The Carbon Footprint Reduction Related to Domestic Heating Using Thermal Power Plant Waste Heat

ABSTRACT

The carbon emissions created using fossil fuels for energy are the first place the carbon to the environment. Thermal power plants that burn coal or natural gas provide a significant part of this energy. It does not seem possible to avoid thermal power plants in the short term in future policies regarding energy. Thus, using the waste heat of these power plants for domestic heating to reduce carbon emissions for energy production also decreasing the global climate crisis is a critical practice. In terms of reducing the carbon footprint and the adverse effects of thermal power plants these practices are necessary steps.

In this study, two scenarios were created to reduce the carbon footprint of heating based on waste heat from the natural gas thermal power plant in Sakarya. This is considered with the district heating system in houses. For domestic heating, natural gas is used in the first scenario, coal is used in the second scenario, and the carbon footprint is determined. Emissions from the power plant's use of coal and natural gas are also determined. District heating using waste heat and its process and installation cost was also analyzed. As a result, it has been revealed that there will be a carbon reduction of 461,161.2 tons/year CO_{2e} when natural gas is not used for domestic heating and 605,159.6 tons/year CO_{2e} when coal is not used. All this is possible by the use of waste heat. The annual carbon emission of the power plant using natural gas was found to be 1,263,260.8 tons/year CO_{2e}, and the emission value was found to be 9,682,554 tons/year CO_{2e} when coal was used in the power plant. The study results will guide policymakers to reduce the carbon footprint of heating using district heating systems, both in Turkey and developing countries where fossil fuel thermal power plants are used.

Keywords: Thermal power plant, waste heat, regional heating, domestic heating emissions, carbon footprint, Sakarya, Türkiye.

1. INTRODUCTION

The most important factor creating the global climate crisis is fossil fuels, which are used in many human activities, especially in energy production, and are carbon sources. The most significant energy production area is thermal power plants that burn fossil fuels. Thermal power plants are designed to convert chemical energy into heat energy and mechanical energy, and this energy into electricity by burning fossil fuels. The water in the boiler section turns into hot steam, and this steam generates electric current with turbines and alternators. A part of the heat initiated by power plants is thrown into the environment [1]. The emissions from thermal power plants account for around 40% of the global carbon emissions connected to energy. Seventy percent of Turkey's greenhouse gas emissions in 2020 came from the energy sector [2]. Given the energy use and future policies in the world, it does not seem possible to stop or prevent the use of thermal power plants in the short term [3]. Accordingly, the use of thermal power plant waste heat gains importance for energy efficiency and carbon footprint reduction. In different energy conservation types, heat transfer is a significant field that is directly connected to systems of economic efficiency [4]. With the district heating system (DHS) established with the waste heat of thermal power plants, fossil fuels used in residences and workplaces are not used, and the carbon footprint resulting from heating is significantly reduced. Incomplete combustion in heating systems, using coal, natural gas, and oil for home heating, and interacting with weather conditions all contribute to air pollution. In winter, domestic heating emissions constitute 80% of the total pollution. [5]. Many studies are in the literature on thermal power plant waste heat and emissions from heating. In the study titled "Energy Analysis of District Heating Capability with Çatalağzı Thermal Power Plant" by H.İ. Topal et al., an analysis was performed with different models [6]. In the study titled “Waste Heat Recovery Technologies and Applications” by H. Jouhara et al., waste heat recovery technologies were used for industrial processes are discussed [7]. C. Forman et al. studied “Estimation of Global Waste Heat Potential.” [8] In the study titled “Thermal Power Plants in Turkey and Their Environmental Impacts” by S. Avcı, suggestions are presented to reduce the negative environmental impacts of fossil fuel thermal power plants [9]. In the study titled "Determination of Urban Greenhouse Gas Emission: The Case of Kocaeli Province" by Ç. Atmaca and O. Sevimoğlu, it was stated that 50.8% of the greenhouse gas emissions in the region were caused by heating [10]. A study funded by the European Union Commission reported that due to the spread of district heating and cooling in thirty-two European countries, annual CO_2 emissions could be reduced by 400 million tons [11]

