Modeling Calorific Values and CO_2 Emissions of Natural Gas and Dimethyl Ether Fuel Blends

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Abstract: The global transition to cleaner energy requires strategies that reduce carbon dioxide emissions while maintaining reliable energy supply. This study developed and validated mathematical models to predict the calorific value and CO_2 emissions of natural gas–dimethyl ether (DME) mixtures across compositions ranging from 0% to 100% DME. Using ideal gas thermodynamics and differential carbon accounting, the models were implemented in Microsoft Excel for accessibility and practical application. Results show that DME blending increases volumetric energy density almost linearly, with each 10% DME addition raising energy density by about 3.8% and achieving a 38% increase at 100% DME compared to pure natural gas. This reduces volumetric flow requirements, offering advantages over hydrogen blending. The CO_2 model, based on lifecycle assessment, indicates that emissions depend primarily on the DME production pathway. Renewable Power-to-X routes using offshore wind can reduce emissions to 8.1 gCO_2eq/MJ—an 85% reduction relative to natural gas—while fossil-based routes may exceed 200 gCO_2eq/MJ. Although experimental validation is still needed, the models align with thermodynamic theory and literature benchmarks. Overall, natural gas–DME blending represents a viable, low carbon fuel bridge technology for lowering emissions, particularly when supported by renewable production pathways and effective policy frameworks.

Keywords: *Natural Gas, Dimethyl Ether, CO_2 Emissions, Calorific Value, Low Carbon Fuels.*

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I. INTRODUCTION

The global energy system faces the dual challenge of meeting increasing energy demands while reducing catastrophic climate change. Natural gas consumption hit a record 4,166 billion cubic meters (bcm) in 2024, growing by 2.9%, mainly driven by China, Russia, and the United States, which together accounted for nearly 60% of the additional demand [1]. Although natural gas is the cleanest-burning fossil fuel, it still significantly contributes to greenhouse gas emissions, with the energy sector responsible for about 75% of global emissions [2]. Dimethyl ether (DME) has become a promising alternative fuel with strong potential to lower emissions and support energy transition. The global DME market, valued at USD 9.41 billion in 2023, is expected to reach USD 20.32 billion by 2032, growing at a compound annual rate of 9.0%, with Asia-Pacific holding 64.4% of the market share [3]. Blending DME with natural gas offers an innovative decarbonization path that exploits their complementary fuel qualities. Studies show that DME combustion can cut CO_2 emissions by 5.2–18.3% for pure applications, with well-to-wheel emissions as low as 67.7 g CO_2/MJ compared to 90.0 g CO_2/MJ for diesel [4].

Calorific value, which quantifies the energy released upon complete combustion of a fuel, serves as a fundamental parameter for assessing fuel performance and designing energy systems. Understanding how this property behaves in fuel blends is essential for optimizing energy output, ensuring system compatibility, and predicting operational requirements. Similarly, accurate prediction of carbon dioxide emissions from these mixtures requires approaches that account for both direct combustion emissions and lifecycle considerations, particularly given the diverse production pathways available for dimethyl ether synthesis.

Natural gas and dimethyl ether possess distinct chemical and physical properties that directly influence their combustion behavior and emission profiles. Natural gas, predominantly composed of methane with varying proportions of higher hydrocarbons, exhibits calorific values typically ranging from 34 to 52 megajoules per cubic meter, depending on composition, producer quality, and regional characteristics. This variability reflects the heterogeneous nature of natural gas sources worldwide [5, 6]. In addition, the combustion of natural gas produces carbon dioxide emissions at rates ranging from 0.05 to 0.0567 kilograms of carbon dioxide per megajoule of energy released, [7 – 9].

Dimethyl ether, with the chemical formula C_2H_6O, presents different combustion characteristics that make it attractive for blending applications. Its volumetric calorific value ranges from 59.2 to 59.4 megajoules per cubic meter, notably higher than natural gas on a volumetric basis. A study by Pamungkas et al. [10] established that dimethyl ether combustion produces near-zero soot emissions, distinguishing it as a clean-burning fuel. However, according to Styring et al. [4], Uddin et al. [11], and Lu et al. [12] the complete environmental profile of dimethyl ether depends critically on its production pathway, which can range from conventional fossil-based synthesis to renewable power-to-X technologies utilizing captured carbon dioxide and green hydrogen.

Table 1 compares natural gas and dimethyl ether properties.

Table 1 Comparison of Natural Gas and Dimethyl Ether Properties

	Natural Gas (NG) / Methane (CH_4)	**Dimethyl Ether (DME)**	**Source**
Chemical Formula	CH_4	$CH_3–O–CH_3$	
Molecular Weight	16	46	
Oxygen Content		~34.8% Of Its Mass	[12]
Carbon-Carbon (C-C) Bonds	Present	Absent	
Oxygen-To-Carbon (O/C) Ratio	Lower	High	
Particulate Emissions	Higher	Significantly Reduced	[12]
Reactivity		Highly Reactive	[13]
CO_2 Emissions Per Mole	1 Mole CO_2	2 Moles CO_2	
Lower Heating Value (LHV)	~50-55 MJ/Kg (Gross Heating Value)	~28 MJ/Kg	[6]
Energy Density on Mass Basis	Higher	Lower	
Production Feedstocks	Fossil Fuel	Natural Gas, Coal, Biomass, CO_2	

Despite growing recognition of DME's potential and widespread natural gas utilization, significant knowledge gaps persist regarding fundamental properties and environmental performance of natural gas-DME fuel mixtures, creating substantial barriers to optimization, commercialization, and policy support. Insufficient quantitative understanding exists regarding how calorific values vary across the full range of blending ratios. While pure component properties are well-documented, non-ideal thermodynamic interactions between natural gas constituents and DME molecules remain inadequately characterized. The absence of validated predictive models represents a significant impediment to fuel development. The relationship between blend composition and carbon dioxide emissions during combustion has not been comprehensively modeled. Although studies demonstrate that pure DME produces lower CO_2 emissions than conventional fuels [4], the emissions profile of mixed fuels depends on complex combustion chemistry. Predictive models accounting for these variables are absent, creating uncertainty in environmental assessments. Critical questions regarding optimal blending ratios require answers grounded in accurate property predictions.

