

Development of Scope 1 GHG Emission Data Acquisition System Based on IoT Platform Using MQTT and ThingSpeak in the Mining Industry

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Abstract—The reporting process of Greenhouse Gas (GHG) emissions in Indonesia remains largely manual, resulting in inefficiencies and inaccuracy, especially within the industrial sector. This study introduces an IoT-based integrated system to automate data acquisition, calculation, and Scope 1 emission reporting. Utilizing MQTT protocol, the system collects real-time CO₂ and CH₄ sensor data, stores it in the ThingSpeak platform, and transfers it to a Laravel database for automated reporting. An iterative-incremental model was applied for development. Functional testing and expert validation confirmed the system's ability to operate continuously and generate reports aligned with national GHG standards.

Keywords—Greenhouse gas, Scope 1, Internet of Things, MQTT, ThingSpeak, automated reporting

I. INTRODUCTION

Indonesia targets a 29% reduction in GHG emissions by 2030 as part of its national commitment to climate mitigation [1]. The mining industry, being one of the largest emission contributors, is under pressure to provide transparent and accurate reports. Unfortunately, current reporting practices remain manual, which causes delays and a lack of precision [2].

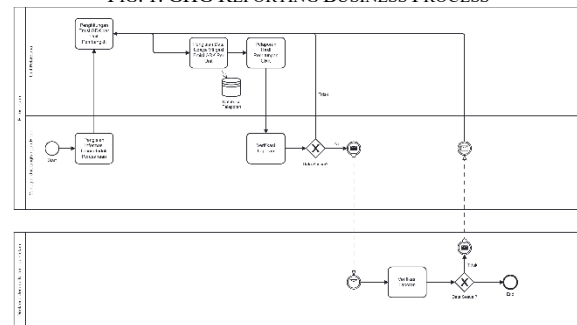
With the advancement of sensor and IoT technology, industries can adopt automated solutions for real-time monitoring. Systems that utilize low-cost sensors to detect CH₄ and CO₂ have proven effective in industrial monitoring [3]. However, these solutions must also align with standardized reporting frameworks, such as those defined by the Intergovernmental Panel on Climate Change (IPCC) [4].

II. SYSTEM ARCHITECTURE

The system uses gas sensors connected to an ESP32 microcontroller. It transmits emission data via MQTT protocol to ThingSpeak cloud services, chosen for its reliability in low-latency IoT applications [5]. The data is then synchronized to a Laravel web database, where further calculations and reports are generated.

Fig. 1 illustrates the business process of emission data acquisition and reporting within the mining industry.

FIG. 1. GHG REPORTING BUSINESS PROCESS



III. METHODOLOGY

An iterative incremental development model was adopted. The project was divided into three main phases:

- Phase 1: Sensor data acquisition and MQTT integration.
- Phase 2: Emission calculation based on fuel consumption and methane volume.
- Phase 3: Report generation and expert validation.

Each phase included analysis, implementation, and functional testing to ensure system performance.

IV. IMPLEMENTATION

A. Data Acquisition Module

The sensors detect gas concentrations and send values to ThingSpeak every 60 seconds. A multithreaded Python script retrieves this data using ThingSpeak's API and stores it locally.

