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Investigation of electricity produced in power plants and used for cooling buildings with a life cycle approach of carbon capture and storage technology

Okan Kon[1], İsmail Caner[2]

Keywords:

Power plants, Electricity production, Degree-day method, Gases harmful, Life cycle emission assessment

Abstract — There are power plants that use different fuels and technologies to produce electricity that is consumed to cool the buildings in the summer period. These power plants emit Gases Harmful to the Environment and Human (GHEH) such as carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matter (PM) as a result of the combustion of the fuels they use while producing electricity. In the study, the number of emissions to be released from the power plants that produce the electricity used for the cooling of the buildings was examined. Emission reduction due to carbon capture and storage system (CCS), which is one of the new technologies that reduce the released emissions, has been investigated. The use of CCS and the emissions from its use are compared. A long-term Life cycle emission assessment has been made. The annual amount of electrical energy in the buildings was determined according to the cooling degree-day method. In the coal-burning systems of Turkey (CCS), 0.187-0.120 kg/m^2 CO_2, 0.00040-0.00026 kg/m^2 SO_2, 0.000322-0.000206 kg/m^2 NO_x, 0.000014-0.000009 kg/m^2 PM emissions have been determined. In natural gas burning systems using CCS, 0.090-0.058 kg/m^2 CO_2, 0.0000018-0.000012 kg/m^2 SO2, 0.000527-0.000337 kg/m^2 NOx, 0.000002-0.000001 kg PM emissions were determined.

Subject Classification (2020):

1. Introduction

Concerns about climate change have led to significant research into developing carbon capture and storage (CCS) technologies, as fossil fuels emitting emissions such as CO_2 are responsible for most of the world's energy production. Key options for emission reductions by 2050 include efficiency improvements in production and end-use consumption, increasing the share of renewable energies, fuel type, and development of carbon capture and storage solutions. In particular, electricity generation with CCS is a potentially important component of low-carbon energy in the long term. Carbon capture and storage is the most suitable option to reduce emissions such as CO_2 from power plants while maintaining to use of fossil fuels to meet the increasing energy demand [1-5]. Life cycle assessment (LCA) is one of the most established environmental assessment methods for modelling the environmental impacts of

[1]okan@balikesir.edu.tr; [2]ismail@balikesir.edu.tr (Corresponding Author)

[1,2]Department of Mechanical Engineering, Faculty of Engineering, Balıkesir University, Balıkesir, Turkey

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producing goods and services throughout their lifecycle. It is an important tool for assessing the inputs, outputs, and potential environmental impacts of a product system throughout its life cycle. It was applied to assess life cycle sustainability. Performing a life cycle assessment of greenhouse gas reduction strategies provides an environmental comparison of reduced emissions. Life cycle assessment calculations are required for a comprehensive comparative assessment of fossil fuel electricity generation in CCS and conventional systems [2, 6-8]. Heating degree-days (HDD) and cooling degree-days (CDD) provide significant convenience in estimating heating and cooling loads of buildings, energy planning, and determining the size of HVAC systems. For the energy analysis of buildings, long-term daily maximum and minimum outdoor temperature values were obtained with the degree-day method. High fuel costs and increasing environmental pollution have brought about increasing efficiency in heating and cooling facilities. A degree-day is a common method used to assist in estimating the energy consumption of buildings, especially in European countries [9].