Hence the focus of this study is to develop and validate comprehensive mathematical models for predicting the calorific values and carbon dioxide emissions of natural gas and dimethyl ether mixtures across varying composition ranges, providing essential tools for fuel characterization, environmental assessment, and optimization supporting global energy transition.

II. MATERIALS AND METHODS

The predictive model for calorific values and carbon dioxide (CO_2) emissions of natural gas and dimethyl ether (DME) mixtures developed in this study is based on an integrated theoretical framework. The first component is the assumption of an ideal gas mixture for calculating volumetric calorific value. This is in line with the thermodynamic principles of an ideal gas mixture. According to Balmer [14], if the components of the mixture behave as an ideal gas, or the whole mixture behaves as an ideal gas, then all extensive properties are additive, and the partial specific properties reduce to the component-specific properties which then help produces simple working equations for all the intensive properties (v, u, h, and s) of the mixture.

The Second component is the use of a differential carbon accounting framework. For natural gas, the model assumes direct combustion emission, which is consistent with the U.S Environmental Protection Agency (EPA) standard for natural gas emission factor. While for DME, the model incorporates net carbon dioxide (CO_2) emissions based on the carbon footprint lifecycle i.e., the carbon dioxide used and emitted in its production process, and end-usage emissions. This lifecycle assessment of DME has been established by multiple literatures on the utilization of CO_2 for DME production [4].

The model was implemented in MS Excel for its accessibility and ease of deployment. Comparisons were done conceptually with the work of Zacepins et al. [15] although not directly applicable to DME, as gas mixture analysis. Their work on the economic modeling of natural gas and hydrogen gas mixture, includes the prediction for calorific values of the mixture and carbon reduction due to %volume of hydrogen added to the natural gas fuel system. This helps to provide the concept, in which the mathematical framework for the predictive model of this study for calorific values and CO_2 emissions of natural gas-DME mixture is formulated. For this study, the net CO_2 emission factor or well-to-wheel carbon footprint of DME data was adapted from the study by Styring et al. [4] which provides specific data points for the well-to-wheel carbon footprint of DME produced from different pathways. Tables 2 and 3 show the CO_2 emission factors of natural gas and DME.

Table 2 Range of CO_2 Emission Factors of Natural Gas

Emission factor (kg CO_2 per MJ)	**Sources**
0.05	[7]
0.0564	[8]
0.0561	[9]
0.056	[16]
0.055	[17]

Table 3 Net CO_2 Emissions Factor of DME When it is Produced Using Different Pathways

Electricity source for DME production	**Heat source for DME production**	**CO_2 source**	**WTW footprint (EU grid for CO_2 capture) [gCO_2eq/MJ]**	**Reduction over fossil comparator**	**WTW footprint (renewables for CO_2capture) [gCO_2eq/MJ]**	**Reduction over fossil comparator**
Offshore wind	Steam	Bioethanol	21.2	77%	17.8	81%
Offshore wind	Steam	DAC	44.7	53%	18.5	80%
Photovoltaic	Steam	Bioethanol	51.4	45%	48.0	49%
GB electricity	Steam	Bioethanol	124.9	Increased	121.6	Increased
Gb electricity	Steam	DAC	148.4	Increased	122.2	Increased
NL electricity	Steam	Bioethanol	204.1	Increased	200.8	Increased
FR electricity	Steam	Bioethanol	38.9	59%	35.5	62%
BE electricity	Steam	Bioethanol	95.1	Increased	91.8	2%
Offshore wind	Natural gas	Bioethanol	18.2	81%	14.8	84%
Offshore wind	MWI	Bioethanol	11.4	88%	8.1	91%

Source: Styring et.al, [4]

The mathematical framework for the model was conceptually adapted from [4] with an assumption of ideal gas fuel mixing principles and some modifications which were made to be applicable for natural gas and dimethyl ether (DME) mixture. The equations are as follows:

The volume of the pure components in the blend is calculated based on the total blend volume, which is a function of time (t) and consumption speed (V):

$$V_{blend} = V \times t \tag{1}$$

$$V_{Natural\ gas} = x_{Natural\ gas} \times V_{blend} \tag{2}$$

$$V_{DME} = x_{DME} \times V_{blend} \tag{3}$$

Where:

V_{blend} = Volume of mixture/blend (m^3); t = time of fuel consumption (hours);

V = Consumption speed (m^3/s); $X_{Natural\ gas}$ = amount of natural gas in the blend (%);

X_{DME} = amount of DME in the blend (%); $V_{Natural}$ gas = Volume of natural gas in the blend (m^3); V_{DME} = Volume of DME in the blend (m^3).

The calorific value of the blend (CV_{blend}) is calculated using a linear additive rule based on the volumetric fractions.

$$CV_{blend} = \frac{(CV_{Natural\ gas} \times V_{Natural\ gas}) + (CV_{DME} \times V_{DME})}{V_{blend}} \tag{4}$$

Where:

CV_{blend} = calorific value of the blend/mixture (MJ/m^3);

$CV_{Natural\ gas}$ = calorific value of natural gas (MJ/m^3);

CV_{DME} = calorific value of DME (MJ/m^3)

The CO_2 emissions model is formulated based on the differential carbon accounting framework. The total emissions of the blend (CO_2blend) are a summation of the contributions from each component

$$CO_{2\,(Fuel\ Mixture)} = (CO_{2\,Natural\ gas\ combustion} \times CV_{Natural\ gas} \times V_{Natural\ gas}) + (CO_{2\,DME} \times HV_{DME} \times V_{DME}) \tag{5}$$

Where:

$CO_{2\ Fuel\ mixture}$ = Combustion emission of gas blend/mixture (g CO_2e);

$CO_{2\ Natural\ gas\ combustion}$ = Direct combustion emission from natural gas (gCO_2e);

$CO_{2\ DME}$, = net lifecycle emission from DME (gCO_2e). This value can be negative

For comparative analysis, the model also calculates the potential calorific value and CO_2 emissions if only pure natural gas were used, as well as the resulting changes from blending.

