emitters and used satellite data to detect emissions from individual plants, revealing high pollution levels over urban areas and fossil fuel extraction sites while identifying pollution sources in rural areas. Although emissions from coal-fired power plants have significantly decreased, they remain a substantial pollution source amid rising power demands from electric vehicles [22].

Kaghembega et al. examined energy savings in buildings across cold and hot regions in China and Africa, developing a modelling approach for heating and cooling in residential buildings. Using RETScreen software, simulations were conducted for 2020, 2030, and 2050, revealing that energy consumption has increased and comfort levels in high-rise buildings are 10–21% higher in hot regions. The comfortable temperature range varied from 20°C to 29°C. Differences between observed and modelled heating and cooling degree days were noted in these regions. Heating methods included heat pumps and district heating, the most common systems. Overall, energy demand in Africa and China is projected to rise significantly by 2050, with China expected to demand 8770 Mtoe and Africa 970 Mtoe of primary energy [23]. Many countries set renewable energy targets to reduce electricity consumption and carbon emissions. Islam et al. focused on using RE to promote environmental sustainability, developing a system of ordinary differential equations to analyse four key variables related to RE. The model effectively increased electricity production and reduced greenhouse gas emissions through positivity tests, stability analysis, and bifurcation analysis. The findings highlighted the importance of integrating RE in the power sector for sustainable environmental practices [24].

Kon and Caner analyzed emissions from power plants that provide electricity for building cooling and assessed the effectiveness of carbon capture and storage (CCS) technology in reducing emissions. They compared the emissions associated with CCS implementation against the emissions it mitigates, conducting a long-term life cycle assessment. Energy consumption in buildings was determined using the cooling degree-day method. The study examined emissions from coal and natural gas systems with CCS, emphasising the reductions achieved through this technology [25].

Kusi et al. assessed energy consumption and carbon emissions of conventional and green buildings by employing building retrofitting techniques through building information modelling (BIM) [26]. Due to their relatively high reserves, Shahzad and Yousaf revealed that coal would remain a primary energy source in several countries over the next two decades. These countries needed to implement specific measures to mitigate the negative impacts on local and global environments. A key challenge was to limit emissions, including particulate matter, nitrogen oxides, sulphur oxides, and carbon oxides. To achieve this reduction, applying advanced and efficient technologies was essential. The article described the operation of coal-fired power plants, discussed their environmental impacts, and recommended technologies to enhance their sustainability [27].

Yurtsever estimated energy consumption for urban residential buildings using electricity data and incorporated heating and cooling degree days for predictions. Months with minimal heating and cooling needs were classified as "base months," which were essential for the analysis. The model was applied to a populous county in Southern Türkiye, demonstrating significant accuracy in total electricity consumption calculations. Its validity was confirmed by comparing theoretical energy usage with coal and wood consumption, revealing distinct annual consumption patterns across different heating methods [28].

Meng et al. collected half-hourly gas consumption data and building characteristics from 89 educational buildings over four years. They incorporated ambient temperature, solar insolation, relative humidity, wind speed, and one-day residual temperature into a three-parameter change-point multivariable regression model to determine the base temperature. This approach produced a base temperature approximately 0.4°C lower than a simpler model's. The analysis indicated that annual heating degree days and daily solar insolation significantly affected base temperature, with some correlation to building location. By considering multiple weather factors, the proposed method improved prediction accuracy for heating degree days compared to traditional methods [29].

Wang and Teng applied a multimodal assessment framework that incorporated recent advancements often overlooked in earlier research to re-evaluate the social costs of certain greenhouse gases. The analysis revealed a significant increase in the estimated costs compared to previous assessments. Furthermore, models that considered economic growth over time indicated a substantial rise in estimates, adding to the uncertainty in the calculations. Despite these uncertainties, the findings suggest that the advantages of implementing mitigation policies for these gases are more substantial than previously recognised [30].

Sözen et al. developed equations using energy and economic indicators to predict net electricity consumption for various consumer groups in Türkiye, supporting investment planning. They trained an artificial neural network (ANN) using three models: the first focused on energy indicators like installed capacity and energy trade, the second on the sectoral share of Gross National Product per capita, and the third on the sectoral share of Gross Domestic Product per capita. The output layer reflected net electricity consumption for 25 consumer groups across all models, highlighting the influence of economic indicators on predictions. Each model demonstrated a perfect fit, confirming the ANN's effectiveness in estimating net electricity consumption [31]. This study aims to calculate the carbon dioxide (CO_2) emissions from thermal power plants using semi-anthracite, bituminous, and lignite coal, methane, propane, and butane for electricity generation during summer when cooling demand is highest. To estimate the electricity consumption of buildings for cooling, the study uses historical climate data from the General Directorate of Meteorology (1929–2023), including average, average maximum, and maximum temperatures, as well as TS 825 temperature values, which define insulation standards based on climate zones. By determining the cooling energy demand and applying carbon emission factors for each fuel type, the study calculates the total CO_2 emissions during the cooling period. This analysis helps assess the environmental impact of fossil fuel-based power generation and provides insights for improving energy efficiency and reducing emissions in the future.

