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KAHRAMANMARAŞ GREENHOUSE GASES EMISSION INVENTORY AND CLIMATE CHANGE ACTION PLANS

KAHRAMANMARAŞ SERA GAZI EMİSYON ENVANTERİ VE İKLİM DEĞİŞİKLİĞİ EYLEM PLANLARI

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ABSTRACT

To combat the effects of climate change, especially the urban heat island effect, and provide a healthier, more sustainable environment, local governments play a crucial role in implementing national policies at the local level. Local governments must develop action plans tailored to their specific conditions, aligned with national strategies. In this context, a greenhouse gas inventory was prepared for Kahramanmaraş, and climate change action plans were identified to reduce emissions and mitigate the impacts of climate change. The proposed actions focus on energy efficiency, renewable energy, waste management, and afforestation. Key measures include improving energy efficiency in buildings (insulation, energy-efficient lighting) and reducing coal consumption, resulting in a total reduction of 152,550 tons of CO_2 emissions. Energy-efficient urban planning in new developments is projected to reduce emissions by 5,462 tons, while energy efficiency measures in the commercial sector could lead to a reduction of 40,048 tons. Expanding public transportation and promoting alternative fuels are expected to save 41,377 tons of emissions. Renewable energy adoption, particularly through rooftop photovoltaic systems, could reduce emissions by 69,045 tons. Improvements in waste management, particularly recycling, would lower emissions by 4,113 tons, and afforestation efforts are estimated to reduce emissions by 2,891 tons. In total, these measures are projected to achieve a reduction of 315,486 tons of CO_2 emissions, significantly contributing to Kahramanmaraş's efforts to combat climate change and promote sustainability.

Keywords: Climate change, emission reduction, local governments, energy efficiency, renewable energy

ÖZET

İklim değişikliğinin etkilerine karşı mücadele etmek, özellikle kentsel ısı adası etkisini azaltmak ve daha sağlıklı, sürdürülebilir bir çevre sağlamak için yerel yönetimlerin, ulusal ölçekte belirlenen politikaları yerel düzeyde uygulama ve yayma konusunda çok önemli görevleri vardır. Yerel yönetimler, kendi özel koşullarını göz önünde bulundurarak ulusal politikalarla uyumlu stratejiler geliştirip, bu sorunu çözmek için yerel ölçekte eylem planları hazırlamalıdır. Bu bağlamda bu çalışmada, Kahramanmaraş ilinin sera gazı envanteri hazırlanmış ve şehre özel olarak uygulanabilecek iklim değişikliği eylem planları ile bu planların emisyon azaltımına katkıları belirlenmiştir. Belirtilen eylemlerde, enerji verimliliği, yenilenebilir enerji, atık yönetimi ve ağaçlandırma alanlarına odaklanmaktadır. Öne çıkan önlemler arasında binalarda enerji verimliliğini artırma (yalıtım, enerji verimli aydınlatma) ve kömür tüketiminin azaltılması yer almakta ve bu önlemler ile toplamda 152.550 ton, yeni kentsel gelişimlerde enerji verimli planlama ile 5.462 ton, ticaret sektöründe enerji verimliliği önlemleriyle 40.048 ton, toplu taşımanın genişletilmesi ve alternatif yakıtların teşvik edilmesi ile 41.377 ton, çatı üstü fotovoltaik sistemler aracılığıyla yenilenebilir enerji kullanımı ile 69.045 ton, atık yönetiminde iyileştirmeler yani özellikle geri dönüşüm ile, 4.113 ton ve ağaçlandırma çalışmaları 2.891 ton CO_2 emisyon azaltımı sağlanabileceği belirlenmiştir. Bu eylemler ile toplamda 315.486 ton CO_2 emisyonu azaltımı gerçekleştirilerek, Kahramanmaraş'ın iklim değişikliğiyle mücadele ve sürdürülebilirlik çabalarına önemli katkılar sağlanabileceği düşünülmektedir.

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Anahtar Kelimeler: İklim değişikliği, emisyon azaltımı, yerel yönetimler, enerji verimliliği, yenilenebilir enerji

INTRODUCTION

Cities with dense populations, production, and consumption tend to have higher pollutant levels, which not only amplify their contributions to climate change but also make them more vulnerable to its impacts. Moreover, cities influence a vast area beyond their boundaries through activities such as trade and transportation. In recent years, extreme weather events such as floods, erosion, heat waves, and droughts have affected many regions of the world, including our country, bringing the issue of climate change to the forefront of global concerns (Bolan et al., 2024). Climate change is one of the most critical problems of the world, negatively affecting all aspects of life, including the natural environment, urban living, development and economy, technology, human rights, agriculture and food, clean water, and health. The Industrial Revolution, marked by increased fossil fuel use, deforestation, land-use changes, industrial processes, rapid population growth, and human activities, has accelerated the accumulation of greenhouse gases in the atmosphere, exacerbating global warming and turning climate change into one of humanity's most significant threats (Venegas et al., 2023).

Scientific studies have proven that climate change is more than an environmental issue; it is a global crisis that will continue to affect the planet in the long term. In the coming decades, Earth will face rising temperatures and changes in precipitation patterns. As part of the preparation for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), which involved thousands of scientists worldwide, it was emphasized that the warming of the climate system is unequivocal, with many changes observed since 1950 being unprecedented (IPCC, 2014). It was further highlighted that human activity is the primary cause of global warming, with the northern hemisphere experiencing the warmest 30-year period in history and surface temperatures continuing to rise since 1850 (Jones et al., 2010). Studies also reveal that recent climate changes have impacted people and natural systems across all continents and oceans, altering precipitation patterns and melting snow and ice masses, thereby disrupting the hydrological cycle and affecting the quality and quantity of water resources.

The impacts of climate change, including increased land and sea temperatures and changes in precipitation patterns, are causing global sea levels to rise, increasing coastal erosion risks, and intensifying natural disasters linked to weather conditions (Dong et al., 2024). Changes in water levels, temperatures, and flows affect sectors such as food supply, agriculture, health, industry, tourism, and transportation, as well as ecosystem integrity. In some regions, including those where our country is located, societies are encountering the adverse effects of climate change more frequently and severely.