$$CV_{Potential} = \frac{CV_{Natural\ gas} \times V_{blend}}{V_{blend}} \quad (6)$$

$$Potential\ CO_{2\ From\ Natural\ gas\ combustion} = CO_{2\ Natural\ gas\ combustion} \times CV_{Potential} \times V_{blend} \quad (7)$$

$$CV_{gained} = CV_{blend} - CV_{Potential} \quad (8)$$

$$Amount_{Reduced} = \frac{CV_{gained}}{CV_{blend}} \times 100\% \quad (9)$$

$$Volume_{Reduced} = Amount_{Reduced} \times V_{blend} \quad (10)$$

$$\begin{aligned} CO_{2\ Fuel\ Mixture\ reduced} &= (CO_{2\ Natural\ gas\ combustion} \times CV_{Natural\ gas} \\ &\times (x_{Natural\ gas} \times Volume_{Reduced})) \\ &+ (CO_{2\ DME} \times CV_{DME} \times (x_{DME} \times Volume_{Reduced})) \end{aligned} \quad (11)$$

$$CO_{2\ Potential\ of\ Fuel\ Mixture} = CO_{2\ Fuel\ mixture} - CO_{2\ Reduced} \quad (12)$$

$$CO_{2\ Emission\ Reduction} = \frac{CO_{2\ Fuel\ mixture\ reduced} - Potential\ CO_{2\ From\ Natural\ gas\ combustion}}{Potential\ CO_{2\ From\ Natural\ gas\ combustion}} / \times 100\% \quad (13)$$

Where:

$CV_{potential}$ = Potential heating value without DME in the blend (MJ/m^3);

Potential $CO_{2\ from\ natural\ gas\ combustion}$ = Potential CO_2 emissions of fuel mixture without DME (gCO_2e);

CV_{gained} = Gained heat value by addition of DME (MJ/m^3);

$Amount_{reduced}$ = Reduced fuel mixture volume required to compensate for the gain of heat value (%);

$Volume_{reduced}$ = Reduced fuel mixture volume required to compensate for the gain of heat value (m^3);

$CO_{2\ fuel\ mixture\ reduced}$ = Reduced fuel mixture CO_2 emission to compensate for volume of gas blend reduced (gCO_2e)

$CO_{2\ Potential\ of\ Fuel\ Mixture}$ = potential fuel mixture CO_2 emission of the same energy output as natural gas (gCO_2e);

$CO_{2\ Emission\ reduction}$ = Amount of CO_2 emission reduction due to (%) DME addition.

The model relies on defined input parameters that were sourced from multiple studies. The model was implemented in MS Excel for ease of computation. The model input parameters are summarized in Table 4.

Table 4 Range of CO_2 Emission Factors of Natural Gas

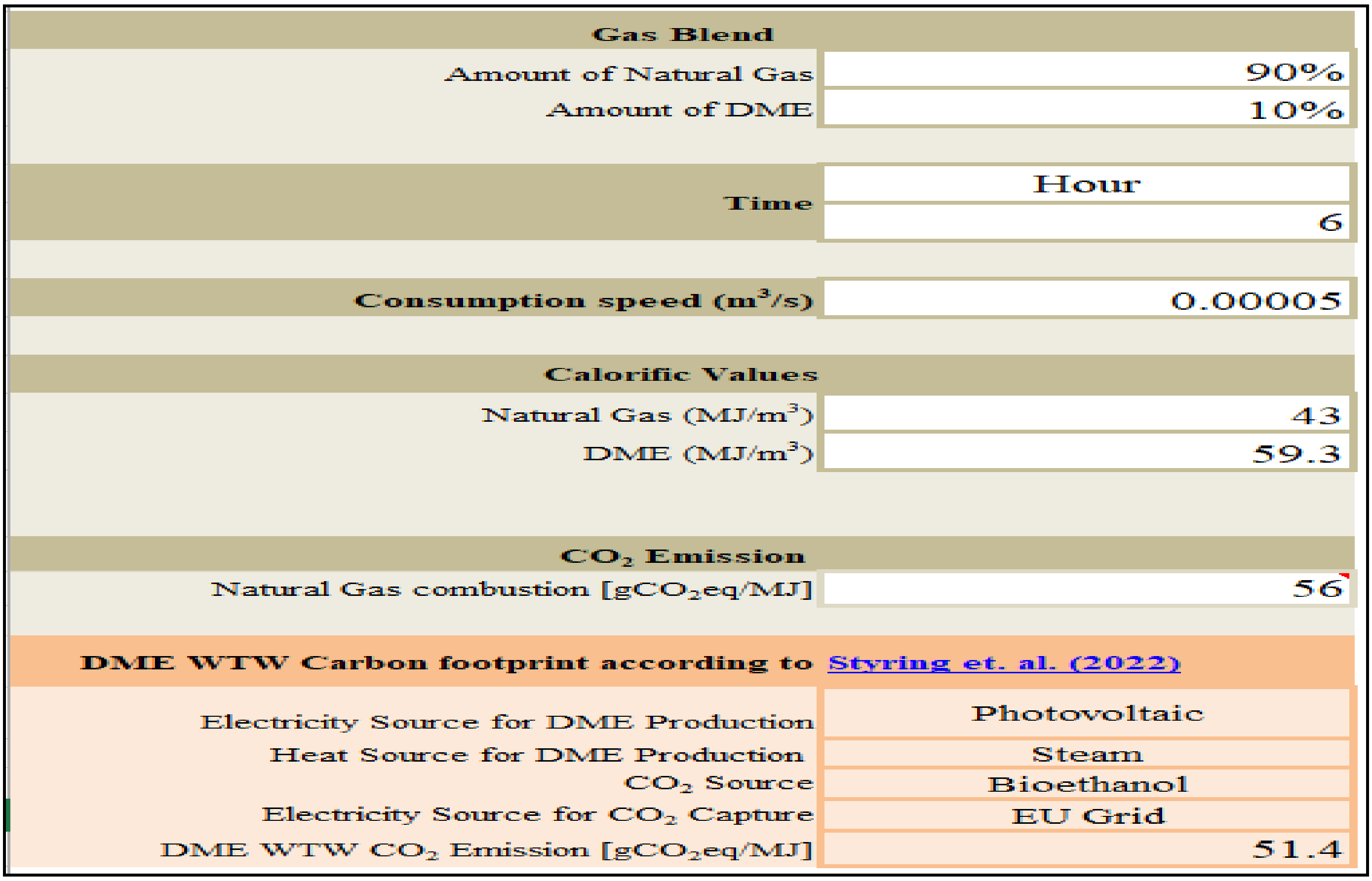
PROPERTY	SYMBOL	Range/Values
Amount of Natural Gas in the Gas Blend (%)	A_{NG}	0-100
Amount of DME in the Gas Blend (%)	A_{DME}	0-100
Time of Combustion (s)	t	21600 (6 hours)
Consumption Speed (m^3/s)	V	0.00005
Natural Gas Heat Value (MJ/m^3)	HV_{NG}	34 - 52
DME Heat Value (MJ/m^3)	HV_{DME}	59.2 – 59.4
Natural gas combustion CO_2 emission (gCO_2eq/MJ)	NG_{C02}	50-56.7
DME net CO_2 emission (gCO_2eq/MJ)	DME_{CO2}	8.1 – 204.1

