Fachbereich
Geoinformatik

# GeoAI für die Datenvalidierung

## Key Concepts um Daten für AI „fit“ zu machen

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# Geospatial Artificial Intelligence

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- “**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).

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# Motivation

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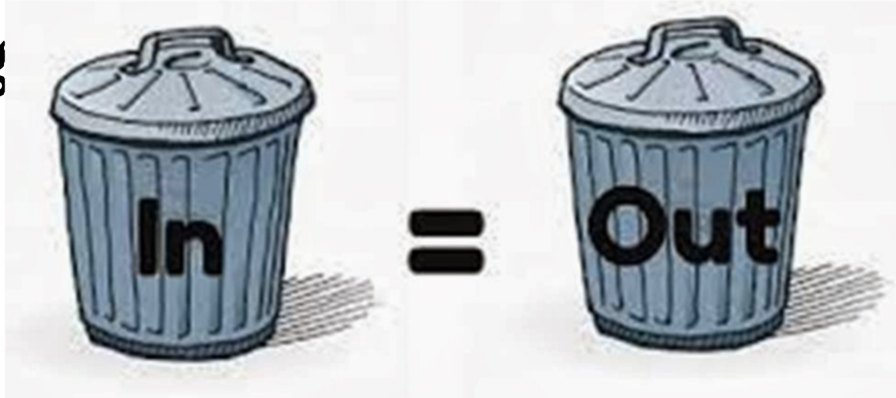
„Garbage in, Garbage out."

AI Models are dependent on training and verification data

- Heterogeneity
- Incompleteness
- Bias
- Flaws



# Data Quality as Critical Success Factor

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| | |
|---|---|
| • **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| • **Timeliness:** | • Outdated data fails to reflect current realities—especially critical in dynamic domains like mobility or energy.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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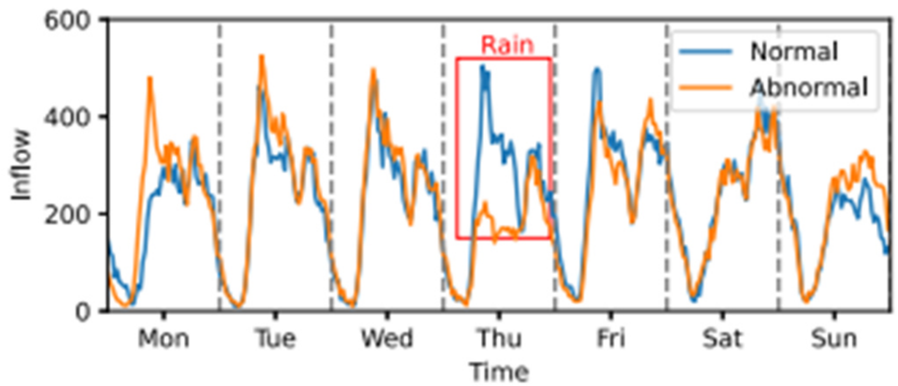
- **GeoAI leverages spatial and temporal patterns** to identify outliers
  - **Spatial context** (e.g. neighborhood similarity, geographic clustering)
  - **Temporal dynamics** (e.g. recurring patterns, seasonality)

- 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 Models spatial dependencies and temporal evolution simultaneously, ideal for dynamic sensor networks.




Deng, L., Lian, D., Huang, Z., & Chen, E. (2022). Graph convolutional adversarial networks for spatiotemporal anomaly detection. *IEEE Transactions on Neural Networks and Learning Systems*, *33*(6), 2416-2428.

# Bias Correction with GeoAI (1)

- 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.

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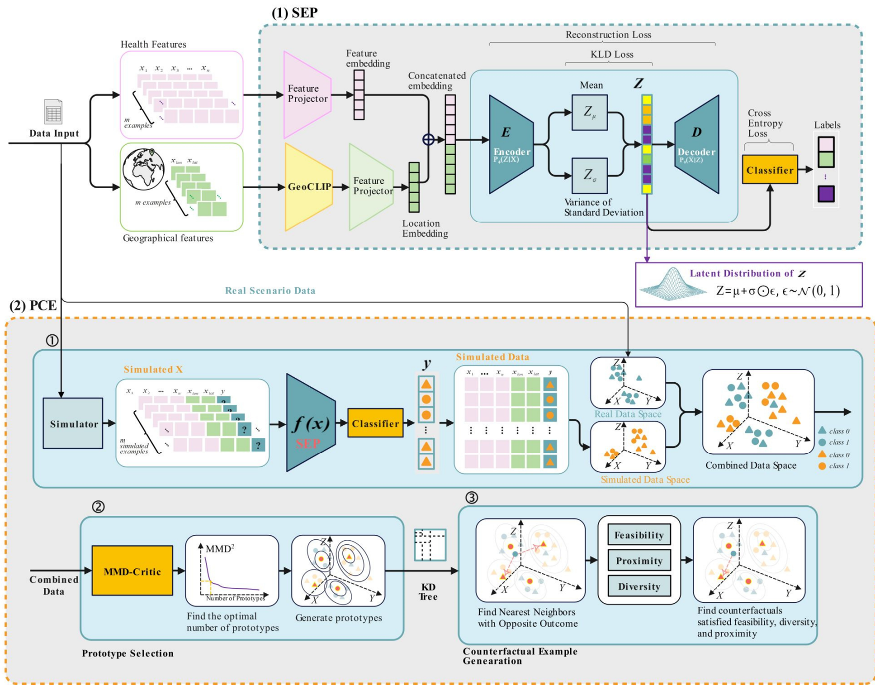
# Bias Correction with GeoAI (2)

