Improvement of landfill methane generation estimation by having meteorological influences

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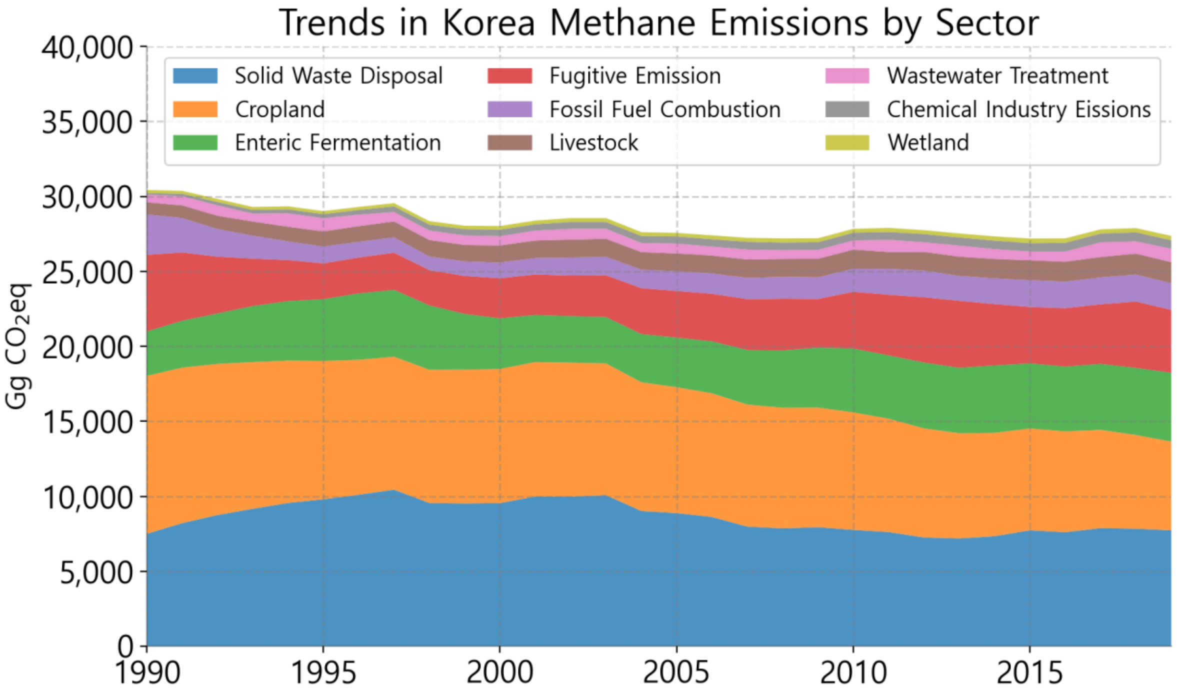
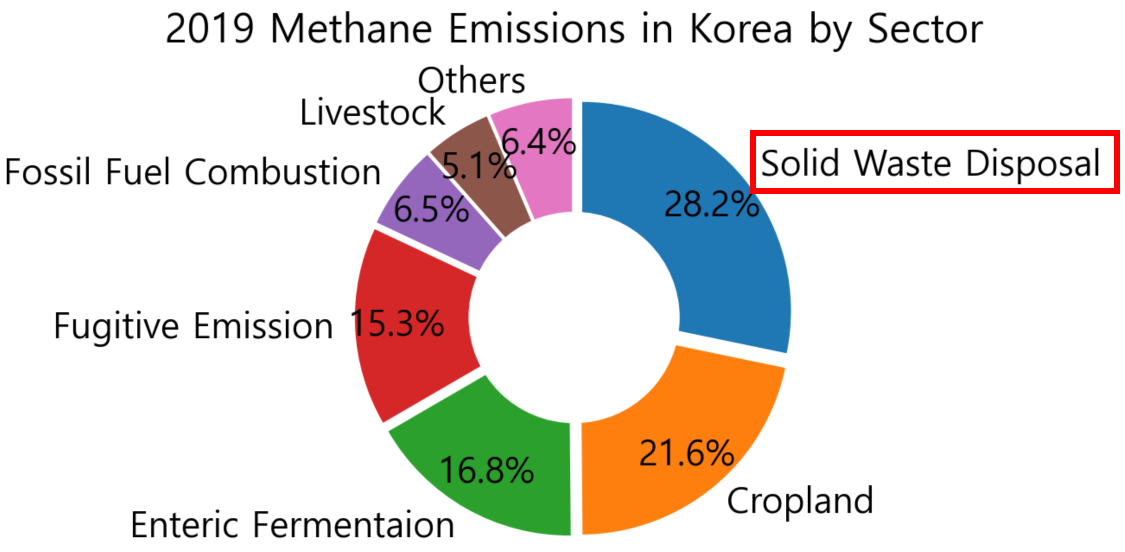
- Methane(CH_4) is the second most significant greenhouse gas, with a short-lived lifetime and a more potent greenhouse effect compared to CO_2, so reducing methane emission is beneficial for both climate mitigation and air quality, as the Global Methane Pledge was adopted.
- In Korea, the solid waste disposal sector is the largest source of anthropogenic methane emissions.
- Well-managing and monitoring of methane emission from landfills can significantly contribute to methane reduction and climate change mitigation.



(GIR of Korea, 2022)



(GIR of Korea, 2022)

1. Introduction

- Landfill methane is affected by meteorological factors such as temperature and precipitation.
- However, the existing landfill methane generation models have limitations.
  - Not reflecting the meteorological conditions.
  - Calculating annually that impossible to identify seasonal characteristics.

Models	IPCC Model	LandGEM (Landfill gas Emissions Estimation Model)
Factors	Mass of waste, Waste composition	Mass of waste
Equation	$Q_{CH_4} = \sum_{i=1}^{n} M_i L_0 e^{-k}$	$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k \frac{M_i}{10} L_0 e^{-kt_{ij}}$
Time resolution	Yearly	Yearly

- Most commonly used
- No temperature and precipitation factors
- Using national default and the IPCC emission factors
- Yearly methane emissions

Q_{CH4} = methane recovered from landfills(m^3/year) n = (year of the calculation)-(initial year of waste acceptance)
k = methane generation rate (year^{-1}) M_{ij} = mass of waste accepted in the ith year (Mg)
L_0 = potential methane generation capacity (m^3/Mg) t_{ij} = age of the jth section of waste mass Mi accepted in the ith year

1. Introduction

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Models	**CLEEN** (Capturing Landfill Emissions for Energy Needs)
Factors	Mass of waste, Waste composition, Temperature, Precipitation
Equation	$Q_{CH_4} = \sum_{i=0}^{n}\sum_{j=0}^{12} k \frac{M_i}{12} L_0 e^{-kt_{ij}}$
Time resolution	Seasonally

- Karanjekar et al.(2015)
- Using temperature and precipitation factors
- Seasonal methane emissions
- However, not suitable for South Korea or other countries due to calibration on select landfills in the USA and Israel.

Q_{CH4} = methane recovered from landfills(m^3/year) n = (year of the calculation)-(initial year of waste acceptance)
k = methane generation rate ($year^{-1}$) M_{ij} = mass of waste accepted in the ith year (Mg)
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Karanjekar, R. V., Bhatt, A., Altouqui, S., Jangikhatoonabad, N., Durai, V., Sattler, M. L., ... & Chen, V. (2015). Estimating methane emissions from landfills based on rainfall, ambient temperature, and waste composition: The CLEEN model. Waste Management, 46, 389-398.

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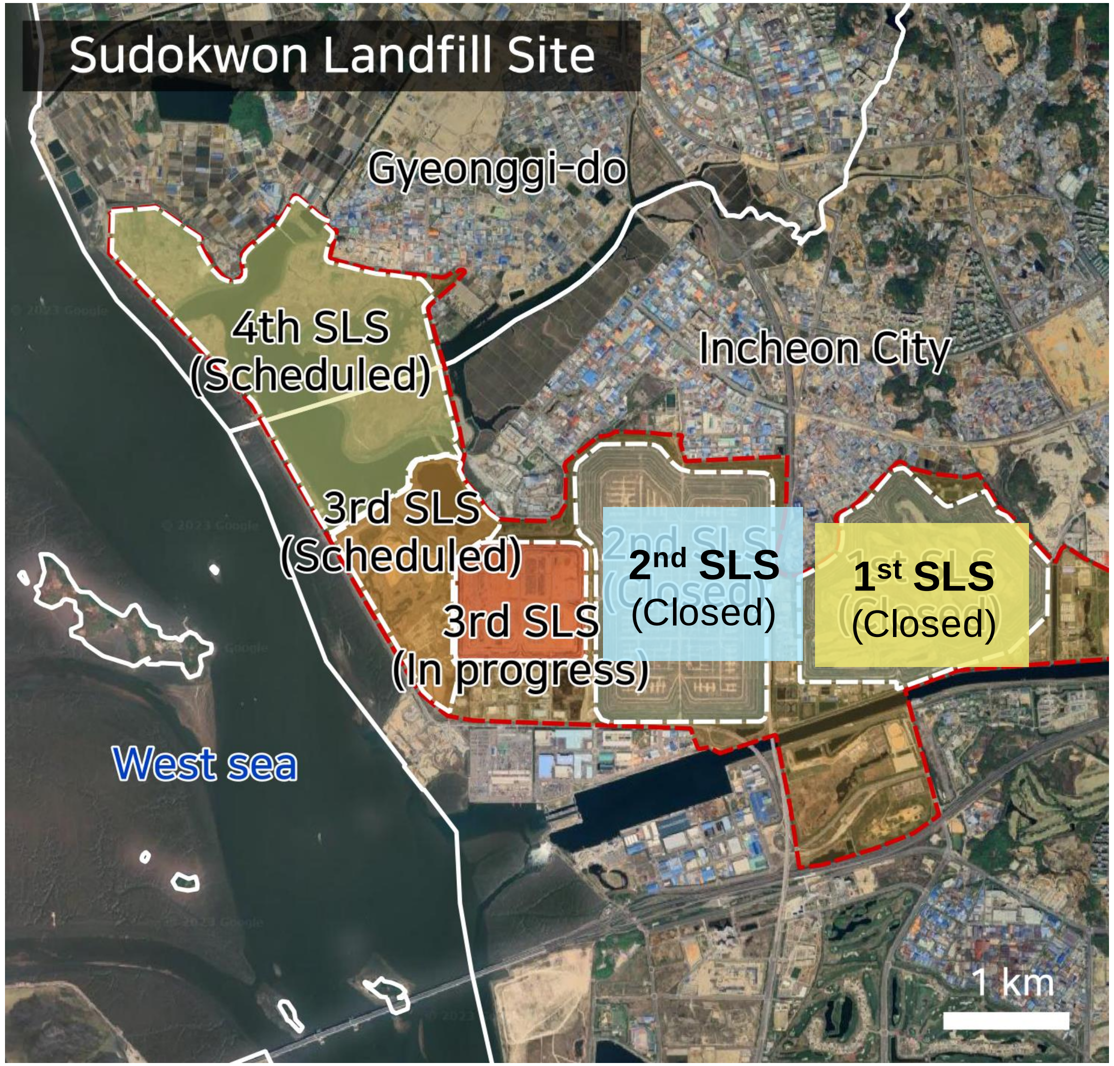
Objective