Rural-to-urban migration triggers unplanned urbanization, exacerbating the urban heat island effect and intensifying warming in cities (Das et al., 2024). Rapid population growth in urban areas causes significant changes in land cover, necessitating more industrial, commercial, and transportation services to accommodate expanding cities. Unplanned urbanization and industrialization alter the heat and water cycles in the atmospheric boundary layer, distinguishing urban climates from rural ones (Tzavali et al., 2015). The urban heat island effect exacerbates global climate change on a local scale, adversely impacting the health of humans and other living beings, quality of life, and energy consumption.

To combat the heightened impacts of climate change, such as the urban heat island effect, and to provide citizens with a livable, healthy, and sustainable environment while reducing climate change-related risks, local governments play a vital role in implementing and expanding nationally determined policies at the local level (Hoppe et al., 2014). In this context, local governments must develop localized strategies and action plans tailored to their unique circumstances, aligning with national policies to address this global issue effectively. In this context, this study investigated the greenhouse gas inventory of Kahramanmaraş city and identified climate change action plans that can be implemented specifically for the city, as well as their contribution to emission reduction.

MATERIAL AND METHODS

The boundaries of the inventory encompass all emission sources within the administrative borders of Kahramanmaraş Province. Within the scope of this reporting, emissions from stationary units, mobile units, and waste have been identified. Based on the available data and emission factors, the inventory includes three greenhouse gases: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The calculated CH_4 and N_2O emissions were converted into carbon dioxide equivalents (CO_2e) and included in the total emissions. The CO_2e conversions were obtained by multiplying the mass of the respective greenhouse gas by the global warming potentials provided in the IPCC Fifth Assessment Report (AR5). Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6), and similar greenhouse gases were excluded from the inventory due to the lack of information regarding the activities causing these emissions (IPCC, 2014).

Direct and indirect emissions from stationary sources, such as residences, commercial/institutional facilities, energy production, and industrial energy use, were considered in the inventory report. Apart from leaks in the natural gas distribution system, no other fugitive emissions within the boundaries were identified and thus not included in the inventory. Although the possibility of leakage from the natural gas distribution system is not ignored, this leakage is not currently included in the inventory due to insufficient data. To determine the emissions from stationary sources, the method outlined in Chapter 2: Stationary Combustion of the IPCC Guidelines for National Greenhouse Gas Inventories was used (IPCC, 2006). Emission quantities were calculated by multiplying activity data by the emission factor associated with the fuel type. The Tier 1 approach is used to calculate CO_2 emissions by multiplying the estimated fuel sold with a default CO_2 emission factor. The approach is represented in Equation 1 (IPCC, 2006).

$$\text{Emission} = \sum_a [\text{Fuel}_a \times \text{EF}_a] \quad (1)$$

Where emission is the total emissions of CO_2 (kg), fuel_a is the fuel sold (TJ), EF_a is the emission factor (kg/TJ) and a is the type of fuel (e.g. petrol, diesel, natural gas, LPG, etc.)

Road transport, rail transport, and aviation were considered as mobile sources, and their direct and indirect emissions were included in the inventory report. For quantifying direct emissions from road vehicles, the methodology outlined in Chapter 3: Mobile Combustion of the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) was used. For calculating emissions from aviation sources, the methodology in Chapter 3, of the same guidance was applied. Emissions from the total municipal solid waste (MSW), biological waste, and wastewater generated and treated within the defined boundaries were included in the inventory. These emissions were calculated in accordance with the IPCC Guidelines for National Greenhouse Gas Inventories-Volume 5 (IPCC, 2006). Both CH_4 and N_2O emissions were calculated as carbon dioxide equivalents (CO_2e).

RESULTS AND DISCUSSION

Data Inventory for Stationary Sources

Sources such as residential buildings, commercial/institutional facilities, energy production, and industrial energy use are considered stationary sources, and the direct and indirect emissions from these sources are included in the inventory report. Fossil fuel consumption for heating and cooking in residential buildings, fossil fuel consumption in commercial/institutional buildings, fossil fuel consumption in manufacturing industries and construction, and the amounts of fuel consumed in energy production facilities within the boundaries that supply the national electricity grid and auto generators producing their energy within the boundaries are provided in Table 1.

Due to the lack of complete and accurate data regarding leakage from the natural gas distribution network, it has been assumed that 100% of the supplied natural gas is consumed. For the calculation of emissions from coal use in residential buildings, the number of independent housing units in the city and the number of natural gas subscribers provided by the Energy Market Regulatory Authority (EMRA) were utilized. Based on a simple assumption, the difference between these two figures was considered to represent the approximate number of coal users in the city. The calculated difference was multiplied by the average coal consumption per household, assumed to be 1.5 tons, to estimate the amount of coal used for heating purposes in Kahramanmaraş.

For fuel types, emission factors and net calorific values were taken from the IPCC guidelines (IPCC, 2006). Fuels used in industrial facilities were classified under "Scope 1 – direct emissions," while emissions from grid electricity consumption were classified under "Scope 2 – indirect emissions" and calculated using the Tier 2 approach. The total amount of electric transmission and distribution losses in Kahramanmaraş was determined to be 159,279.595 MWh through the Turkish Electricity Transmission Company (TEİAŞ). Since the sectoral distribution of the transmission and distribution losses could not be determined, it was not evaluated on a sectoral basis but included in the Scope 2 total. The fuel types and annual consumption amounts of energy production facilities within the boundaries connected to the grid were obtained from EMRA's 2020 Natural Gas Market Sector Report and the 2020 Environmental Status Report (ESR) of the Kahramanmaraş Provincial Directorate of Environment, Urbanization, and Climate Change.

