Fachbereich
Geoinformatik

GeoAI für die Datenvalidierung

Key Concepts um Daten für AI „fit“ zu machen

Paris-Lodron-University Salzburg
Department of Geoinformatics – Z_GIS

Johannes Scholz

Department of Geoinformatics – Z_GIS
Paris-Lodron-University Salzburg

johannes.scholz@plus.ac.at
www.zgis.at || www.johannesscholz.net
https://linkedin.com/in/johannes-scholz-gisc
@Joe_GISc
@Joe_GISc@mastodon.online
@joegisc.bsky.social

Z_GIS

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Geospatial Artificial Intelligence

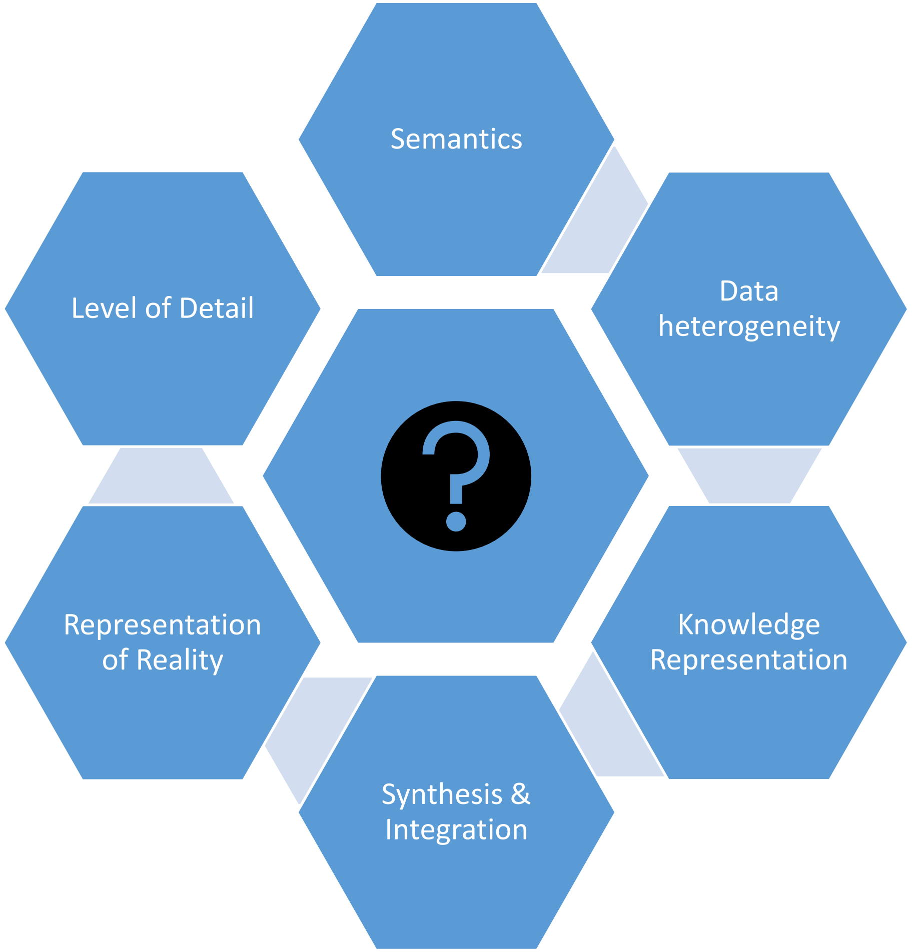
- "**GeoAI** can be regarded as a study subject to **develop intelligent computer programs** to mimic the processes of **human perception, spatial reasoning**, and **discovery** about **geographical phenomena** and **dynamics**
  - to advance our knowledge,
  - to solve problems in human environmental systems and their interactions,
  - with a focus on spatial contexts and roots in geography or GIScience." (Gao, 2021)

- **Spatially explicit models incorporating spatial contexts** (Yan et al., 2018) can **outperform traditional nonspatial AI** models in many tasks:
  - image classification,
  - geographic knowledge graph summarization (Yan et al., 2019),
  - and geographic question-answering problems (Mai et al., 2019).

GeoAI – Additional Questions?

- Questions that may surface when:
  - Representing
  - Manipulating
  - Storing
  - Analyzing, and
  - Visualizing

Geographic Data …!