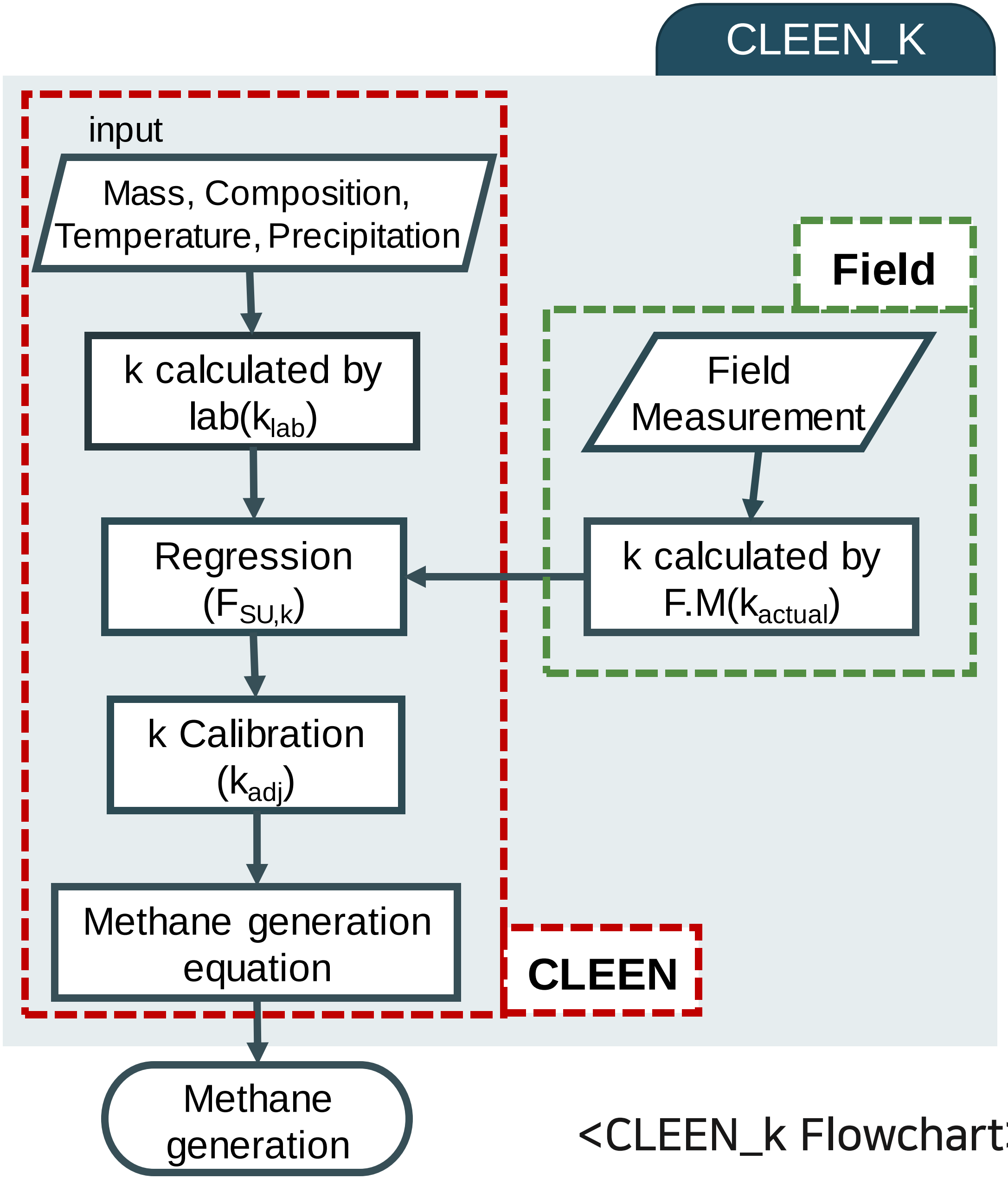
- Reducing the uncertainty in estimating landfill methane emissions by improving the methodology from tier 2 to tier 3.
- Estimating of landfill methane generation by having meteorological conditions. (Temperature & Precipitation)
- Improving the time resolution of the model from yearly to seasonally.
- Using machine learning to estimate the past and the future methane generations.

- **The Sudokwon Landfill Site (SLS)**
  - The largest landfill in Korea located in Incheon.
  - It receives waste from 64 regions within the metropolitan area.
  - The population is about 5.3 million people.
  - It's No. 1 in the world for landfill waste per day (20,000 ton/day) and No. 6 for landfill area (2.51 km^2).

- The 1st Landfill Site (1st SLS)
  - Period : Feb 1992 ~ Oct 2000
  - Area : 4.09 km^2
  - Waste : 6,425 Mt.

- The 2nd Landfill Site (2nd SLS)
  - Period : Oct 2000~ Oct 2018
  - Area : 3.78 km^2
  - Waste : 8,018 Mt.





<CLEEN_k Flowchart>

- **CLEEN_k**
  - Landfill methane generation calculating model based on CLEEN model, optimized in Korea SLS field measurement data.

- **CLEEN_k Equation**

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=1}^{4} k M_{ij} L_0 e^{-k t_{ij}}$$

Q_{CH4} = methane recovered from landfills (m^3/year)

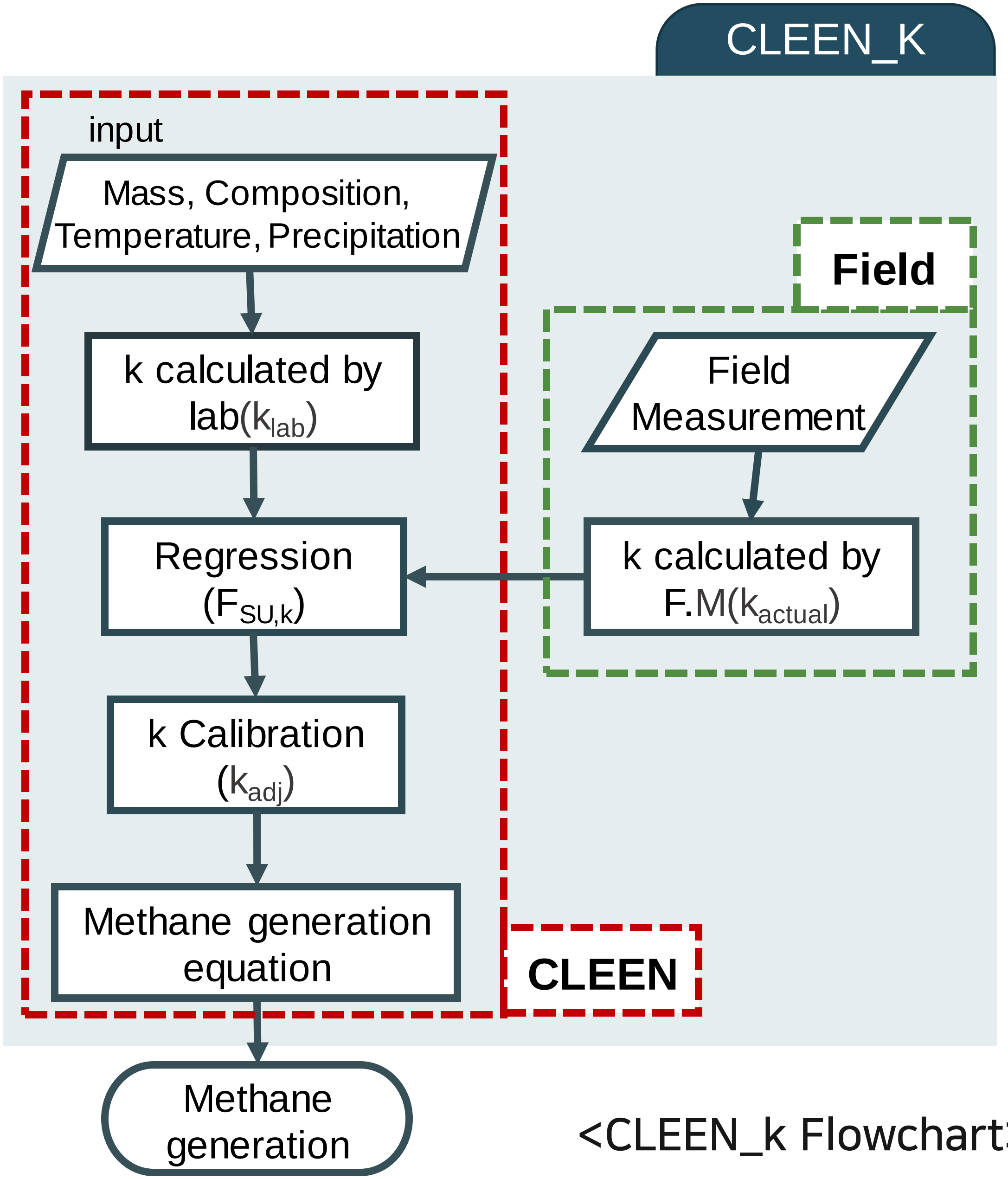
n = (year of the calculation)-(initial year of waste acceptance)

k = = methane generation rate ($year^{-1}$)

M_{ij} = mass of waste accepted in the ith year (Mg)

L_0 = potential methane generation capacity (m^3/Mg)

t_{ij} = age of the jth section of waste mass Mi accepted in the ith year (ex, 3year 1st quarter)