The present study assumes that the waste heat of the Natural Gas Power Plant in Sakarya province will be used for domestic heating with the district heating system. The consumption of natural gas or coal used for heating will disappear, and two different scenarios have been created. In the first possible scenario, emissions are first determined to have come from the use of natural gas in homes as a source of heating, and then emissions are determined to have come from the burning of natural gas in power plants. In the second scenario, it is assumed that the coal-fired power plant comparable to the natural gas power plant's existing output capacity is a natural gas power plant. Its emissions are determined to set an example for coal-fired power plants. It has been accepted that using this waste heat in houses will eliminate the use of coal for domestic heating, and this reduction in carbon emissions has been calculated. In addition, the process and installation costs of the waste heat system were determined. With the results obtained in this study, it is emphasized that the district heating systems be made utilizing the waste heat of thermal power plants to reduce the carbon footprint of heating. Therefore, the significance of using waste heat from thermal power plants and reducing carbon emissions from heating is offered to policymakers as a remedy in energy planning rather than developing additional energy sources to meet demand.

2. MATERIAL AND METHOD

Sakarya is located in the Marmara Region of Turkey and had a population of 1,075,463 in 2022 [2]. The Natural Gas Power Plant in Sakarya is the largest in Turkey and has an installed power of 2449 MWe. The power plant can meet all the electrical energy needs of 3,601,227 people with an average electricity production of 13,079,658,404 KW [12].

Natural gas consumption in Sakarya province is 437,711,687 m^3 in total. There are 256,725 active subscribers throughout the province, and the annual consumption of a subscriber is 950 m3 [13]. On the contrary, the average annual coal consumption per household is two tons, and considering that all-natural gas subscribers in the province use coal, it is accepted that the total consumption is 500,000 tons of coal [14].

In the first scenario created for carbon emission reduction, the carbon emission created by the natural gas power plant was determined. The province as a whole uses natural gas for home heating, and the accompanying carbon emissions are included in Table 1. When natural gas is not consumed in 256,725 residences with the district heating system, these emissions from domestic heating will be reduced. The Tier-1 Intergovernmental Panel on Climate Change (IPCC) method was used in the carbon emission calculation (Formula 1,2). The Global Warming Potential (GWP) for greenhouse gases used in the calculations are 1 for CO_2, 29.8 for Methane (CH_4), and 273 for Nitrous Oxide (N_2O) [15].

The Tier 1 method is fuel-based, since emission from all sources of combustion can be estimated on the basisi of the quantities of fuel combusted and average emission factors. Tier 1 emission factors are available for all relevant direct greenhouse gases. IPCC, 2006)

Tier 1 formula: (IPCC, 2006):

Emission= Fuel x Emission Factor (Formula 1) (IPCC)

Emission (tCO_2)=Fuel (TJ, t ya da Nm^3) x Emission Factor (tCO_2 /TJ,tCO_2 /t) x Conversion Factor(TJ/Gg)

(Formula 2) (IPCC)

The results of this formula are multiplied by the GWP value of each greenhouse gas separately to obtain the total amount of carbon emissions.

The data used in the first scenario for emission calculations in scenario 1 are shown in Table 1.

Table 1 Data of First Scenario

Resources	Data
Number of Residences	256,725
Average of a Residence Natural Gas Consumption	950 m^3/year
Emission Factor (Natural gas)	1.88496 Kg/m^3 CO_2
	0.,000168 Kg/m^3 CH_4
	0.00000336 Kg/m^3 N_2O

In the second scenario, firstly, carbon emission was calculated by accepting that the Natural Gas Power Plant is a coal-fired thermal power plant equivalent to its production potential. It has been accepted that coal is used in all residences in Sakarya, whereas natural gas is used for heating. Therefore, the coal used for heating these homes will not be consumed, and the decrease in carbon emissions has been computed when district heating is applied using the waste heat of the power plant. The data used for emission calculations in the second scenario are shown in Table 2.