When we examined the literature; Eide et al. analysed the costs of the carbon capture system (CCS) depending on the percentage of carbon capture considering the natural gas and coal-fired plant system. They studied the emission reduction of carbon capture systems (CCS) in coal and natural gas power systems [1]. Giannoulakis et al. examined a power plant producing electricity via fossil fuel with carbon capture and storage (CCS) and carbon capture and without storage in terms of both life cycle assessment and Levelized cost of electricity calculations [2]. Young et al. investigated the life cycle environmental effects of amine solvent-based carbon capture systems on ammonia production, oil refineries, supercritical and subcritical powder coal power plants, and natural gas combined cycle power plants [8]. Cruz et al. conducted an overview of the LCA of CCS/CCU technologies found in the literature through a comprehensive bibliometric analysis of publications from 1995 to 2018 to highlight the current status and future challenges. By applying the LCA of CCS/CCU technologies; countries, institutions and research areas were determined by analysing performance indicators using science mapping software tools [6]. Odeh and Cockerill examined life-cycle emissions from three types of fossil fuel-based power plants: supercritical pulverized coal (super-PC), natural gas combined cycle (NGCC) and integrated gasification combined cycle (IGCC) with and without CCS [5]. DeLlano-Paz et al. proposed a model that includes all production costs for different technologies with portfolio theory is applied to both economically and environmentally efficient electricity generation. The results show that the EU technology portfolio proposed by the International Energy Agency for the 2030 horizon is far from efficient [10]. Volkart et al. made a systematic comparison of the LCA-based environmental performance of fossil and wood power plants as well as cement production with and without CCS for 2025 and 2050 in Europe. They have shown that cement plants are well suited for the implementation of CCS [3]. Altun et al. aimed to evaluate the effectiveness of additional envelope insulation investments to be made at the early design stage in buildings. In the study, the effectiveness of insulation application according to TS 825 was investigated in two different processes short-term (savings in annual heating energy need, additional insulation cost and additional greenhouse gas emission) and life cycle (life cycle cost and greenhouse gas emission). In addition, the payback periods of the additional investment made in terms of cost and greenhouse gas were also analysed [11]. Cristina et al. examined the impact of Carbon Capture and Storage units on the environmental, energy and economic performance of Brazilian electricity generation. The study was conducted to capture CO_2 emitted from thermoelectricity using coal and natural gas [12]. Cho and Strezov, using the information obtained from the life cycle assessment (LCA), examined the environmental impacts of combustion-based electricity generation technologies from six different energy sources (hard coal, brown coal, natural gas, diesel, landfill gas and wood biomass) [7]. Singh et al. evaluate and compares the life cycle impacts of various coal and natural gas power generation chains for CO_2 capture, transport and storage. It is based on a hybrid model that uses detailed physical data for all processes and economic data for the infrastructure of the power plant and the CO_2 capture facility. These analyses explain the environmental benefits resulting from CCS with different technologies [4]. Karkour et al. evaluated the cost of electricity generation in G20 countries using the global life-cycle impact assessment (LCIA) method. In the study, a life cycle impact assessment based on endpoint modelling (LIME3) was made. Using this method, it has been shown that it is possible to accurately determine which sources or emissions have an environmental impact in each country [13]. Treyer and Bauer examined the environmental impacts of current and future electricity consumption in the United Arab Emirates (UAE). They investigated different scenarios of future energy production in the UAE based on the Life Cycle Assessment (LCA). The environmental performance of potential power sources (natural gas, oil, nuclear, solar, wind) in the UAE has been compared across power generation chains [14]. Koornneef et al. used a life cycle assessment methodology to assess the environmental impacts of three pulverized coal-fired electricity supply chains with and without carbon capture and storage (CCS). A detailed greenhouse gas (GHG) amount and environmental benefits resulting from carbon capture and storage (CCS) for the three chains have been determined [15]. On the other hand, Singh et al. used a hybrid Life Cycle Assessment approach to evaluate the environmental impacts of large-scale power plants based on International Energy Agency (IEA) scenarios using Carbon dioxide Capture and Storage (CCS), which generates electricity by burning coal and natural gas [16]. Hammond and Spargo examined potential design paths for the capture, transport and storage of CO2 from power plants in the United Kingdom (UK). In the study, energy and carbon analyses of power plants using coal with CCS (Carbon capture and storage) and without CCS were made. Both existing and new CCS technologies have been evaluated [17]. He et al. proposed an economic distribution model of the savings that will occur as a result of reducing CO2 emissions in gas-fired power plants. In this economic review, the post-combustion carbon capture system and power plant are analysed [18]. Kisa et al. examined 19 electricity generation technologies including 12 life-cycle phases for technology analysis based on carbon emission reduction in Electricity generation. For the life-cycle phase of each technology; four parameters were used, covering material consumption, energy return rates, business requirements and greenhouse gas emissions [19].

The study aims to examine Gases Harmful to the Environment and Human (GHEH) such as carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter (PM) that will occur during the production of electricity used for cooling of buildings in power plants in summer. Environmental effects have been investigated in the electricity production of power plants using different technologies. In these power plants, the carbon capture and storage (CCS) system has been researched as a new technology that reduces emissions to the environment. With the use of this technology, calculations based on 20 years of long-term life cycle emission assessments have been made. The degree-day method and wall, floor, and ceiling heat transfer coefficient were used to determine the annual energy consumption of the buildings. While determining the heating and cooling degree-days used for heating and cooling of a particular region, daily average outdoor temperatures are used in the literature. In this study, daily maximum and minimum outdoor temperatures are used for more detailed heating and cooling degree-days and, accordingly, more realistic values for energy consumption estimates in buildings. Fuels such as coal, natural gas, fuel oil and LPG are used as energy sources during the heating period. On the other hand, very little electricity is used for heating purposes. In the cooling period, the buildings are cooled with electricity. Therefore, in this study, the electricity consumption of our country during the cooling period has been taken into account. The released emissions from power plants that produce this electricity have been examined.

2. Methodology

2.1. Cooling Degree-Day Calculation

According to the 21-year data, cooling degree-day values were determined according to the calculation method given below by using the daily maximum ($t_{\max}$), daily minimum ($t_{\min}$) and basic temperature (t_b). Cooling degree-day value was found for 22 °C basic temperature [9]. Cooling degree-day value, if

$$t_{\max} > t_b, t_{\min} < t_b, \text{and } (t_{\max} - t_b) < (t_b - t_{\min}) CDD_{day} = 0.25(t_{\max} - t_b) \tag{2.1}$$

$$t_{\max} > t_b, t_{\min} < t_b, \text{and } (t_{\max} - t_b) > (t_b - t_{\min}) CDD_{day} = 0.5(t_{\max} - t_b) - 0.25(t_b - t_{\min}) \tag{2.2}$$

$$t_{\max} > t_b \text{ and } t_{\min} > t_b \; = 0.5(t_{\max} + t_{\min}) - t_b \tag{2.3}$$

$$CDD_{year} = \sum_{\text{days}} \mathrm{CDD_{day}} \tag{2.4}$$

$$CDD_{year} = \frac{\sum_{21\text{ years}} \mathrm{CDD_{year}}}{21} \tag{2.5}$$

2.2. Electricity Consumption and Life Cycle Emissions Assessment for Cooling Period

The amount of electricity consumed per year in the cooling period [20],

$$\mathrm{E_C} = \frac{0.024 \cdot \mathrm{U} \cdot \mathrm{CDD}}{\mathrm{COP}} \tag{2.6}$$

Here, CDD is cooling degree-day, COP (taken as 2.5) is cooling coefficient performance and U is heat transfer coefficients of the building envelope. For life cycle emissions assessment (LCEA), emissions to be generated by energy consumption for the long term are calculated. The life cycle emission assessment calculation equation is [11],

$$\mathrm{LCEA} = \mathrm{C_{gg,fuel}} \sum_{t=1}^{N} \frac{\mathrm{E_C}}{(1+\mathrm{i_{gg}})^t} \tag{2.7}$$

Here, $C_{gg,fuel}$ is unit CO_2, SO_2, NO_x and PM emissions from the combustion of fuel in power plants (kg-emissions/kWh_{fuel}), i_{gg} is the percentage impact of gas emissions (in this study, it was taken as 5%), N is life (20-year life was taken in this study) and EC is cooling seasons energy consumption.