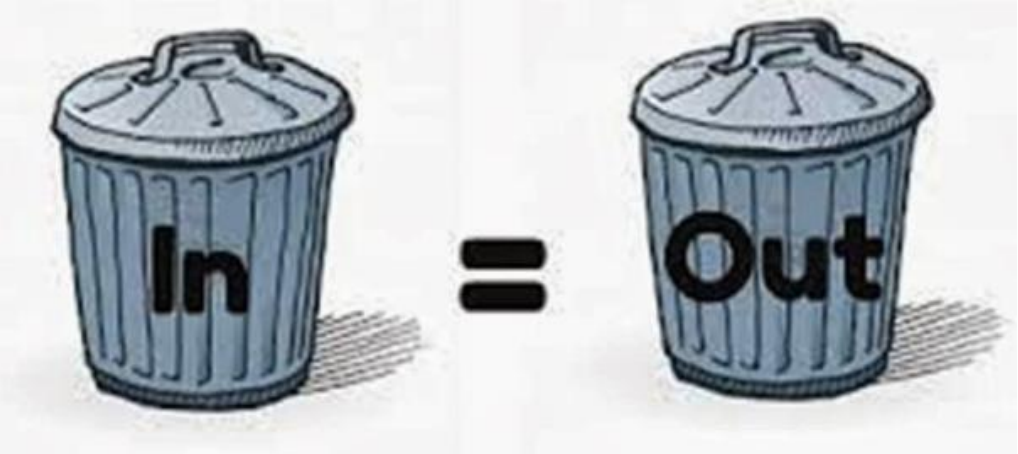


Motivation

„Garbage in, Garbage out.“

AI Models are dependent on training and verification data

- Heterogeneity
- Incompleteness
- Bias
- Flaws



Data Quality as Critical Success Factor

- **Completeness:**
  - Missing values can distort patterns or hide important relationships.
- **Consistency:**
  - Inconsistent formats or conflicting entries complicate modeling and interpretation.
- **Representativeness:**
  - Skewed samples result in unfair or non-generalizable models
- **Timeliness:**
  - Outdated data fails to reflect current realities—especially critical in dynamic domains like mobility or energy. ng and interpretation.

GeoAI for Anomaly Detection

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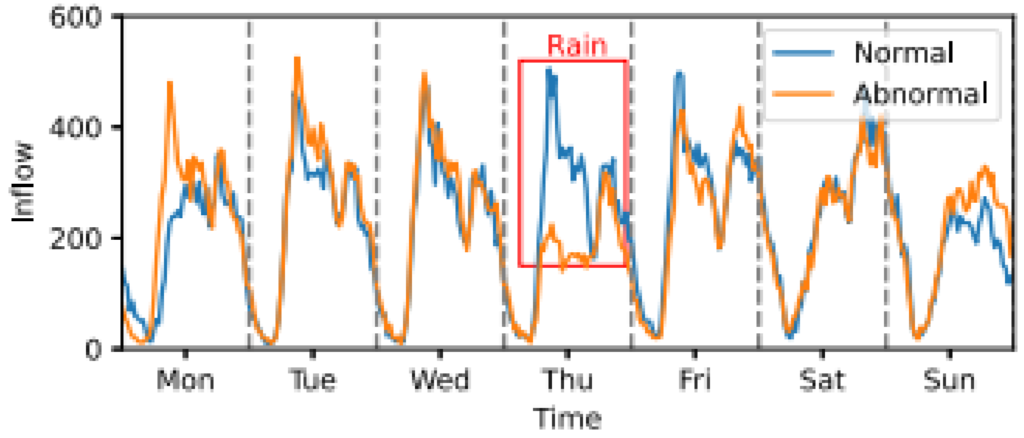
- **GeoAI leverages spatial and temporal patterns** to identify outliers
  - **Spatial context** (e.g. neighborhood similarity, geographic clustering)
  - **Temporal dynamics** (e.g. recurring patterns, seasonality)

- Key Methods:
  - **DBSCAN:** Density-based clustering to detect spatial outliers without needing labeled data.
  - **Autoencoders:** Neural networks trained to reconstruct input—large reconstruction errors signal anomalies.
  - **ST-GCN** (Spatio-Temporal Graph Convolutional Networks): Models spatial dependencies and temporal evolution simultaneously, ideal for dynamic sensor networks.