FIG. 2. SENSOR DATA ACQUISITION AND LOG OUTPUT

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[2025-06-20 13:40:37.481] [INFO] [SensorFetcher] Inserted entry id 5004
[2025-06-20 13:40:37.491] [INFO] [SensorFetcher] Inserted entry id 5005
[2025-06-20 13:40:37.501] [INFO] [SensorFetcher] Inserted entry id 5006
[2025-06-20 13:40:37.511] [INFO] [SensorFetcher] Inserted entry id 5007
[2025-06-20 13:40:37.521] [INFO] [SensorFetcher] Inserted entry id 5008
[2025-06-20 13:40:37.531] [INFO] [SensorFetcher] Inserted entry id 5009
[2025-06-20 13:40:37.541] [INFO] [SensorFetcher] Inserted entry id 5010
[2025-06-20 13:40:37.551] [INFO] [SensorFetcher] Inserted entry id 5011
[2025-06-20 13:40:37.561] [INFO] [SensorFetcher] Inserted entry id 5012
[2025-06-20 13:40:37.571] [INFO] [SensorFetcher] Inserted entry id 5013
[2025-06-20 13:40:37.581] [INFO] [SensorFetcher] Inserted entry id 5014
[2025-06-20 13:40:37.591] [INFO] [SensorFetcher] Inserted entry id 5015
[2025-06-20 13:40:37.601] [INFO] [SensorFetcher] Inserted entry id 5016
[2025-06-20 13:40:37.611] [INFO] [SensorFetcher] Inserted entry id 5017
[2025-06-20 13:40:37.621] [INFO] [SensorFetcher] Inserted entry id 5018
[2025-06-20 13:40:37.631] [INFO] [SensorFetcher] Inserted entry id 5019
[2025-06-20 13:40:37.641] [INFO] [SensorFetcher] Inserted entry id 5020
[2025-06-20 13:40:37.651] [INFO] [SensorFetcher] Inserted entry id 5021
[2025-06-20 13:40:37.661] [INFO] [SensorFetcher] Inserted entry id 5022
[2025-06-20 13:40:37.671] [INFO] [SensorFetcher] Inserted entry id 5023
[2025-06-20 13:40:37.681] [INFO] [SensorFetcher] Inserted entry id 5024
[2025-06-20 13:40:37.691] [INFO] [SensorFetcher] Inserted entry id 5025
[2025-06-20 13:40:37.701] [INFO] [SensorFetcher] Inserted entry id 5026
[2025-06-20 13:40:37.711] [INFO] [SensorFetcher] Inserted entry id 5027
[2025-06-20 13:40:37.721] [INFO] [SensorFetcher] Inserted entry id 5028
[2025-06-20 13:40:37.731] [INFO] [SensorFetcher] Inserted entry id 5029
[2025-06-20 13:40:37.741] [INFO] [SensorFetcher] Inserted entry id 5030
[2025-06-20 13:40:37.751] [INFO] [SensorFetcher] Inserted entry id 5031
[2025-06-20 13:40:37.761] [INFO] [SensorFetcher] Inserted entry id 5032
[2025-06-20 13:40:37.771] [
```

$$E = \sum (A_i \cdot EF_i \cdot X_i) \quad (1)$$

Where E is total emissions, A_i is activity data, EF_i is emission factor, and CF is the correction factor.

C. Report Generation

The system generates daily, monthly, and annual reports in tabular form and exports them via the Laravel dashboard.

FIG. 3. EMISSION REPORTING LOG OUTPUT

```

2025-06-20 13:40:28,065 [WARNING] [Report] Invalid sensor id for GHG 2025 06 19, skipping to avoid FK error.
2025-06-20 13:40:28,065 [WARNING] [Report] Invalid sensor id for GHG 2025 06 19, skipping to avoid FK error.
2025-06-20 13:40:28,766 [WARNING] [Report] Invalid sensor id for GHG 2025 06 19, skipping to avoid FK error.
2025-06-20 13:40:28,766 [WARNING] [Report] Invalid sensor id for GHG 2025 06 19, skipping to avoid FK error.
2025-06-20 13:40:28,856 [INFO] [FugitiveEmission] waiting for 24 hours before the next run...
2025-06-20 13:40:28,941 [INFO] [Report] Insertion GHG_2025_06_09 inserted.
2025-06-20 13:40:29,035 [INFO] [Report] Insertion GHG_2025 06 08 inserted.
2025-06-20 13:40:29,172 [INFO] [Report] Insertion GHG_2025_06_07 inserted.
2025-06-20 13:40:29,224 [INFO] [Report] Insertion GHG_2025 06 06 inserted.
2025-06-20 13:40:29,311 [INFO] [Report] Insertion GHG_2025 06 05 inserted.
  
```

V. RESULTS AND DISCUSSION

The system performed continuous 24-hour cycles with less than 3% packet loss during sensor-to-cloud transmission. Emission values matched manual calculations with <5% deviation. Reports were verified by an environmental expert and met reporting criteria defined in [1], [4].

The MQTT protocol and ThingSpeak integration allowed lightweight, reliable transmission with minimal overhead [5].

VI. CONCLUSION

This research demonstrated that real-time Scope 1 emission monitoring is achievable using IoT, MQTT, and cloud platforms. The system enhances reporting efficiency, data accuracy, and regulatory compliance in the mining industry. Future work may include AI-based anomaly detection and expanding to Scope 2 or 3 emissions.

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