The TS 825 standard is a Turkish regulation for thermal insulation in buildings. It sets minimum thermal resistance values for building components (walls, roofs, floors, windows, doors) to improve energy efficiency, reduce heating/cooling costs, and enhance comfort. The standard is part of Türkiye's efforts to improve energy performance and sustainability in construction, with specific requirements based on different climate zones. Compliance is mandatory for new constructions and major renovations. The heat transfer coefficient values for the building envelope—including external walls, ceilings, floors, and windows—were taken from TS 825. The indoor temperature for calculating cooling degree days was set at 22 °C. The process of electricity production in the power plant is illustrated in Figure 1. The process consists of six main components: the cooling tower, generator, turbine, heater, precipitator, and stack. Additionally, there are pre-heaters, intermediate heaters, and both low and high-pressure turbines.

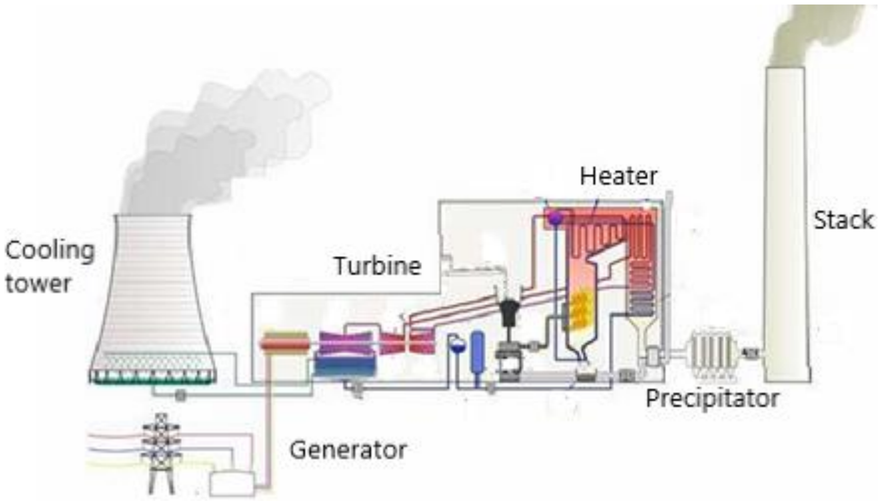

Figure 1. Electricity Generation Process in a Power Plant [32]

2. MATERIAL and METHOD

Cooling energy requirement in cooling period energy calculations in buildings [33-36],

$$Q_C = U_w.CDD + U_c.CDD + U_f.CDD + U_{win}.CDD \quad (1)$$

Here, Q_c is the cooling period building energy demand, U_w is the heat transfer coefficient of the external wall, U_c is the heat transfer coefficient of the ceiling, U_f is the heat transfer coefficient of the floor, and U_{win} is the heat transfer coefficient of the window.

$$\text{If } T_0 > T_i$$

$$CDD = 30\sum_{1}^{12}(T_0 - T_i) \quad (2)$$

$$\text{If } T_0 \leq T_i \quad (3)$$

$$CDD = 0$$

CDD refers to cooling degree days, Ti is the indoor temperature (set at 22 °C), and T_0 is the outdoor temperature. Table 1 presents the recommended building envelope heat transfer coefficients for all cities in our country as specified in TS 825. U_w, U_c, and Uf belong to the building envelopes heat transfer coefficients. U_{win} is the windows heat transfer coefficient.

$$E_C = \frac{0.024.Q_C.CDD}{COP} \tag{4}$$

The annual cooling energy requirement per unit area for the building is represented as E_c, while COP denotes the cooling performance value set at 2.5 for this study [36-39].

Table 1. Recommended building envelope heat transfer coefficients according to TS 825 for all cities [35]

Cities	Heat Transfer Coefficient (W/m². K)				Cities	Heat Transfer Coefficient (W/m². K)			
	U_w	U_c	U_f	U_{win}		U_w	U_c	U_f	U_{win}
Adana	0.66	0.43	0.66	1.8	Kahramanmaraş	0.57	0.38	0.57	1.8
Adıyaman	0.57	0.38	0.57	1.8	Karabük	0.48	0.28	0.43	1.8
Afyonkarahisar	0.48	0.28	0.43	1.8	Karaman	0.48	0.28	0.43	1.8
Ağrı	0.36	0.21	0.36	1.8	Kars	0.36	0.21	0.36	1.8
Aksaray	0.48	0.28	0.43	1.8	Kastamonu	0.38	0.23	0.38	1.8
Amasya	0.57	0.38	0.57	1.8	Kayseri	0.38	0.23	0.38	1.8
Ankara	0.48	0.28	0.43	1.8	Kilis	0.57	0.38	0.57	1.8
Antakya	0.66	0.43	0.66	1.8	Kırıkkale	0.48	0.28	0.43	1.8
Antalya	0.66	0.43	0.66	1.8	Kırklareli	0.48	0.28	0.43	1.8
Ardahan	0.36	0.21	0.36	1.8	Kırşehir	0.48	0.28	0.43	1.8
Artvin	0.48	0.28	0.43	1.8	Kocaeli	0.57	0.38	0.57	1.8
Aydın	0.57	0.38	0.57	1.8	Konya	0.48	0.28	0.43	1.8
Balıkesir	0.57	0.38	0.57	1.8	Kütahya	0.48	0.28	0.43	1.8
Bartın	0.57	0.38	0.57	1.8	Malatya	0.48	0.28	0.43	1.8
Batman	0.57	0.38	0.57	1.8	Manisa	0.57	0.38	0.57	1.8
Bayburt	0.38	0.23	0.38	1.8	Mardin	0.57	0.38	0.57	1.8
Bilecik	0.48	0.28	0.43	1.8	Mersin	0.66	0.43	0.66	1.8
Bingöl	0.48	0.28	0.43	1.8	Muğla	0.57	0.38	0.57	1.8
Bitlis	0.38	0.23	0.38	1.8	Muş	0.38	0.23	0.38	1.8
Bolu	0.48	0.28	0.43	1.8	Nevşehir	0.48	0.28	0.43	1.8
Burdur	0.48	0.28	0.43	1.8	Niğde	0.48	0.28	0.43	1.8
Bursa	0.57	0.38	0.57	1.8	Ordu	0.57	0.38	0.57	1.8
Çanakkale	0.57	0.38	0.57	1.8	Osmaniye	0.57	0.38	0.57	1.8
Çankırı	0.48	0.28	0.43	1.8	Rize	0.57	0.38	0.57	1.8
Çorum	0.48	0.28	0.43	1.8	Sakarya	0.57	0.38	0.57	1.8
Denizli	0.57	0.38	0.57	1.8	Samsun	0.57	0.38	0.57	1.8