Table 1. Energy Consumption in Residential, Commercial/Institutional, Industrial, and Energy Production Facilities

Category	**Consumption Item**	**Unit**	**Amount**	**Reference**
Residential Buildings	Natural Gas Consumption	Sm³	156,707,410.9	EMRA, 2020b
	Coal Consumption	Ton	204,192	-
	Fuel Oil Consumption	Ton	208.64	EMRA, 2020c
	Total Electricity Consumption	MWh	569,611	EMRA, 2020a
	LPG Consumption	Ton	11,154	EMRA, 2020d
Commercial/Institutional Buildings	Natural Gas Consumption	Sm³	32,582,571.99	EMRA, 2020b
	Total Electricity Consumption	MWh	666,779	EMRA, 2020a
Industrial Facilities	Natural Gas Consumption	Sm³	86,345,922.41	EMRA, 2020b
	Fuel Oil Consumption	Ton	14,354.06	EMRA, 2020c
	Total Electricity Consumption	MWh	2,546,242	EMRA, 2020a
	LPG Consumption	Ton	633	EMRA, 2020d
Energy Production Facilities	Natural Gas Consumption	Sm³	106,570,952.2	EMRA, 2020b
	Coal Consumption	Ton	5,281,034	SER, 2020

Data Inventory for Mobile Sources

Road transportation, railway transportation, and aviation are considered mobile sources, and the direct and indirect emissions from these sources are included in the inventory report. Within this scope, Table 2 presents the amounts of fuel sold for road and railway transportation in Kahramanmaraş, categorized by type.

Table 2. Fuel and Electricity Consumption in Road and Railway Transportation in Kahramanmaraş

Category	**Consumption Item**	**Unit**	**Amount**	**Reference**
Road Transportation	Gasoline	Ton	20,595.238	EMRA, 2020c
	Diesel	Ton	197,061.359	EMRA, 2020c
	LPG	Ton	67,452	EMRA, 2020d
Railway Transportation	Total Electricity Consumption	MWh	3,183.84	TCDD, 2020

Diesel	Ton	404	TCDD, 2020

In railway transportation, if rail systems operate solely on grid electricity, their electricity consumption is identified; if they operate using other fuel sources, the fuel types and their consumption are determined. Data on fuel and electricity consumption for calculating emissions from railway transportation were obtained from the statistical yearbook published by the Turkish State Railways (TCDD) for 2019-2020. The amounts of diesel and electricity consumed in railway transportation were approximately calculated based on the passenger and freight transport data provided for Turkey and specifically for Kahramanmaraş.

For emissions from aviation, emissions caused during landing and takeoff (LTO) cycles were included in the inventory. Greenhouse gas emissions were calculated separately for each LTO cycle using the Tier 2 approach. In line with this approach, LTO data for each domestic and international aircraft type were obtained from both the General Directorate of State Airports Authority (DHMİ) and Kahramanmaraş Airport (Table 3). The emissions calculated according to the LTO approach only include the emissions caused during takeoff, which have been included in the Kahramanmaraş inventory (Fong et al., 2015).

Table 3. The LTO Data for Kahramanmaraş Airport

Landing	Take-off	Domestic Flights	International Flights	Reference
939	939	1870	8	DHMI, 2020

In the calculation of aviation-related emissions, the B738 aircraft type was selected as the aircraft that landed and took off the most in Kahramanmaraş, in line with the Kahramanmaraş province data of the State Airports Authority (DHMİ). The 2780 kgCO_2/LTO value belonging to this aircraft type was used.

Data Inventory for Wastes

The emissions caused by the total municipal solid waste (MSW), biological waste, and wastewater generated and treated within the defined boundaries have been included in the inventory. In this context, the annual amount of waste sent to landfill sites and the annual volume of treated wastewater are provided in Table 4.

Table 4. The Annual Amount of Waste Sent To Landfill Sites and the Annual Volume of Treated Wastewater

	Unit	Amount	Reference
Waste disposal	Ton/year	237,476.7	SER, 2020
Wastewater Treatment (Advanced treatment)	m^3/day	110,000	SER, 2020
Wastewater Treatment (Biological treatment)	m^3/day	27,162	SER, 2020

Data Inventory for Other Sources: Industrial Processes and Product Use (IPPU)

Direct emissions from non-energy industrial processes have been included in the inventory and incorporated into the Scope-1 total. In this context, the Industrial Processes and Product Use (IPPU) fata for Kahramanmaraş Province are provided in Table 5.

Table 5. Industrial Processes and Product Use Data for Kahramanmaraş Province

	Unit	Amount	Reference
Clinker production	ton	3,036,000	Koleli et al., 2015; SER, 2020
Cement production	ton	5,179,680	Koleli et al., 2015; SER, 2020

Greenhouse Gases Emission Inventory

The total carbon footprint of Kahramanmaraş was calculated as ***15,007,740 t*** $\boldsymbol{CO_2e}$ (Table 6). This value reflects the cumulative greenhouse gas emissions associated with various economic activities and energy consumption patterns in the city. As depicted in Figure 1, a significant majority of these emissions, 87.89%, originated from "Scope 1—Direct Emissions." These include emissions released directly from sources owned or controlled by entities within the city, such as fuel combustion in residential, industrial, and transportation sectors. Meanwhile, the remaining 12.11% of emissions fall under "Scope 2—Indirect Emissions," which are associated with the generation of electricity, heat, or steam consumed by the city. These two categories highlight distinct yet interconnected sources of greenhouse gas emissions that require targeted mitigation strategies.

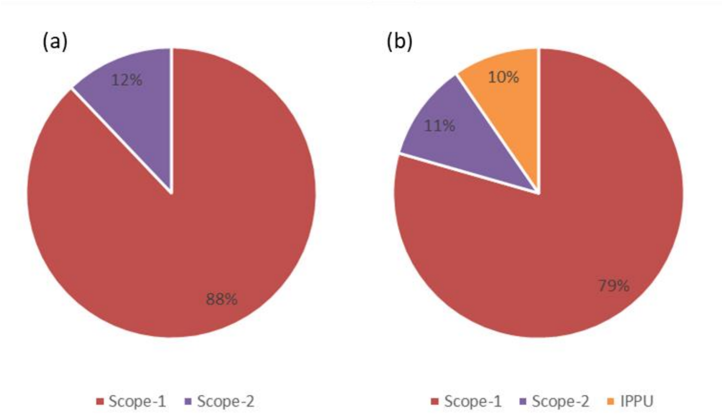

Figure 1. (a) Distribution of Emissions Based on Scope-1 and Scope-2 Emissions **(b)** Distribution of Emissions Including Industrial Production and Processes (IPPU)

Direct emissions account for the largest share of Kahramanmaraş's carbon footprint. The dominance of Scope 1 emissions reflects the heavy reliance on fossil fuels for heating, industrial processes, and transportation (Emborg et al., 2024). The residential sector, for instance, predominantly uses natural gas and coal for heating, contributing significantly to direct emissions. Similarly, the industrial sector characterized by energy-intensive activities such as cement production, textile manufacturing, and metal processing—generates substantial greenhouse gases. Transportation is another major contributor, with emissions resulting from the combustion of gasoline and diesel in private and commercial vehicles.