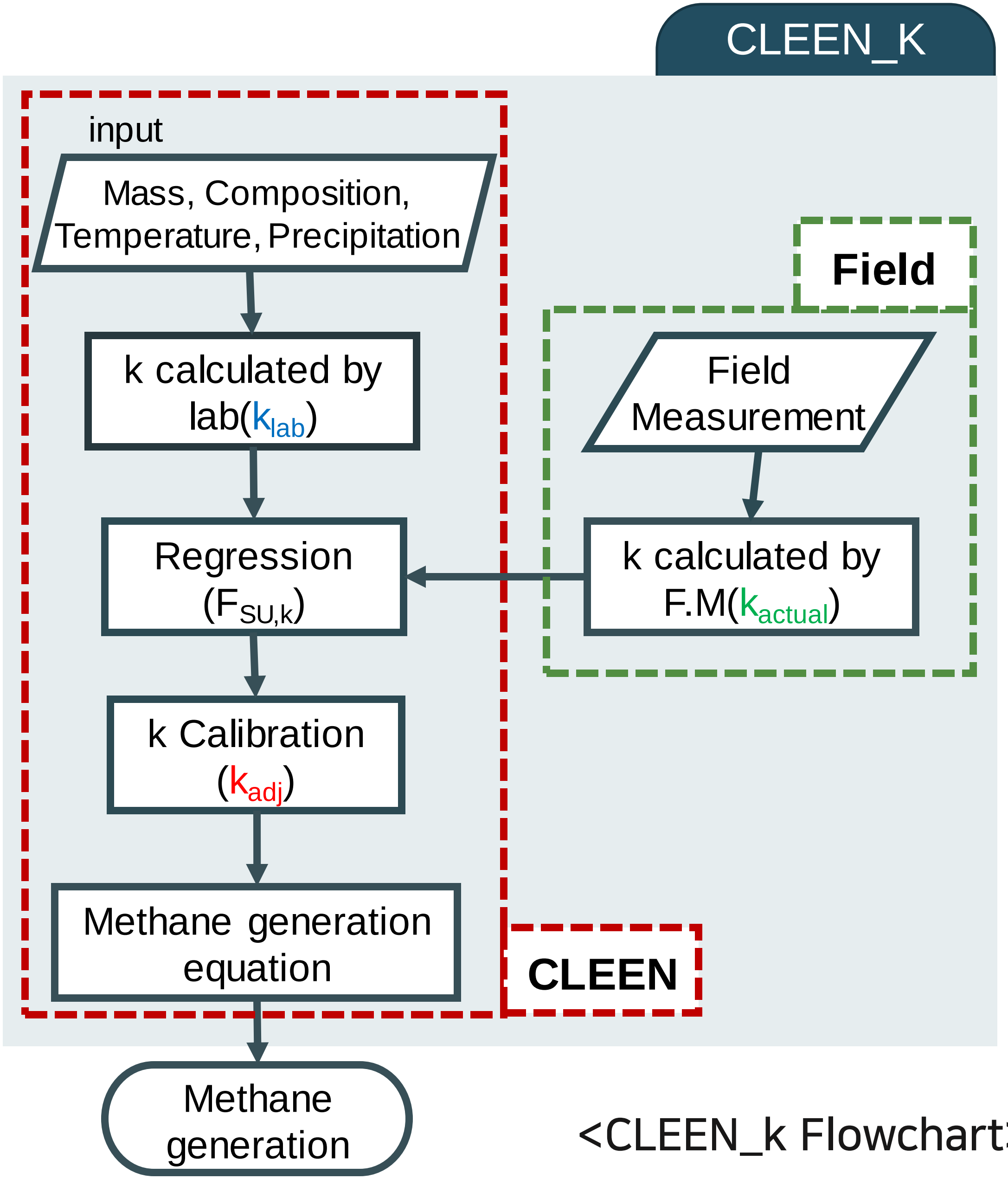


<CLEEN_k Flowchart>

- **Input**
  - Mass of waste, Waste composition, Seasonal temperature and precipitation

- **L_0 (Methane Generation Potential, m^3CH_4/Mg)**
  - Based on BMP(Biochemical Methane Potential) test
  - The 1st landfill: 40.2 m^3CH_4/Mg (Median of 33.7~46.7 m^3CH_4/Mg) (Park et al., 2020)
  - The 2nd landfill: 47.5 m^3CH_4/Mg (Median of 37~58 m^3CH_4/Mg) (Jeon et al., 2007)

Park, J. K., Chong, Y. G., Tameda, K., & Lee, N. H. (2020). Applying methane and carbon flow balances for determination of first-order landfill gas model parameters. Environmental Engineering Research, 25(3), 374-383.
Jeon, E. J., Bae, S. J., Lee, D. H., Seo, D. C., Chun, S. K., Lee, N. H., & Kim, J. Y. (2007, October). Methane generation potential and biodegradability of MSW components. In Sardinia 2007 eleventh international waste management and landfill symposium.



<CLEEN_k Flowchart>

- **k (First order decay constant, year^{-1})**
  - k_{lab} : k from the waste decomposition experiment
  - k_{actual} : k from the field measurement
  - k_{adj} : k used to calculate the final methane generation

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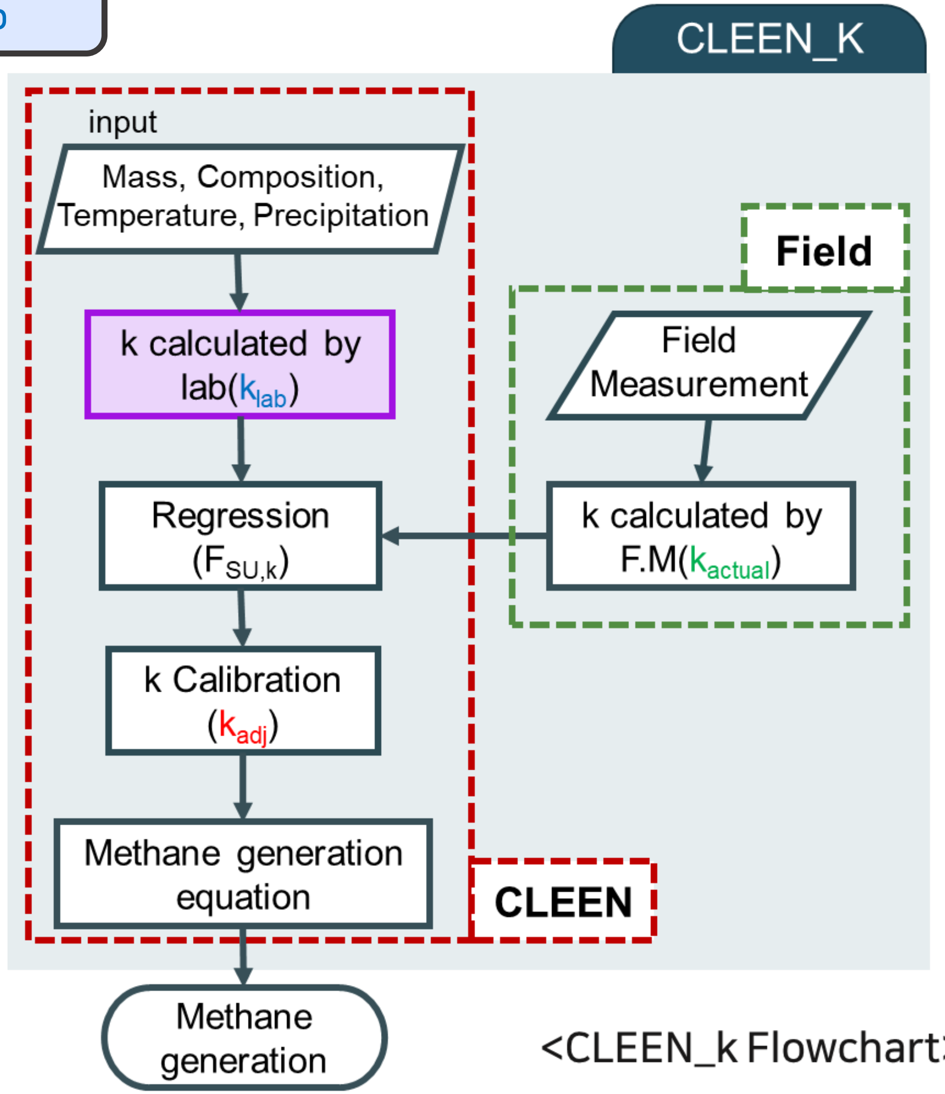
k_{lab}



<CLEEN_k Flowchart>

$$log_{10}k_{lab} = -3.02658 - 0.0067282R^2 + 0.069313R + 0.00172807(R \times F) + 0.01046T - 0.01152T + 0.00418TX + 0.00598Y$$

k_{lab} = lab-scale first order decay constant (year^{-1})
R = average annual rainfall (mm/year)
T = ambient temperature (K) TX = % textile in landfill waste (%)
Y % yard in landfilled waste(%) Y = % food in landfilled waste(%)

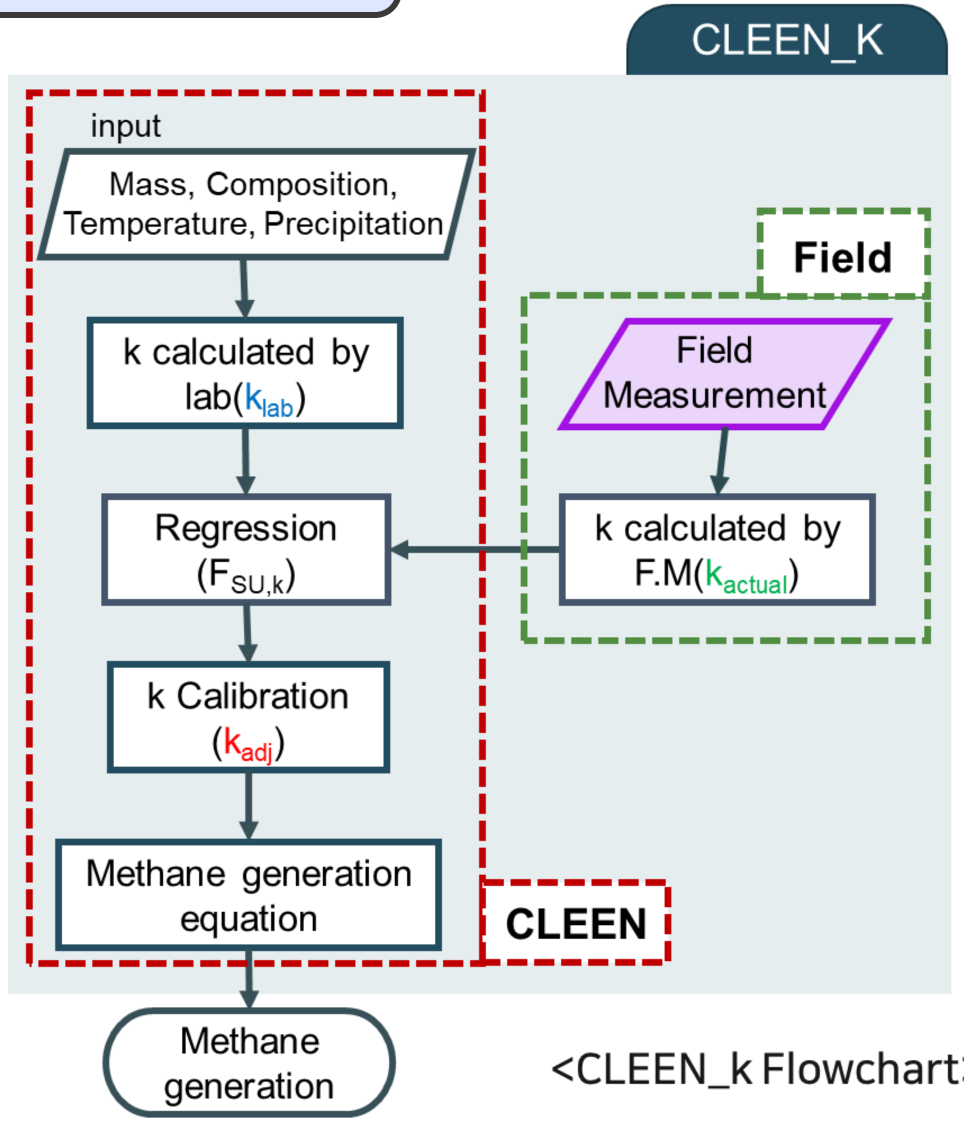
(Karanjekar et al., 2015)

- Calculate the k_{lab} based on waste composition, temperature and precipitation under the laboratory condition.
- MLR model for results adjusted R^2 of 0.754.
- It's a result of controlled environment and microbial access.

