Development and implementation of geoML for CO_2 monitoring within Agricultural Digital Twins

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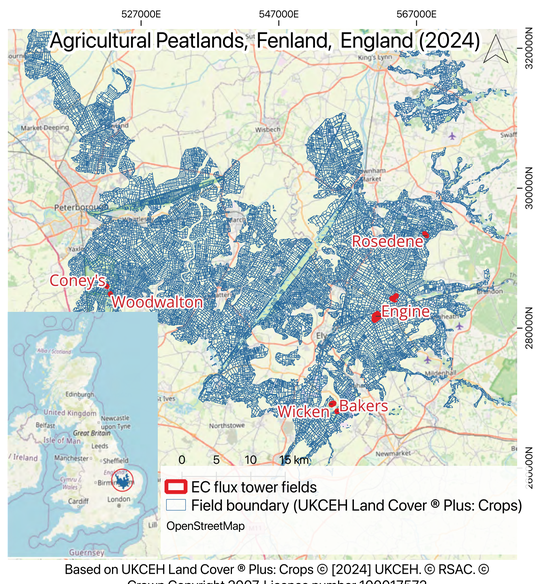
CO_2 emissions from agricultural drained peatlands

- Drainage of peatlands for cultivation increases **aerobic decomposition** in the peat layer, therby accelerating GHG release.
- **>7.5 %** of world's wetlands had been drained for agriculture and produce **~833 Mt CO2eq** annually[1].
- East Anglian Fens—one of UK's most important agricultural regions—produce **~24% of the UK's peatland emissions[2].**



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Knowledge gap

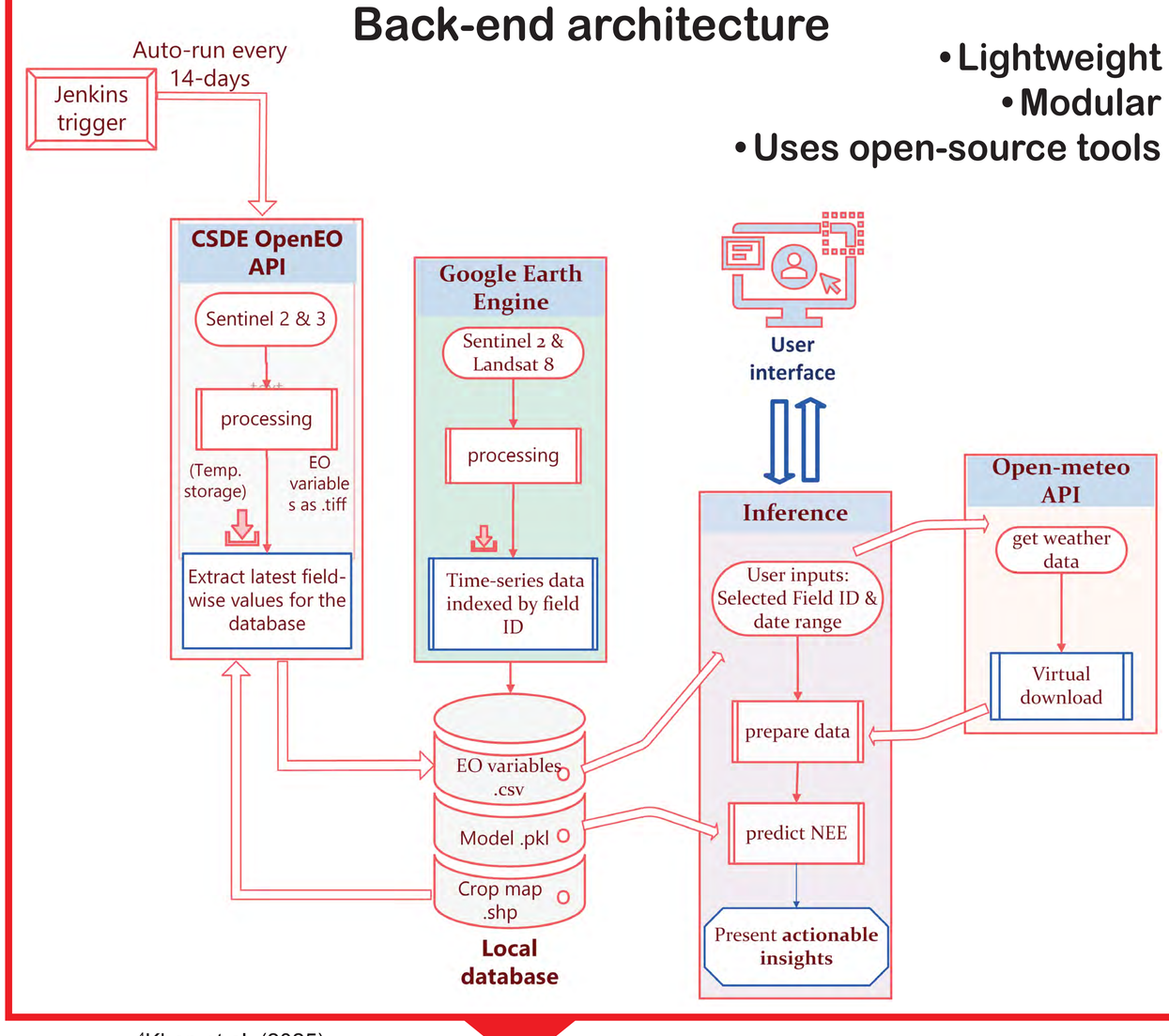
- Need for multiscale, spatio-temporal monitoring of CO_2 fluxes to reach **Net Zero goals by 2050.**
- Existing Geospatial Machine Learning (GeoML) models are: a) not developed for/calibrated in **drained peatland ecosystems** b) static, **require specialized expertise** to operate or interpret.
- Lack of **operationalizing frameworks** for implementation of GeoML within decision support systems such as Digital Twins.