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Bias Correction with GeoAI (1)

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- GeoAI integrates **spatial context to detect and mitigate bias** that arises from geographic (and/or demographic) imbalances.
- Spatial fairness-aware learning ensures that models treat regions and populations equitably, even when data availability varies.

- Key Methods
  - **Reweighting**: Adjusts the influence of overrepresented regions or groups to balance model learning.
  - **Fairness-aware algorithms**: Incorporate fairness constraints during training to reduce disparate impact.
  - **Spatial stratification**: Ensures that training samples are geographically diverse and representative.

Wang, Z., Wu, N., Cao, Q., Xia, J., Liu, Z., Xie, Y., ... & Mai, G. (2025). GeoBS: Information-Theoretic Quantification of Geographic Bias in AI Models. *arXiv preprint arXiv:2509.23482*.
Xie, Y., Jia, X., Chen, W., & He, E. (2023). Heterogeneity-aware deep learning in space: Performance and fairness. In Handbook of Geospatial Artificial Intelligence (pp. 151-176). CRC Press.

Bias Correction with GeoAI (2)

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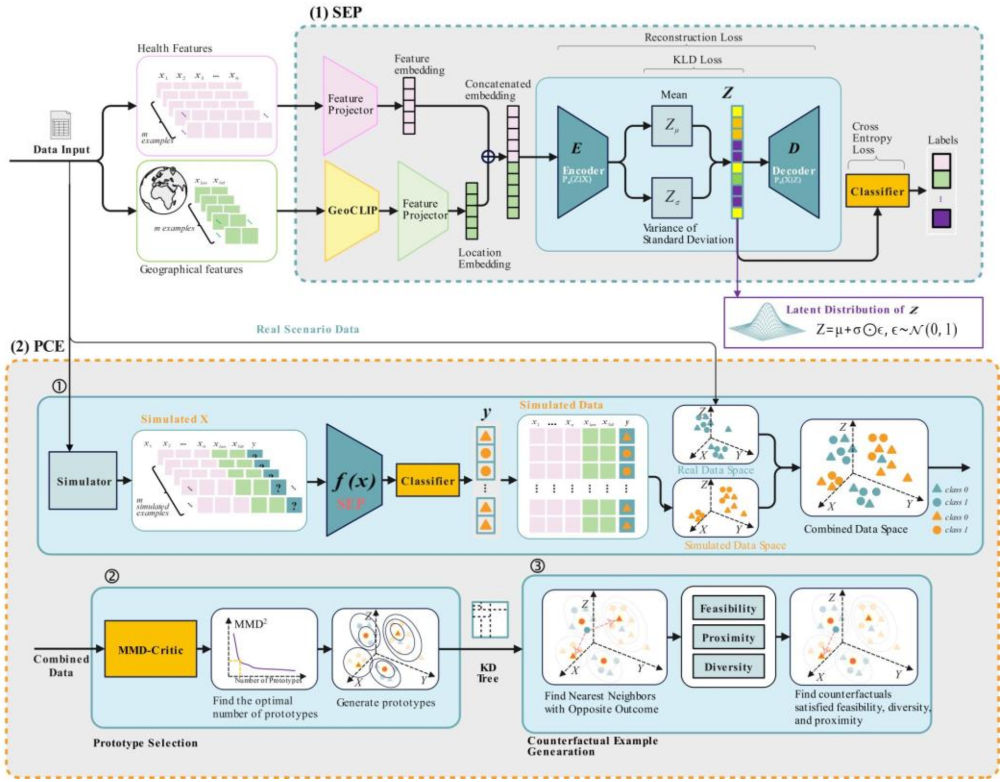
- Some issues we should pay attention to:
  - **Spatial Autocorrelation**: Nearby locations often share similar characteristics. Fairness-aware models must account for this to avoid overfitting to dense urban clusters.
  - **Sensitive Attributes**: In geospatial contexts, attributes like income level, ethnicity, or infrastructure access may correlate with location—raising fairness concerns.
  - **Representation Bias**: Volunteered geographic information (VGI) and sensor data often reflect the interests of more connected or affluent communities.

- **Counterfactual Fairness in Spatial Models:**
  - Ensure that predictions remain consistent if a **location's demographic profile** were different.