→ Needs to be calibrate to actual landfill characteristics

Karanjekar, R. V., Bhatt, A., Altouqui, S., Jangikhatoonabad, N., Durai, V., Sattler, M. L., ... & Chen, V. (2015). Estimating methane emissions from landfills based on rainfall, ambient temperature, and waste composition: The CLEEN model. Waste Management, 46, 389-398.

k_{actual}
(Field Measurement)



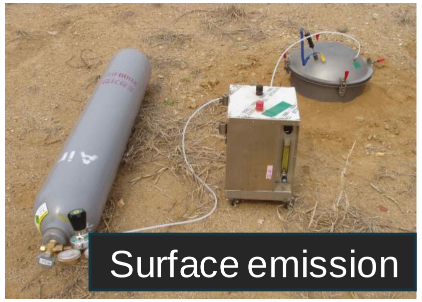
<CLEEN_k Flowchart>

- **Field Measurements**
  - Site : The sudokwon landfill site (1st and 2nd SLS)
  - Period : 2005 Spring ~ 2019 Winter (60)
  - Data : Seasonal averaged
  - Source : The SLC.(Sudokwon Landfill Cooperation)

- **Field Methane Generation(Q_{CH_4})**

= Gas collection + Surface emission + Gas flaring

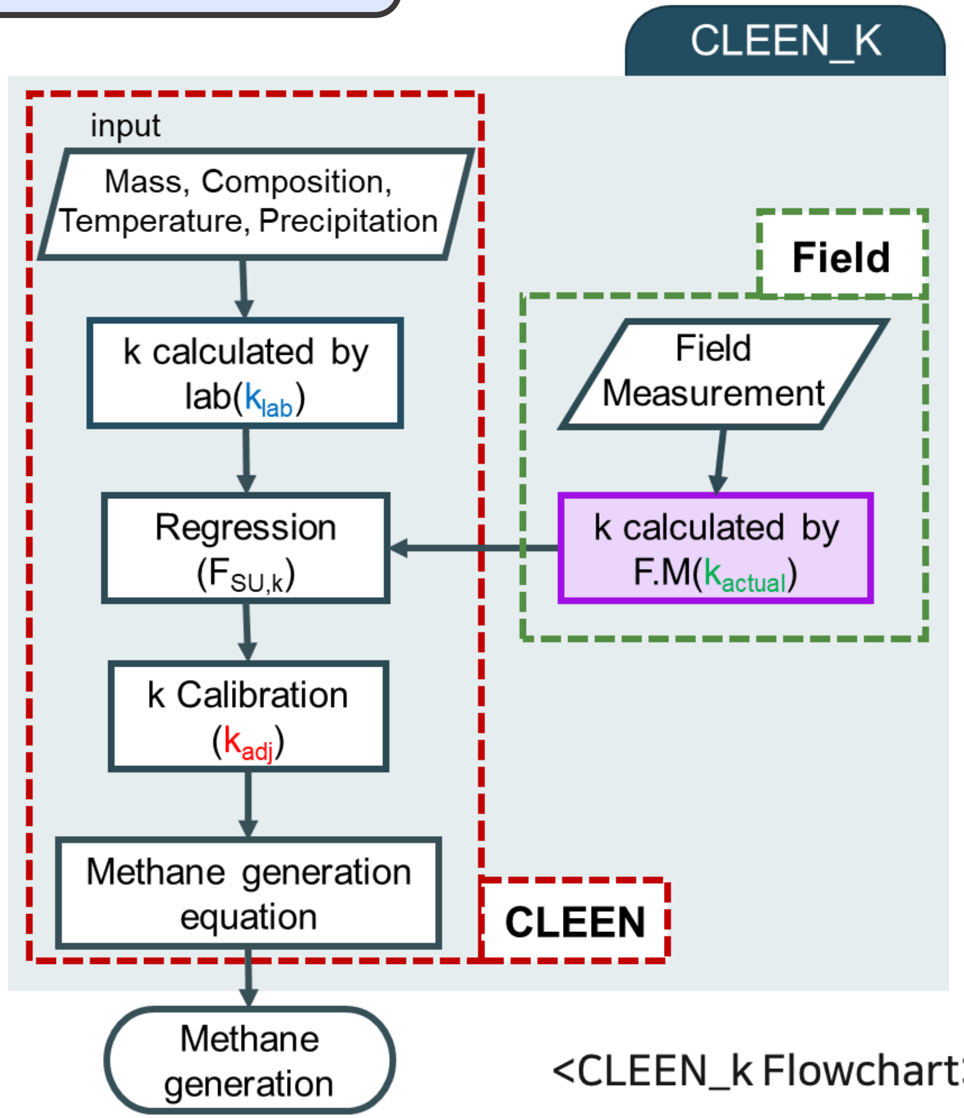
(SLC.)



(SLC.)

(Google Image)

k_{actual}
(Field Measurement)



<CLEEN_k Flowchart>

- **First Order Decay**

$$Q_{CH_4} = k_{actual} M_i L_0 e^{-k_{actual}}$$

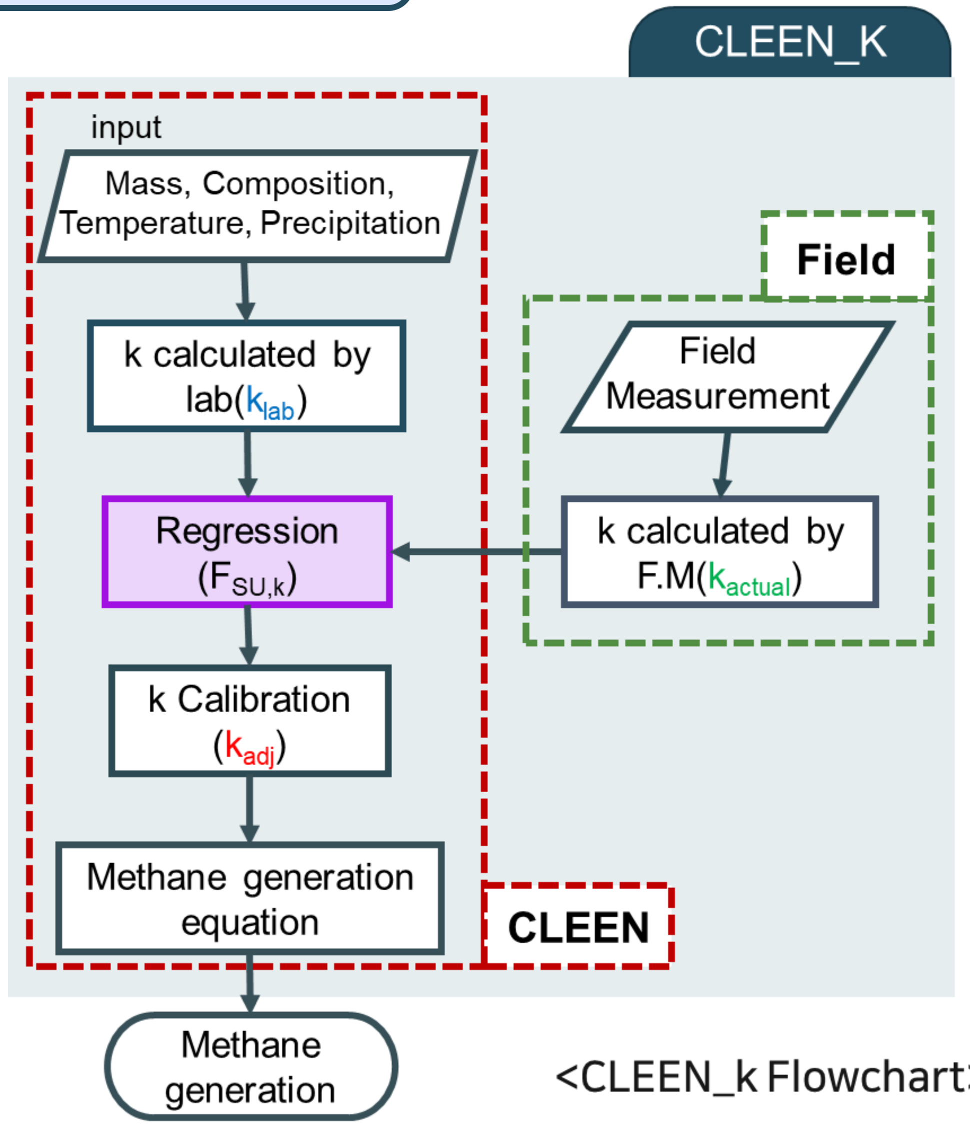
Q_{CH4} = methane from field measurement(m3/season)
k = first order decay constant(/year)
Mi = mass of wasate deposited in the season 'I' within the landfill(Mg)
L0 = ultimate methane generation potential(m3/Mg)

➔ Calculation of k_{actual} that best simulates field measurements

✓ k_{actual} can only be calculated when the field measurement data existing.