Diyarbakır	0.57	0.38	0.57	1.8	Şanlıurfa	0.57	0.38	0.57	1.8
Düzce	0.57	0.38	0.57	1.8	Şırnak	0.57	0.38	0.57	1.8
Edirne	0.57	0.38	0.57	1.8	Siirt	0.57	0.38	0.57	1.8
Elâzığ	0.48	0.28	0.43	1.8	Sinop	0.57	0.38	0.57	1.8
Erzincan	0.38	0.23	0.38	1.8	Sivas	0.38	0.23	0.38	1.8
Erzurum	0.36	0.21	0.36	1.8	Tekirdağ	0.57	0.38	0.57	1.8
Eskişehir	0.48	0.28	0.43	1.8	Tokat	0.48	0.28	0.43	1.8
Gaziantep	0.57	0.38	0.57	1.8	Trabzon	0.57	0.38	0.57	1.8
Giresun	0.57	0.38	0.57	1.8	Tunceli	0.48	0.28	0.43	1.8
Gümüşhane	0.38	0.23	0.38	1.8	Uşak	0.48	0.28	0.43	1.8
Hakkâri	0.38	0.23	0.38	1.8	Van	0.38	0.23	0.38	1.8
Iğdır	0.48	0.28	0.43	1.8	Yalova	0.57	0.38	0.57	1.8
Isparta	0.48	0.28	0.43	1.8	Yozgat	0.38	0.23	0.38	1.8
İstanbul	0.57	0.38	0.57	1.8	Zonguldak	0.57	0.38	0.57	1.8
İzmir	0.66	0.43	0.66	1.8					

Table 2 shows the amounts of carbon dioxide emitted from power plants producing electricity using different fuels. It also gives the C, H, O, S, and N ratios and the lower heating and efficiency values of fuels.

Table 2. Amounts of carbon dioxide emitted from power plants producing electricity using different fuels and chemical properties [1]

Fuel	CO_2 Emission (kg/kWh)	wt %					LHV (MJ/kg)	μ
		C	H_2	O_2	S	N_2		
Semi anthracite	0.369	89.6	3.8	1.6	1.4	3.6	27.85	0.65
Bituminous	0.336	83.3	5.7	1.3	1.4	8.3	32.21	0.65
Lignite	0.333	72.3	5.2	0.9	1.4	20.2	26.45	0.65
Methane	0.210	74.9	25.1	-	-	-	50.17	0.90
Propane	0.246	81.7	18.3	-	-	-	46.29	0.88
Butane	0.253	82.6	17.4	-	-	-	44.61	0.88

3. RESULTS AND DISCUSSIONS

For all cities in Türkiye, the highest cooling degree day (CDD) value for average temperature was recorded in Şanlıurfa at 936, with an average value of 210. Batman had the highest CDD for average temperature at 2,136, Ardahan's average was 938 and Bitlis recorded the lowest at 141. The highest CDD for maximum temperature was found in Adana at 5,592, with Bitlis averaging 3,779 and recording the lowest at 1,695. According to TS 825, the highest CDD was 543, with an average of 107. Cooling degree day values for all other cities are presented in Figure 2. The building envelope heat transfer coefficients, according to TS 825 and based on climate zones, vary between

0.36-0.66 W/m²·K for external walls, 0.21-0.43 W/m²·K for the roof, and 0.36-0.66 W/m²·K for the floor, while the coefficient for windows is 1.8 W/m²·K. The amount of carbon dioxide released during electricity production in power plants is 0.369 kg/kWh for semi-anthracite, 0.336 kg/kWh for bituminous coal, 0.333 kg/kWh for lignite coal, 0.210 kg/kWh for methane, 0.246 kg/kWh for propane, and 0.253 kg/kWh for butane.

