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# GREENHOUSE GAS EMISSIONS FROM NATURAL GAS FLARING: A CASE STUDY OF GAS FIELDS IN SERBIA

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***Abstract:*** *Gas flaring represents a significant source of greenhouse gas emissions in the oil and gas industry. This paper analyzes emissions of carbon dioxide ($CO_2$) and methane ($CH_4$) generated during natural gas flaring, as well as their global warming potential (GWP). Particular attention is given to emissions of unburned methane resulting from incomplete combustion in flare systems, due to its high global warming potential. Even small amounts of unburned methane can significantly contribute to total greenhouse gas emissions. Based on the compositional analysis of natural gas from different gas fields in Serbia, calculations of the total $CO_2$ emission factor and global warming potential were performed. The results indicate that the composition of the gas mixture significantly affects emission values, with gas fields containing higher concentrations of carbon dioxide exhibiting higher $CO_2$ emission factors, while the presence of ethane, propane, and heavier hydrocarbons contributes to increased GWP values. The obtained results highlight the importance of optimizing the flaring process and improving emission control measures in order to reduce negative environmental impacts.*

***Keywords:*** *Natural Gas flaring, natural gas composition, $CO_2$, methane, global worming potential.*

## 1. INTRODUCTION

Energy is crucial for economic growth and development; however, its production and consumption contribute significantly to global environmental issues such as climate change [1]. Fossil fuels remain the primary energy source worldwide [2]. The combustion of fossil fuels, including oil and natural gas, represents a major source of greenhouse gas emissions, which substantially contribute to global warming and climate change. [3].

Greenhouse gases are a natural component of the atmosphere; yet, a significant increase in their concentration has been observed over the past few decades as a result of human activities. Although present in very low concentrations in the atmosphere, they are exceptionally effective at trapping heat, making them extremely detrimental to the environment [1].

Gas flaring represents one of the major sources of greenhouse gas emissions in the upstream oil and gas industry and contributes significantly to atmospheric $CO_2$ emissions, particularly in regions where associated gas is routinely flared [4].

This paper presents the calculation of the total carbon dioxide emission factor and global warming potential (GWP) based on the real component composition of natural gas from various gas fields in Serbia, in order to precisely determine the real environmental impact of the flaring process.

## 2. GREENHOUSE GAS EMISSIONS FROM FLARING

Flaring represents a controlled process of burning excess natural gas that cannot be utilized or transported due to safety, technological, or economic reasons [5,6]. The primary role of a flare is the safe removal of flammable gases from the production system, thereby preventing pressure buildup and reducing the risk of accidents [5]. In addition to emergency situations, flares are also utilized during regular plant operations, routine start-ups and shut-downs, equipment testing, or when there is no suitable infrastructure for collecting and processing produced gas [6,7].

During the complete combustion of hydrocarbons, carbon dioxide ($CO_2$) and water vapor are produced, while carbon monoxide (CO), unburned methane ($CH_4$), volatile organic compounds (VOC) and other components can be produced due to incomplete combustion [5]. Due to their high global warming potential, $CO_2$ and $CH_4$ emissions are particularly significant, representing the dominant greenhouse gases associated with the flaring process [5,7].

Flare efficiency represents the percentage at which hydrocarbons are oxidized to carbon dioxide and water. In ideal conditions, combustion is almost complete, however, in real conditions, efficiency is affected by wind speed, gas composition, flow, torch design and air mixing mechanism. Reduced efficiency leads to increased emissions of unburnt methane and carbon monoxide, thereby escalating the overall environmental impact of the process [8].

The composition of natural gas significantly impacts the total emissions generated by combustion. In addition to methane content, ethane, propane, and higher hydrocarbons play an important role, as does the presence of carbon dioxide naturally occurring within the reservoir. Unlike hydrocarbons, which are converted to $CO_2$ during combustion, naturally present carbon dioxide does not participate in the combustion reaction but is instead directly emitted into the atmosphere. Therefore, differences in the component composition of natural gas can significantly affect the overall $CO_2$ emission factor and global warming potential [7].

