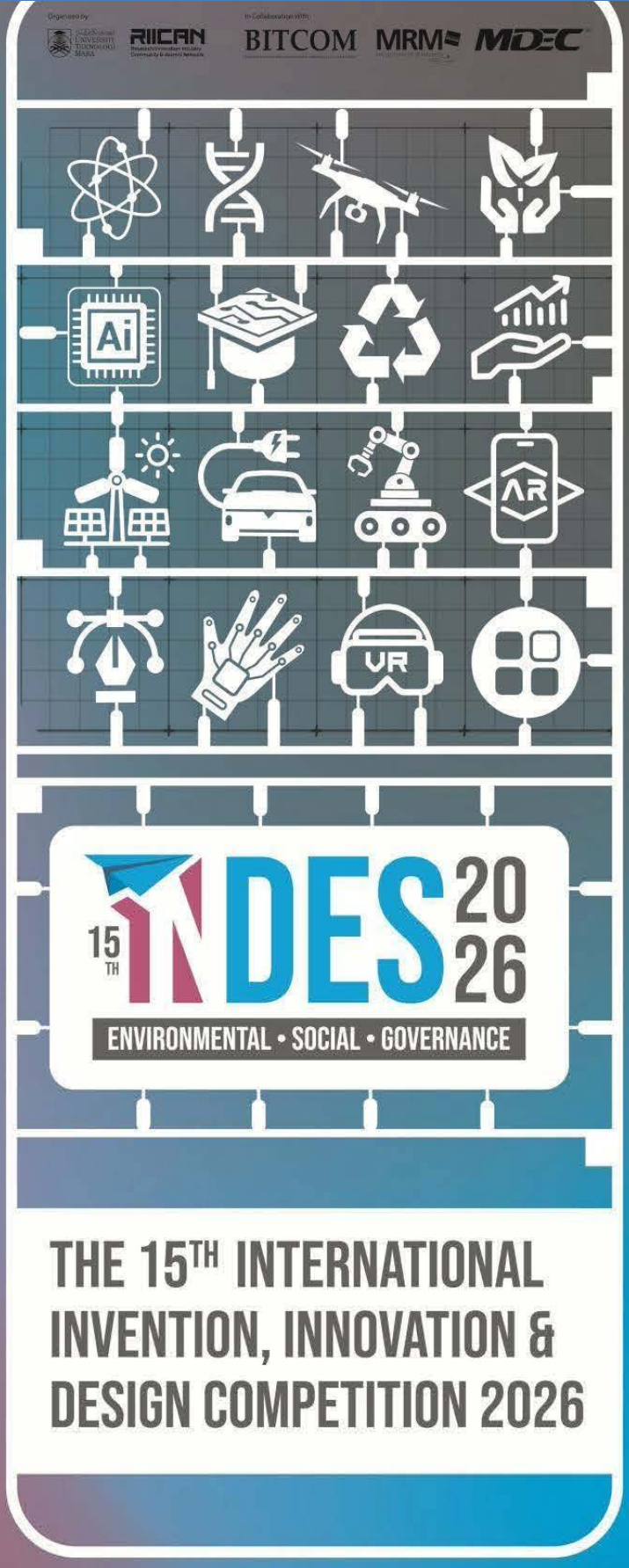


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THE 15th INTERNATIONAL
INVENTION, INNOVATION &
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Delphi: Dynamic Simulation Application for Intelligent CO_2 Emission Prediction in Scope 1 Monitoring for Small-Scale Facility Planning

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ABSTRACT

The oil and gas industry remains one of the largest contributors to global CO_2 emissions, accounting for nearly 15% of energy-related emissions (IEA, 2023). In Malaysia, small-to-mid-scale facilities such as modular platforms, crude refineries, and satellite production units face increasing pressure to quantify and mitigate their Scope 1 emissions from combustion and process equipment. Current estimation methods are mostly retrospective, relying on post-operational data, which limits their usefulness during the design and planning phases. To address this limitation, this project introduces a digital simulation platform that enables early-stage emission assessment and efficiency analysis for small-scale facility configurations. Delphi, a web-based application, is a system that allows users to create and configure, save, and load multiple facility projects. It integrates a 3D interactive layout configuration tool, enabling users to define equipment while automatically computing the total crude throughput, power generation, and corresponding scope 1 CO_2 emissions, thus evaluating the efficiency of facilities configuration quantitatively and analytically, as well as the integration of AI analysis. On the ground factor, the emission estimation engine incorporates standardized methodologies from the IPCC (2006), US EPA (2023), API Compendium (2009), and IOGP Report 446 (2022) to ensure industrial accuracy and credibility.