Addressing Scope 1 emissions requires sector-specific action plans. In the residential sector, initiatives to promote energy-efficient buildings and the use of renewable energy sources, such as solar panels, can significantly reduce fossil fuel dependence (Garg et al., 2019). For the industrial sector, technological upgrades to improve energy efficiency, coupled with the adoption of low-carbon production methods, are critical (Wang et al., 2018). In transportation, transitioning to electric or hybrid vehicles and enhancing public transportation infrastructure can help minimize direct emissions (Gordon, 2013).

Although Scope 2 emissions constitute a smaller portion of the total carbon footprint, they represent an area with substantial mitigation potential. These emissions are primarily linked to electricity consumption in residential, commercial, and industrial sectors. The dependency on electricity generated from fossil fuels exacerbates the carbon footprint, underscoring the need for a transition to renewable energy sources.

Increasing the share of renewable energy in the electricity mix is a key strategy to reduce Scope 2 emissions (Robinson et al., 2022). Investments in solar and wind energy projects can harness Kahramanmaraş's natural potential for renewable energy production. Additionally, energy efficiency measures—such as the use of LED lighting, energy-efficient appliances, and smart grids—can lower electricity consumption and, consequently, reduce indirect emissions. Policymakers should also consider incentivizing energy audits and retrofitting programs for industrial and commercial facilities to enhance energy efficiency (Tanaka, 2011).

To address both Scope 1 and Scope 2 emissions effectively, a comprehensive and integrated climate action plan is essential. For example, expanding the use of renewable energy sources across all sectors is critical. Initiatives could include subsidizing solar panel installations, incentivizing wind energy projects, and facilitating grid integration for renewable energy producers (Qadir et al., 2021). Energy efficiency programs should target residential, industrial, and transportation sectors. Building codes must be updated to mandate energy-efficient designs, while financial incentives can encourage businesses to adopt energy-efficient technologies. Developing a robust public transportation network can reduce reliance on private vehicles. Investments in electric buses, metro systems, and bike-sharing programs can also contribute to emission reductions (Bullock et al., 2017). Introducing carbon pricing mechanisms, such as carbon taxes or cap-and-trade systems, can provide economic incentives for reducing emissions. Revenues generated from these mechanisms can be reinvested in green infrastructure and renewable energy projects. Public education campaigns are vital to foster behavioral changes. Raising awareness about energy conservation, waste reduction, and sustainable consumption can empower individuals to contribute to emission reduction efforts. Robust monitoring and evaluation frameworks are necessary to track progress in emission reduction efforts. Developing a city-wide greenhouse gas inventory can help identify emission hotspots and prioritize intervention areas.

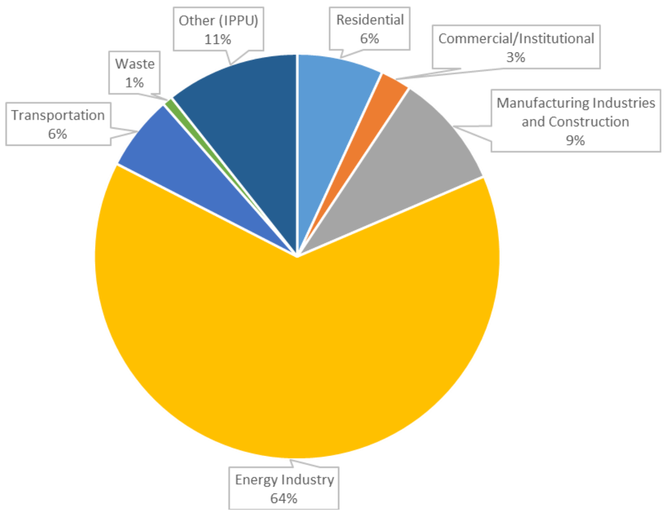

Figure 2. Distribution of Emissions by Source Category within Total Emissions

In this section, an in-depth analysis is conducted based on source categories to elaborate on the broader picture summarized in the previous section. By examining Figure 2, it becomes evident that the energy industry, which includes natural gas cycle power plants and thermal power plants, ranks first, contributing 64% to the total carbon footprint. Following the energy industry, direct emissions originating from non-energy industrial processes and product use (IPPU), such as clinker and cement production, are the next largest contributors.

Table 6. Greenhouse Gas Inventory of Kahramanmaraş (Distributions at Scope-1, 2, and 3)

Sources	Scope-1	Scope-2	Scope-3
Stationary Sources	10,576,837.44	1,814,462	-
Transportation	892,443.0456	2,753	2,610.42
Waste	121,698.01	-	-
Industrial Processes	1,596,936	-	-
Total	13,187,914.5	1,817,215	2,610.42

Within the scope of stationary sources, emissions were primarily calculated for residential areas, commercial/institutional buildings, the manufacturing industry, construction activities, and the energy industry.

Stationary source-based emissions constitute 82.5% of the total emissions, with 64.3% of these stemming from the energy industry. This significant contribution is attributed to the fact that Kahramanmaraş is one of the major energy production hubs in Turkey, hosting several thermal power plants. Furthermore, 86% of emissions from stationary sources fall under Scope 1 (Direct Emissions), while the remaining 14% are categorized under Scope 2 (Indirect Emissions). One striking finding from the analysis is the per capita greenhouse gas (GHG) emissions, which amount to 12.84 tCO_2e. This value highlights the substantial environmental burden per individual and underscores the need for effective mitigation strategies tailored to the region's specific emission profile.