Ma, J., Guo, R., Zhang, A., & Li, J. (2023, August). Learning for counterfactual fairness from observational data. In *Proceedings of the 29th ACM SIGKDD conference on knowledge discovery and data mining* (pp. 1620-1630).
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Zhang, J., Mu, L., Zhang, D., Chen, Z., Rajbhandari-Thapa, J., Pagan, J. A., ... & Zhou, Z. (2025). SpaCE: a spatial counterfactual explainable deep learning model for predicting out-of-hospital cardiac arrest survival outcome. International Journal of Geographical Information Science, 1-32.

GeoAI for Semantic Enrichment

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- **Semantic enrichment** refers to enhancing **raw geospatial data with meaningful, contextual information** – improving **interpretability** & **usability** for **downstream tasks**

Ontology + (Geo)Data = (Geo)Knowledge Graph

- GeoAI Capabilities:
  - **Text + Location Fusion:** Combine textual metadata (e.g., descriptions, tags) with geolocation to classify or cluster features.
  - **Embedding Techniques:** with NLP, LLMs or BERT generating semantic vectors for objects, places and/or events.
  - **Ontology Integration:** Link data to structured vocabularies (e.g., INSPIRE themes, GeoNames) for interoperability.

Qiu, Q., Zheng, S., Tian, M., Li, J., Ma, K., Tao, L., & Xie, Z. (2024). A deep neural network model for Chinese toponym matching with geographic pre-training model. *International Journal of Digital Earth*, *17*(1), 2353111.

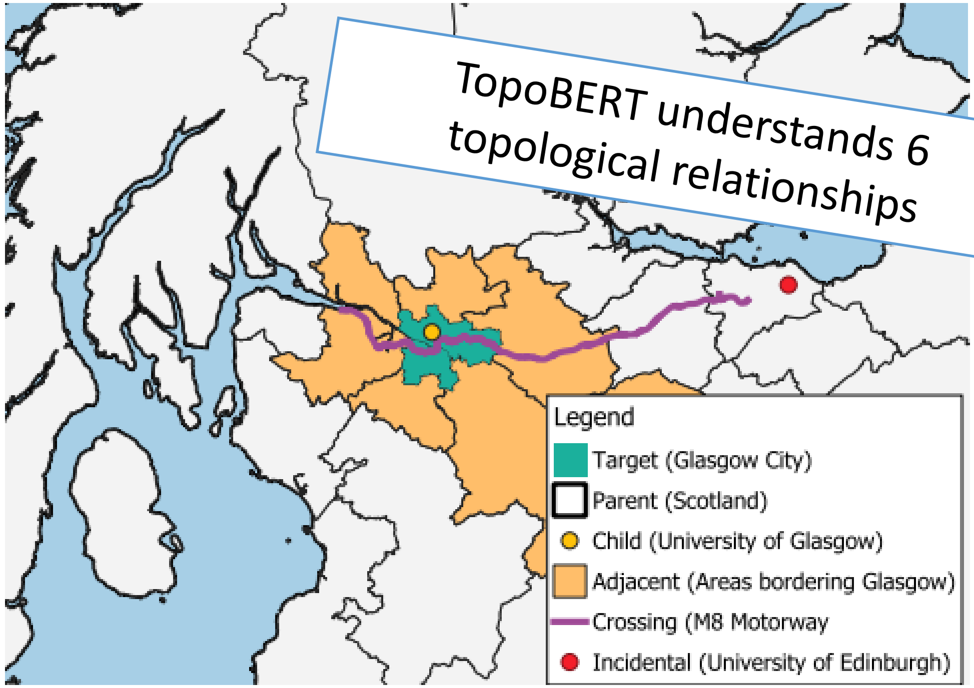
GeoAI for Semantic Enrichment

GeoBERT

"London is a city in Ontario, Canada. Its station, situated on York Street, has rail links to the neighbouring towns of Woodstock, and onward to Toronto."

- **GeoBERT**
  - built around a Bidirectional Encoder Representations from Transformers (BERT) model (Devlin et al., 2019)
  - BERT can extract syntactical and semantic information from sentences, including:
    - subject/object/verb relationships (Nastase and Merlo, 2023)
    - and capturing structural linguistic information (Jawahar et al., 2019).
  - BERT has also been shown to be effective in identifying spatial relationships within natural language (Shin et al., 2020),
    - "Tom is on the box"
    - "The cat is in the house"

TopoBERT understands 6 topological relationships



Shingleton, J., & Basiri, A. (2024). Enhancing toponym identification: Leveraging Topo-BERT and open-source data to differentiate between toponyms and extract spatial relationships. *AGILE: GIScience Series*, *5*, 1-10.
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Qiu, Q., Zheng, S., Tian, M., Li, J., Ma, K., Tao, L., & Xie, Z. (2024). A deep neural network model for Chinese toponym matching with geographic pre-training model. *International Journal of Digital Earth*, *17*(1), 2353111.