2.3. Emission Data based on the Carbon Capture and Storage Systems (CCS)

In the study, it is accepted that coal and natural gas are used as fuel in power plants that produce electricity. Carbon Capture and Storage systems (CCS) are used as a new technology for emission reduction. Gases Harmful to the Environment and Human (GHEH) values such as carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter (PM) emissions that will occur due to these fuels and technology are given in Table 1.

Table 1. Gases Harmful to the Environment and Human (GHEH) Occurring During Electricity Generation in Power Plants Using Different Fuels and Systems [10]

GHEH	Coal	Coal – CCS	Natural Gas	Natural Gas – CCS
CO_2 (kg/kWh)	0.7341	0.1010	0.3561	0.0487
SO_2 (gr/kWh)	0.0735	0.0218	0.0088	0.0098
NO_X (gr/kWh)	0.1825	0.1737	0.2547	0.2842
PM (gr/kWh)	0.0093	0.0077	0.0012	0.0012

3. Results and Discussions

The highest electrical energy consumption due to building envelope components occurs in Şanlıurfa city. Şanlıurfa province is in the 2nd climate zone. Although the heat transfer coefficient of the building envelope components is lower than the first climate zone, it is the city with the highest electrical energy consumption due to its cooling degree day values are much higher. It has been determined that the lowest electrical energy consumption due to building envelope components is in Ardahan city, which is in the fifth climate zone. For Ardahan, both the building envelope heat transfer coefficients and the cooling degree-day values are the lowest. Among the metropolitan cities, Istanbul, which is located in the second climate zone, has the highest electricity consumption due to building envelope components. These values and the electrical energy consumption values depending on the building envelope components for other cities in our country are given in Tables 2 and 3.

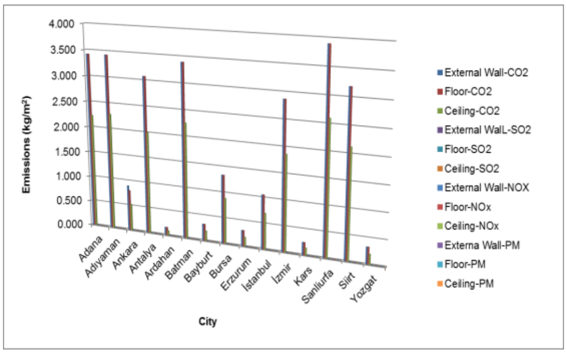
The building envelope in Table 2 is given based on the recommended heat transfer coefficients heating period in the Turkish insulation standard TS 825. For this reason, the heat transfer coefficients of the building envelope should be re-determined in order to reduce the cooling energy (electrical energy), especially in the first and second climate zones where cooling is made. The electrical energy consumed for the purpose of cooling the buildings constitutes a very important amount in all energy consumption.

For emission values, when the values given for some cities depending on the basic indicators in Figure 1 and for our country in Table 4 are examined for conventional coal-burning systems in Turkey where CCS is not used, total of 107.553-68.834 kg/m^2 CO2, 0.010768-0.006892 kg/m^2 SO_2, 0.026738-0.017112 kg/m^2 NO_x and 0.001363-0.000872 kg/m^2 PM emissions depending on the building components were found. In coal-burning systems using CCS, emissions of 14.797-9.470 kg/m^2 CO_2, 0.003194-0.002044 kg/m^2 SO_2, 0.025449-0.016287 kg/m$_2$ NO_x, 0.001128-0.000722 kg PM have been detected. For conventional natural gas burning systems in Turkey where CCS is not used, an average of 52.172-33.390 kg/m^2 CO2, 0.001289-0.000825 kg/m^2 SO_2, 0.037316-0.023882 kg/m^2 NO_x and 0.000176-0.000113 kg/m^2 PM emissions were found depending on the building components. In natural gas burning systems using CCS, 7.135-4.566 kg/m^2 CO_2, 0.001436-0.000919 kg/m^2 SO_2, 0.041638-0.026649 kg/m^2 NO_x, 0.000176-0.000113kg/m^2 PM emissions were determined.

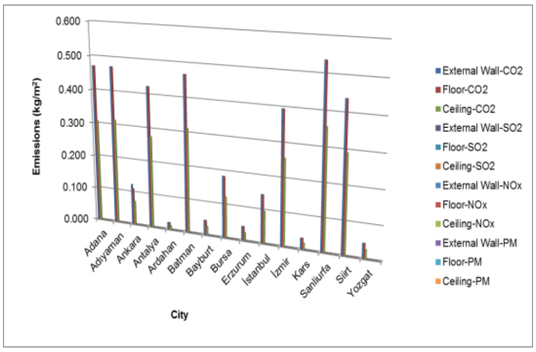
When the values given for life cycle emission assessment for some cities depending on the basic indicators in Figure 2 and for our country in Table 5 are examined for conventional coal-burning systems in Turkey where CCS is not used, total of 40.540-25.946 kg/m^2 CO2, 0.004059-0.002598 kg/m^2 SO_2, 0.010078-0.006450 kg/m^2 NO_x and 0.000514-0.000329 kg/m^2 PM emissions depending on the building components were found. In coal-burning systems using CCS, emissions of 5.578-3.570 kg/m^2 CO_2, 0.001204-0.000770 kg/m^2 SO_2, 0.009592-0.006139 kg/m^2 NO_x, 0.000425-0.000272 kg PM have been detected. For conventional natural gas burning systems in Turkey where CCS is not used, an average of 19.665-12.586 kg/m^2 CO_2, 0.001167-0.000747 kg/m^2 SO_2, 0.014066 -0.009002 kg/m^2 NO_x and 0.000066-0.000042 kg/m^2 PM emissions were found depending on the building components. In natural gas burning systems using CCS, 2.689-1.721 kg/m^2 CO_2, 0.000541-0.000346 kg/m^2 SO_2, 0.015695-0.010045 kg/m^2 NO_x, 0.000066-0.000042 kg/m^2 PM emissions were determined.