With all input data entered, the next step was to calculate the calorific values and CO_2 emissions of the fuel mixture, and other properties (established in the mathematical formulation) using the input data. Furthermore, a comparative analysis was done to evaluate the differences in calorific values between natural gas and natural gas-DME blend.

Finally, a comparative analysis was conducted to evaluate the CO_2 emissions of the fuel mixture based on DME production pathways. This was done by varying the concentrations of DME in the blend while selecting different production pathways.

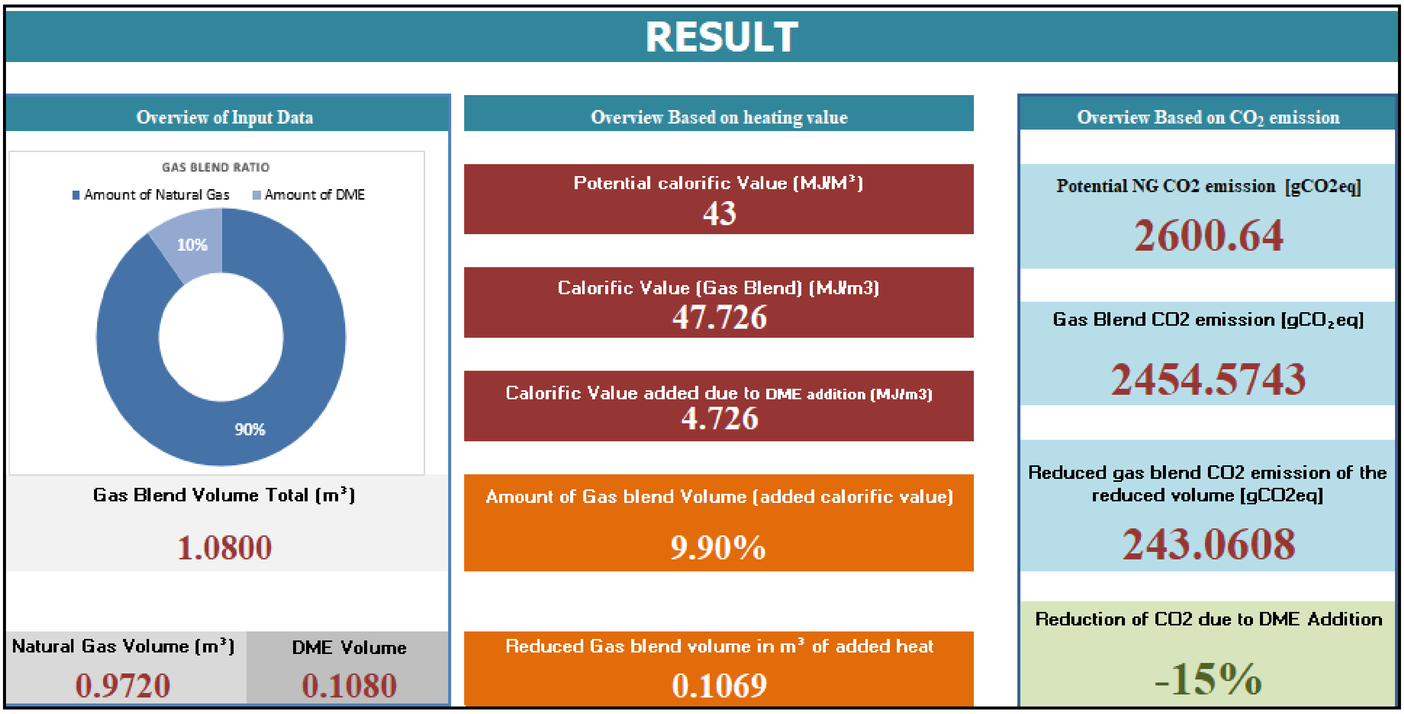
III. RESULTS AND DISCUSSION

For the presentation of calculations and predictive model results, an Excel interface was developed. This interface allows users to change several parameters, such as: amount of DME in the fuel mixture, consumption speed of the fuel mixture, calorific values, CO_2 emission factor, and DME production pathways. Figure 1. illustrates the User input. Figure 2 shows the model result for 20% of DME in the fuel mixture using the mid-range values of 43 MJ/m³ for natural gas and 59.3 MJ/m³ for DME, when the DME production pathways is: Solar photovoltaic as electricity source for DME production plant, steam as heat source for DME production, EU grid as electricity source for carbon capture technology, and Bioethanol plant as the source of bulk CO_2.