Expanding on the contributions of the energy industry, it is important to note that natural gas cycle power plants and thermal power plants are central to the energy production landscape in Kahramanmaraş. These facilities primarily utilize fossil fuels, which are significant sources of CO_2 emissions due to the combustion of coal, natural gas, or oil. The reliance on such energy sources not only contributes to high carbon emissions but also exacerbates air quality issues, potentially impacting public health (Finkelman et al., 2021). According to the International Energy Agency (IEA), thermal power plants account for nearly 40% of global CO_2 emissions, making regions heavily reliant on such facilities particularly critical in achieving climate targets (IEA, 2020). The non-energy industrial processes and product use (IPPU) sector also plays a pivotal role in Kahramanmaraş's carbon footprint. The production of clinker and cement is especially emission-intensive due to the calcination process, where limestone ($CaCO_3$) is heated to produce lime (CaO), releasing substantial amounts of CO_2 (Teran et al., 2024). Studies indicate that cement production alone contributes approximately 8% of global CO_2 emissions (Andrew, 2019). This aligns with the findings in Kahramanmaraş, where the IPPU sector is the second-largest contributor to the region's emissions profile.

Residential and commercial buildings also contribute significantly to stationary emissions, primarily through heating, cooling, and electricity consumption. The energy demand in these sectors is typically met by fossil fuels or grid electricity, which, in the context of Kahramanmaraş, is largely sourced from carbon-intensive thermal power plants. Improving energy efficiency in buildings and transitioning to renewable energy sources could substantially reduce emissions in these categories. According to the Intergovernmental Panel on Climate Change (IPCC), implementing energy-efficient technologies in buildings can reduce emissions by 50-90% compared to traditional practices (IPCC, 2014).

Manufacturing and construction activities further add to the stationary emissions profile. These sectors consume significant amounts of energy and materials, such as steel and cement, which are inherently carbon-intensive. The transition to low-carbon technologies, including the use of alternative fuels, waste heat recovery, and renewable energy integration, is essential for mitigating emissions from these sectors. Research shows that adopting best practices in energy-intensive industries can lead to a 20-30% reduction in emissions (Worrell et al., 2018). The breakdown of stationary emissions into Scope 1 and Scope 2 provides valuable insights into the nature of emission sources. Scope 1 emissions, which constitute 86% of stationary emissions, are direct emissions from fuel combustion in facilities or equipment owned or controlled by the entity. These include emissions from boilers, furnaces, and vehicles. On the other hand, Scope 2 emissions, which account for 14% of stationary emissions, are indirect emissions resulting from the generation of purchased electricity, heat, or steam. The high proportion of Scope 1 emissions in Kahramanmaraş underscores the dominance of direct combustion processes in the region's emission profile. Strategies targeting fuel switching, efficiency improvements, and carbon capture and storage (CCS) could be particularly effective in addressing these emissions.

The per capita GHG emissions of 12.84 tCO_2e in Kahramanmaraş are notably higher than the global average, which stood at approximately ~4.79 tCO_2e in 2021 (Global Carbon Atlas, 2021). This disparity highlights the need for region-specific interventions that address the unique characteristics of Kahramanmaraş's emission sources. Public awareness campaigns, policy incentives for renewable energy adoption, and investments in low-carbon infrastructure are critical for reducing per capita emissions while fostering sustainable development. In conclusion, the carbon footprint analysis of Kahramanmaraş reveals a predominantly stationary source-driven emissions profile, with the energy industry and IPPU sectors being the primary contributors. The findings underscore the importance of targeted mitigation strategies, including transitioning to renewable energy sources, enhancing energy efficiency, and adopting low-carbon technologies. Addressing these challenges requires a collaborative effort involving policymakers, industry stakeholders, and the public to achieve a sustainable and low-carbon future for the region.

Climate Action Plans for Kahramanmaraş

Although the results of mitigation actions are not immediately apparent, they are practices that provide global benefits (IPCC, 2014). On the other hand, the results of adaptation activities can be observed in both the short and long term and can directly benefit the local level. This situation presents itself as a local policy choice that should be considered in the integration of climate action strategies. Indeed, today's local climate change strategies include not only action plans for emission reduction in specific sectors such as energy, transportation, and waste but also adaptation action plans with equal importance (Musco, 2010). In the framework of mitigation policies, energy, transportation, buildings (construction), and waste sectors are prominent (Seto et al., 2014). Many local climate action plans focus on actions to reduce greenhouse gas emissions from these sectors, proposing technical, administrative, and financial solutions for these actions. One of the key solutions to reduce emissions in the energy sector in cities is to ensure energy efficiency in almost all urban services. Energy efficiency is essential for combating climate change, as well as for reducing energy costs in cities. In urban transportation, promoting notable practices such as improving public transportation systems, renewing public transport vehicles based on energy efficiency, using bicycles as a means of urban transportation, and encouraging urban mobility plans for pedestrian-friendly living is important for the climate fight (Banister, 2008). Efficiency measures to be taken within the framework of urban waste management also contribute to combating climate change (Yang et al., 2023). Likewise, in the housing sector, new neighborhoods and buildings should be constructed using energy-efficient standards to reduce greenhouse gas emissions. The tables below provide examples of activities that local governments can undertake to reduce greenhouse gas emissions in cities and the co-benefits of these activities.