Table 2. Cooling degree day (CDD) and heat transfer coefficient values of external walls (U_w), floor (U_f) and ceiling (U_c) and electricity energy consumption in cities in Turkey [9, 10, 21]

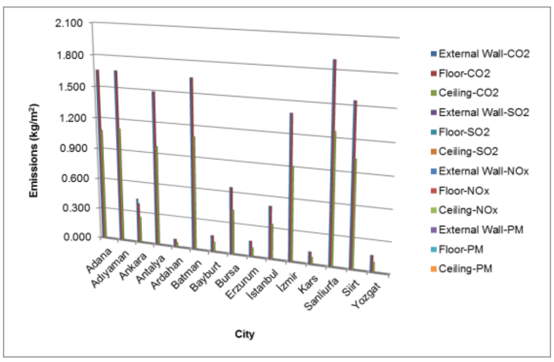
City	Heat Transfer Coefficient (W/m².K)			Climate zone	Cooling degree-day	Electricity consumption (kWh/m²)		
	External wall (U_w)	Floor (U_f)	Ceiling (U_c)			External wall (U_w)	Floor (U_f)	Ceiling (U_c)
Highest electricity consumption								
Sanliurfa	0.57	0.57	0.38	2	970	5.308	5.308	3.539
Adıyaman	0.57	0.57	0.38	2	853	4.668	4.668	3.112
Adana	0.66	0.66	0.43	1	735	4.657	4.657	3.034
Batman	0.57	0.57	0.38	2	845	4.624	4.624	3.083
Siirt	0.57	0.57	0.38	2	793	4.339	4.339	2.893
Lowest electricity consumption								
Ardahan	0.36	0.36	0.21	5	61	0.211	0.211	0.123
Kars	0.36	0.36	0.21	5	96	0.332	0.332	0.194
Erzurum	0.36	0.36	0.21	5	122	0.422	0.422	0.246
Bayburt	0.38	0.38	0.23	4	121	0.441	0.441	0.267
Yozgat	0.38	0.38	0.23	4	122	0.445	0.445	0.269
Metropolitans								
Istanbul	0.57	0.57	0.38	2	262	1.434	1.434	0.956
Ankara	0.48	0.43	0.28	3	265	1.221	1.094	0.712
İzmir	0.66	0.66	0.43	1	617	3.909	3.909	2.547
Bursa	0.57	0.57	0.38	2	333	1.822	1.822	1.215
Antalya	0.66	0.66	0.43	1	661	4.188	4.188	2.729

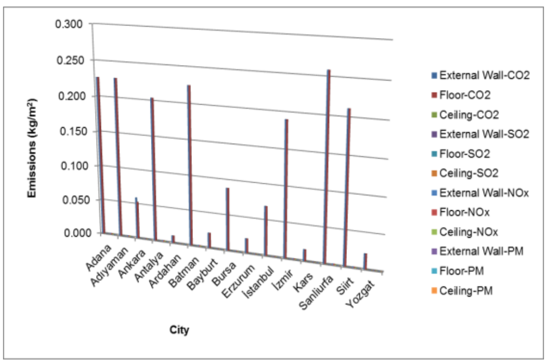


(a)



(b)





(c) (d)

Figure 1. In power plants, released emissions based on the use of a) Coal, b) Coal-CCS, c) Natural Gas, d) Natural Gas-CCS