- 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).
Ma, J., Guo, R., Wan, M., Yang, L., Zhang, A., & Li, J. (2022, February). Learning fair node representations with graph counterfactual fairness. In Proceedings of the fifteenth ACM international conference on web search and data mining (pp. 695-703).
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

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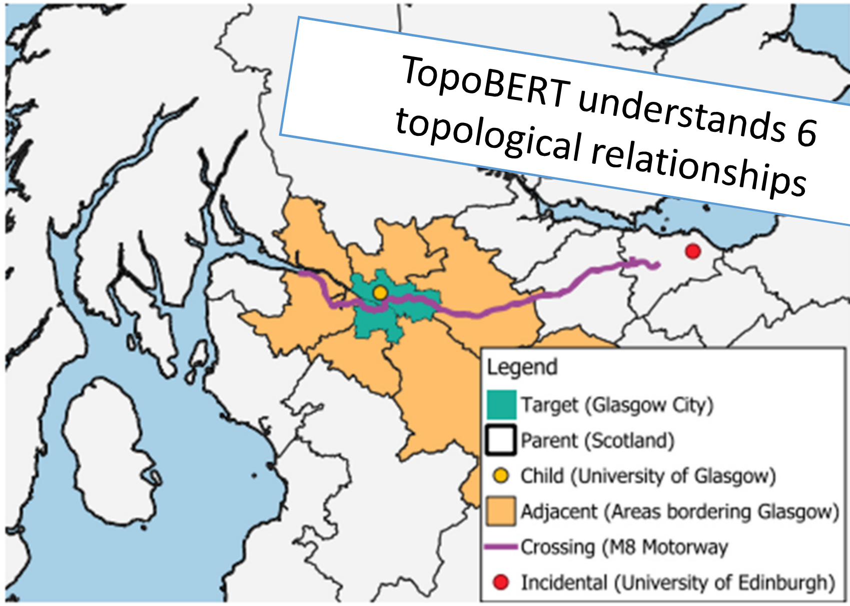
- **GeoBERT**
  - built around a Bidirectional Encoder Representations from Transformers (BERT) model (Devlin et al., 2019)
  - BERT can extract syntactical and semantic information from sentences, including:
    - subject/object/verb relationships (Nastase and Merlo, 2023)
    - and capturing structural 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"