Applications in Selected Projects

Virtual Shepherd

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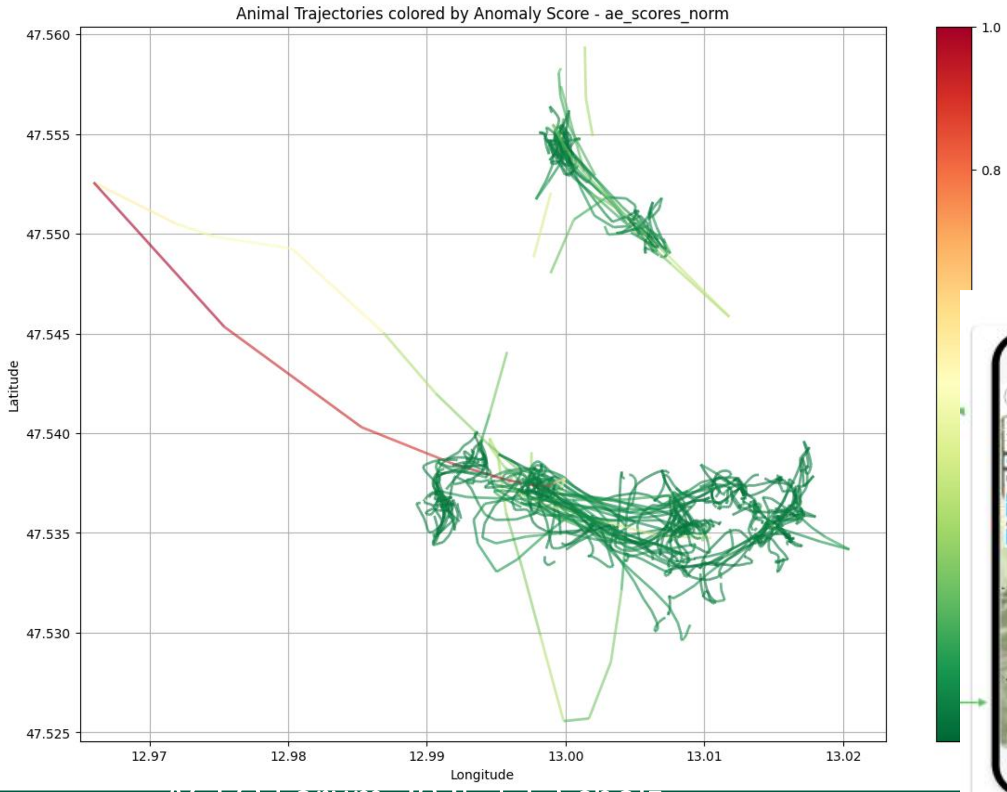
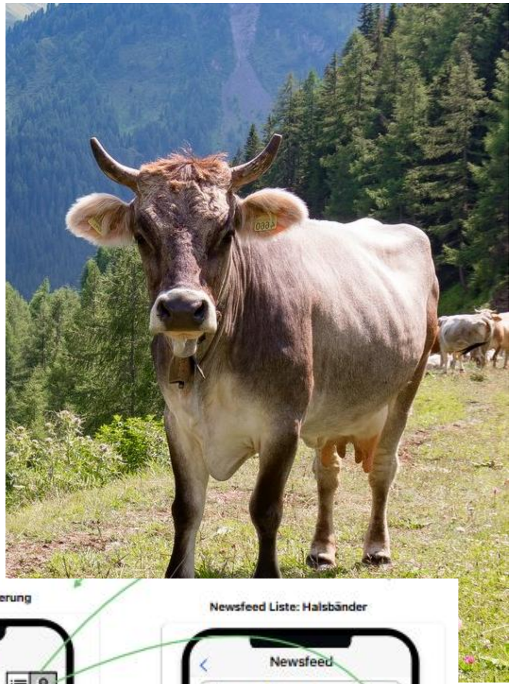
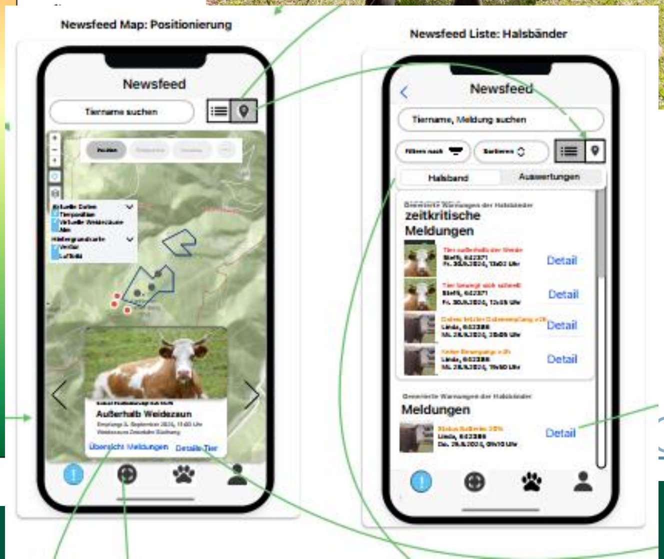
TU Wien Informatics · Moving Layers · Viehfinder