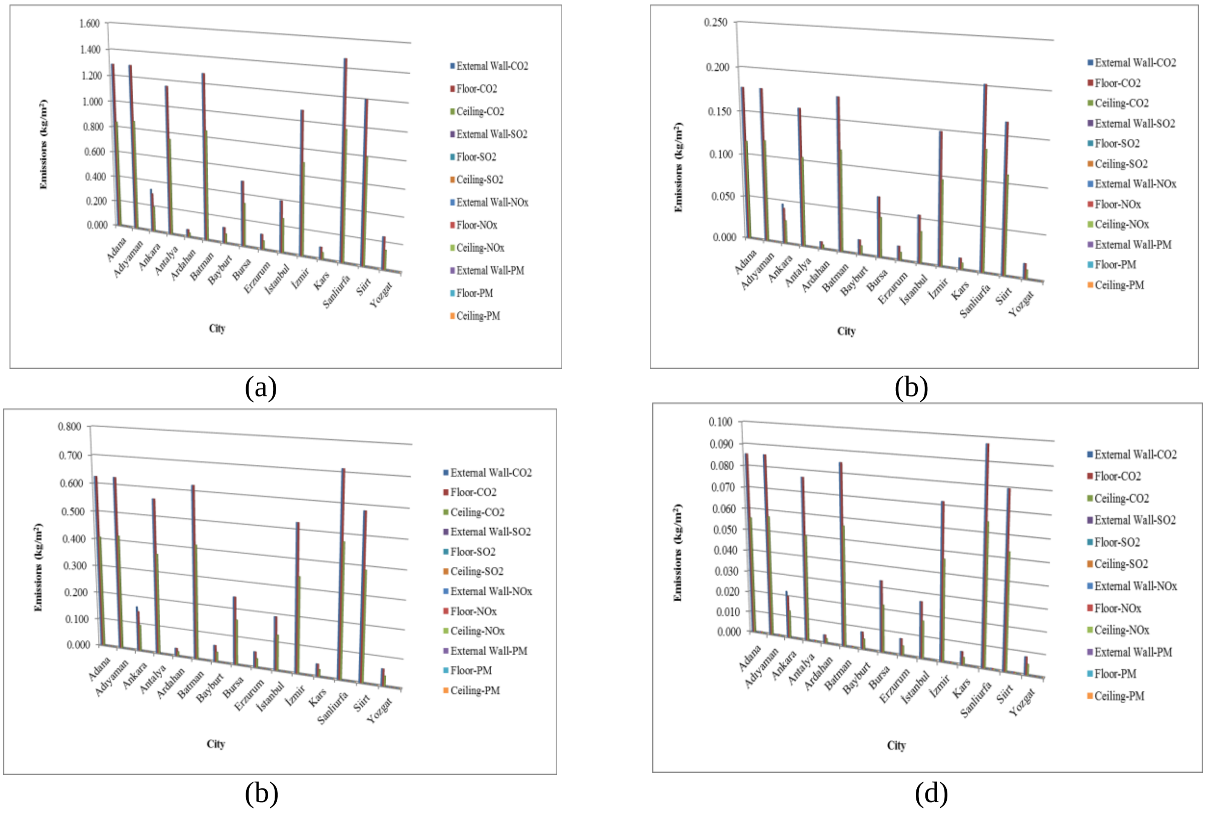


Figure 2. In power plants, life cycle emissions assessments based on the use of a) Coal, b) Coal-CCS, c) Natural Gas, d) Natural Gas-CCS

Table 3. Electricity consumption based on the Cooling degree day (CDD) and heat transfer coefficient values of external walls (U_W), floor (U_F) and ceiling (U_C) in all cities in Turkey [1,8]

Province	External wall (U_W)	Floor (U_F)	Ceiling (U_C)	Climate zone	Cooling degree-day (CDD)	External wall	Floor	Ceiling
Adana	0.66	0.66	0.43	1	735	4.657	4.657	3.034
Adıyaman	0.57	0.57	0.38	2	853	4.668	4.668	3.112
Afyonkarahisar	0.48	0.43	0.28	3	216	0.995	0.892	0.581
Ağrı	0.36	0.36	0.21	5	193	0.667	0.667	0.389
Aksaray	0.48	0.43	0.28	3	285	1.313	1.176	0.766
Amasya	0.57	0.57	0.38	2	328	1.795	1.795	1.197
Ankara	0.48	0.43	0.28	3	265	1.221	1.094	0.712
Antakya	0.66	0.66	0.43	1	623	3.947	3.947	2.572
Antalya	0.66	0.66	0.43	1	661	4.188	4.188	2.729
Ardahan	0.36	0.36	0.21	5	61	0.211	0.211	0.123
Artvin	0.48	0.43	0.28	3	128	0.590	0.528	0.344
Aydın	0.57	0.57	0.38	2	694	3.798	3.798	2.532
Balıkesir	0.57	0.57	0.38	2	369	2.019	2.019	1.346
Bartın	0.57	0.57	0.38	2	178	0.974	0.974	0.649
Batman	0.57	0.57	0.38	2	845	4.624	4.624	3.083
Bayburt	0.38	0.38	0.23	4	121	0.441	0.441	0.267
Bilecik	0.48	0.43	0.28	3	232	1.069	0.958	0.624
Bingöl	0.48	0.43	0.28	3	507	2.336	2.093	1.363
Bitlis	0.38	0.38	0.23	4	264	0.963	0.963	0.583

Table 3. (Continue)