Table 2 Data of Second Scenario

Resources	Data
Number of Residences	256,725
Average of a Residence Coal Consumption	2 tone/year
Fuel Amount of the Power Plant (Lignite)	8,000,000 Tone/year
Emission Factor (Coal)	101000 kg/ TJ (CO_2)
	10 kg / TJ (CH_4)
	1.5 kg/TJ (N_2O)

3. RESULTS and DISCUSSION

A feasibility study was conducted regarding the DHS application in different natural gas power plants with an installed power of 1350 MWe in Turkey. The findings showed that 200,000 houses could be heated with this waste heat. [16] When the values in this case study are compared with the thermal power plant in Sakarya with an installed power of 2449 MWe, it is seen that this power plant can provide heating for 256,725 houses. In addition, converting waste heat energy in thermal power plants into usable energy would boost the overall efficiency of the power plant, leading to more effective utilization of energy sources.

The average amount of natural gas used in electricity generation in the Sakarya natural gas power plant is 450,000,000 m^3. Accordingly, it has been calculated that 1,263,260.8 tons/year of CO_{2e} is emitted to the atmosphere due to electricity generation at the power plant.

The carbon emission to be released to the atmosphere, depending on the natural gas consumption used for domestic heating, is calculated as 461,161.2 tons/year CO_2e. The calculation takes the change factor for natural gas in the IPCC Tier 1 method as 1. When the district heating system is used, the carbon footprint caused by this heating will be reduced (Table 3).

Table 3 Emission for First Scenario

Emission Resources		Emission
Natural Gas	CO_2 Emission	459,720.5 ton/year CO_2e
	N_2O Emission Equivalent	223.7 ton/year CO_2e
	CH_4 Emission Equivalent	1221 ton/year CO_2e
Total		461,161.2 ton/year CO_2e

By the second scenario, when the natural gas cycle power plant is assumed to be a coal-fired power plant with installed power and electricity generation capacity, it is calculated that an average of 8,000,000 tons/year of coal will be burned. Coal-fired power stations often employ lignite, poor-quality coal with a low calorific value. Fuel consumption was estimated using IPCC net calorific values due to this coal's high carbon emission value. The fuel consumption value of 8,000,000 tons of coal, which is the fuel consumption of the power plant, is 95,200,000 TJ.

Regarding the emission factors for coal, it is 101,000 kg/TJ for CO_2, 10 kg/TJ for CH_4, and 1.5 kg/TJ for N_2O. In light of these data, 9,682,554 tons/year of eCO_2 will be released into the atmosphere because of burning coal in the power plant. With the calculations in line with these data, the carbon footprint that will emerge from burning coal in the power plant is shown in Table 4.

Table 4. Power Plant Emission for Second Scenario

Emission Resources		Emission
Lignite	CO_2 Emission	9,615,220 ton/yearCO_2e
	N_2O Emission Equivalent	28,369.6 ton/year CO_2e
	CH_4 Emission Equivalent	38,984.4 ton/yearCO_2e
Total		9,682,554 ton/year CO_2e

The fuel consumption value of 500,000 tons of coal, considered to be consumed in residential heating, was calculated as 5,950,000 TJ. According to the calculations based on burning coal for heating, 605,159.6 tons/year of CO_2e emissions will be generated from the residences. When waste heat is used, this emission will be prevented from being released into the atmosphere.

Carbon footprint values according to coal consumption are shown in Table 5.

Table 5 Residential Coal Use Emissions for the Second Scenario

Emission Resources		Emission
Coal	CO_2 Emission	600,950 ton/yearCO_2e
	N_2O Emission Equivalent	2436.5 ton/year CO_2e
	CH_4 Emission Equivalent	1773.1 ton/year CO_2e
Total		605,159.6 ton/year CO_2e

A closed circuit 500 MW coal-fired power plant uses 8.4 million m^3 of water annually [19]. Therefore, if a 2449 MW natural gas power plant is a coal-fired power plant, the annual amount of water to be used will be higher. If this proposal is approved, the DHS application will reduce the power plant's water usage, hence decreasing the amount of water vapor discharged into the atmosphere.