## 3. METHODOLOGY

This paper analyzes the influence of natural gas composition on the total carbon dioxide emission factor and global warming potential. The calculation of the total $CO_2$ emission factor was conducted based on the volumetric composition of natural gas from the analyzed gas fields. Based on this composition, the heating value and the mass fraction of carbon contained in the combustible components of the gas were determined, with the mass of $CO_2$ generated by combustion being calculated using the stoichiometric ratio between carbon and carbon dioxide. Total $CO_2$ emissions represent the sum of reaction emissions resulting from the complete combustion of hydrocarbons and the $CO_2$ present in the natural gas as an inert (ballast) component.

The global warming potential was determined by taking into account the $CO_2$ emissions resulting from combustion and the unburnt methane emissions caused by incomplete flaring. A flare combustion efficiency of 99% was adopted in the calculation, with the remaining fraction of methane being treated as unburnt emissions. $CO_2$ was taken as the reference gas with a GWP value of 1, whereas a 100-year GWP factor in the range of 27–30 was applied for methane [2].

Total carbon dioxide emission factor:

$$KCO_2 = \frac{m_{uCO_2}}{H} \quad (1)$$

Where: 3,67 - stoichiometric ratio

$m_{uCO_2}$ - total mass of carbon dioxide emitted during combustion

H- heating value of the fuel per unit mass

Total mass of carbon dioxide emitted during combustion:

$$m_{u_{CO_2}} = 3{,}67 \cdot gc_g + m_{CO_2} \quad (2)$$

Where: $g_{C_g}$ - mass fraction of combustible carbon in the gas
$m_{CO_2}$ - mass of carbon dioxide in the ballast

Due to incomplete combustion during flaring, the mass of emitted $CO_2$ generated by combustion is lower than in the case of complete combustion. Due to incomplete combustion, there is also a fugitive emission of methane, so the contribution to GWP is the sum of of the impacts of both methane and carbon dioxide.

Global warming potential is calculated using the following equation:

$$GWP = 1 \cdot (\eta_{comb} \cdot 3{,}67 \cdot gc_g + m_{CO_2}) + m_{CH_4} \cdot 28 \quad (3)$$

Where: $m_{CH_4}$ - mass of methane emitted due to incomplete flaring (fugitive emission)

$\eta_{comb}$ – flare combustion efficiency

$$m_{CH_4} = m_s \cdot g_{CH_4} \cdot (1 - \eta_{comb}) \quad (4)$$

Where: $m_s$ - total mass of gas
$g_{CH_4}$ - ass fraction of methane in the gas

### 3.1. Natural Gas Composition and Results of Emissions Calculation During Flaring

The analysis was performed using compositional data from 10 characteristic natural gas fields located in the Pannonian Basin of Serbia, representing a wide range of gas compositions and $CO_2$ contents. Table 1 presents the compositional analysis of natural gas from the different gas fields in Serbia, while Table 2 summarizes the calculated total $CO_2$ emission factor values and GWP for each analyzed field.

**Table 1**. Natural gas composition for various gas fields [2]

| GAS FIELD | Methane | Ethane | Propane | i-butane | n-butane | Pentane | Higher hydrocarbons -hexane | Nitrogen | Carbon dioxide |
|---|---|---|---|---|---|---|---|---|---|
| 1.Kikinda | 84.05 | 6.16 | 2.67 | 1.68 | | 2.01 | | 3.44 | 0.02 |
| 2.Mokrin | 79.78 | 7.55 | 3.43 | 2.45 | | 1.14 | 2.2 | 2.3 | 1.15 |
| 3.Srbobran | 75.15 | 1.95 | 0.5 | 0.12 | 0.25 | 0.16 | | 11.9 | 10 |
| 4.Kikinda-varoš | 85.3 | 3.9 | 2.8 | 2.1 | | | | 5.9 | |
| 5.Begejci | 97.39 | 0.28 | 0.08 | 0.03 | 0.02 | | | 2.15 | 0.05 |
| 6.Nikolinci | 70.1 | 0.3 | 0.09 | 0.02 | 0.02 | 0.01 | | 26.4 | 3.06 |
| 7.Miloševo | 28.76 | 0.65 | 0.41 | 0.19 | | | | 6.94 | 63.05 |
| 8.Gornji breg | 96.63 | 0.06 | 0.01 | 1.75 | | | | 1.75 | 1.55 |
| 9.Bečej | 9.3 | | | | | | | 6.7 | 84 |
| 10.Karađorđevo | 95.48 | 0.62 | 0.55 | | 0.18 | | | 1.48 | 1.25 |