- Virtual Fencing and Virtual Shepherd that supervises lifestock in Alpine regions
- Detection of anomalies in cow movement
  - Trajectories
  - Additional sensors (accelerometer, temperature, …)
- GeoAI:
  - Autoencoder-based anomaly detection
  - Edge Devices(!)







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RegioWoodTrain

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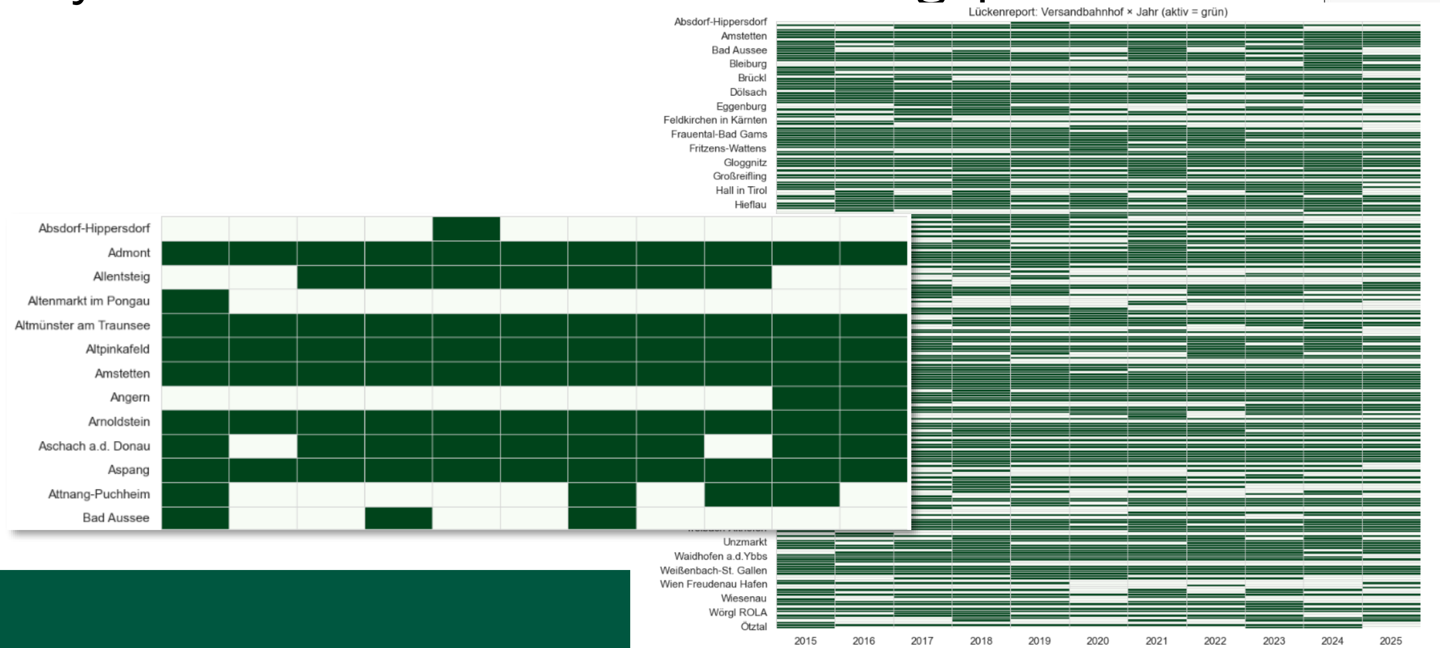