The calculations for the first and second scenarios were compared. According to these results shown in Table 6, when the emissions arising from the consumption of coal and natural gas used for heating in the residences in Sakarya are evaluated, the amount of carbon emissions due to the consumption of coal in the residences is higher than the amount resulting from the combustion of natural gas (Figure 1). Still, reducing carbon emissions from both fuel types is crucial to slowing the global climate crisis.

Table 6 Comparison of emission values for two scenarios

	Scenario1		Scenario 2	
Emisson Resources	DomesticHeating Natural Gas	Power Plant Natural Gas	Domestic Heating Coal	Power plant Lignite
Activation Data	243,888,750m^3/year	464,772,483.5m^3/year	500,000 ton /year (5,950,000 TJ)	8,000,000 ton/year (95,200,000 TJ)
Emission	461,161.2 ton/year CO_2e	1,263,260.8 ton/year CO_2e	605,159.6 ton/year CO_2e	9,682,554 ton/year CO_2e

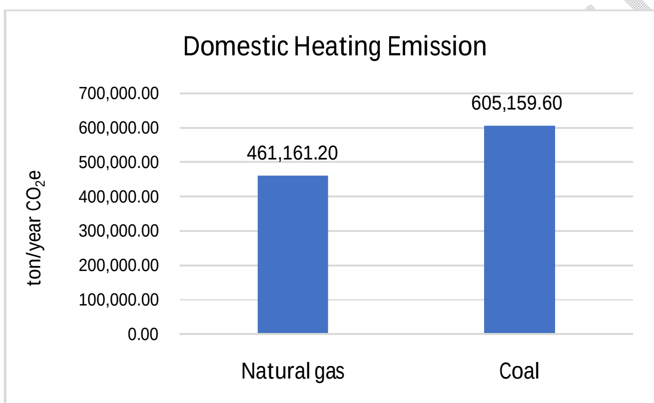

Figure 1. Annual Emission of Domestic Heating for First and Second Scenario

The difference between the emission that occurs when natural gas is used as fuel in the power plant and the carbon emission that occurs when coal is burned is also huge, illustrated in Figure 2. Moreover, this emission discrepancy is exacerbated by the fact that the power station burns low-caloric lignite as fuel.

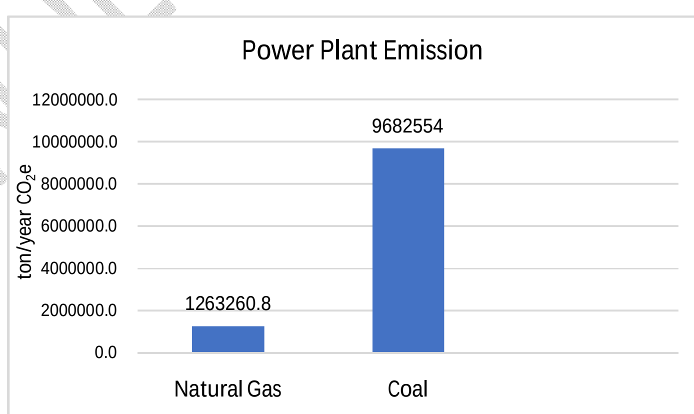

Figure 2. Annual Emission of Power Plant for First and Second Scenario

Calculating the emissions created by the power plant according to both fuel types is critical to see the difference. More importantly, these emissions will decrease when the waste heat of the power plant is transferred to the district heating system.

Several research projects have examined the feasibility of recycling industrial waste heat. The usable amount of waste heat in the existing thermal power plants in Türkiye is 9 million tons of oil equivalent on average, which is equal to 50% of the total annual natural gas consumption. Using this energy for home heating might cut Turkey emissions of greenhouse gases by as much as 22 percent [16]. It is reported that with the Soma Thermal Power Plant district heating project implemented as an exemplary project, a carbon emission reduction of 5.72 tons per residence will be achieved [17]. Therefore, evaluating the waste heat of existing thermal power plants with district heating systems will be essential for reducing carbon footprint. In addition, 7,872,230,000 m^3 of water is drawn from 55 thermal power plants. Approximately 93% of this water is used as cooling water [2]. Therefore, in addition to reducing emissions, DHS projects will save water lost from evaporation in waste cooling towers.