**Table 2.** Calculated values of the total $CO_2$ emission factor and GWP for 10 characteristic fields.

| GAS FIELD | Total $CO_2$ emission factor (kg/GJ) | GWP (kg $CO_2e$/kg gas) |
|---|---|---|
| 1.Kikinda | 57.6677 | 2.3666 |
| 2.Mokrin | 59.7328 | 2.6335 |
| 3.Srbobran | 69.1129 | 2.0431 |
| 4.Kikinda-varoš | 56.8446 | 2.1631 |
| 5.Begejci | 55.1110 | 1.9784 |
| 6.Nikolinci | 59.8220 | 1.5515 |
| 7.Miloševo | 274.7539 | 2.5829 |
| 8.Gornji breg | 57.3050 | 2.1397 |
| 9.Bečej | 1045.7865 | 2.6318 |
| 10.Karađorđevo | 56.6564 | 2.0408 |

Figure 1 shows the total $CO_2$ emission factor across different gas fields in the Republic of Serbia.

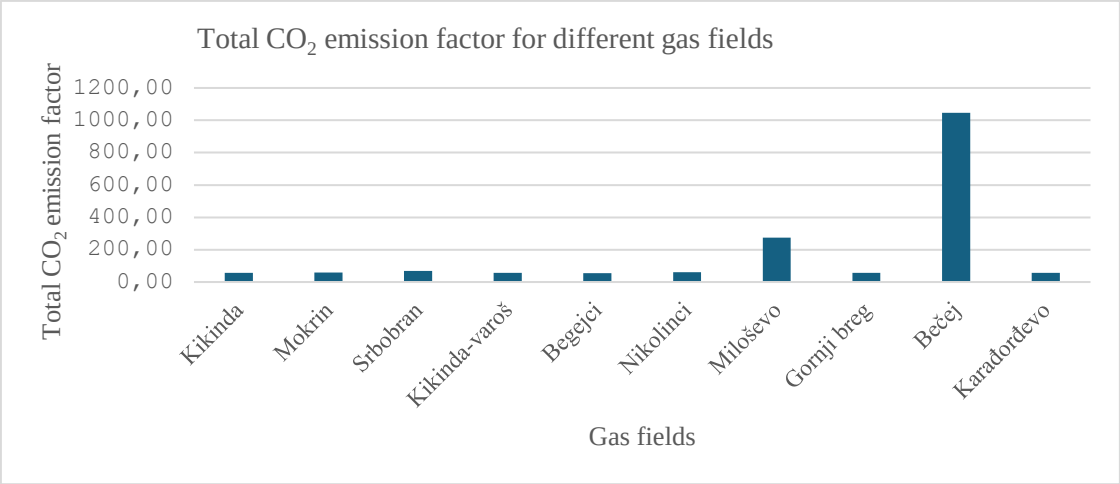



***Figure 1.*** *Total $CO_2$ emission factor for different gas fields*

Most of the gas fields have relatively uniform total $CO_2$ emission factor values (55–60 kg/GJ), whereas the Bečej (1045.78 kg/GJ) and Miloševo (274.75 kg/GJ) stand out with significantly higher values. This is due to the very high carbon dioxide content in the natural gas from these fields, which is 84% for Bečej and 63.05% for Miloševo, respectively.

Figure 2 presents the global warming potential for the analyzed gas fields.