2. Material and Methods

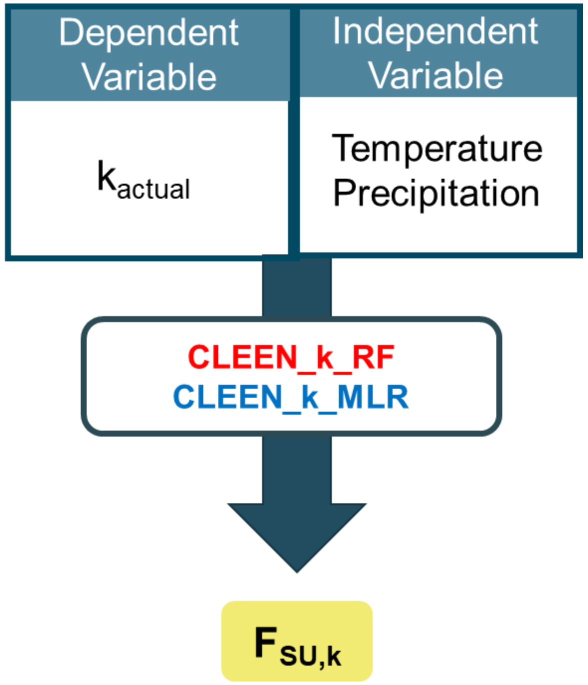
$F_{SU,k}$
(Calibration Factor)



<CLEEN_k Flowchart>

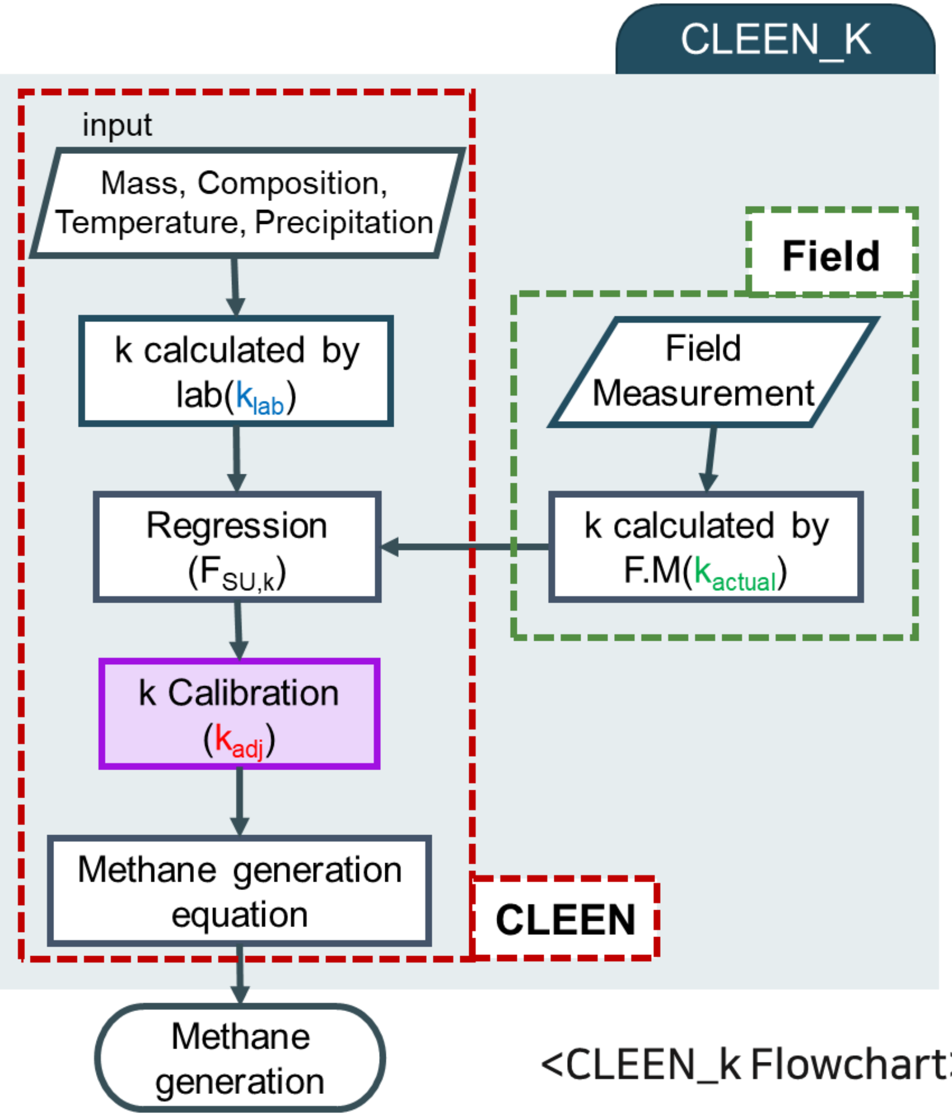
- Calculate $F_{SU,k}$ to calibrate k_{lab} to estimate k_{adj}, which can be used as a proxy for k_{actual} for periods when field measurements are absent.

- $F_{SU,k}$ is calculated from a regression with k_{actual} as the dependent variable and temperature and precipitation as the independent variables.



- Comparing Regression methods
  - Random Forest Regression (CLEEN_k_RF)
  - Multi Linear Regression (CLEEN_k_MLR)

k_{adj}



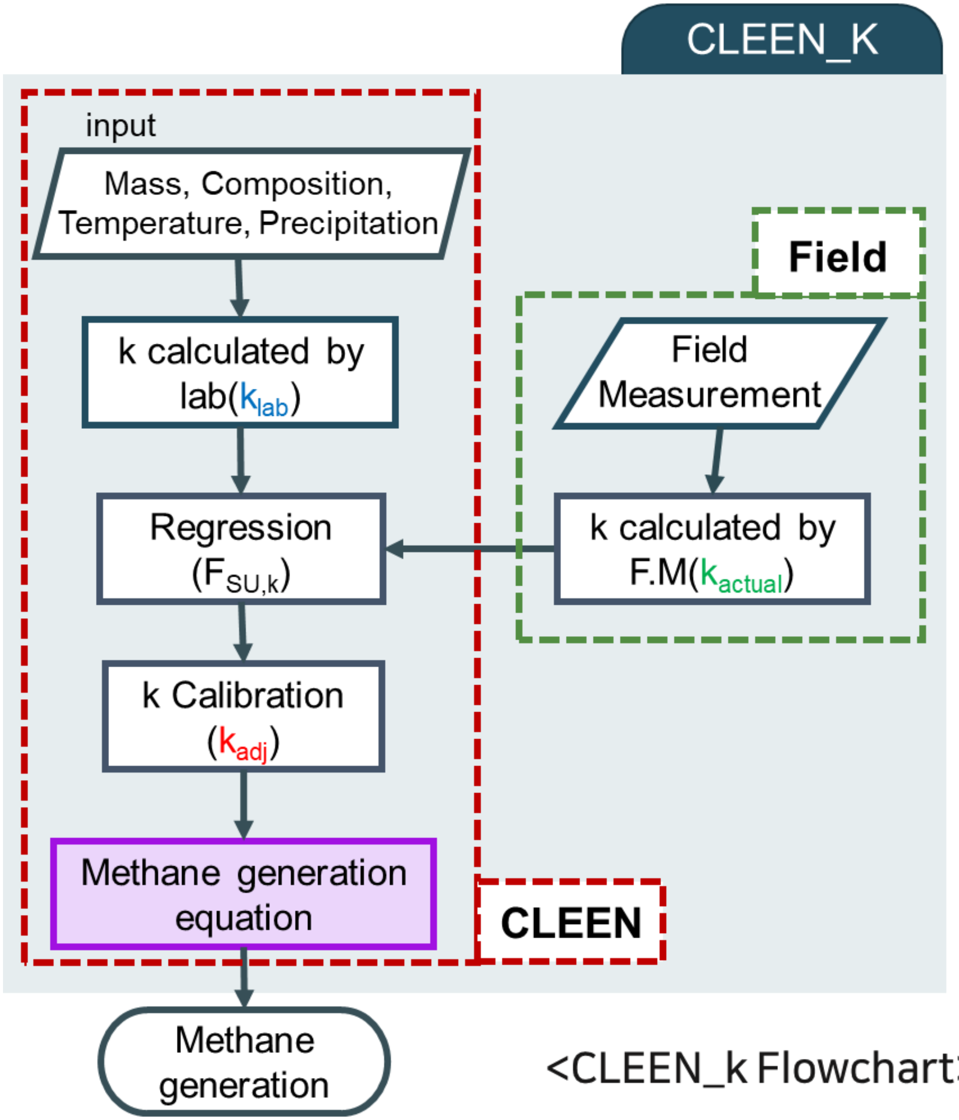
<CLEEN_k Flowchart>

$$k_{adj} = F_{SU,k} \times k_{lab}$$

- k_{adj} : k used to calculate the final methane generation
- $F_{SU,k}$: Calibration factor based on field measurement
- k_{lab} : k based on laboratory condition

- Calibrate k_{lab} from laboratory conditions to $F_{SU,k}$ to reflect the on-site characteristics of the 1st SLS.

Estimation of Methane Generation



<CLEEN_k Flowchart>

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=1}^{4} k_{adj} M_{ij} L_0 e^{-k_{adj} t_{ij}}$$

Q_{CH4} = methane recovered from landfills (m^3/year)

n = (year of the calculation)-(initial year of waste acceptance)

k = = methane generation rate (year^{-1})

M_{ij} = mass of waste accepted in the ith year (Mg)

L_0 = potential methane generation capacity (m^3/Mg)