When using the temperature values in TS 825 as a reference, an average electrical energy consumption of 3.491 kWh/m² was calculated. The electrical energy demand in the first climate region, which includes Adana, Antakya, Antalya, İzmir, and Mersin, was determined to be 18.505 kWh/m².

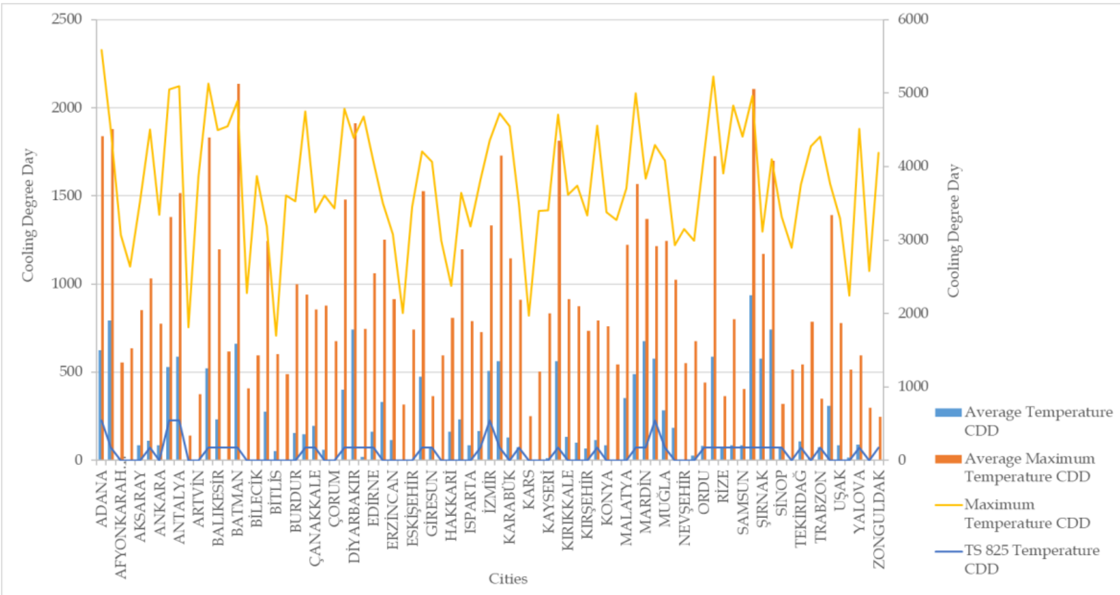

Figure 2. Cooling degree-day (CDD) values for all cities depending on different temperatures

When considering the average temperatures for electricity consumption across all cities, the average consumption value is 6.617 kWh/m², with the highest electricity consumption occurring in Şanlıurfa at 29.832 kWh/m². For the highest average temperature, the average electricity consumption is 28.667 kWh/m², the highest recorded consumption is 68.079 kWh/m² in Batman, and the lowest is 3.695 kWh/m² in Ardahan. When examining the highest temperature, the average electricity consumption rises to 114.927 kWh/m², with the highest being 190.575 kWh/m² in Adana and the lowest at 45.390 kWh/m² in Bitlis. Based on TS 825 data, the average electricity consumption value is 3.491 kWh/m². Electricity consumption data for all other cities at varying temperatures are presented in Figure 3.

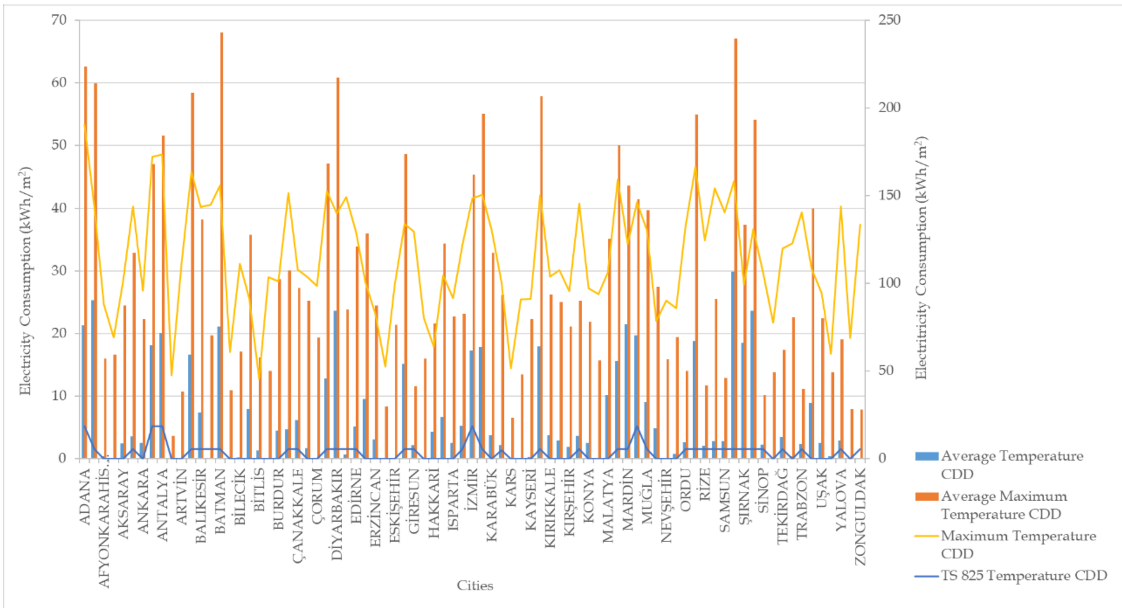

Figure 3. Electricity consumption depends on different temperatures for all cities