Our approach

- Develop a **Random Forest Regression model** trained on Eddy Covariance flux tower, Earth Observation, and meteorological data from drained agricultural peatlands **to predict Net Ecosystem Exchange of CO_2**
- Develop a lightweight, modular **framework to implement GeoML** within Digital Twins systems.
- Deploy the framework to operationalize the model into a **biweekly, field-scale CO_2 flux monitoring system.**

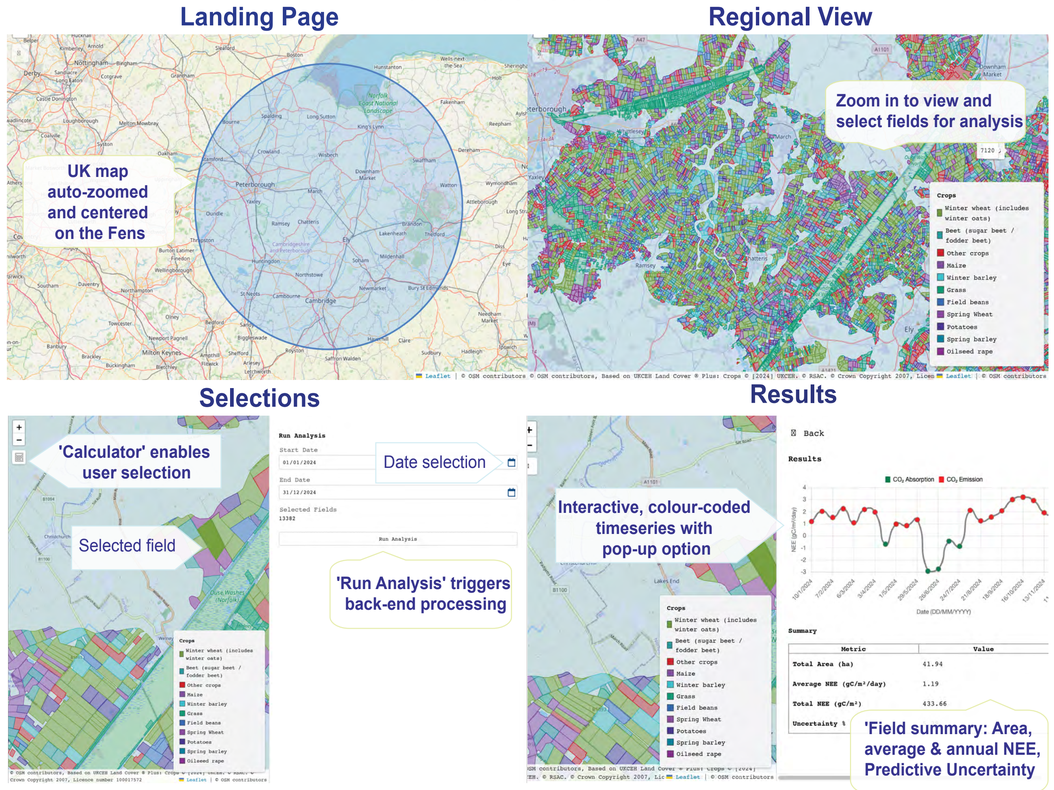
Back-end architecture

- **Lightweight**
- **Modular**
- **Uses open-source tools**



[4]Khan et al. (2025)

Front-end



Results

- The RF model shows an accuracy of **77%** with **R^2 =0.79; NRMSE = 8.67%**; The average predictive uncertainty of **±1.69gC/m²/d** for biweekly fluxes.