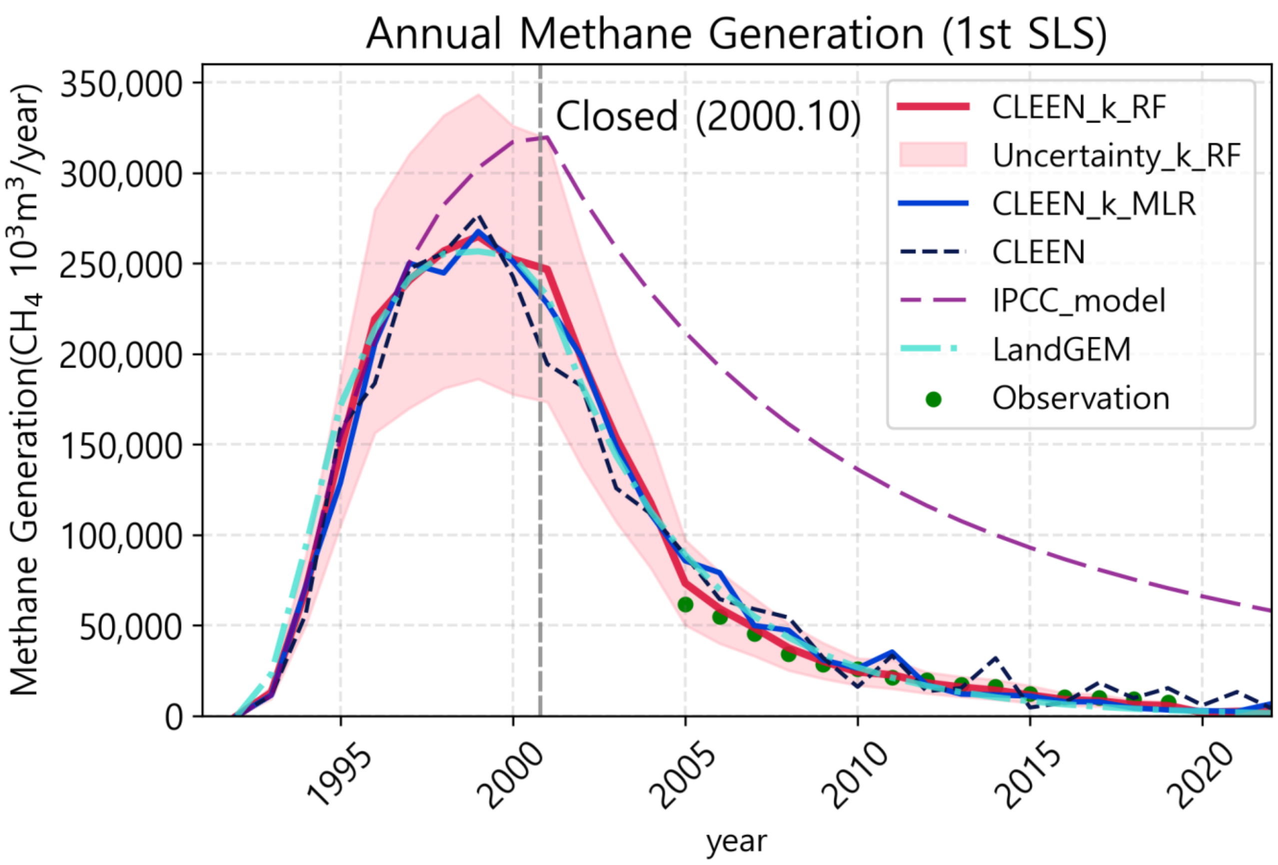
t_{ij} = age of the jth section of waste mass Mi accepted in the ith year (ex, 3year 1st quarter)

- Use a calibrated k_{adj} based on the field measurements.
- Estimate the seasonal methane generation.

1

The 1st Sudokwon Landfill Site

Comparison of the models by year



- **Model's emission factors**
  - CLEEN_k_RF : Fitted to the landfill's field conditions with random forest
  - CLEEN_k_MLR : Fitted to the landfill's field conditions with multi linear regression
  - CLEEN : Fitted to another landfill's field conditions
  - IPCC model : Country specific + Default
  - LandGEM : Optimized with BMP Test (Park et al., 2020)

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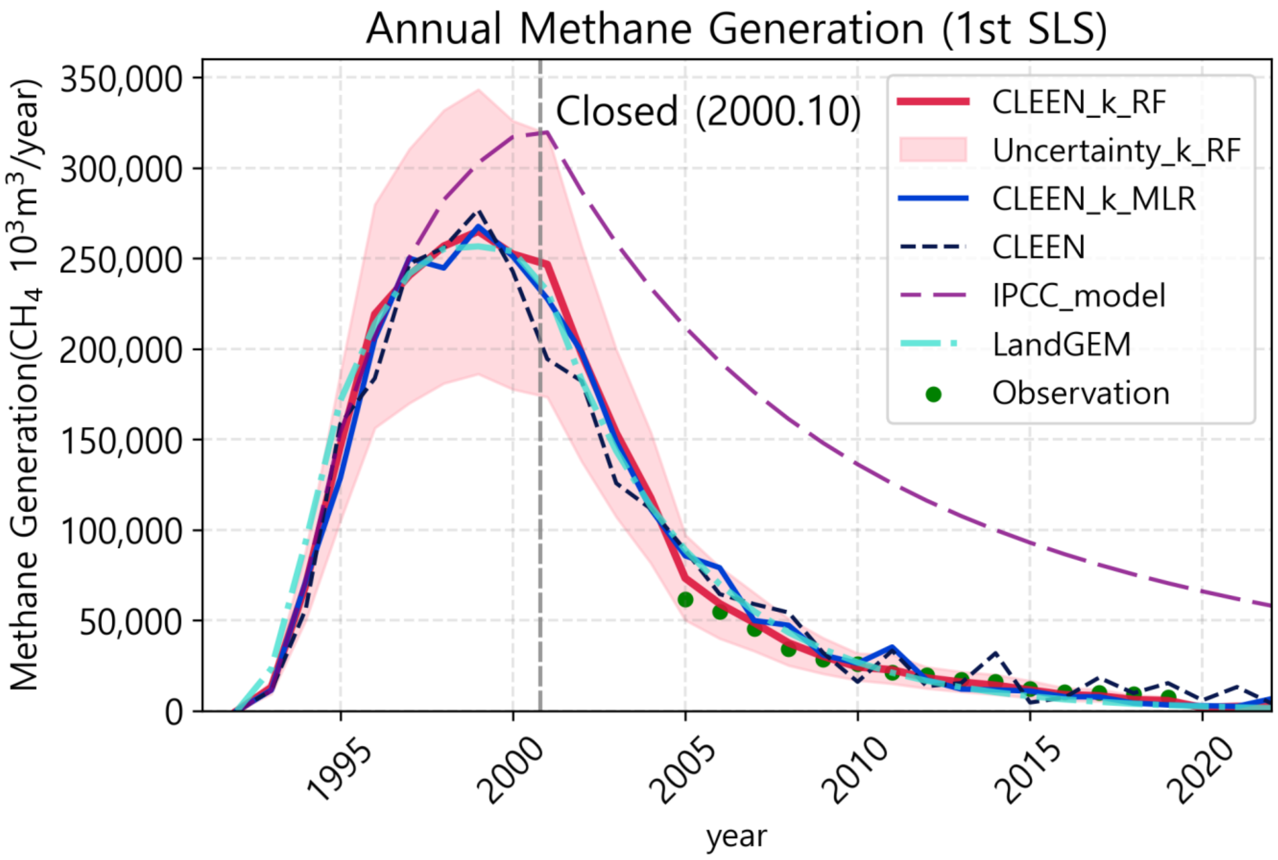
1

The 1st Sudokwon Landfill Site

Comparison of the models by year



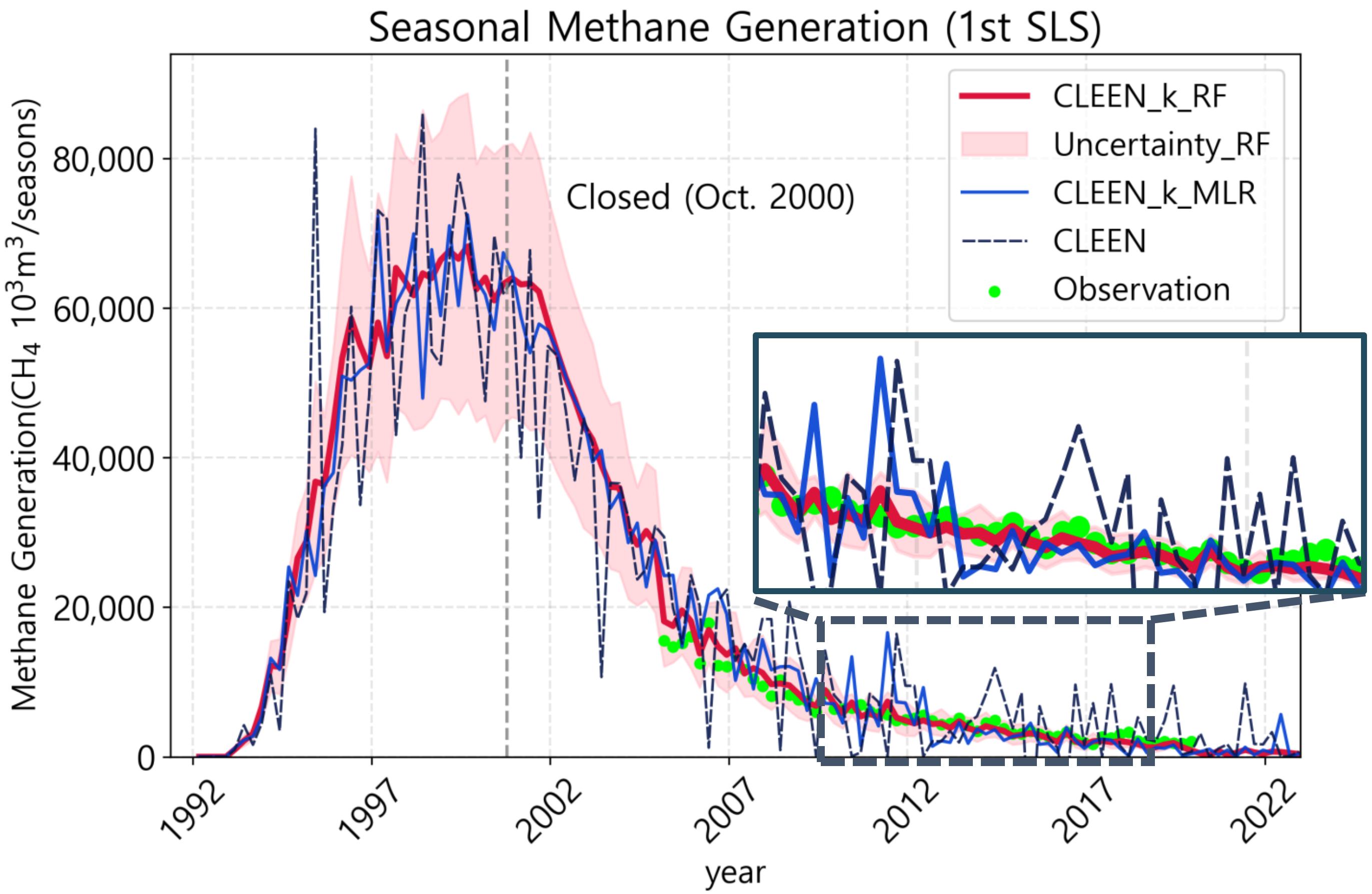
- IPCC Model is overestimated than other models.
- CLEEN_k, CLEEN_k_MLR, CLEEN, LandGEM, optimized for the Sudokwon landfill, are better simulate the observation data.

→ To estimate accurate landfill methane generation, it is necessary to use the landfill optimized emission factors

2

The 1st Sudokwon Landfill Site

Methane Generation by season



- Methane Generations at the 1st SLS
- The uncertainty is the min/max of each activity data

T : Temperature uncertainty (±0.3℃)

P : Precipitation uncertainty (±3%)

W_a : Waste uncertainty (±30%)

W_c : Waste composition uncertainty (±10%)

During the field measurement period(2005~2019)

- The correlation coefficient(r) of the field measurements and model results is significant.