The carbon dioxide (CO_2) emissions from power plants using semi-anthracite fuel, based on average temperatures across all cities, average 2.442 kg/m², with the highest emissions occurring in Şanlıurfa at 11.008 kg/m². When considering the highest average temperature, the average CO_2 emission rises to 10.578 kg/m², peaking at 25.121 kg/m² in Batman and dropping to 1.364 kg/m² in Ardahan. For the highest temperatures recorded, the average CO_2 emissions reach 42.408 kg/m², with a maximum of 70.322 kg/m² in Adana and a minimum of 16.752 kg/m² in Bitlis. According to TS 825 data, the average CO_2 emission is 1.288 kg/m². Emission data for other cities and varying temperatures are presented in Figure 4.

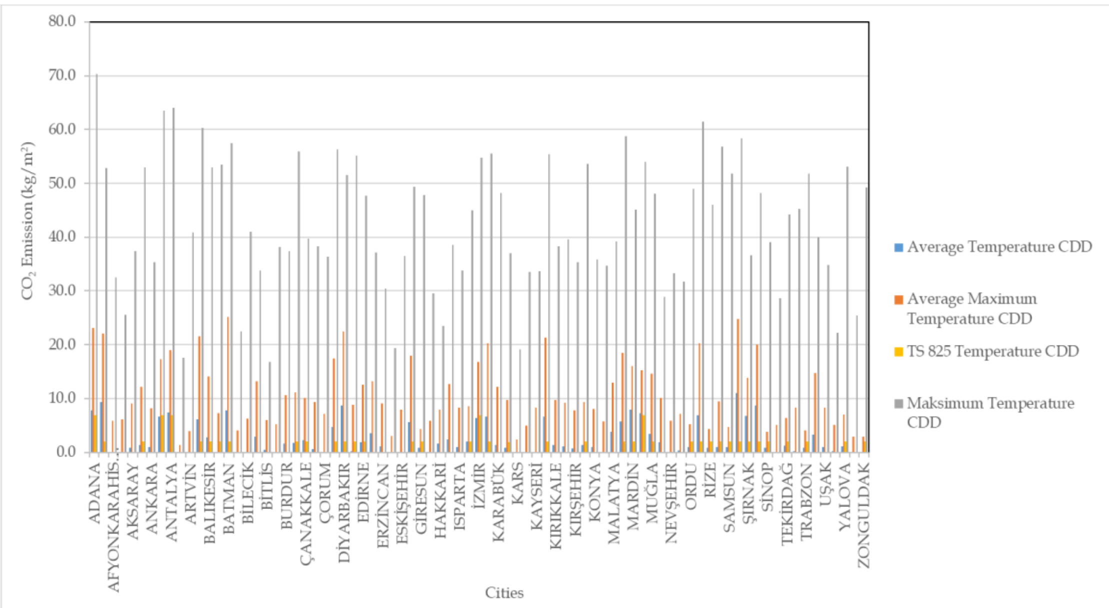

Figure 4. Carbon dioxide emissions from power plants producing electricity using semi-anthracite coal as fuel depending on different temperatures for all cities

For power plants using bituminous coal, the average CO_2 emission based on average temperatures is 2.223 kg/m², with the highest recorded in Şanlıurfa at 10.024 kg/m². Considering the highest average temperature, the average CO_2 emission is 9.632 kg/m², with a peak of 22.874 kg/m² in Batman and a low of 1.242 kg/m² in Ardahan. At the highest temperature, the average CO_2 emission increases to 38.616 kg/m², peaking at 64.033 kg/m² in Adana and dropping to 15.254 kg/m² in Bitlis. The average CO_2 emission based on TS 825 data is 1.173 kg/m², with further emissions from other cities illustrated in Figure 5.