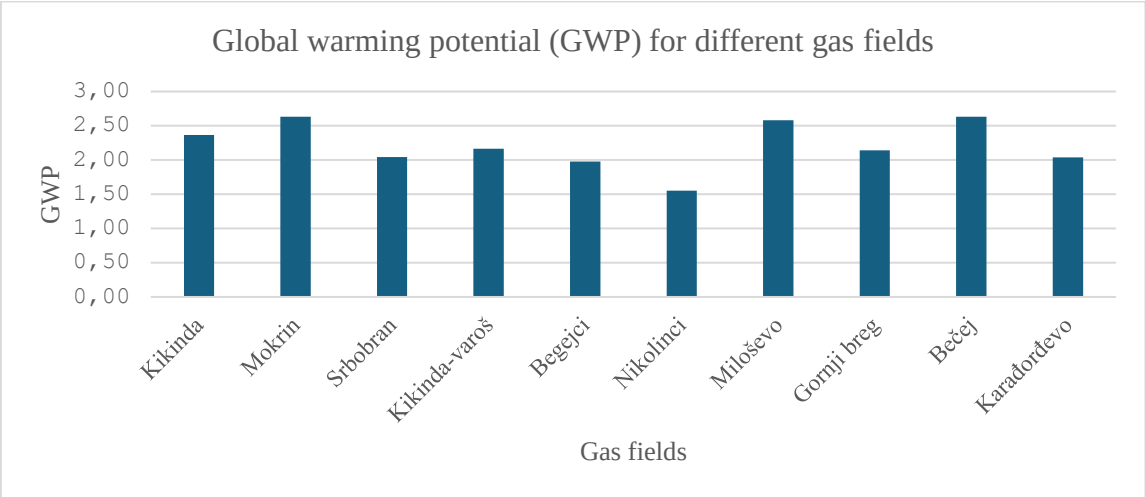



***Figure 2.*** *Global warming potential (GWP) for different gas fields*

The obtained values depend on the natural gas composition, with the highest values achieved by the Mokrin (2.57 kg $CO_2e$/kg gas), Kikinda (2.33 kg $CO_2e$/kg gas), and Kikinda-Varoš (2.12 kg $CO_2e$/kg gas) gas fields. The results show that a high methane content is not the only factor influencing the GWP, the presence of ethane, propane, and higher hydrocarbons also has a significant impact. This is confirmed by the example of Gornje Breg, which, despite a methane content of 96.63%, achieves a slightly lower GWP due to the low fraction of heavier hydrocarbons.

Figure 3 illustrates the effect of methane content on the total emission factor for various gas fields (field labels 1–10 correspond to the field numbering in Table 1).

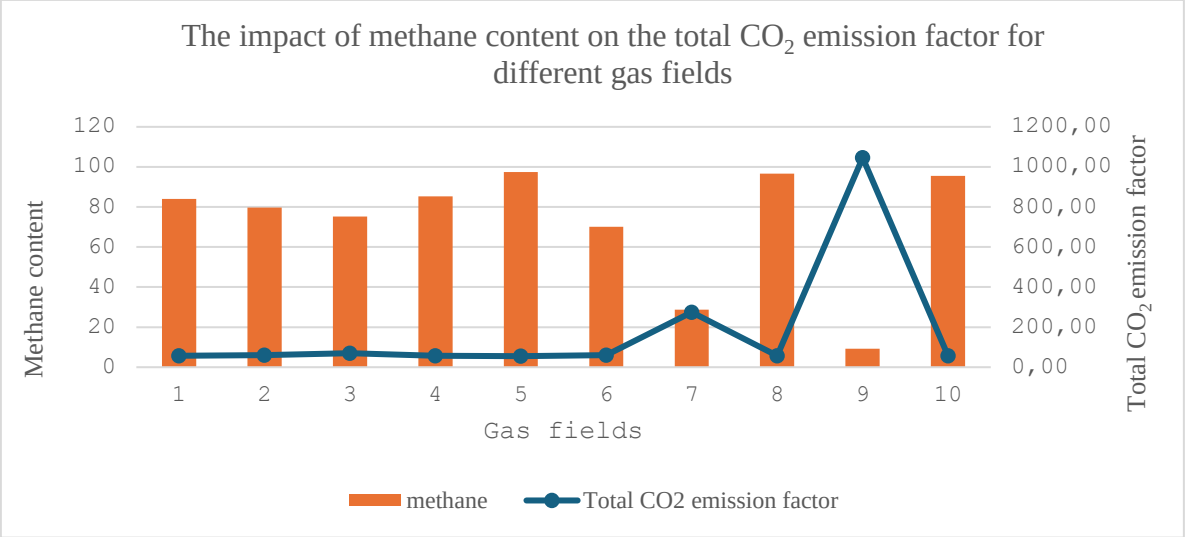



***Figure 3.*** *The impact of methane content on the total $CO_2$ emission factor for different gas fields*

Figure 4 illustrates the effect of carbon dioxide content on the total $CO_2$ emission factor for various gas fields.