Gas Blend	
Amount of Natural Gas	90%
Amount of DME	10%
Time	Hour 6
Consumption speed (m^3/s)	0.00005
Calorific Values	
Natural Gas (MJ/m^3)	43
DME (MJ/m^3)	59.3
CO_2 Emission	
Natural Gas combustion [gCO_2eq/MJ]	56
DME WTW Carbon footprint according to	Styring et. al. (2022)
Electricity Source for DME Production	Photovoltaic
Heat Source for DME Production	Steam
CO_2 Source	Bioethanol
Electricity Source for CO_2 Capture	EU Grid
DME WTW CO_2 Emission [gCO_2eq/MJ]	51.4

Fig 1 User Input Interface



RESULT

Overview of Input Data

Gas Blend Volume Total (m^3)
1.0800

Natural Gas Volume (m^3)
0.9720

DME Volume
0.1080

Overview Based on heating value

Potential calorific Value (MJ/M^3)
43

Calorific Value (Gas Blend) (MJ/m3)
47.726

Calorific Value added due to DME addition (MJ/m3)
4.726

Amount of Gas blend Volume (added calorific value)
9.90%

Reduced Gas blend volume in m^3 of added heat
0.1069

Overview Based on CO_2 emission

Potential NG CO2 emission [gCO2eq]
2600.64

Gas Blend CO2 emission [gCO_2eq]
2454.5743

Reduced gas blend CO2 emission of the reduced volume [gCO2eq]
243.0608

Reduction of CO2 due to DME Addition
-15%

Fig 2 Result Interface for the Model

➢ *Impact of Natural Gas and DME Blending on Calorific Value*

Figure 3 shows that the calorific values of the fuel mixture (gas blend) increase with an increase in the percentage of DME.

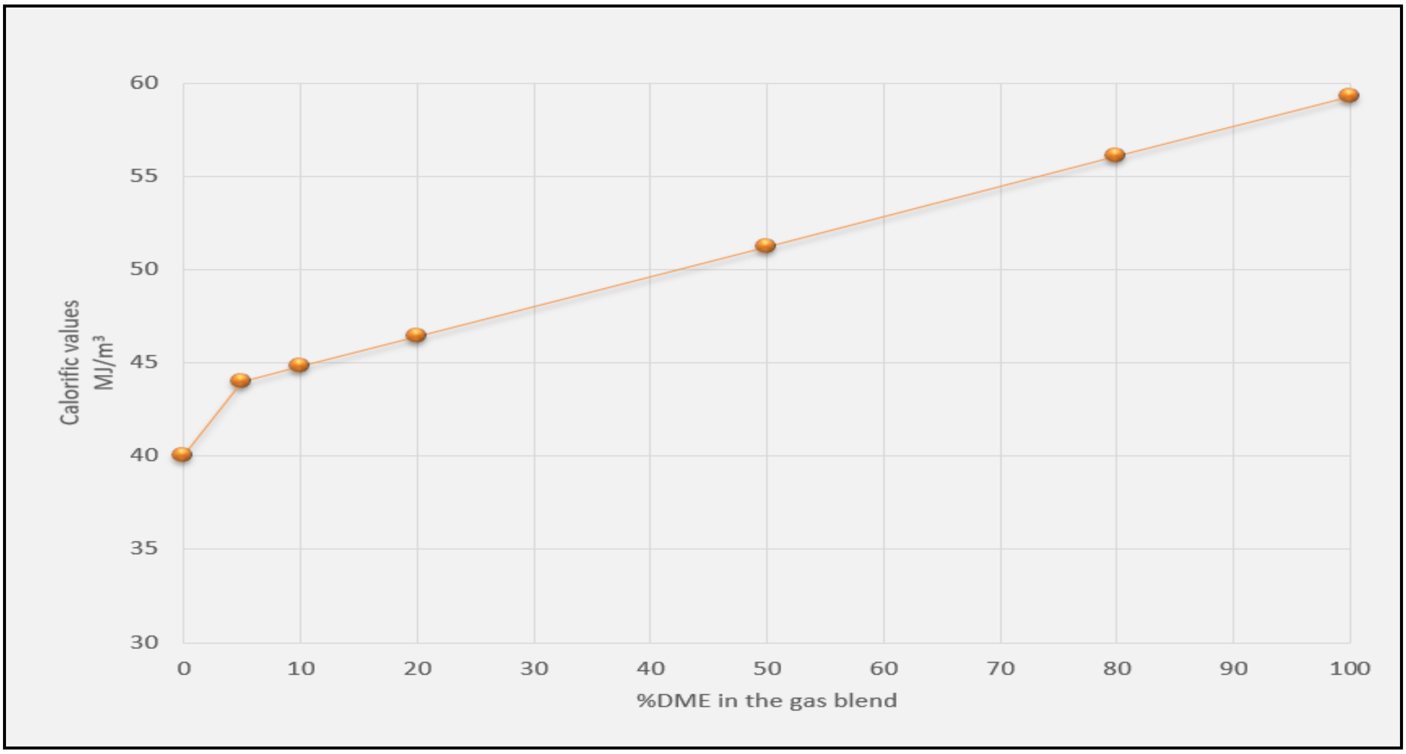


Fig 3 Impact of Varying % DME on Calorific Value.

The modeling results demonstrate a clear positive linear relationship between DME concentration and the volumetric calorific value of the fuel mixture (gas blend), as illustrated in Figure 3. This trend is consistent with fundamental thermodynamic principles governing ideal gas mixtures and is due to the substantial difference in volumetric energy densities between the two fuel components. With natural gas exhibiting a calorific value range of 34-52 MJ/m³ and DME ranging from 59.2-59.4 MJ/m³, the addition of DME systematically elevates the energy content per unit volume of the blend.

The rate of calorific value increase, represented by the slope of the relationship in Figure 3, is directly proportional to the differential between the selected natural gas and DME calorific values. For instance, when using mid-range values (43 MJ/m³ for natural gas and 59.3 MJ/m³ for DME), each 10% volumetric addition of DME increases the blend's calorific value by approximately 1.63 MJ/m³. This translates to a 3.8% improvement in volumetric energy density for every 10% DME substitution. At maximum DME concentration (100%), the energy density increases by approximately 38% compared to pure natural gas at these reference values.

This quantitative enhancement has profound implications for fuel consumption efficiency. Achieving equivalent energy delivery with the natural gas – DME (NG-DME) blend requires a proportionally reduced volumetric flow rate. For a 20% DME blend under the specified conditions, the model predicts a volume reduction of approximately 7.6% to deliver the same total energy as pure natural gas. This phenomenon is contrary to natural gas-hydrogen blending, where hydrogen's lower volumetric energy density (approximately 12.3 MJ/m³) necessitates increased flow rates to maintain equivalent energy output [15].