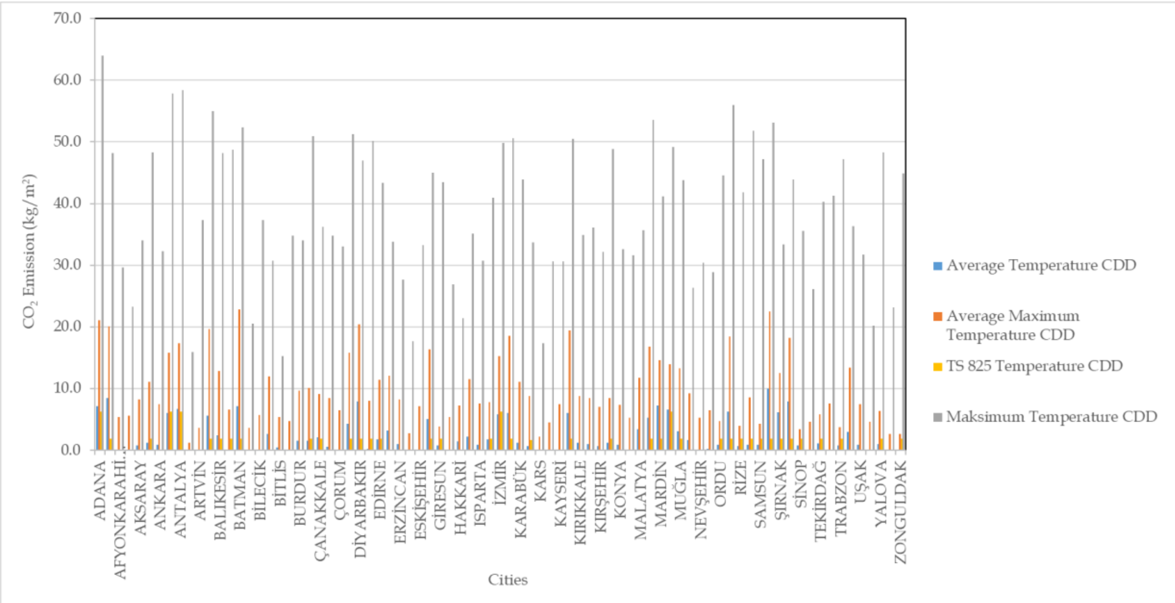

Figure 5. Carbon dioxide emissions from power plants producing electricity using bituminous coal as fuel depending on different temperatures for all cities

The average CO_2 emission for lignite coal is 2.204 kg/m², with the highest emissions again in Şanlıurfa at 9.934 kg/m². Considering the highest average temperature, the average emission is 9.546 kg/m², peaking at 22.670 kg/m² in Batman and dropping to 1.231 kg/m² in Ardahan. At the highest temperature, the average CO_2 emission is 38.271 kg/m², with a maximum of 63.462 kg/m² in Adana and a minimum of 15.118 kg/m² in Bitlis. According to TS 825, the average CO_2 emission is 1.162 kg/m², with emissions from other cities and temperatures shown in Figure 6.

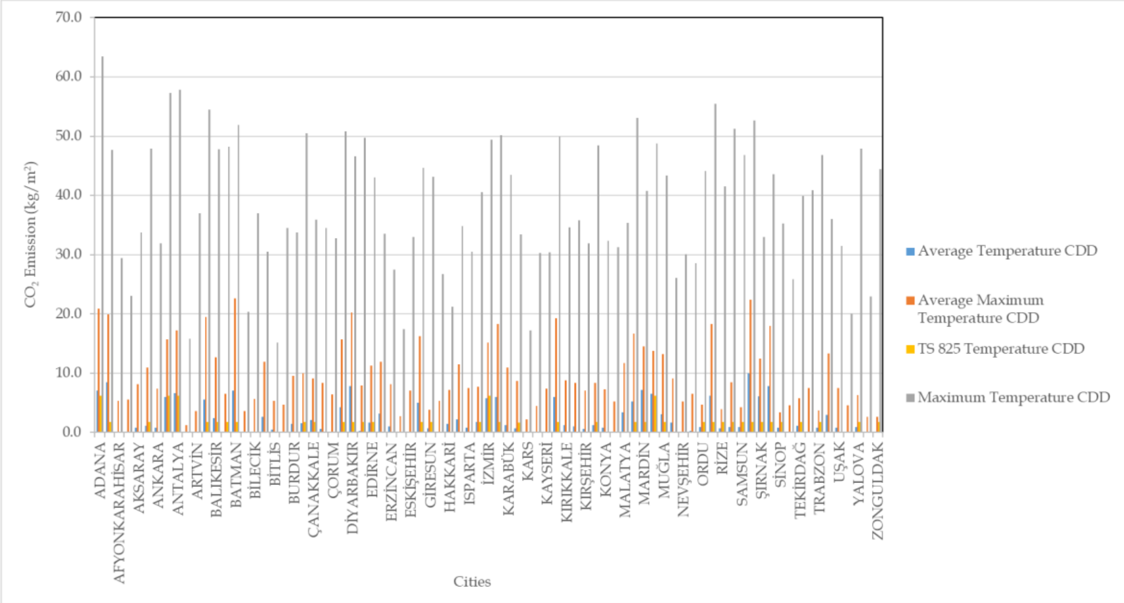

Figure 6. Carbon dioxide values emitted from power plants producing electricity using lignite coal as fuel depending on different temperatures for all cities

The CO_2 emissions from power plants generating electricity using methane fuel, considering average temperatures across all cities in Türkiye, average 1.390 kg/m², with the highest emissions occurring in Şanlıurfa at 6.265 kg/m². When accounting for the highest average temperatures, the average CO_2 emissions increase to 6.020 kg/m², peaking at 14.297 kg/m² in Batman and dropping to 0.776 kg/m² in Ardahan. For the highest temperatures recorded, the average CO_2 emission is 24.135 kg/m², with a maximum of 40.021 kg/m² in Adana and a minimum of 9.534 kg/m² in Bitlis. TS 825 data shows the average CO_2 emission is 0.773 kg/m². Emission data for other cities and varying temperatures are shown in Figure 7.