Türkiye is dependent on external sources for 73% of total energy. Besides, the total waste heat of thermal power plants in Turkey is 35 million MWht/year [18]. By putting this thermal power plant waste heat to good use, we can lessen our reliance on imported fuel and increase our energy independence. Especially in the province of Sakarya, where Turkey's largest natural gas thermal power plant is located, waste heat from this power plant will reduce the city's carbon footprint and air pollution caused by heating. Reducing the carbon footprint of cities will reduce national carbon emissions.

3.1 Cost

The infrastructure setup phase is the most expensive and difficult part of DHS applications. Our study assumes that the waste heat will be transmitted to the residences using the existing natural gas line. Thus, the infrastructure installation cost has been neglected in the calculations.

In DHS installation: the heat generation cost is 29,075,666 TL,

Maintenance and personnel cost 986,000 TL,

The total operating cost was calculated as 30,129,666 TL.

Calculations are based on the July 2022 exchange rate. 1 Dollar = 17 TL, 1 Euro = 18 TL.

Against this cost, in the scenarios created, it will be possible to make a profit by evaluating the carbon emissions to be reduced by the DHS application in the voluntary carbon market. It has been agreed that DHS will be considered voluntarily on the Chicago climate exchange with certified emission reduction. In this exchange, the price of CO_2 is $15 per ton [20]. Accordingly, 6,917,418 $ gains will be achieved with the emission reduction to be created when natural gas is not consumed, and 9,075,000 $ profit will be obtained with the emission reduction created when coal is not consumed.

Furthermore, when homes no longer need coal or natural gas to keep warm, the associated per-home coal or gas cost will go away. The average price of 1 ton of coal in 2022 was determined as 3024 TL [2]. When two tons/year of coal is consumed for a house, the annual expenditure will be 6048 TL. The average natural gas consumption fee per house is 1990 TL [21]. As a result of the DHS application, these payments will be eliminated, and only the waste heat cost transmitted by DHS will be reflected to the consumer. The consumption charge will be determined by the amount shown on the heat metre in the building's lobby. This will provide an average of 25-50% reduction in heating-related expenditures. The decrease in heating costs will allow the savings to be shifted to other areas, the economy to grow, and the quality of life of people to increase.

The high initial setup cost can be considered an obstacle to disseminating DHS systems. However, installing DHS systems in existing thermal power plants with minimal conversions will be possible. It is possible to reduce these costs with new technologies to be developed for new power plants. In addition, it will be possible for these costs to be amortized in a short time with the carbon trade that will be provided by carbon reduction.

4. CONCLUSION

Due to energy policies in Turkey, thermal power plants will not be abandoned in the short term. Therefore, it becomes essential and necessary to reduce carbon emissions from domestic heating due to waste heat from existing and newly established thermal power plants and DHS applications. Using DHS in domestic heating provides cheap heating, increases energy efficiency, and decreases foreign dependency on energy. The district heating system prevents the water vapor that will be formed in the power plants from being released into the atmosphere. Thus, reducing the urban heat island and global warming contribution. With district heating, air pollution, which increases in the winter months, is also significantly reduced

With the dissemination of the regional heating system, reducing carbon emissions from heating will be a severe step in preventing the climate crisis. As a result, it will be easier to reach the targets stated in the "National Climate Change Strategy Document." Turkey has indicated that it can make a 21% reduction from the increase in the greenhouse gas reduction intent statement, depending on the Paris Agreement. The use of waste heat is an important alternative to achieve this and further reduce the reduction. In addition to reducing the emissions of thermal power plants using regional waste heat, the importance of reducing emissions from heating has emerged.

Additionally, it will be an important alternative source for giving up coal as it will reduce the use of coal due to heating. Our study, conducted within the framework of the importance of local studies, will pave the way for reducing the carbon footprint in cities by applying the district heating application in other thermal power plants and will serve as a planning resource for local administrators and decision-makers. Particularly, the widespread use of DHSs, which have many examples in the world and underdeveloped countries, will set a benchmark in terms of reducing emissions caused by heating.