Keyword: Emission modelling; process simulation; facility layout optimisation; combustion-based estimation; carbon intensity analysis; AI-driven engineering insights

1. INTRODUCTION

To address the limitations of manual application of established standards, Delphi was developed as a lightweight, web-based CO_2 simulation platform that integrates facility layout modelling with standardized emission calculation methodologies. The system incorporates 3D facility's equipment layout, configurable parameters, real-time estimation of combustion and process-related emissions, and dynamic visualizations of carbon intensity, fuel distribution, and equipment contributions. An embedded AI-assisted analytical module (Delphi GPT) enhances interpretability by summarizing emission patterns and generating optimisation recommendations [6].

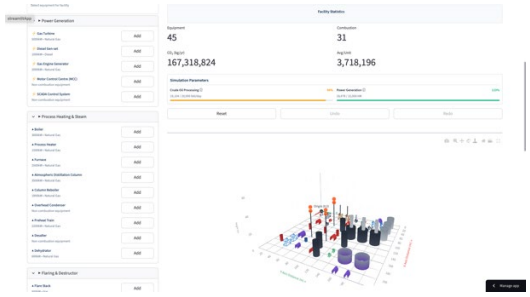


Figure 1 3D Facility Canvas

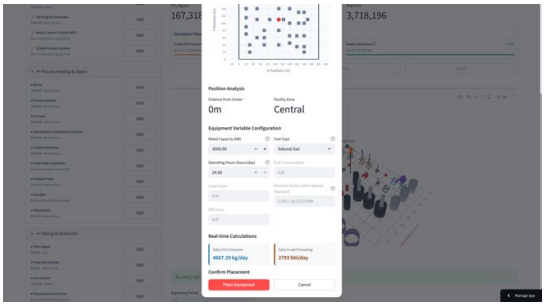


Figure 2 Equipment Configuration

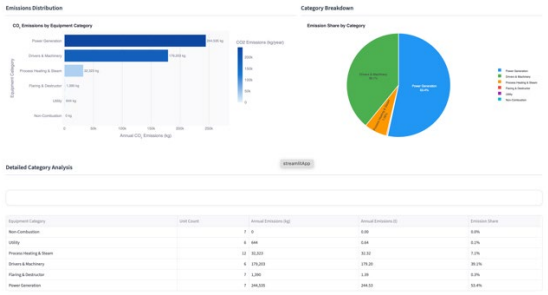


Figure 3 Data Analytics and Visualization

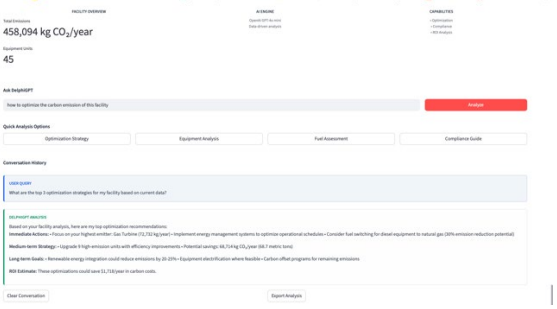


Figure 4 Delphi GPT

2. METHODOLOGY

2.1 System Architecture

The methodology adopted in this study integrates engineering-based emission modelling with digital simulation architecture to enable real-time Scope 1 CO_2 estimation for small-scale oil and gas facilities. The approach consists of three main components: system architecture design, standardized emission quantification, and AI-assisted analytical processing. The Delphi platform was developed using a modular web-based architecture built with Python. CSS and Streamlit framework. The system incorporates three core layers: (i) a front-end interface for facility layout modelling, (ii) a back-end emission engine for standardized CO_2 calculations, and (iii) a reporting module for visualisation and performance evaluation. The front-end employs a 3D grid-based canvas, coordinate placement functionalities with configurable operating parameters.

2.2 Emission Calculation Engine

Emission calculations follow established Scope 1 methodologies from the IPCC Guidelines [1], API Compendium [2], and EPA stationary combustion protocols [3], supported by organisational quantification requirements under ISO 14064 [4] and IOGP performance indicators [5]. It applies a Tier 1 activity-based approach, where emissions are computed by fuel consumption, heating duty, or power demand multiplied by the corresponding emission factors. The general model is expressed as:

$$CO_2 = ActivityRate \times EmissionFactor$$

Equipment-specific factors, including those for natural gas, diesel, LPG, and combustion air demand were embedded into the engine. Multi-scenario configurations allow users to modify load conditions, equipment combinations, and operating hours to perform comparative assessments.