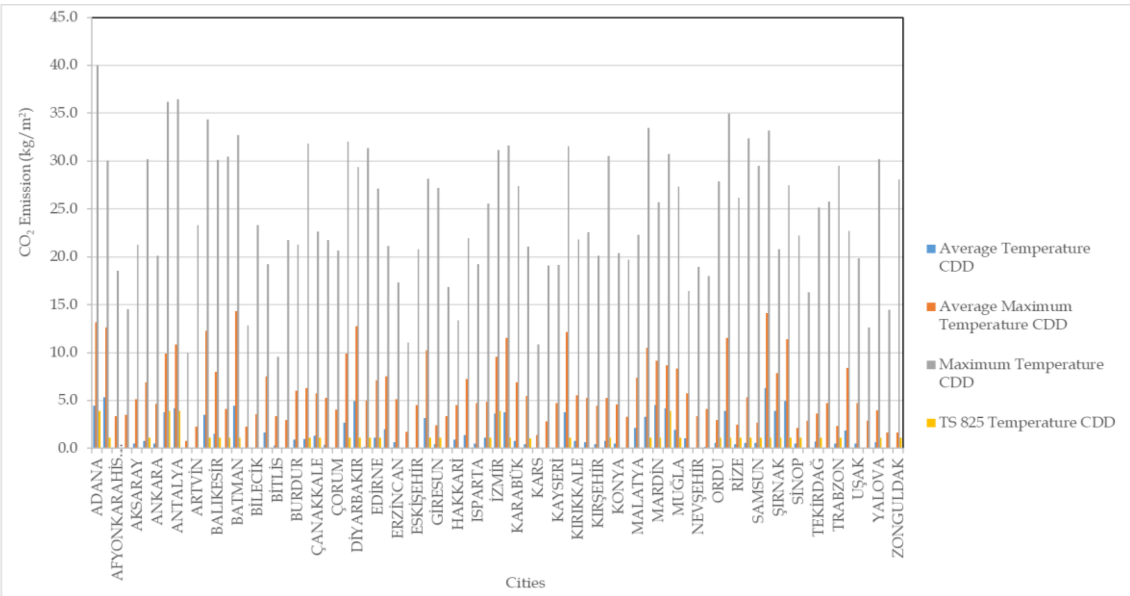

Figure 7. Carbon dioxide emissions from power plants producing electricity using methane as fuel depending on different temperatures for all cities

Power plants using propane fuel, the average CO_2 emission based on average temperatures is 1.628 kg/m², with the highest emissions in Şanlıurfa at 7.339 kg/m². Considering the highest average temperature, the average emission is 7.052 kg/m², peaking at 16.747 kg/m² in Batman and dropping to 0.909 kg/m² in Ardahan. At the highest temperature, the average CO_2 emission rises to 28.272 kg/m², with a maximum of 46.882 kg/m² in Adana and a minimum of 11.168 kg/m² in Bitlis. The average CO_2 emission, according to TS 825 data, is 0.859 kg/m². Emissions from other cities and their varying temperatures are illustrated in Figure 8.

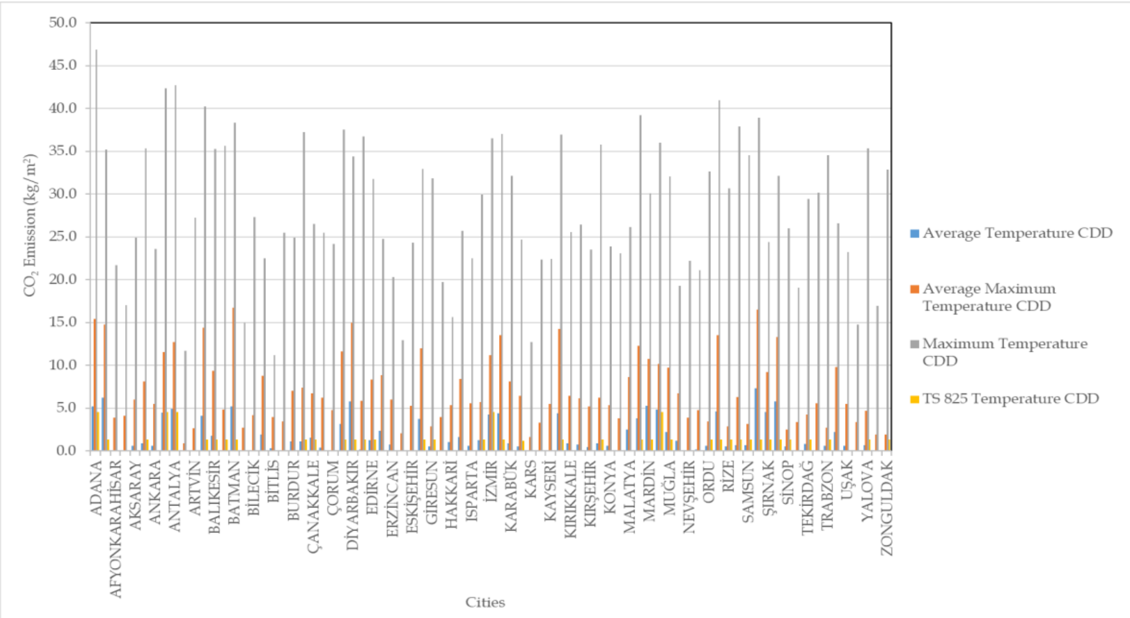

Figure 8. Carbon dioxide emissions from power plants producing electricity using propane as fuel depending on different temperatures for all cities

The average CO_2 emission for butane fuel is 1.674 kg/m², with the highest emissions in Şanlıurfa at 7.548 kg/m². When considering the highest average temperature, the average emission is 7.253 kg/m², peaking at 17.224 kg/m² in Batman and dropping to 0.935 kg/m² in Ardahan. For the highest temperatures, the average CO_2 emission is 29.077 kg/m², with a maximum of 48.216 kg/m² in Adana and a minimum of 11.486 kg/m² in Bitlis. TS 825 data shows the average CO_2 emission is 0.883 kg/m². Emission data for all other cities and their varying temperatures are presented in Figure 9.