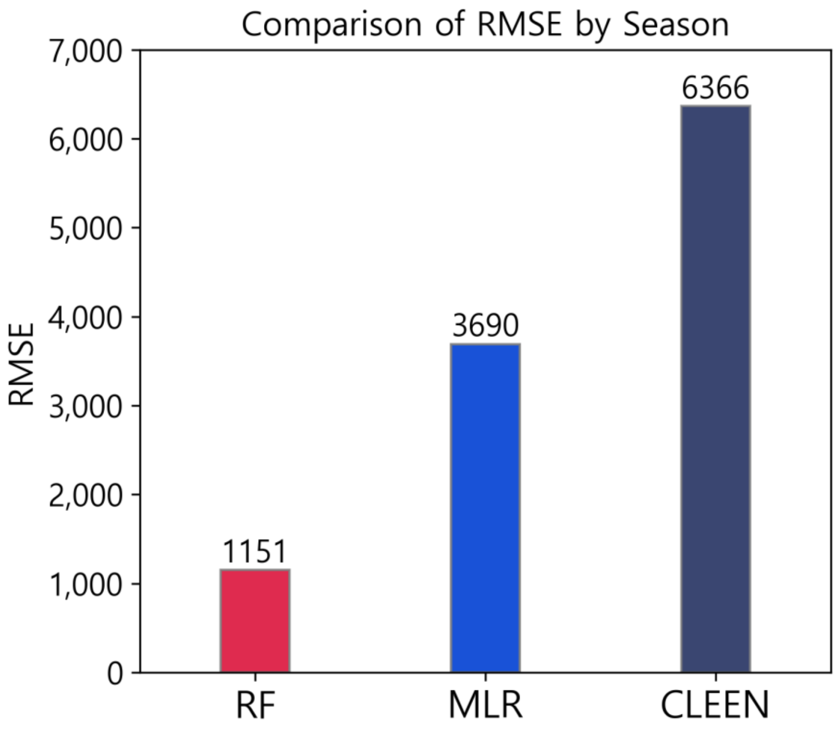
RF: 0.985 / MLR: 0.897 / CLEEN: 0.632

3

The 1st Sudokwon Landfill Site

Comparison of the model performance

- The RMSE (Root Mean Squared Error) between the field measurements and model results.

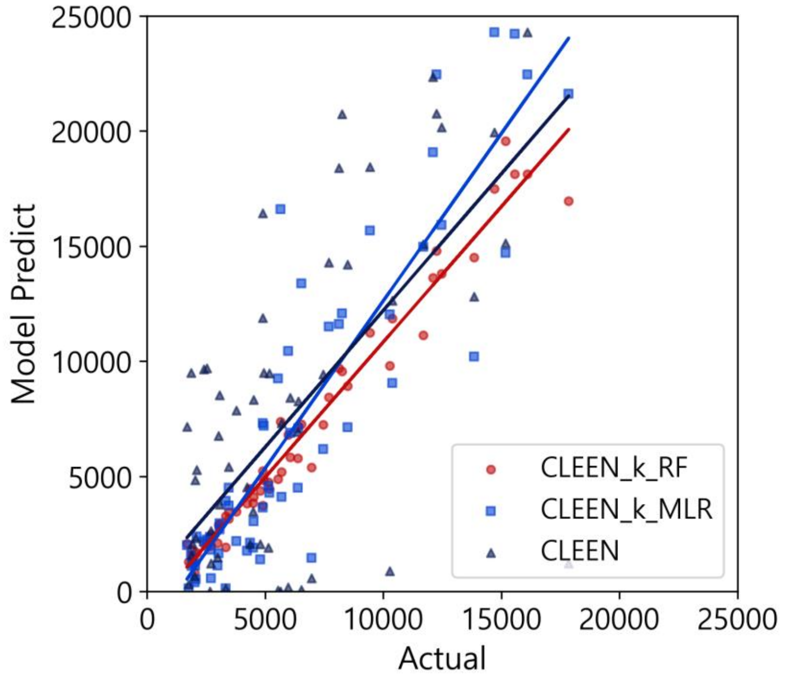


CLEEN_k_RF (1151)

< CLEEN_k_MLR (3690)

< CLEEN (6366)

- The R^2 between the field measurements and model results.



CLEEN_k_RF : R^2 = 0.9705

CLEEN_k_MLR : R^2 = 0.8045

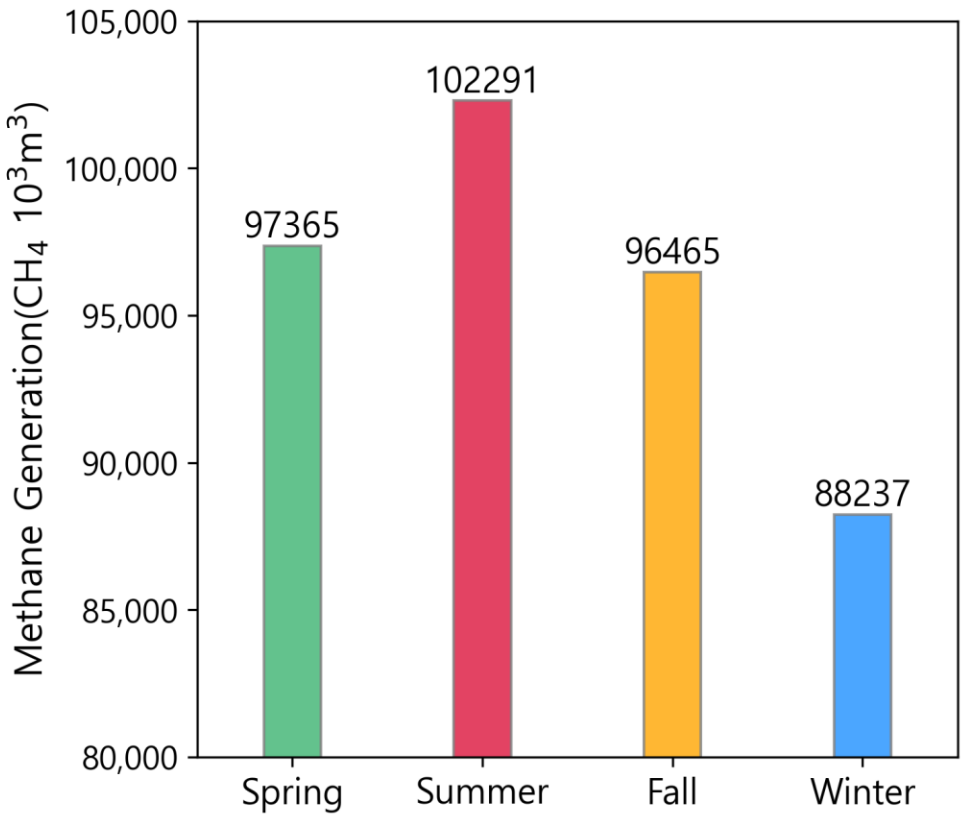
CLEEN : R^2 = 0.3994

The CLEEN_k with random forest regression model appears to best simulate the field data.

4

The 1st Sudokwon Landfill Site

Seasonal methane generation



- The comparison of total methane emissions by season from 2005 to 2019

  Summer > Spring > Fall > Winter

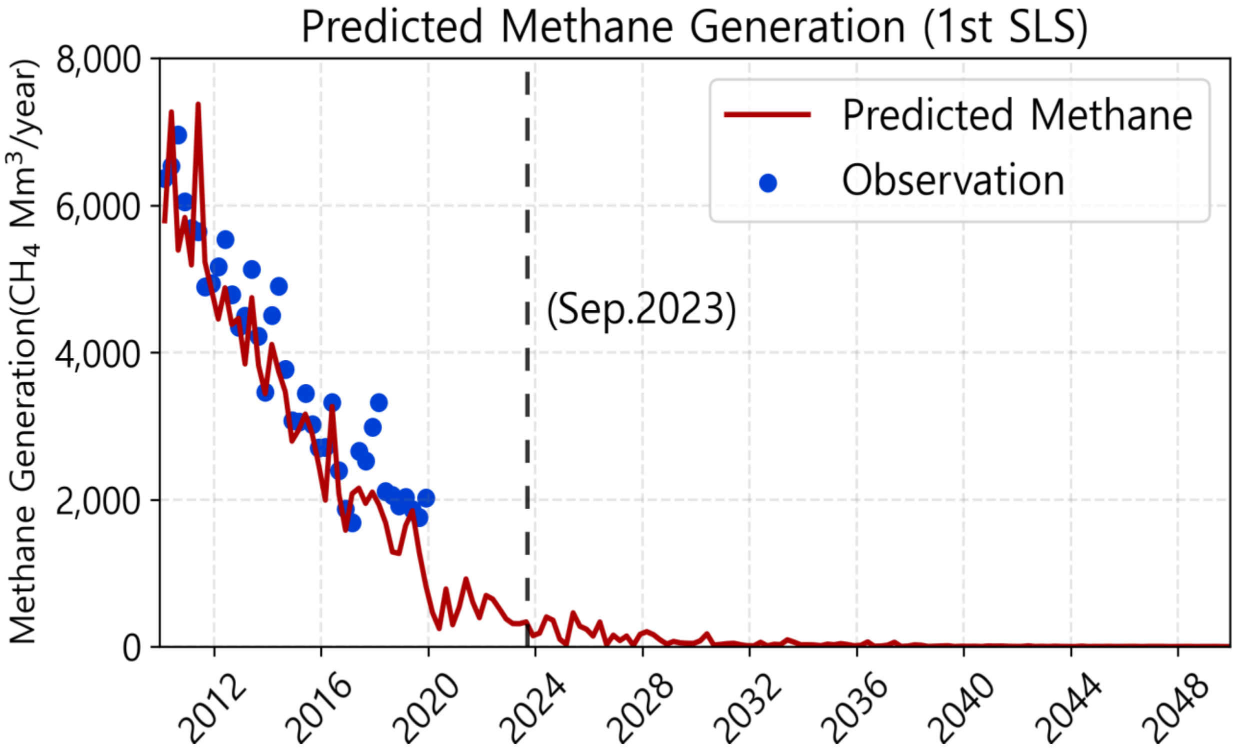
- The most methane was simulated in summer when temperatures and precipitation were highest, and the least in winter when temperatures were lower, hindering microbial waste degradation.