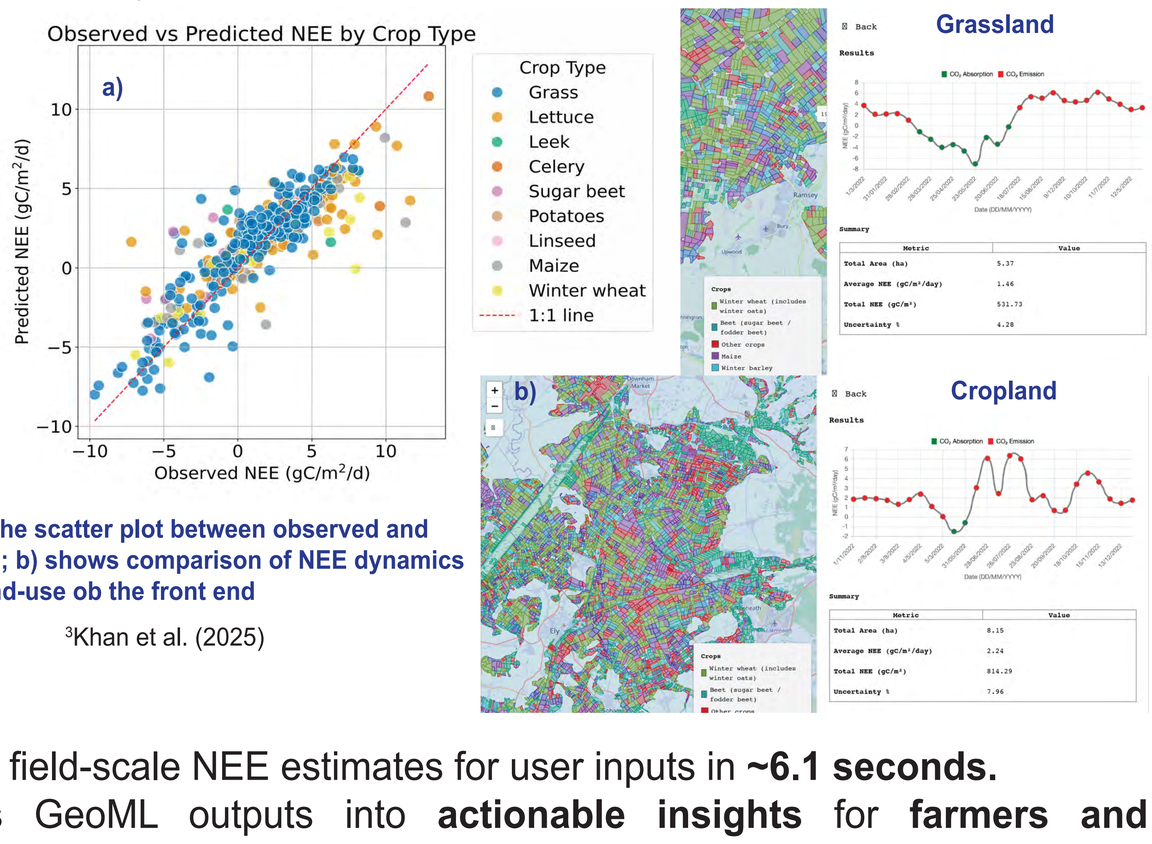


Fig a) Shows the scatter plot between observed and predicted NEE; b) shows comparison of NEE dynamics in different land-use ob the front end

[3]Khan et al. (2025)

- Provides field-scale NEE estimates for user inputs in **~6.1 seconds.**
- Converts GeoML outputs into **actionable insights** for **farmers and policymakers.**
- Integrates into **Digital Twin architectures** without changing existing logic or pipelines.

Conclusions

- Work presents the first AI-driven end-to-end solution for generating actionable insights for farmers and policymakers to support reduction of CO_2 fluxes from drained agricultural peatlands of England.

***Funded by Engineering and Physical Sciences Research Council (EPSRC) and UK Research and Innovation (UKRI), grant number EP/Y00597X/1**

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