Due to the geographical and climatic conditions of Kahramanmaraş, heating loads do not dominate building energy consumption. Although natural gas is widely distributed, heating is mostly achieved using air conditioners, which often fail to meet the desired comfort levels in winter. On the other hand, cooling loads are significantly high during the summer, making insulation crucial for comfort in both seasons. Residential energy consumption accounts for 6.7% of Kahramanmaraş's greenhouse gas emissions. If thermal insulation is applied to 30% of existing buildings, including facades, roofs, and windows, it is estimated that electricity consumption could decrease by 5%, and heating energy demand could be reduced by 30%. This would result in savings of 10,933 MWh of electricity, 14,103,666 m^3 of natural gas, and a reduction of 31,846.61 tCO_2e in greenhouse gas emissions. Lighting systems also play a significant role in residential energy use, with studies in Turkey indicating that lighting accounts for 10-20% of total electricity consumption in homes. If 75% of households in Kahramanmaraş adopt energy-efficient LED lighting systems, lighting-related electricity consumption could be reduced by 50-80%, leading to a 10% overall reduction in electricity consumption. This transition could save 65,600 MWh of electricity and prevent 30,195.68 tCO_2e emissions. Behavioral changes in households are another critical factor in reducing energy consumption. Simple adjustments in lighting and device usage habits could lower total residential energy use by approximately 5%. To encourage such changes, local authorities plan to establish advisory centers in Kahramanmaraş, providing information on energy-saving opportunities, new technologies, and service providers. These centers will offer brochures on renewable energy technologies, efficient lighting, energy-efficient appliances, insulation, and public transportation use. Collaboration with district municipalities is recommended to maximize the reach and impact of these initiatives. Through these efforts, potential savings include 36,444 MWh of electricity and a reduction of 17,775.17 tCO_2e in emissions. Lastly, imported coal used in residences contributes 2.4% to Kahramanmaraş's total greenhouse gas inventory. Plans to reduce residential coal consumption by 20% are projected to save 40,838 tons of coal and reduce greenhouse gas emissions by 72,734 tCO_2e. Together, these strategies highlight the significant potential for reducing energy consumption and greenhouse gas emissions in Kahramanmaraş through a combination of technological upgrades, behavioral shifts, and targeted policy measures.

Table 8 highlights a sub-action focusing on urban transformation and energy-efficient new building construction in Kahramanmaraş, a key area of the city's development efforts. Large-scale urban transformation projects are being implemented, with specific zones designated for redevelopment. Approximately 5,395 buildings have been identified as risky and are targeted for replacement with new, energy-efficient residential units. The estimated outcome of this initiative is the construction of 5,395 new independent residential units. By incorporating energy-efficient design principles, proper insulation, and energy-efficient systems, it is projected that these buildings could achieve energy savings of 30-40%. The estimated savings from this initiative include 3,274 MWh of electricity, 2,080,312 cubic meters of natural gas, and a reduction of 5,462 tons of CO_2 emissions. This action represents a significant step in improving the city's sustainability, as it not only addresses the need for safer housing but also contributes to long-term energy savings and a reduction in carbon emissions. By focusing on energy-efficient construction, this urban transformation project supports both environmental and economic goals, demonstrating a commitment to reducing the city's overall carbon footprint (Moloney et al., 2015).

Table 7. Action 1: Reducing Energy Consumption in Existing Buildings through Energy Efficiency Practices

Sub-Action	Current Status	Activities	Emission Savings
1.1: Thermal Insulation	In Kahramanmaraş, due to geographical and climatic conditions, heating loads do not dominate the energy consumption of the building stock. Despite the distribution of natural gas, heating is mostly achieved using air conditioners, and the desired comfort level in winter is often not met. However, cooling loads in summer are high, and insulation is essential for comfort in both cases. Energy consumption from residences accounts for 6.7% of Kahramanmaraş's greenhouse gas emissions.	If thermal insulation is applied to 30% of the existing buildings (facades, roofs, and windows), it is estimated that electricity consumption will be reduced by 5% and energy for heating by 30%, resulting in significant savings.	10,933 MWh electricity, 14,103,666 m^3 natural gas savings, 31,846.61 tCO_2e emissions reduction
1.2: Use of Energy-Efficient Lighting Systems (LED)	Various studies in Turkey indicate that lighting accounts for about 10-20% of total electricity consumption in homes. Assuming 75% of existing residences in Kahramanmaraş switch to energy-efficient lighting systems, lighting-related electricity consumption could decrease by 50-80%, leading to an overall 10% reduction in electricity consumption.	Replacement of the most frequently used lighting systems and eventually all systems in residences with LED lighting.	65,600 MWh electricity savings, 30,195.68 tCO_2e emissions reduction
1.3: Awareness Training/Campaigns on Energy Efficiency	Household behavior is a significant factor in residential energy consumption. Changing habits for lighting and device usage can reduce total residential energy consumption by approximately 5%.	Local authorities will establish advisory centers in Kahramanmaraş where residents and workers can access information about energy consumption, savings, new technologies, and service providers. These centers will provide brochures and information on renewable energy technologies, efficient lighting, energy-efficient electronic devices, insulation, and public transport usage. Collaboration with district municipalities is recommended.	36,444 MWh electricity savings, 17,775.17 tCO_2e emissions reduction
1.4: Reduction of Coal Consumption	Imported coal consumed in residences constitutes 2.4% of the total greenhouse gas inventory.	It is planned to reduce coal consumption in residences by 20%.	40,838 tons of coal savings, 72,734 tCO_2e emissions reduction

Table 9 outlines several sub-actions focused on improving energy efficiency in commercial buildings in Kahramanmaraş, which account for a significant portion of the city's energy consumption. The energy use of non-residential buildings, including public buildings, constitutes around 17% of the city's total energy consumption, and measures like thermal insulation, awareness campaigns, and energy-efficient lighting can help reduce this figure. Sub-Action 3.1 targets thermal insulation in existing commercial buildings. Insulation is considered a cost-effective energy efficiency measure due to the higher energy consumption and prices in commercial buildings compared to residential buildings. The goal is to apply insulation to 30% of these buildings, potentially reducing electricity consumption by 5%. This action is expected to result in 12,000 MWh in electricity savings and a reduction of 5,523 tons of CO_2 emissions. Sub-Action 3.2 focuses on awareness campaigns for energy efficiency in commercial buildings. With electricity consumption in non-residential buildings representing about 16% of the city's total, lighting accounts for a significant portion. By conducting information and awareness campaigns targeting commercial building owners, it is estimated that 5% of energy savings can be achieved in 75% of these buildings. The projected savings from this initiative are 25,000 MWh in electricity and 11,507 tons of CO_2 emissions reduction. Sub-Action 3.3 addresses the implementation of energy-efficient lighting systems in commercial buildings. With high energy consumption and costs in these buildings, replacing lighting with more efficient systems has proven to be cost-effective, often with a payback period of less than a year. It is estimated that applying energy-efficient lighting to 75% of commercial buildings could lead to a 10% reduction in electricity consumption. This action is expected to save 50,008 MWh of electricity and reduce CO_2 emissions by 23,018 tons. These initiatives collectively contribute to a significant reduction in both energy consumption and carbon emissions, aligning with the city's goals for sustainability and energy efficiency.