Province	External wall (U_W)	Floor (U_F)	Ceiling (U_C)	Climate zone	Cooling degree-day (CDD)	External wall	Floor	Ceiling
Bolu	0.48	0.43	0.28	3	158	0.728	0.652	0.425
Burdur	0.48	0.43	0.28	3	354	1.631	1.461	0.952
Bursa	0.57	0.57	0.38	2	333	1.822	1.822	1.215
Çanakkale	0.57	0.57	0.38	2	354	1.937	1.937	1.291
Çankırı	0.48	0.43	0.28	3	281	1.295	1.160	0.755
Çorum	0.48	0.43	0.28	3	202	0.931	0.834	0.543
Denizli	0.57	0.57	0.38	2	586	3.207	3.207	2.138
Diyarbakır	0.57	0.57	0.38	2	763	4.175	4.175	2.783
Düzce	0.57	0.57	0.38	2	229	1.253	1.253	0.835
Edirne	0.57	0.57	0.38	2	363	1.986	1.986	1.324
Elazığ	0.48	0.43	0.28	3	477	2.198	1.969	1.282
Erzincan	0.38	0.38	0.23	4	314	1.145	1.145	0.693
Erzurum	0.36	0.36	0.21	5	122	0.422	0.422	0.246
Eskişehir	0.48	0.43	0.28	3	201	0.926	0.830	0.540
Gaziantep	0.57	0.57	0.38	2	645	3.529	3.529	2.353
Giresun	0.57	0.57	0.38	2	161	0.881	0.881	0.587
Gümüşhane	0.38	0.38	0.23	4	171	0.624	0.624	0.378
Hakkari	0.38	0.38	0.23	4	302	1.102	1.102	0.667
Iğdır	0.48	0.43	0.28	3	433	1.995	1.787	1.164
Isparta	0.48	0.43	0.28	3	263	1.212	1.086	0.707
İstanbul	0.57	0.57	0.38	2	262	1.434	1.434	0.956
İzmir	0.66	0.66	0.43	1	617	3.909	3.909	2.547
Kahramanmaraş	0.57	0.57	0.38	2	707	3.869	3.869	2.579
Karaman	0.48	0.43	0.28	3	301	1.387	1.243	0.809
Kars	0.36	0.36	0.21	5	96	0.332	0.332	0.194
Kastamonu	0.38	0.38	0.23	4	161	0.587	0.587	0.355
Kayseri	0.38	0.38	0.23	4	238	0.868	0.868	0.526
Kırıkkale	0.48	0.43	0.28	3	300	1.382	1.238	0.806
Kırklareli	0.48	0.43	0.28	3	325	1.498	1.342	0.874
Kırşehir	0.48	0.43	0.28	3	244	1.124	1.007	0.656
Kilis	0.57	0.57	0.38	2	714	3.907	3.907	2.605
Kocaeli	0.57	0.57	0.38	2	302	1.653	1.653	1.102
Konya	0.48	0.43	0.28	3	275	1.267	1.135	0.739
Kütahya	0.48	0.43	0.28	3	179	0.825	0.739	0.481
Malatya	0.48	0.43	0.28	3	517	2.382	2.134	1.390
Manisa	0.57	0.57	0.38	2	661	3.617	3.617	2.411
Mardin	0.57	0.57	0.38	2	764	4.181	4.181	2.787
Mersin	0.66	0.66	0.43	1	606	3.840	3.840	2.502
Muğla	0.57	0.57	0.38	2	510	2.791	2.791	1.860
Muş	0.38	0.38	0.23	4	382	1.394	1.394	0.843
Nevşehir	0.48	0.43	0.28	3	184	0.848	0.760	0.495
Niğde	0.48	0.43	0.28	3	220	1.014	0.908	0.591
Ordu	0.57	0.57	0.38	2	206	1.127	1.127	0.751
Osmaniye	0.57	0.57	0.38	2	596	3.261	3.261	2.174
Rize	0.57	0.57	0.38	2	173	0.947	0.947	0.631

Table 3. (Continue)

Province	External wall (U_W)	Floor (U_F)	Ceiling (U_C)	Climate zone	Cooling degree-day (CDD)	External wall	Floor	Ceiling
Sakarya	0.57	0.57	0.38	2	276	1.510	1.510	1.007
Samsun	0.57	0.57	0.38	2	165	0.903	0.903	0.602
Şanlıurfa	0.57	0.57	0.38	2	970	5.308	5.308	3.539
Siirt	0.57	0.57	0.38	2	793	4.339	4.339	2.893
Sinop	0.57	0.57	0.38	2	156	0.854	0.854	0.569
Sivas	0.38	0.38	0.23	4	171	0.624	0.624	0.378
Tekirdağ	0.57	0.57	0.38	2	212	1.160	1.160	0.773
Tokat	0.48	0.43	0.28	3	262	1.207	1.082	0.704
Trabzon	0.57	0.57	0.38	2	191	1.045	1.045	0.697
Tunceli	0.48	0.43	0.28	3	512	2.359	2.114	1.376
Uşak	0.48	0.43	0.28	3	285	1.313	1.176	0.766
Van	0.38	0.38	0.23	4	156	0.569	0.569	0.344
Yalova	0.57	0.57	0.38	2	258	1.412	1.412	0.941
Yozgat	0.38	0.38	0.23	4	122	0.445	0.445	0.269
Zonguldak	0.57	0.57	0.38	2	99	0.542	0.542	0.361

The CO_2, SO_2, NO_x, and PM emission amounts of power plants using the conventional system and carbon capture storage system (CSS) are given in Figure 1, which are released into the atmosphere during electrical energy production. Power plants use coal and natural gas as fuel. The life cycle emission assessment based on oil and natural gas for a 20-year life and a 5% emission increase is shown in Figure 2. Emission values depending on the lowest, highest, average and general total values for our country depending on the building envelope components are given in Table 4. In Table 5, Life Cycle Emissions Assessment (LCEA) related to different building envelope components (5%- and 20-years life) for our country is explained.

Table 4. Emission values for Turkey based on different building envelope components

Parameter	CO_2			SO_2		
	External wall	Floor	Ceiling	External wall	Floor	Ceiling
Coal						
Average	1.361	1.327	0.871	0.000136	0.000133	0.000087
Highest	3.896	3.896	2.598	0.000390	0.000390	0.000260
Lowest	0.155	0.155	0.090	0.000015	0.000015	0.000009
Total	107.553	104.872	68.834	0.010768	0.010500	0.006892
Coal-CCS						
Average	0.187	0.183	0.120	0.000040	0.000039	0.000026
Highest	0.536	0.536	0.357	0.000116	0.000116	0.000077
Lowest	0.021	0.021	0.012	0.000005	0.000005	0.000003
Total	14.797	14.429	9.470	0.003194	0.003114	0.002044
Natural Gas						
Average	0.660	0.644	0.423	0.000016	0.000016	0.000010
Highest	1.890	1.890	1.260	0.000047	0.000047	0.000031
Lowest	0.075	0.075	0.044	0.000002	0.000002	0.000001
Total	52.172	50.872	33.390	0.001289	0.001257	0.000825
Natural Gas-CCS						
Average	0.090	0.088	0.058	0.000018	0.000018	0.000012
Highest	0.258	0.258	0.172	0.000052	0.000052	0.000035
Lowest	0.010	0.010	0.006	0.000002	0.000002	0.000001
Total	7.135	6.957	4.566	0.001436	0.001400	0.000919