DME blending offers notable volumetric efficiency benefits but also poses infrastructure challenges. Reduced flow rates for the same energy output can:

- Ease pressure on transmission networks, extending capacity.
- Boost storage energy density, improving energy security.
- Lower volumetric fuel use in end applications, enhancing efficiency.

However, existing natural gas systems are designed for methane's combustion behavior. DME's higher cetane number, different air-fuel ratios, and altered flame characteristics require system adjustments [18]. A thorough infrastructure assessment should include experimental tests for combustion stability, efficiency across blend ratios, safety evaluations, and cost–benefit analyses—especially for large-scale industrial and power generation systems where reliability is critical.

➢ *Impact of DME Blending on Carbon Dioxide Emissions*

The analysis of CO_2 emissions from NG-DME blends reveals a critically important finding: the environmental performance of these fuel mixtures is not inherently determined by the DME component itself, but rather is fundamentally contingent upon the production pathway employed for DME synthesis. This conclusion, supported by the comparative analysis presented in Figure 4, demonstrates that the relationship between DME concentration and net carbon emissions can be either strongly negative (indicating substantial emissions reductions) or strongly positive (indicating emissions increases) depending exclusively on the carbon intensity of the DME production process.

For DME produced via renewable energy-based Power-to-X pathways, the model predicts significant and progressive emissions reductions as DME concentration increases:

- *Offshore Wind + Microwave Irradiation (MWI):*

This pathway, with a well-to-wheel carbon footprint of only 8.1 gCO_2eq/MJ (as reported by Styring et al., 2022), represents the most environmentally favorable production route. At 20% DME concentration, this pathway achieves approximately 17% CO_2 emissions reduction compared to pure natural gas. At 50% DME, emissions reductions exceed 42%, and at 100% DME (representing complete displacement of natural gas), emissions are reduced by approximately 85% relative to pure natural gas combustion.

- *Offshore Wind + Natural Gas Heat and Offshore Wind + Steam:*

These pathways, with carbon footprints of 14.8 and 17.8 gCO_2eq/MJ respectively, also deliver substantial emissions reductions, though somewhat less dramatic than the MWI pathway. For a 50% blend, these pathways achieve approximately 35-40% emissions reductions.

- *Solar Photovoltaic + Steam:*

This pathway (48.0 gCO_2eq/MJ) provides moderate emissions reductions, with a 50% blend achieving approximately 14-16% reduction compared to pure natural gas. Conversely, DME produced using carbon-intensive electricity grids results in emissions increases rather than reductions:

- *GB (Great Britain) Electricity + Steam:*

With a carbon footprint of 121.6 gCO_2eq/MJ, this pathway produces net emissions significantly higher than natural gas combustion (approximately 50-56 gCO_2eq/MJ). A 50% blend using this DME production pathway would result in approximately 55% higher emissions compared to pure natural gas.

- *NL (Netherlands) Electricity + Steam:*

This represents the most carbon-intensive pathway examined (200.8 gCO_2eq/MJ), with 50% blending resulting in emissions increases exceeding 100% compared to pure natural gas baseline.

These findings conclusively demonstrate that the descriptor “clean” or “green” for DME is misleading without explicit specification of production pathway. The 25-fold variation in well-to-wheel carbon footprints (from 8.1 to 204.1 gCO_2eq/MJ) across different production routes indicates that production methodology, rather than fuel chemistry alone, determines environmental outcomes.