Table 8. Action 2: Energy-efficient Planning of Newly Designated Residential Areas in Kahramanmaraş

Sub-Action	Current Status	Activities	Emission Savings
2.1: Urban Transformation and Energy-Efficient New Building Construction	Urban transformation is one of the key focus areas in Kahramanmaraş. Large-scale urban transformation and development project areas have been designated across the city. Approximately 5,395 risky buildings have been identified in the province.	It is estimated that 5,395 new independent residential units will be constructed. Through proper energy-efficient design, insulation, and efficient energy systems, 30-40% energy savings can be achieved in these units.	3,274 MWh electricity, 2,080,312 m^3 natural gas savings, 5,462 tCO_2e emissions reduction

Table 9. Action 3: Reducing Energy Consumption in Existing Commercial Buildings through Energy Efficiency Practices

Sub-Action	Current Status	Activities	Emission Savings
3.1: Thermal Insulation in Existing Commercial Buildings	The energy consumption of non-residential buildings, including public buildings, constitutes approximately 17% of Kahramanmaraş's energy usage. Given the higher energy consumption and prices in commercial buildings compared to residences, energy efficiency measures such as insulation are cost-effective. It is estimated that applying insulation to 30% of these buildings could reduce electricity consumption by 5%.	Raising awareness among commercial building owners about the importance of thermal insulation.	12,000 MWh electricity savings, 5,523 tCO_2e emissions reduction
3.2: Awareness Campaigns for Energy Efficiency in Commercial Buildings	Electricity consumption in non-residential buildings accounts for about 16% of the city's total consumption. A significant portion of this consumption is due to lighting. Awareness campaigns can be very effective in achieving 5% energy savings in 75% of these buildings.	Conducting information and awareness campaigns targeted at commercial buildings.	25,000 MWh electricity savings, 11,507 tCO_2e emissions reduction
3.3: Energy-Efficient Lighting in Existing Commercial Buildings	The high energy costs and consumption in commercial buildings make energy-efficient lighting systems cost-effective, with a payback period of less than a year in similar projects. It is estimated that implementing such measures in 75% of commercial buildings could result in 10% electricity savings.	Conducting targeted information and awareness campaigns for commercial buildings.	50,008 MWh electricity savings, 23,018 tCO_2e emissions reduction

Table 10 outlines two sub-actions focused on enhancing public transportation and adopting alternative technologies in Kahramanmaraş to reduce fuel consumption and greenhouse gas emissions. Sub-Action 4.1 promotes the use of public transportation as an alternative to private vehicles, which has been steadily increasing in the city. Public transportation is expected to save approximately 5% of total fuel consumption, leading to a significant reduction in greenhouse gas emissions. Activities include encouraging public institutions to adopt shuttle services, expanding bike lanes, promoting cycling, implementing light rail systems, and converting roads to encourage walking and public transport. These measures are expected to save 1,029 tons of gasoline, 9,853 tons of diesel, and reduce CO_2 emissions by 34,553 tons. Sub-Action 4.2 involves the transition of public transportation to alternative fuels, with plans to convert 25% of the public transport fleet to electric or hybrid vehicles. The operation of 50 electric buses is anticipated, leading to energy savings of 14,826 MWh and a reduction of 6,824 tons of CO_2 emissions. These actions aim to improve the sustainability of the city's transport sector while reducing both energy consumption and carbon footprint.

Table 10. Action 4: Promoting Public Transportation to Reduce Motor Vehicle Traffic

Sub-Action	Current Status	Activities	Emission Savings
4.1: Promotion of Public Transportation	Bus-based public transportation continues to play a significant role, while private vehicle use is steadily increasing. Promoting public transportation could save approximately 5% of total fuel consumption and significantly reduce greenhouse gas emissions.	Encouraging public institutions without shuttle services to adopt them, increasing bike lanes and promoting cycling, implementing light rail public transportation, establishing rail systems in natural green areas, and narrowing vehicle roads to encourage walking and public transportation.	1,029 tons of gasoline, 9,853 tons of diesel savings, 34,553 tCO_2e emissions reduction
4.2: Use of Alternative Technologies and Fuels	Planning is required for converting the public transportation fleet to alternative fuel vehicles.	Converting 25% of the public transport fleet to electric/hybrid vehicles.	Operation of 50 electric buses, 14,826 MWh energy savings, 6,824 tCO_2e emissions reduction

Sub-Action 5.1 focuses on increasing awareness of photovoltaic (PV) applications on urban roofs in Kahramanmaraş. As one of the leading renewable energy technologies, the PV market in the city is growing rapidly, with declining prices. The activity involves awareness campaigns addressing regulations and technical aspects of installing PV systems in urban areas. It is estimated that a 100 MW PV investment capacity can be achieved, resulting in electricity savings of 150,000 MWh and a reduction of 69,045 tons of CO_2 emissions. This initiative promotes the use of renewable energy to enhance sustainability in urban environments.