Table 1 Emission Engine Standards

Dataset	Used For	Data

IPCC 2006 Guidelines – Volume 2 (Energy)	Tier 1–2 CO_2 emission factors	Natural Gas; 56.1 $kgCO_2/GJ$
API Compendium 2009	Equipment-specific combustion factors	Gas Turbine (NG); 58-60 $kgCO_2/GJ$
ISO 14064-1:2018	GHG accounting & reporting framework	*CO = ActivityData x EF*
IOGP Report 446	Carbon intensity benchmarking	0.15 – 0.20 tCO_2 / tonne crude

3. FINDINGS

3.1 Facility Simulation Configuration

Table 2 Emission Engine Standards

	Facility Configuration		Performance Metrics	
	Medium Load	High Load	Unit	Benchmark
No. of Equipment	18	32	Count	-
Major Equipment	Heater, Boiler, Compressor, Pump	Gas Turbine, Diesel Gen-set, Heater, Flare, Reboiler	-	-
Power Output	8500	18200	kW	-
Daily Throughput	6800	14000	barrels/day	-
Fuel Type	Natural Gas, Diesel	Natural Gas, Diesel	-	-
CO_2 Emission	180-240	380-520	tCO_2/day	-
CO_2 per Equipment	10-13	12-16	tCO_2/day/unit	-
CO_2 Intensity	0.15-0.18	0.17-0.20	tCO_2/tonne crude	0.15-0/20
Energy Intensity	0.95-1.05	1.00-1.12	$kgCO_2$/kWh	0.90-1.20

Note. CO2 = Carbon dioxide. Benchmark values are based on IOGP Report 446 and upstream emission intensity studies in the Asia-Pacific region.

The performance of Delphi was evaluated using representative facility configurations to assess its capability in modelling Scope 1 CO_2 emissions under varying operating conditions. The medium-load configuration, incorporating heaters, boilers, and compressors, produced approximately 180–240 tCO_2/day, while the high-load configuration, consisting of gas turbines, diesel generators, and full process units, generated significantly higher emissions of 380–520 tCO_2/day. These results align with upstream benchmarks reported by Acevedo Blanco and Gallo [7] and Li et al. [9], where it consistently contributes the majority of emissions in small to mid-scale production systems.

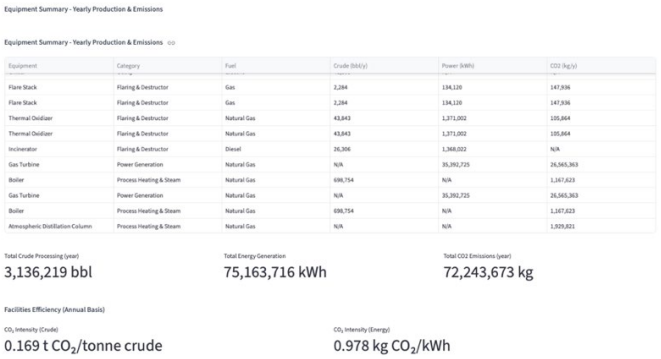


Figure 5 Production & Emission for High Load Facility

3.2 Tolerance Validation

$$Fuel\ Input = \frac{Rated\ Capacity}{Thermal\ Efficiency}$$

$$Fuel\ Input = \frac{3000}{0.85} = 3529.41\ kW_{thermal}$$

$$Energy_{daily} = 84{,}705.88\ kWh/day$$

$$CO_2 = Energy_{daily} \times EF$$

$$CO_2 = 84{,}705.88 \times 0.0551$$

$$CO_{2base} = 4662.24\ kgCO_2/day$$

$$CO_{2,adjusted} = CO_2 \times F_{combustion} \times F_{operation}$$

$$CO_{2,adjusted} = 4662.24 \times 0.95 \times 0.90$$

$$CO_{2,adjusted} = 3986.22\ kgCO_2/day$$

$$Tolerance = \frac{3986.22 - 4662.24}{4662.24} \times 100\%$$

$$\boldsymbol{Tolerance = -14.5\%}$$

The emission calculation is based on energy-derived fuel consumption, where fuel input is obtained by dividing the rated capacity by thermal efficiency. The resulting energy output is converted into daily energy consumption, which is then multiplied by a standardized emission factor to estimate baseline CO_2 emissions. Adjustment factors accounting for combustion efficiency and operational conditions are applied to improve accuracy. The results indicate a **reduction of approximately 14.5% from the baseline emission**, reflecting real-world system performance

4. CONCLUSION

This study developed Delphi, a lightweight web-based platform for early-stage CO_2 emission assessment in small-scale oil and gas facilities. By integrating facility layout modelling with standardized Scope 1 methodologies (IPCC [1], API [2], EPA [3], ISO 14064 [4], and IOGP [5]) and real-time visualisation, the system enables rapid and consistent emission estimation at both equipment and facility levels. Scenario testing showed strong alignment with established upstream benchmarks [7]–[11], confirming its suitability for conceptual design and early decision-making. The integration of AI-driven insights further enhances usability by supporting interpretation and optimisation of emission performance. Although currently limited to Scope 1 and small-scale applications, Delphi provides a scalable foundation for future expansion across broader emission scopes and industrial domains.

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