Table 4. (Continue)

Parameter	NO_x			PM		
	External wall	Floor	Ceiling	External wall	Floor	Ceiling
Coal						
Average	0.000338	0.000330	0.000217	0.000017	0.000017	0.000011
Highest	0.000969	0.000969	0.000646	0.000049	0.000049	0.000033
Lowest	0.000038	0.000038	0.000022	0.000002	0.000002	0.000001
Total	0.026738	0.026072	0.017112	0.001363	0.001329	0.000872
Coal-CCS						
Average	0.000322	0.000314	0.000206	0.000014	0.000014	0.000009
Highest	0.000922	0.000922	0.000615	0.000041	0.000041	0.000027
Lowest	0.000037	0.000037	0.000021	0.000002	0.000002	0.000001
Total	0.025449	0.024815	0.016287	0.001128	0.001100	0.000722
Natural Gas						
Average	0.000472	0.000461	0.000302	0.000002	0.000002	0.000001
Highest	0.001352	0.001352	0.000901	0.000006	0.000006	0.000004
Lowest	0.000054	0.000054	0.000031	0.000000	0.000000	0.000000
Total	0.037316	0.036386	0.023882	0.000176	0.000171	0.000113
Natural Gas-CCS						
Average	0.000527	0.000514	0.000337	0.000002	0.000002	0.000001
Highest	0.001508	0.001508	0.001006	0.000006	0.000006	0.000004
Lowest	0.000060	0.000060	0.000035	0.000000	0.000000	0.000000
Total	0.041638	0.040600	0.026649	0.000176	0.000171	0.000113

Table 5. Life Cycle Emissions Assessment (LCEA) for Turkey (5% and 20 years) depending on different building envelope components

Parameter	CO_2			SO_2		
	External wall	Floor	Ceiling	External wall	Floor	Ceiling
Coal						
Average	0.513	0.500	0.328	0.000051	0.000050	0.000033
Highest	1.469	1.469	0.979	0.000147	0.000147	0.000098
Lowest	0.058	0.058	0.034	0.000006	0.000006	0.000003
Total	40.540	39.530	25.946	0.004059	0.003958	0.002598
Coal-CCS						
Average	0.071	0.069	0.045	0.000015	0.000015	0.000010
Highest	0.202	0.202	0.135	0.000044	0.000044	0.000029
Lowest	0.008	0.008	0.005	0.000002	0.000002	0.000001
Total	5.578	5.439	3.570	0.001204	0.001174	0.000770
Natural Gas						
Average	0.249	0.243	0.159	0.000015	0.000014	0.000009
Highest	0.712	0.712	0.475	0.000042	0.000042	0.000028
Lowest	0.028	0.028	0.017	0.000002	0.000002	0.000001
Total	19.665	19.175	12.586	0.001167	0.001138	0.000747
Natural Gas-CCS						
Average	0.034	0.033	0.022	0.000007	0.000007	0.000004
Highest	0.097	0.097	0.065	0.000020	0.000020	0.000013
Lowest	0.004	0.004	0.002	0.000001	0.000001	0.000000
Total	2.689	2.622	1.721	0.000541	0.000528	0.000346

Table 5. (Continue)

Parameter	NO_x			PM		
	External wall	Floor	Ceiling	External wall	Floor	Ceiling
Coal						
Average	0.000128	0.000124	0.000082	0.000007	0.000006	0.000004
Highest	0.000365	0.000365	0.000243	0.000019	0.000019	0.000012
Lowest	0.000015	0.000015	0.000008	0.000001	0.000001	0.000000
Total	0.010078	0.009827	0.006450	0.000514	0.000501	0.000329
Coal-CCS						
Average	0.000121	0.000118	0.000078	0.000005	0.000005	0.000003
Highest	0.000348	0.000348	0.000232	0.000015	0.000015	0.000010
Lowest	0.000014	0.000014	0.000008	0.000001	0.000001	0.000000
Total	0.009592	0.009353	0.006139	0.000425	0.000415	0.000272
Natural Gas						
Average	0.000178	0.000174	0.000114	0.000001	0.000001	0.000001
Highest	0.000510	0.000510	0.000340	0.000002	0.000002	0.000002
Lowest	0.000020	0.000020	0.000012	0.000000	0.000000	0.000000
Total	0.014066	0.013715	0.009002	0.000066	0.000065	0.000042
Natural Gas-CCS						
Average	0.000199	0.000194	0.000127	0.000001	0.000001	0.000001
Highest	0.000569	0.000569	0.000379	0.000002	0.000002	0.000002
Lowest	0.000023	0.000023	0.000013	0.000000	0.000000	0.000000
Total	0.015695	0.015304	0.010045	0.000066	0.000065	0.000042

The average heat transfer coefficient for the external wall is 0.51, 0.49 for the floor and 0.32 W/m^{2}K for the ceiling for Turkey. The average cooling degree day value was determined as 360. The total electrical energy consumption of the building envelope components connected to the external wall is calculated as 146,509, 142,859 for the floor and 93,767 kWh/m^2 for the ceiling. During the cooling period, a significant amount of electricity is consumed to cool the buildings. The majority of this electricity is produced from power plant power plants that burn coal and natural gas. During this electricity generation, high amounts of harmful emissions are released into the atmosphere. Newly developed carbon capture and storage (CCS) technologies are used to reduce harmful emissions released into this atmosphere. Thanks to this technology, the emission values released into the atmosphere are taken to a more controllable level. The two parameters that are effective in the electrical energy consumption for the cooling of the buildings during the cooling period are the building envelope heat transfer coefficient and the cooling degree day value. As a result of the calculations and examinations, it has been seen that the cooling degree-day value and the heat transfer coefficients of the building envelope are very effective for electrical energy consumption. The most decisive parameter in the electrical energy consumption of the buildings is the cooling degree days.