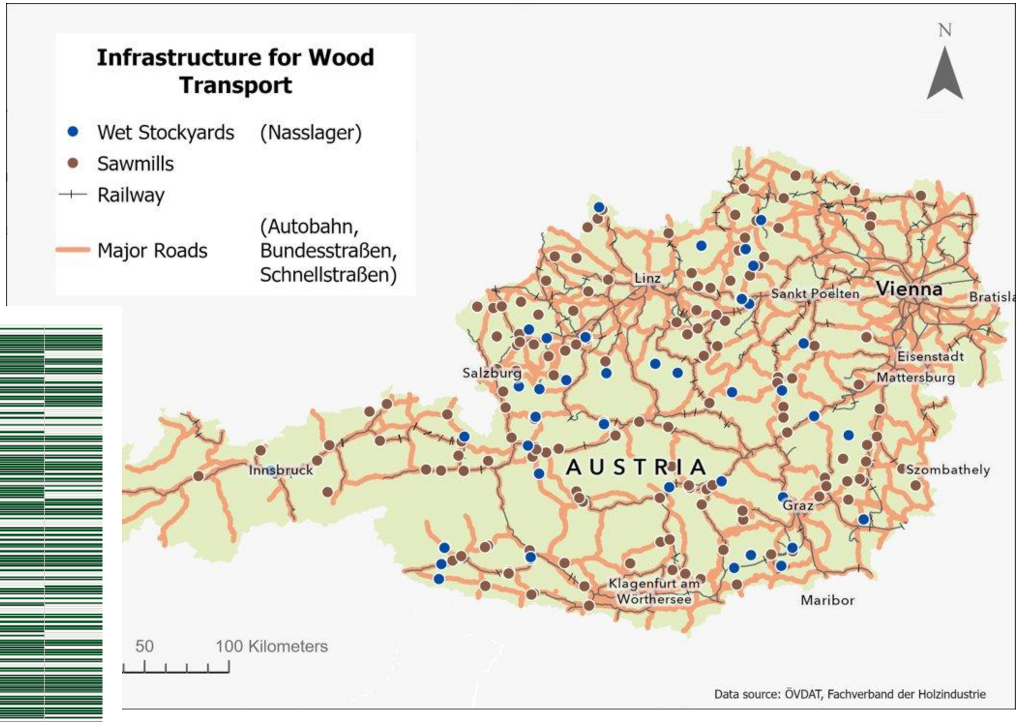
- The project develops cooperative, AI-driven strategies to shift wood transport toward climate-friendly rail logistics, improving resilience and sustainability in Austria's regional supply chains.
- ST-GNNs based on a graph-based representation of the data
- Identification of missing data and usage of synthetic data to close some "data gaps"