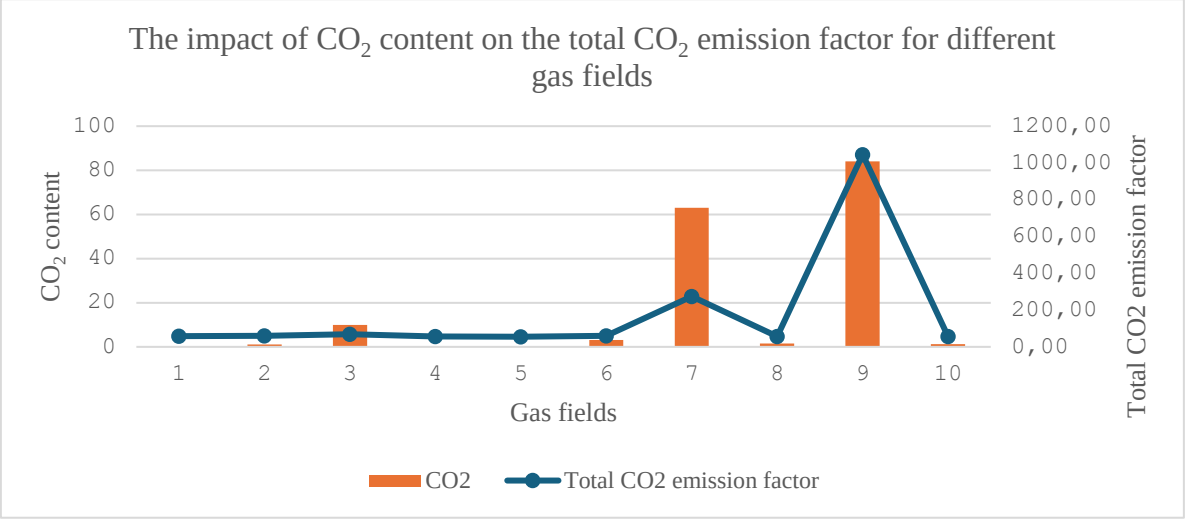



***Figure 4***. *The impact of $CO_2$ content on the total $CO_2$ emission factor for different gas fields*

The results show that methane content does not have a pronounced direct effect on the emission factor value, while an increase in the carbon dioxide fraction leads to a significant increase in the emission factor. This is because the carbon dioxide present in the natural gas does not undergo transformation during combustion, but is directly emitted into the atmosphere as a ballast component, while simultaneously significantly reducing the heating value of the gas. Consequently, the Bečej and Miloševo gas fields, with high $CO_2$ contents, stand out with significantly higher total emission factor values compared to the other analyzed fields. The obtained results confirm that the total emission factor primarily depends on the carbon dioxide content in the gas mixture, while the influence of methane content is considerably less pronounced.

Figure 5 illustrates the effect of methane content on the global warming potential for various gas fields.