In the study, it was determined that the use of carbon capture and storage (CCS) systems decreased 86% CO_2 emissions, 70% SO_2 emissions, 5% in NO_x emissions and 17% in PM emissions in power plants burning coal compared to conventional systems. Accordingly, coal-fired power plants using CCS give much better results in terms of reducing CO_2 emissions. On the other hand, much lower results were observed in NO_x emission. Compared to conventional systems, the use of carbon capture and storage (CCS) systems showed an 86% decrease in CO_2 emissions, an 11% increase in SO_2 emissions, an 11% increase in NOx emissions, and no change in PM emissions in coal-fired power plants. As can be seen, although it is very suitable for reducing CO_2 emissions in power plants that burn natural gas, it creates an increase in SO_2 and NO_x emissions. Considering SO_2 and NO_x emissions, carbon capture and storage

(CCS) systems do not give positive results. According to this information, when all emission types are considered, it is seen that the use of carbon capture and storage (CCS) technology is a more suitable system for coal-fired power plants.

The cooling degree-day value decreases as the climate zone increases. Cooling degree-day values are higher in the first climate zone, which is the hot climate zone. The cold climatic zone is lower in the fourth and fifth climatic zones. With this, while the wall, roof and ceiling heat transfer coefficient are higher in the first climate zone, it is lower in the fifth climate zone.

4. Conclusions

When the results are examined, Turkey's average electrical energy consumption is calculated as 1.855 kWh/m^2 for the wall, 1.808 kWh/m^2 for the roof and 1.187 kWh/m^2 for the ceiling. Accordingly, for conventional coal-burning systems in Turkey where CCS is not used, an average of 1.361-0.871 kg/m^2 CO_2, 0.000136-0.000087 kg/m^2 SO_2, 0.000217-0.00338 kg/m^2 NO_x and 0.000011-0.000017 kg/m^2 PM emissions depending on the building components were found. In coal-burning systems using CCS, emissions of 0.187-0.120 kg/m^2 CO_2, 0.00040-0.00026 kg/m^2 SO_2, 0.000322-0.000206 kg/m^2 NO_x, 0.000014-0.000009 kg PM have been detected. For conventional natural gas burning systems in Turkey where CCS is not used, an average of 0.660-0.423 kg/m^2 CO_2, 0.000016-0.000010 kg/m^2 SO_2, 0.000472-0.000302 kg/m^2 NO_x and 0.000002-0.000001 kg/m^2 PM emissions were found depending on the building components. In natural gas burning systems using CCS, 0.090-0.058 kg/m^2 CO_2, 0.0000018-0.000012 kg/m^2 SO_2, 0.000527-0.000337 kg/m^2 NO_x, 0.000002-0.000001 kg/m^2 PM emissions were determined. NO_x emission occurs in higher amounts for both conventional and CCS systems burning natural gas, compared to systems burning coal. The highest electrical energy consumption was determined in the province of Sanliurfa and the lowest in the province of Ardahan. While the cooling-degree day value is the highest in Sanliurfa, it has the lowest value in Ardahan.

Based on 20-year life and a 5% percentage impact of gas emissions, for conventional coal-burning systems in Turkey where CCS is not used, an average of 1.469-0.979 kg/m^2 CO_2, 0.000147-0.000098 kg/m^2 SO_2, 0.000365-0.000243 kg/m^2 NO_x and 0.000019-0.000012 kg/m^2 PM emissions depending on the building components were found. In coal-burning systems using CCS, emissions of 0.071-0.045 kg/m^2 CO_2, 0.000015-0.000010 kg/m^2 SO_2, 0.000121-0.000078 kg/m^2 NO_x, 0.000005-0.000003 kg PM have been detected. For conventional natural gas burning systems in Turkey where CCS is not used, an average of 0.249-0.159 kg/m^2 CO_2, 0.000015-0.000009 kg/m^2 SO_2, 0.000178-0.000114 kg/m^2 NO_x and 0.0000008-0.0000005 kg/m^2 PM emissions were found depending on the building components. In natural gas burning systems using CCS, 0.034-0.022 kg/m^2 CO_2, 0.000007-0.000004 kg/m^2 SO_2, 0.000199-0.000127 kg/m^2 NO_x, 0.0000008-0.0000005 kg/m^2 PM emissions were determined.

The first and most important application to reduce energy savings in buildings is to reduce the heat transfer coefficient of building envelopes (wall, ceiling and floor). Thus, it is necessary to increase the insulation thickness of the building envelope. Thereby, the heat transfer coefficients of the buildings will decrease and the associated energy consumption will decrease.

With the use of the carbon capture and storage (CCS) system for the power plant that produces electricity, it is necessary to reduce the environmental impact and make forward-looking predictions. Thus, it is very important for our country to develop new technologies and combustion systems to reduce the environmental impact of power plant power plants and to reduce carbon and other emissions. With the newly developed technologies and combustion systems, a more sustainable environment and living standard will be achieved by reducing both energy consumption and emission for our country. Today, with more applications of power plants the carbon capture and storage (CCS) systems, will have a very positive effect in terms of underground storage and environmental disposal of carbon captured without environmental release.

The emissions that power plants will release to the environment during electricity production will have a very negative impact on people's health and the ecosystem. Significant economic expenditures will be required to mitigate these effects. Reducing the impact of these emissions also has economic value. This will also have a negative economic impact on our country.

Author Contributions

All the authors contributed equally to this work. They all read and approved the last version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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