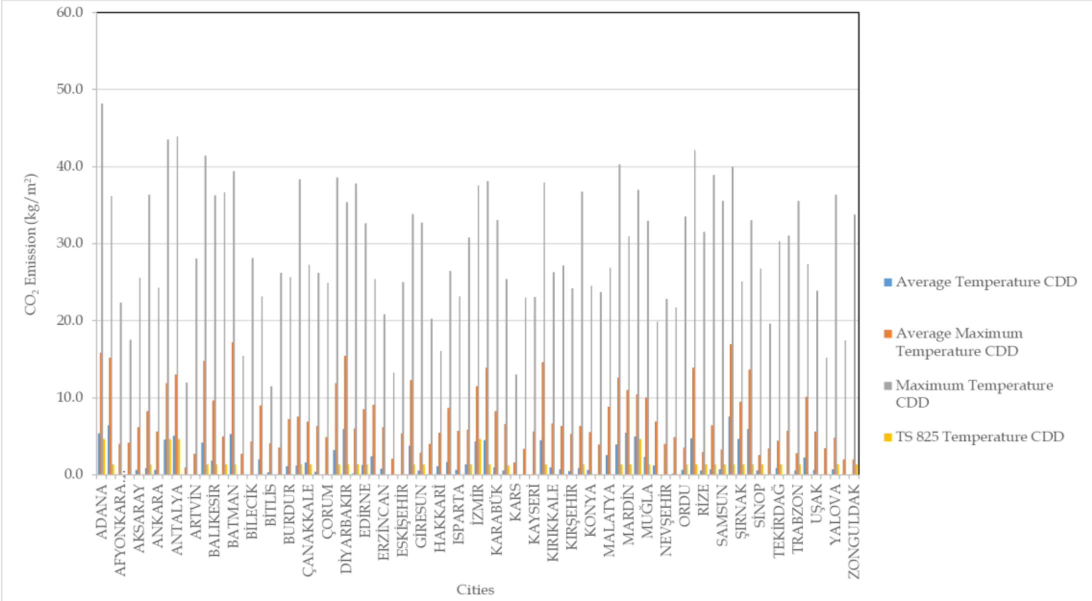

Figure 9. Carbon dioxide emissions from power plants producing electricity using butane as fuel depending on different temperatures for all cities

For all cities in Türkiye, the most significant factor affecting electricity consumption during the cooling period and the CO_2 emissions from power plants using semi-anthracite, bituminous coal, lignite coal, methane, propane, and butane fuels is outdoor temperature, specifically the cooling degree day values calculated accordingly. Additionally, the heat transfer coefficient of the building envelope is another key parameter in calculating electricity consumption during the cooling period, with the indoor temperature set at 22 °C for cooling degree day calculations.

4. CONCLUSIONS

For all cities in our country, the highest electrical energy demand was calculated to occur in Şanlıurfa, with 29.832 kWh/m² for average outdoor temperatures; in Batman, with 68.079 kWh/m² for average highest temperatures; and in Adana, with 190.575 kWh/m² for highest temperatures. Using TS 825 temperature values as a reference, the electrical energy demand in the first climate region, the hottest, was determined to be 18.505 kWh/m².

The average electrical energy demand was calculated as 6.6173 kWh/m² for average outdoor temperatures, 28.667 kWh/m² for average maximum temperatures, and 114.9274 kWh/m² for the highest recorded temperatures. Using the TS 825 temperature values as a reference, the average electrical energy demand was determined to be 3.491 kWh/m².

The study calculated carbon dioxide (CO2) emissions from power plants using different fuels for electrical energy in buildings based on average and highest temperature values. CO2 emissions from coal-fired power plants were found to range from 11.008 to 70.332 kg/m² for semi-anthracite, 10.004 to 64.033 kg/m² for bituminous coal, and 9.934 to 63.462 kg/m² for lignite. Emissions for methane ranged from 6.265 to 40.021 kg/m², while propane and butane had 7.339 to 46.882 kg/m² and 7.548 to 48.216 kg/m², respectively. Thus, the highest CO_2 emissions occurred with semi-anthracite fuel, while the lowest was associated with methane. It has been observed that power plants generating electricity from methane produce lower emissions.

One of the most critical measures to reduce CO_2 emissions released into the atmosphere is to enhance the insulation of the building envelope. To achieve this, the heat transfer coefficient values recommended in the TS 825 insulation standard for the building envelope should be lowered. This will reduce the consumption of electricity and other energy sources in both summer and winter. Consequently, adopting new technologies, such as carbon capture and storage, in electricity generation plants to minimise emissions is essential.

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