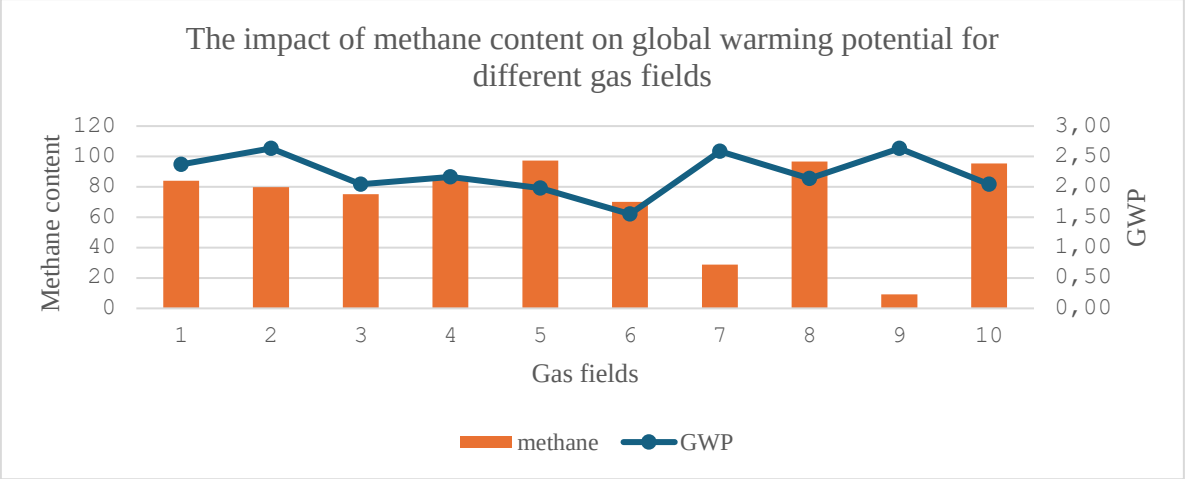



***Figure 5.*** *The impact of methane content on global warming potential for different gas fields*

Figure 6 illustrates the effect of carbon dioxide content on the global warming potential for various gas fields.

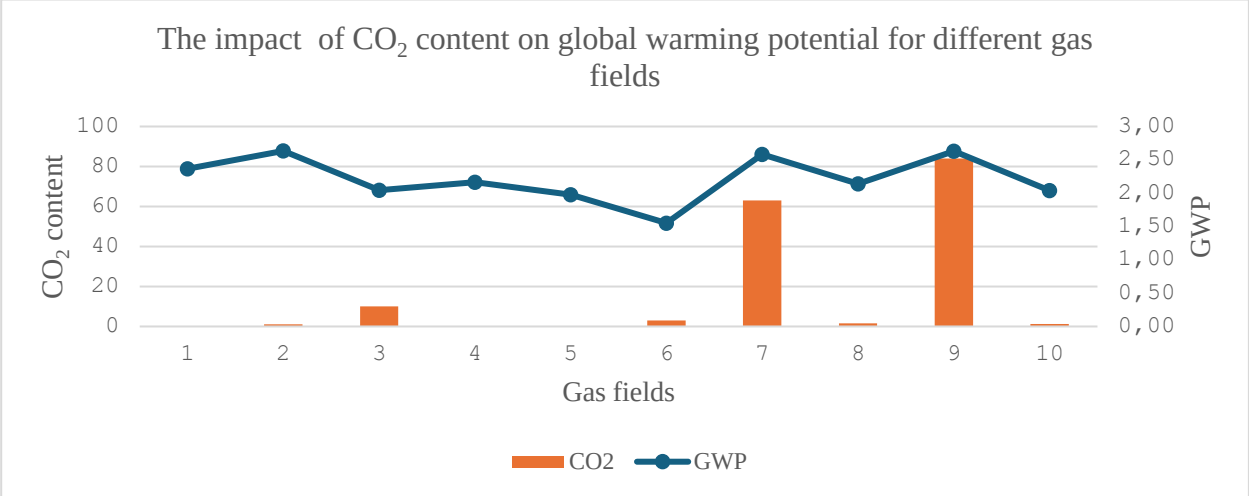



***Figure 6.*** *The impact of $CO_2$ content on global warming potential for different gas fields*

The presented results indicate that there is no simple linear relationship between methane or carbon dioxide content and GWP. Gas fields with high methane content do not necessarily achieve the highest GWP values, indicating that the global warming potential depends on the total composition of the natural gas. The highest GWP values are exhibited by gas fields that, in addition to methane, contain a higher fraction of ethane, propane, and other higher hydrocarbons.

Figure 7 shows the contribution structure of carbon dioxide and methane to the GWP for various gas fields.