REFERENCES

[1] Kaçmaz, Ş. & Demirpolat, H., Flue Gas Treatment Technology to Prevent Environmental Pollution From Thermal Power Plant: A Case Study Seyitömer Thermal Power Plant Application. European Journal of Science and Technology Special Issue 2022; 34, pp. 645-651, 2022

[2] Turkish Statistical Institute TUİK. (2022). No Title. Available: https://www.tuik.gov.tr/

[3] Carbon Brief. (2022). Carbon Brief, Power Plants. Available: https://www.carbonbrief.org/mapped-worlds-coal-power-plants.

[4] Al-Obaidi, A.R., Thermal flow and heat performance analyses in circular pipe using different twisted tape parameters based on design of experiments, Wiley Online Library, 2022; https://doi.org/10.1002/htj.22641

[5] Gümrükçüoğlu Yiğit, M., Urban Air Pollution Monitoring By Using Geographic Information Systems: A Case Study From Sakarya, Turkey, Carpathian Journal of Earth and Environmental Sciences, 2011; Vol.6, No.2, p.73-84.

[6] Topal, H. İ., Eyriboyun, M. K. V. M. The Feasibility Energy Analysis of Çatalagzı Thermal Electricity Power Plant For District Heating Application. J. of Thermal Science and Technology, 2017; 37 (1) , 139-146 .

[7] Jouhara,H., Khordehgah,N., Almahmoud, S., Delpech, B., Chauhan, A., Tassou,S. A., Waste heat recovery technologies and applications, Thermal Science and Engineering Progress, 2018; 6, pp. 268-289

[8] Forman, C., Muritala, I.K., Pardemann, R., Meyer, B., Estimating the global waste heat potential, Renewable and Sustainable Energy Reviews, 2016; 57, 1568-1579.

[9] Avcı, S., Termal Power Plants in Turkey and Their Environmental Effects. Istanbul University Journal of Geography , 2012; 0, (13), 1-26

[10] Atmaca, Ç., Sevimoğlu, O., Determination of City-Based Greenhouse Gas Emissions: The Case Study of Kocaeli Province. Journal of the Institute of Science and Technology , 2020; 10 (3), 1616-1627.

[11] Atik. H., The Transition Towards A Low Carbon and Climate Resilient Society within the EurepeanUnion Countires and Turkey: An Empirical Analysis, International Relationship, 2017; 14, (54), 127-147.

[12] ENKA Energy, (2021) Gebze&Adapazarı Natural gas Power Plant. Available: www.enka.com/tr

[13] Adapazarı Gas Distribution Company, 2021, Sakarya, Turkey

[14] Sakarya Governorship Provincial Directorate of Environment, Urbanization and Climate Change, 2019, Sakarya Turkey

[15] IPCC. (2006). IPCC Guidelines for National Greenhouse Gas Inventories 2006. Available: https://www.ipcc-nggip.iges.or.jp/public/2006gl/

[16] Türkiye Waste Heat and Regional Heating Potential Report R 2-1, The Scientific and Technological Research Council of Turkey, Marmara Research Center, Institute of Material, Researching and Developing Methods for Converting Thermal Power Plant Waste Heat to Benefit to Increase Energy Efficiency and Heating Application in Buildings (TSAD) (2007).

[17] Sav, M., Çiçek, Z., Kaya, G., (2014), Certification of the reduction provided by the thermal power plant waste heat evaluation Project, Urban Heating/ Soma Projec. Available:, http://www.yenienerji.com/makale

[18] TUBITAK Report, R2-2, (2008), Researching and Developing Methods for Converting Thermal Power Plant Waste Heat to Benefit to Increase Energy Efficiency. Available: http://www.tsad.org.tr

[19] Yıldız, D., Water Use in Power Plant. 2012; Available: https://supolitikalaridernegi.org/2021/12/27/termik

[20] Walsh, M.J., (2011). Chicago Climate Exchange CCX. Available: http://www.chicagoclimatex.com/

[21] GAZBIR. (2022). Natural gas distribution sector report. Available: https://www.gazbir.org.tr/