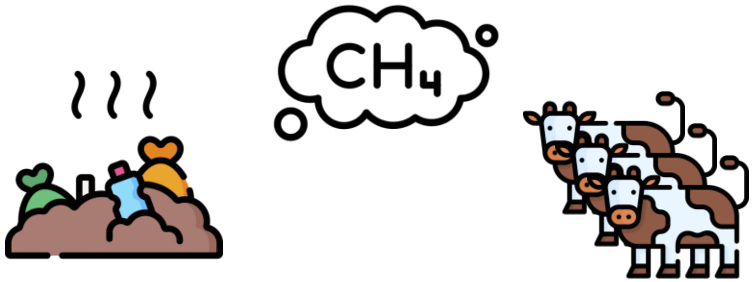
6

The 1st Sudokwon Landfill Site

The future methane generation

- Predict the future methane generation with RCP 8.5 scenario meteorological data.
  - Using the HadGEM3-RA forecast model. (Korea Meteorological Administration, 2018)
- Methane is keep generated after the landfill is closed in 2000 over 50 years.
- From 2023 to 2100,
  - The 1st landfill : 6 CH_4 Mm^3 = 41,417 cattle's CH_4 /year



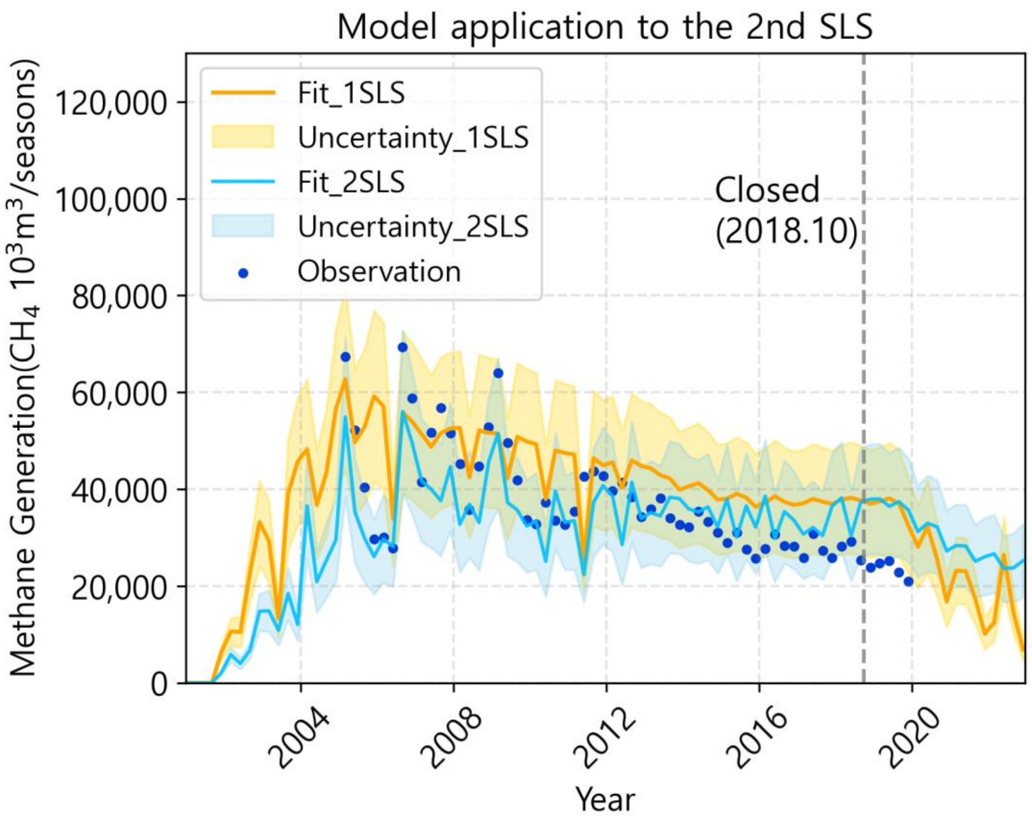


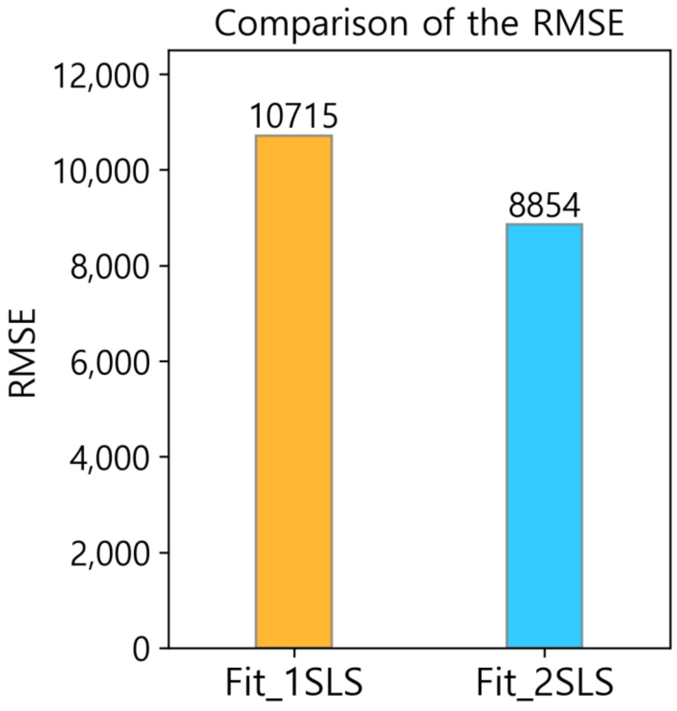
5

The 2nd Sudokwon Landfill Site

Model application to the 2nd SLS

- Applied the CLEEN_k model trained on the 1st SLS to the 2nd SLS.
- The model fitted to the 1st SLS has more error than the model fitted to the 2nd SLS.
- The model needs to be trained for each landfill site.





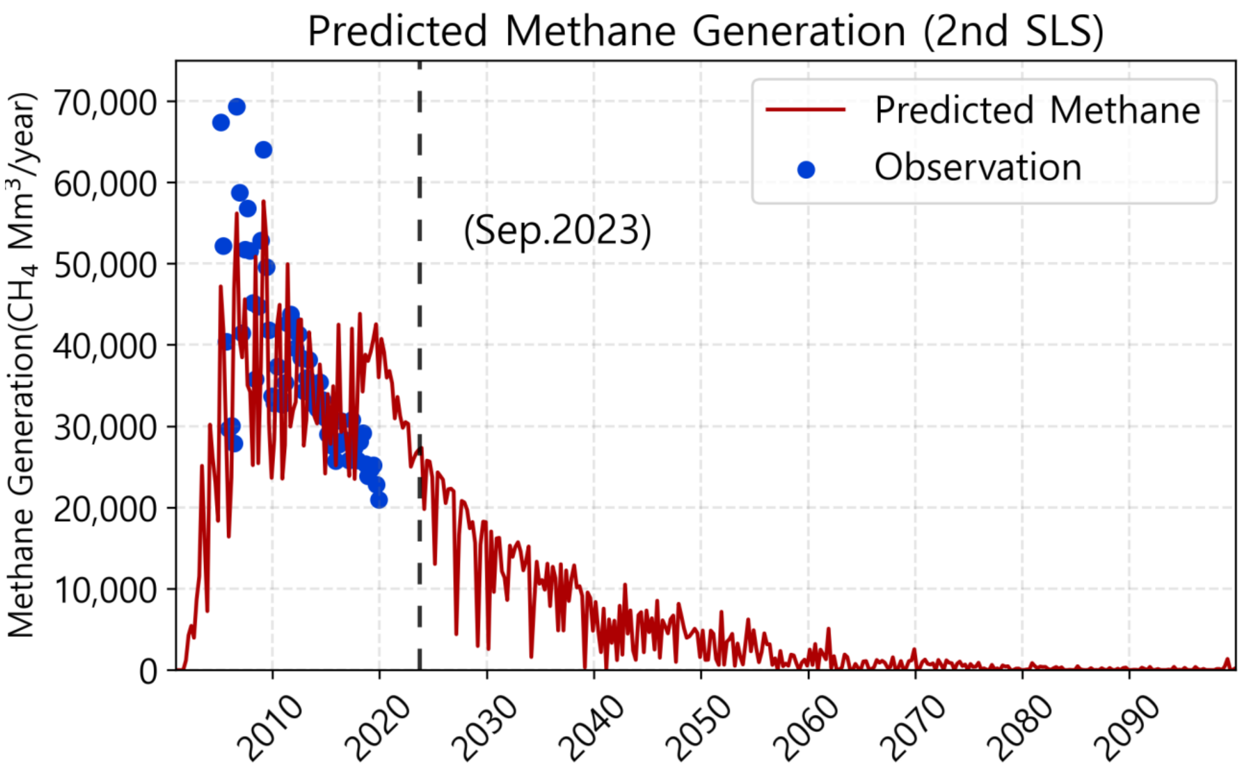
6

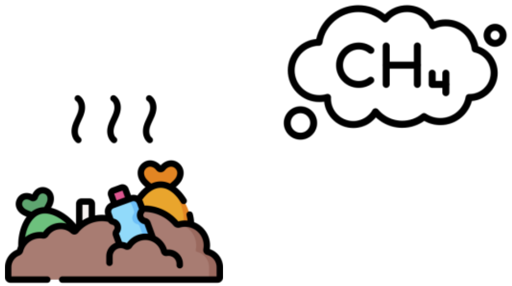
The 2nd Sudokwon Landfill Site

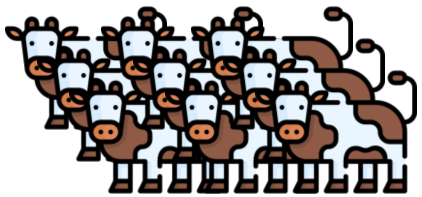
The future methane generation

- Predict the future methane generation with RCP 8.5 scenario meteorological data.
  - Using the HadGEM3-RA forecast model. (Korea Meteorological Administration, 2018)
- Methane is keep generated after the landfill is closed over 80 years.
- From 2023 to 2100,
  - The 2nd landfill : 1,349 CH_4 Mm^3

    = 9,022,410 cattle's CH_4 /year







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- By enhancing the methodology from tier 2 to tier 3, reduced the uncertainty of the estimate methane from landfills, a major anthropogenic methane source.
- The CLEEN_k model is optimized for the Sudokwon landfill by reflecting the characteristics of the landfill field measurement.
- The CLEEN_k model can be detailed in time by season and reflect weather conditions to effectively estimate for changes in methane generation in response to climate change.
- Understanding current methane emissions is crucial for accurately estimating methane inventory, which can be effectively utilized in formulating methane reduction strategies.

Thank you for listening

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