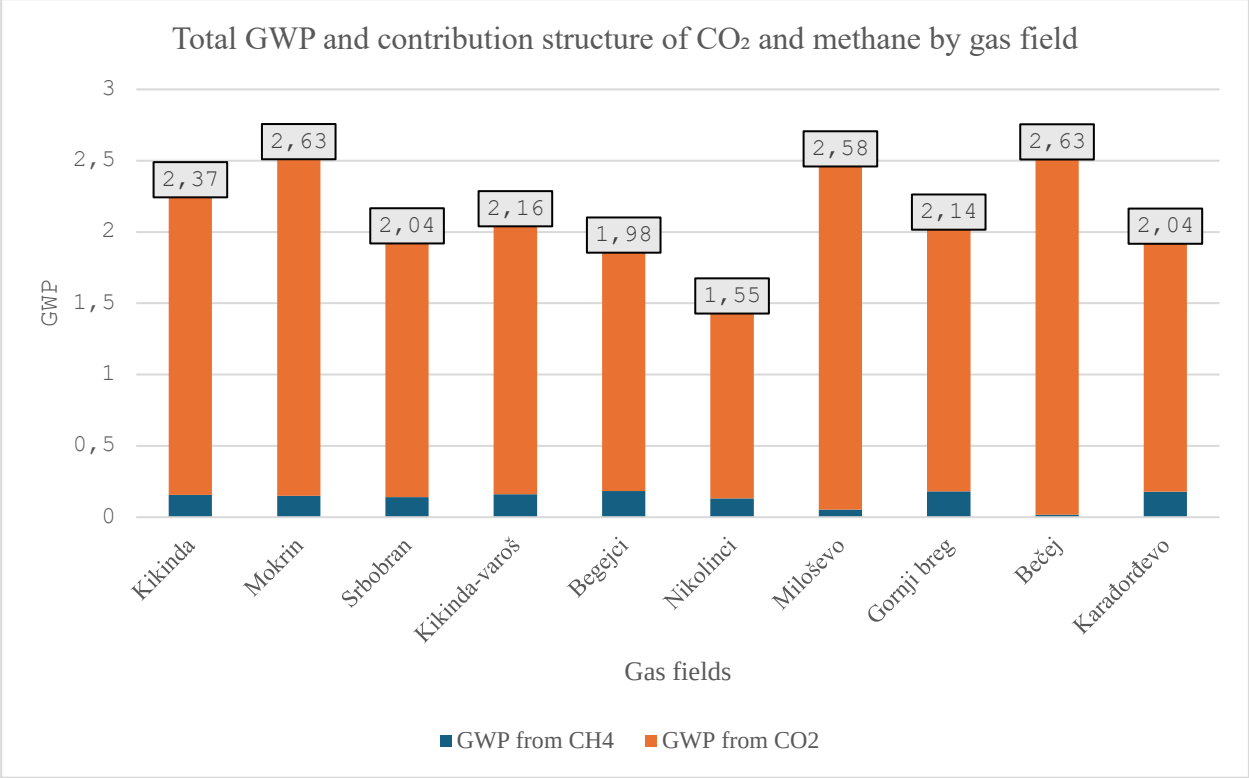



***Figure 7**. Total GWP and contribution structure of $CO_2$ and methane by gas field*

The dominant portion of the total GWP originates from $CO_2$ generated by flaring and from gas ballast. However, due to the extremely high impact factor of methane ($GWP_{CH4}$ = 28), even very small masses of unburned methane from fugitive emissions account for a noticeable share of the overall footprint. Therefore, maintaining high flare efficiency is a key measure for reducing the total GWP.

## 3. CONCLUSION

This study presents an assessment of greenhouse gas emissions generated during natural gas flaring based on the actual composition of natural gas from Serbian gas fields. The proposed methodology enables the calculation of both the total $CO_2$ emission factor and the global warming potential (GWP), taking into account not only combustion products but also naturally occurring carbon dioxide and methane slip caused by incomplete combustion.

The results demonstrate that the total $CO_2$ emission factor is primarily controlled by the carbon dioxide content in the gas mixture, while the GWP depends on the overall hydrocarbon composition rather than methane concentration alone. Gas fields characterized by elevated $CO_2$ content, particularly Bečej and Miloševo, exhibit substantially higher emission factors than the remaining analyzed fields.

These findings indicate that accurate environmental assessment of gas flaring requires consideration of the complete natural gas composition. The proposed approach may therefore contribute to more reliable greenhouse gas inventories and support the implementation of measures aimed at reducing emissions from flare systems.

## ACKNOWLEDGMENT

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