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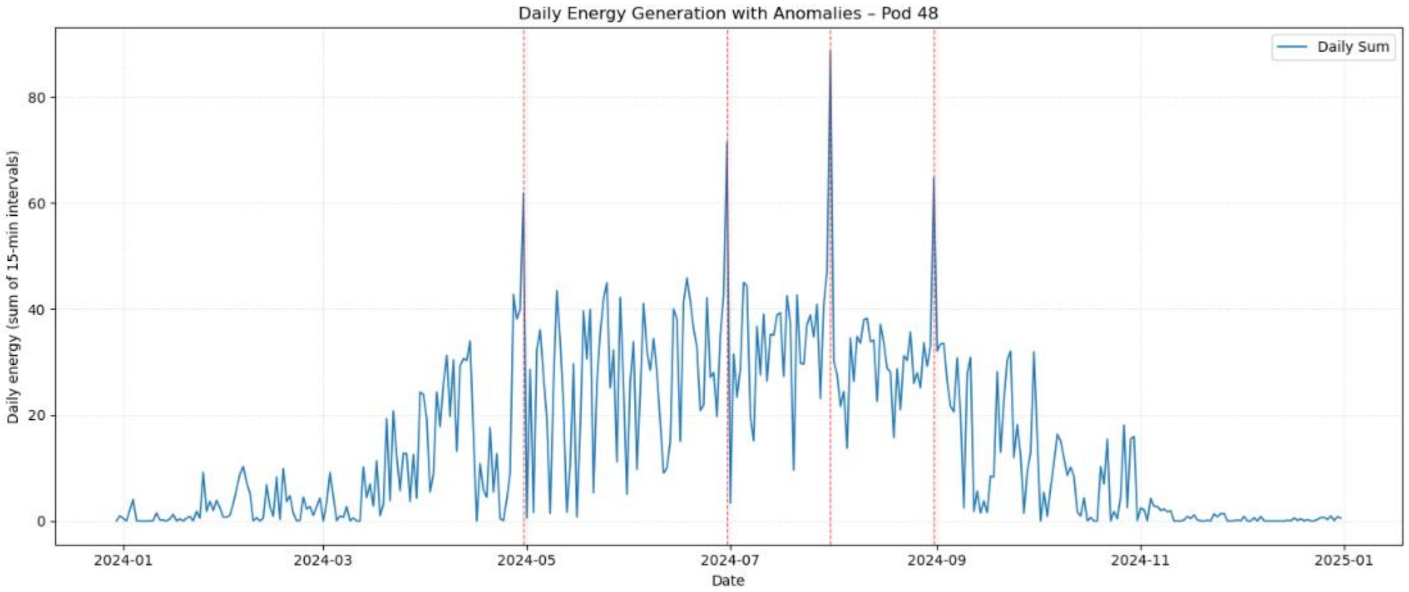
iKlimEt

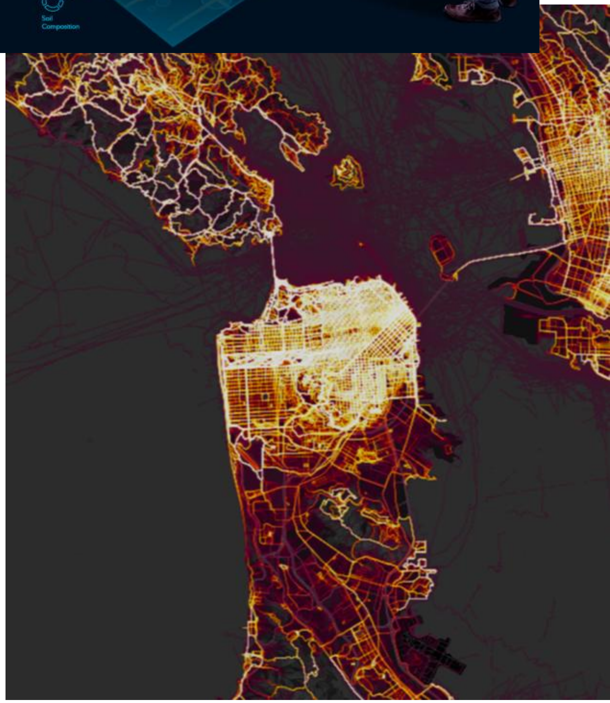
- The iKlimEt project develops AI-driven simulation tools for integrated, climate-resilient energy system planning, focusing on sector-coupled optimization and validating them through a case study in Styria to support Austria’s 2040 climate neutrality goals.

- LSTM autoencoder detects anomalies in smart meter time series data (energy generation).
  - Divided into daily sliding windows (96 values of 15 minutes each) with a 12-hour overlap and then normalised so that all pods are comparable.
- Each sliding window therefore represents one day of energy generation → training data.
- Reconstruction errors were calculated, and windows with the highest errors top 3% were marked as anomalies.



Summary

- **Why GeoAI?**
  - Enhances AI models with spatial reasoning & geographic context
  - Tackles challenges in data quality, bias, and semantic richness
- **Core Use Cases**
  - **Anomaly Detection:** DBSCAN, Autoencoders, ST-GCN
  - **Bias Correction:** Reweighting, fairness-aware learning, spatial stratification
  - **Semantic Enrichment:** GeoBERT, TopoBERT, Ontology integration



GeoAI bridges spatial intelligence and machine learning to improve data quality, fairness, and interpretability—critical for robust, ethical AI systems

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johannes.scholz@plus.ac.at
www.zgis.at || www.johannesscholz.net
https://linkedin.com/in/johannes-scholz-gisc
@Joe_GISc
@Joe_GISc@mastodon.online
@joegisc.bsky.social

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