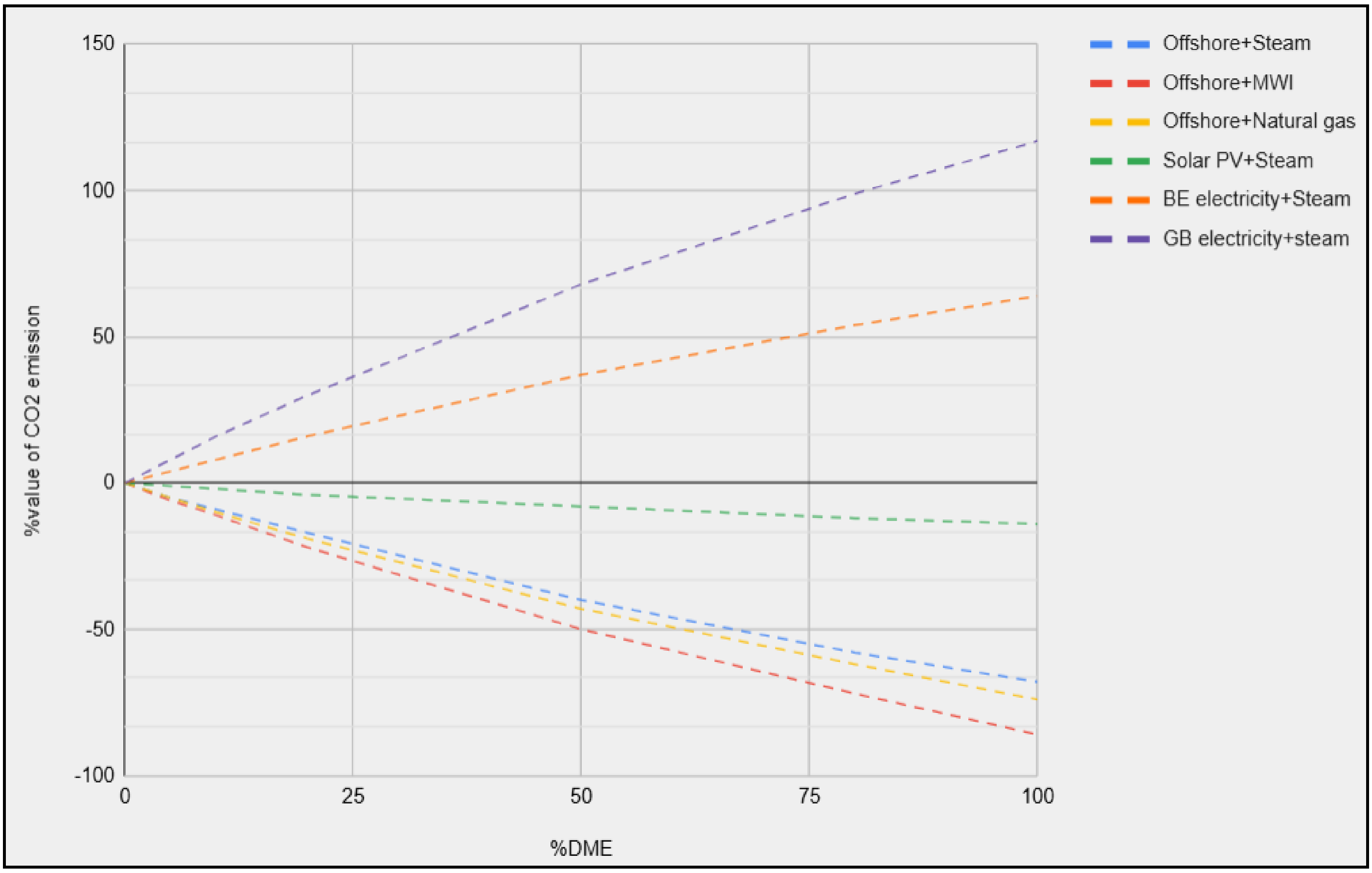


Fig 4 Comparison of Fuel Mixture Emission Based on DME Production Pathways

- *Comparison of Fuel Mixture to Natural Gas-Hydrogen Mixture Based on the Amount of Energy Released*

The model's result in Figure 2 shows a reduction in the fuel mixture volume if the same energy output, i.e., the potential calorific value of 100% natural gas fuel, is to be considered. Figure 5 shows the comparison for the same energy output between a natural gas-hydrogen fuel mixture (the values were adapted from the model built by Zacepins et al. [15] and a natural gas-dimethyl ether (DME) mixture in this study. The blue bar represents the volume of 100% natural gas, while the yellow bar shows the resulting volume after adding either hydrogen or DME. Notably, hydrogen addition increases the volume, whereas DME addition decreases it, reflecting their differing energy release characteristics compared to pure natural gas.

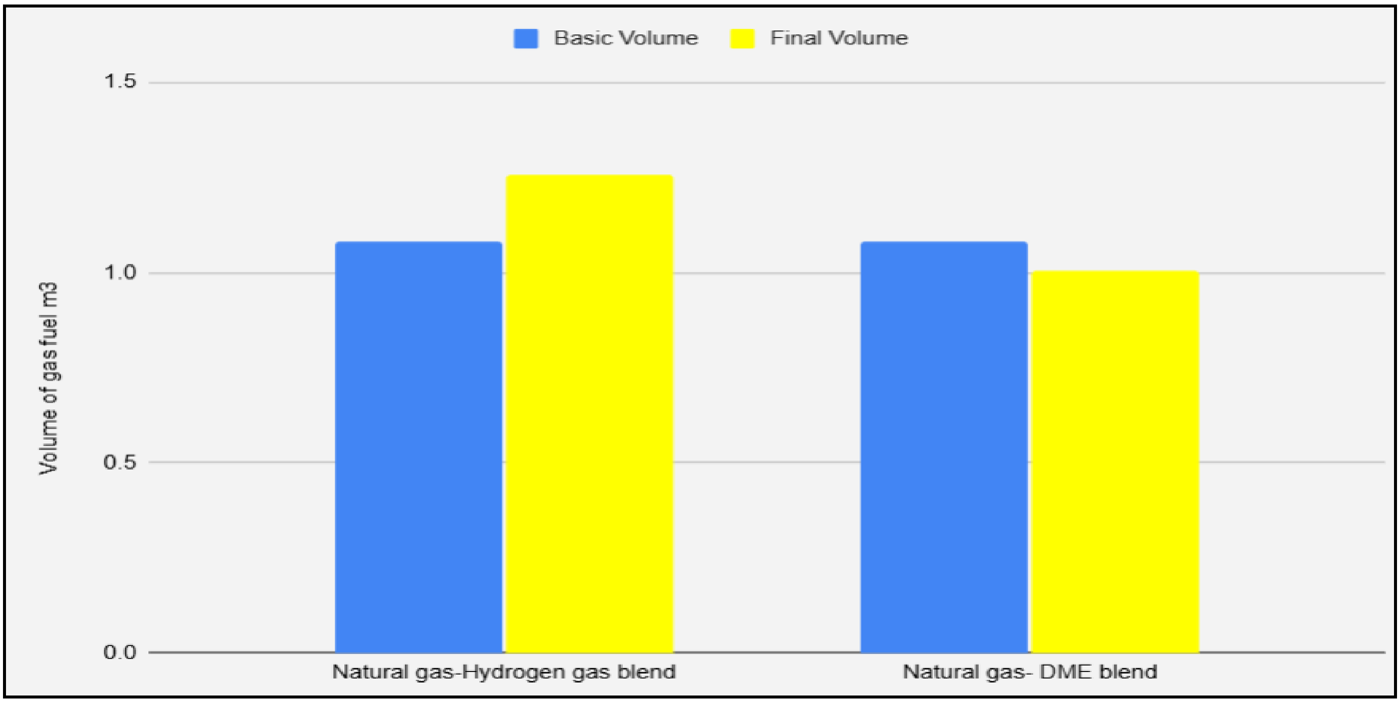


Fig 5 Comparison of Volume Used Based on the Amount of Energy Released

- *Model Validation and Comparison with Published Literature*

Although no experimental data currently exist for natural gas–DME mixtures, the model's predictions align with thermodynamic theory and observed behavior in similar fuel systems, supporting its validity. The linear relationship between blend composition and calorific value reflects the additive nature of energy in ideal gas mixtures [14]. Comparison with the natural gas–hydrogen model by Zacepins et al. [15] shows consistent similarities and relationships, with differences in volumetric flow reflecting the distinct energy densities of hydrogen and DME—further reinforcing the model in this study theoretical basis.

The emissions model in this study aligns closely with empirical lifecycle data, using pathway-specific carbon footprints from Styring et al. [4] who conducted detailed well-to-wheel analyses for nine DME production routes. Similar studies by Lu et al. [12] and Issayev et al. [13] further confirm DME's high reactivity, strong energy contribution, and efficient combustion—reinforcing the reliability of this study. Furthermore, the predicted CO_2 reductions for renewable DME match findings by Kim and Boehman [19] who reported about 50% lower emissions for DME-glycerol blends, and Rossi et al. [20] who observed similar benefits in LPG/DME-fueled Euro 6 vehicles.