Table 11. Action 5: Expansion of Renewable Energy Applications in Kahramanmaraş

Sub-Action	Current Status	Activities	Emission Savings
5.1: Awareness of Photovoltaic (PV) Applications on Urban Roofs	Photovoltaic (PV) is one of the leading renewable energy technologies for Kahramanmaraş. The PV market is growing rapidly, and prices are declining.	Awareness campaigns about regulations and technical issues for installing PV systems in urban built-up areas. It is estimated that a PV investment capacity of 100 MW can be achieved in urban areas.	150,000 MWh electricity savings, 69,045 tCO_2e emissions reduction

Sub-Action 6.1 aims to increase awareness of waste recycling practices in Kahramanmaraş, where waste characterization data from the city's solid waste landfill reveals significant amounts of recyclable materials. The total waste generated in the city amounts to 670 tons per day or 244,550 tons annually. Among this waste, 4.4% consists of paper and cardboard, 19.7% plastic, 2.6% glass, and 0.6% metal, representing substantial recycling opportunities. The proposed activities focus on recycling significant quantities of these materials, including 10,760 tons of paper/cardboard, 48,176 tons of plastic, 6,358 tons of glass, and 1,467 tons of metal. These recycling efforts are expected to contribute to a reduction of 4,113 tons of CO_2 emissions. The breakdown of emissions reductions includes

1,904 tons from paper/cardboard, 1,975 tons from plastic, 190 tons from glass, and 44 tons from metal. This initiative highlights the potential environmental benefits of recycling and emphasizes the need for increased awareness and action in waste management. By diverting recyclable materials from landfills, the city can significantly reduce its carbon footprint, promote sustainability, and contribute to a circular economy (Haris et al., 2024).

Table 12. Action 6: Waste Management

Sub-Action	**Current Status**	**Activities**	**Emission Savings**
6.1: Awareness of Waste Recycling Practices	According to waste characterization data at the city's solid waste landfill, 4.4% is paper and cardboard, 19.7% is plastic, 2.6% is glass, and 0.6% is metal. Daily waste amounts to 670 tons, equivalent to 244,550 tons annually.	Recycling 10,760 tons of paper/cardboard, 48,176 tons of plastic, 6,358 tons of glass, and 1,467 tons of metal.	4,113 tCO_2e emissions reduction (1,904 from paper/cardboard, 1,975 from plastic, 190 from glass, 44 from metal)

Sub-Action 7.1 focuses on forest afforestation in Kahramanmaraş, which has a total of 205,620 hectares of forested area. The proposed activity involves creating ecological corridors within urban areas, including parks, groves, afforestation zones, and gardens, to support the urban ecosystem. These green spaces are intended to enhance the city's environmental health and promote biodiversity. The initiative assumes that each tree reduces CO_2 emissions by ~22 kg annually (Gül et al., 2018). By increasing the number of trees in the city by 25%, it is estimated that a reduction of 2,891.5 tons of CO_2 emissions could be achieved. This afforestation project plays a key role in reducing the city's carbon footprint and improving air quality, while also contributing to overall climate change mitigation efforts. The creation of green spaces and urban forests provides both environmental and social benefits, enhancing the quality of life for city residents.

Table 13. Action 7: Forest Rehabilitation and Afforestation

Sub-Action	**Current Status**	**Activities**	**Emission Savings**
7.1: Forest Afforestation	There are 205,620 ha of forest area in the province.	Ecological corridors that will support the urban ecosystem, such as parks, groves, afforestation areas, and gardens, should be created in cities.	Assuming that 1 tree reduces CO_2 by ~22 kg per year, if the number of trees is increased by 25%, 2891.5 tCO_2e emission reduction will be achieved.

The above tables outline various actions aimed at reducing CO_2 emissions in Kahramanmaraş, focusing on energy efficiency, renewable energy, waste management, and afforestation. These initiatives contribute to the city's broader climate change mitigation efforts. Energy efficiency measures in existing buildings play a central role in emission reduction. Insulation improvements, energy-efficient lighting systems, and awareness campaigns are expected to significantly reduce CO_2 emissions, totaling 79,816 tons. Additionally, efforts to reduce coal consumption are projected to cut 72,734 tons of CO_2. These measures address residential and commercial buildings, aiming to optimize energy use and minimize waste. In new urban developments, energy-efficient planning and construction are prioritized. This includes the integration of thermal insulation and energy-saving designs in newly built residential areas, leading to a reduction of 5,462 tons of CO_2. The commercial sector also plays a key role in emissions reduction. Energy efficiency measures such as insulation, awareness campaigns, and energy-efficient lighting in existing commercial buildings are expected to reduce emissions by 40,048 tons. These actions are critical for addressing the sector's high energy consumption. Public transportation expansion and the promotion of alternative fuel technologies are crucial for reducing traffic-related emissions. Expanding public transport is expected to save 34,553 tons of CO_2 while switching to alternative technologies and fuels in public transportation will contribute an additional 6,824 tons. Renewable energy adoption is encouraged through awareness campaigns about photovoltaic applications on urban rooftops. This initiative alone is projected to reduce emissions by 69,045 tons, promoting clean energy use and decreasing dependency on fossil fuels. Waste management improvements, particularly through recycling awareness, are expected to reduce CO_2 emissions by 4,113 tons. Meanwhile, forest rehabilitation and afforestation efforts, including the planting of additional trees, will lead to a reduction of 2,891 tons of CO_2. Collectively, these actions will result in a total CO_2 reduction of 315,486 tons, marking significant progress in the city's efforts to reduce emissions, improve sustainability, and address climate change challenges.

CONCLUSION

Local governments are pivotal in addressing climate change at the local level, translating national policies into actionable strategies tailored to their unique conditions. Kahramanmaraş has taken significant steps in this regard, developing a climate change action plan to reduce greenhouse gas emissions and enhance sustainability. This comprehensive plan prioritizes energy efficiency, renewable energy, waste management, and afforestation, reflecting a multi-faceted approach to environmental stewardship. Key initiatives include enhancing energy efficiency in residential and commercial buildings, promoting sustainable urban planning, encouraging public transportation, and adopting renewable energy technologies like rooftop photovoltaic. Waste management improvements and afforestation efforts further support the city's commitment to reducing its environmental footprint. Looking ahead, continued efforts to integrate sustainable practices into urban development and public infrastructure will be essential. Future recommendations include scaling up renewable energy projects, fostering community awareness programs, and leveraging advanced technologies for waste and resource management. Additionally, enhancing regional collaboration and accessing international climate funds can amplify these efforts. Kahramanmaraş's proactive measures not only contribute to local climate resilience but also set an example for other cities seeking to combat climate change and create healthier, more sustainable communities.

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