IV. CONCLUSION

This study developed and validated mathematical models for predicting the calorific value and CO_2 emissions of natural gas–DME mixtures across different blend ratios. The models fill key gaps in existing research and provide useful tools for evaluating fuel performance and environmental impact in the context of global energy transition goals.

Results show that DME blending increases the heating value of natural gas in a nearly linear pattern—each 10% DME addition raises energy density by about 3.8%, and a 100% DME blend provides roughly 38% more energy per unit volume than pure natural gas. This means less gas volume is needed to deliver the same energy, unlike hydrogen blends, which increase flow requirements.

The CO_2 emissions model, based on lifecycle assessment, demonstrates that environmental outcomes depend heavily on how DME is produced. Renewable Power-to-X routes using wind energy can cut emissions by over 85%, while fossil-based electricity sources may raise them. This underscores the fact that production pathway and not just fuel chemistry play a critical role in determining true environmental impact.

Though direct experimental validation is still lacking, the models align well with thermodynamic theory and comparable fuel systems, making them reliable theoretical tools. Their insights support fuel design, infrastructure planning, and policy development, while also guiding future experimental studies.

DECLARATIONS

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➢ *Competing Interest:*

The authors have no competing interests to declare that are relevant to the content of this article.

➢ *Author Contribution*

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Adeyemi Taofeek Opemipo, Ekanem Stephen Anthony and Victor Joseph Aimikhe. The first draft of the manuscript was written by Adeyemi Taofeek Opemipo and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

REFERENCES

[1]. CEDIGAZ. (2025). CEDIGAZ first estimates 2025. Available at https://www.cedigaz.org/cedigaz-first-estimates-2025/

[2]. United Nations Development Programme. (2025). What is the sustainable energy transition and why is it key to tackling climate change? Available at https://climatepromise.undp.org/news-and-stories/what-sustainable-energy-transition-and-why-it-key-tackling-climate-change

[3]. Fortune Business Insights. (2024). Dimethyl ether [DME] market size, analysis: Global report 2024-2032. Available at https://www.fortunebusinessinsights.com/dimethyl-ether-market-104309

[4]. Styring, P., Sanderson, P. W., Gell, I., Skorikova, G., Sánchez Martínez, C., García García, G., & Sluijter, S. N. (2022). Carbon footprint of Power-to-X derived dimethyl ether using the sorption-enhanced DME synthesis process. Frontiers in Sustainability, 3, 1057190. https://doi.org/10.3389/frsus.2022.1057190

[5]. MET Group. (2021). Calorific value of natural gas. Available at https://group.met.com/en/media/energy-insight/calorific-value-of-natural-gas/

[6]. The Engineering ToolBox (2003). Higher Calorific Values of Common Fuels: Reference & Data. Available at: https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html

[7]. The Engineering ToolBox (2009). Combustion of Fuels - Carbon Dioxide Emission. Available at https://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html

[8]. Energy Transition Model. (n.d.). Emission. Available at https://docs.energytransitionmodel.com/main/co2-emission-factors/

[9]. U. S E.P.A, (2024), Greenhouse Gas Equivalencies Calculator - Calculations and References. Available at https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator-calculations-and-references

[10]. Pamungkas, W. A., Budiman, A. W., Inayati, I., Margono, M., Sembodo, B. S. T., Mersitarini, D., … & Mahendra, I. (2024). A Review of DME Manufacturing: Process and Catalyst Studies. In E3S Web of Conferences (Vol. 481, p. 01002). EDP Sciences

[11]. Uddin, Md Mosleh; Simson, Amanda; Wright, Mark Mba, (2020). "Techno-economic and greenhouse gas emission analysis of dimethyl ether production via the bi-reforming pathway for transportation fuel," Energy, Elsevier, vol. 211(C).

[12]. Lu, M., Fu, Z., Yuan, X., Wu, J., & Sabir, S. W. (2021). Numerical Simulation of Turbulent Non-premixed Combustion Processes for Methane and Dimethyl Ether Binary Fuels. ACS omega, 6(10), 6629–6642. https://doi.org/10.1021/acsomega.0c05418

[13]. Issayev G, Giri B.R, Elbaz A.M, Shrestha K.P, Mauss F, Roberts W.L, Farooq A. (2022). Ignition delay time and laminar flame speed measurements of ammonia blended with dimethyl ether: A promising low carbon fuel blend, Renewable Energy, Volume 181, 1353-1370. https://doi.org/10.1016/j.renene.2021.09.117.

[14]. Balmer R. T., (2011). Modern Engineering Thermodynamics, ScienceDirect, ch. 12, pg 405. https://doi.org/10.1016/C2009-0-20199-1

[15]. Zacepins, A., Kotovs, D., Komasilovs, V., & Kviesis, A. (2024). Economic Modelling of Mixing Hydrogen with Natural Gas. Processes, 12(2), 262. https://doi.org/10.3390/pr12020262

[16]. Hone, D. (2011). Natural gas, CO_2 emissions and climate change. Shell Blogs. https://blogs.shell.com/2011/09/19/naturalgas/

[17]. Howarth, R. W., & Marino, R. (2019). Fossil Fuel Emissions. Available at https://www.research.howarthlab.org/fossilfuelemissions.php

[18]. Anggarani, Riesta & Setyo Wibowo, Cahyo & Rulianto, Dimitri. (2014). Application of Dimethyl Ether as LPG Substitution for Household Stove. Energy Procedia. 47. 227–234. 10.1016/j.egypro.2014.01.218.

[19]. Kim T and Boehman A. L (2023). Development of novel dimethyl ether – Glycerol blends with improved viscosity and miscibility for potential compression-ignition engine application. Fuel, 346(39):128301. DOI:10.1016/j.fuel.2023.128301

[20]. Rossi T, Lixi S, Grosso M, and Puricelli S (2024). Fuel consumption and exhaust emissions from Euro 6d vehicles fueled by innovative LPG/DME blend. Journal of the Energy Institute 117(2):101851. DOI:10.1016/j.joei.2024.101851