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."*




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.
Shingleton, J., & Basiri, A. (2025). How close is" close"? An analysis of the spatial characteristics of perceived proximity using Large Language Models. *AGILE: GIScience Series*, *6*, 11.
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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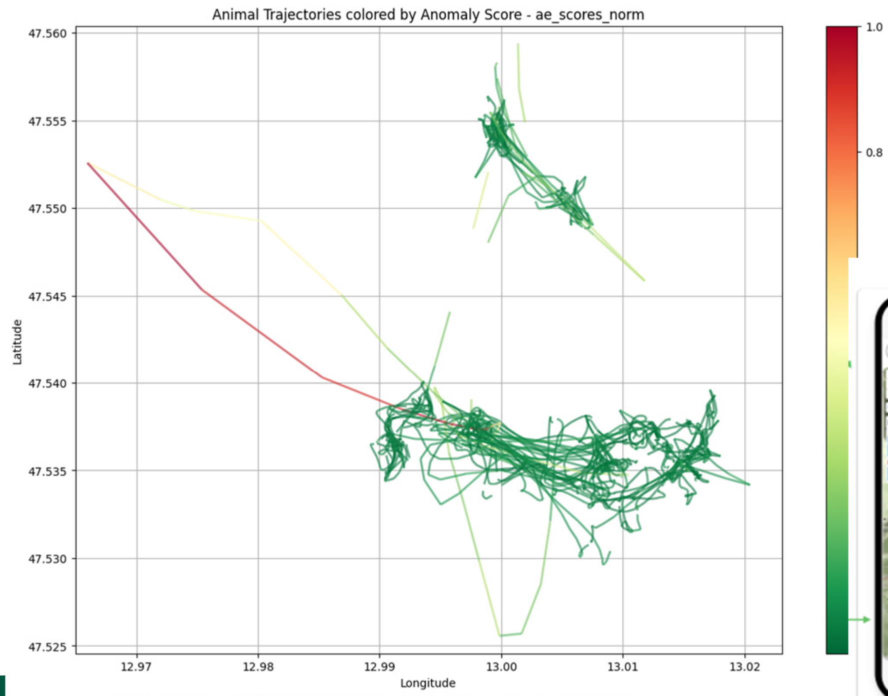
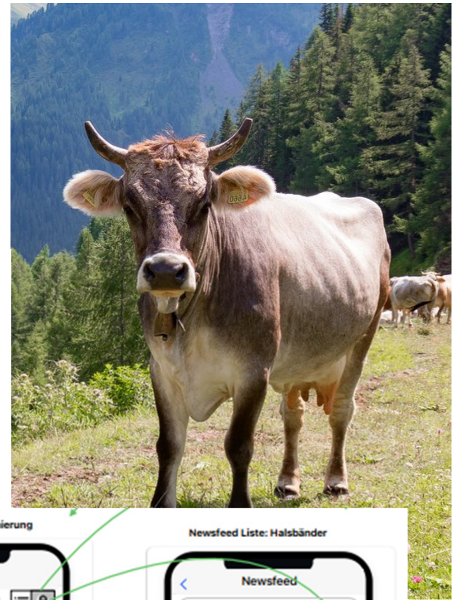
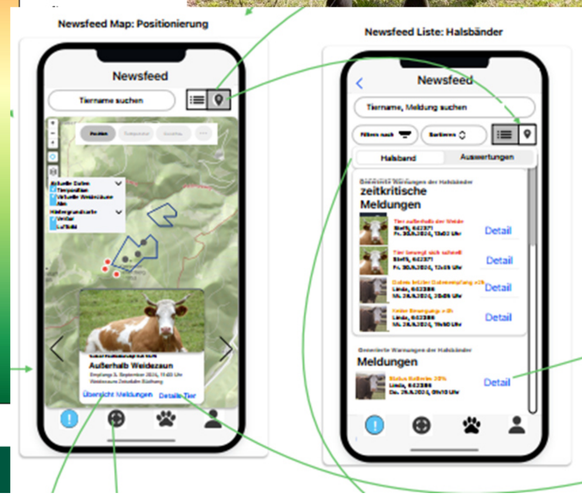
- Virtual Fencing and Virtual Shepherd that supervises lifestock in Alpine regions
- Detection of anomalies in cow movement
  - Trajectories
  - Additional sensors (accelerometer, temperature, …)
- GeoAI:
  - Autoencoder-based anomaly detection
  - Edge Devices(!)





# RegioWoodTrain

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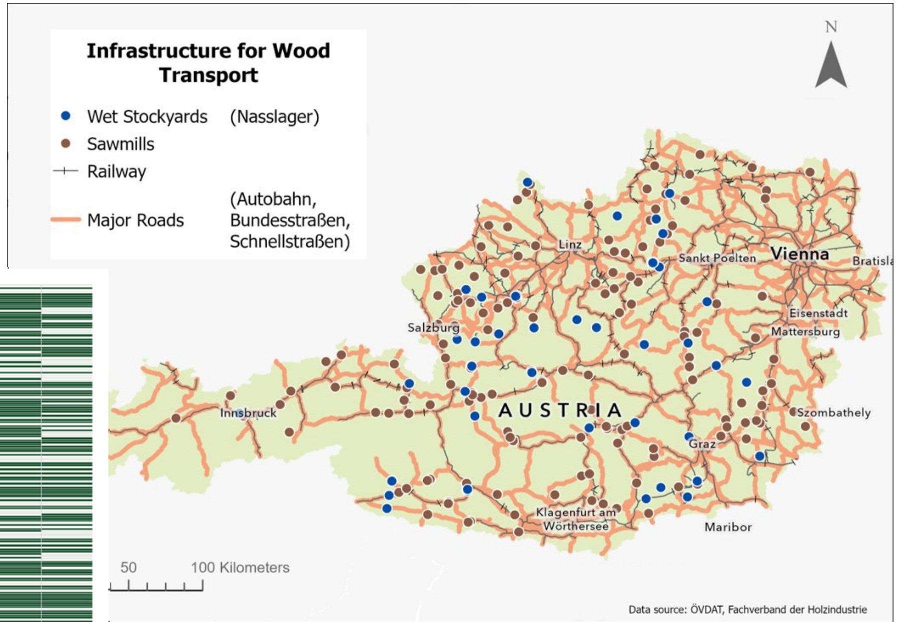
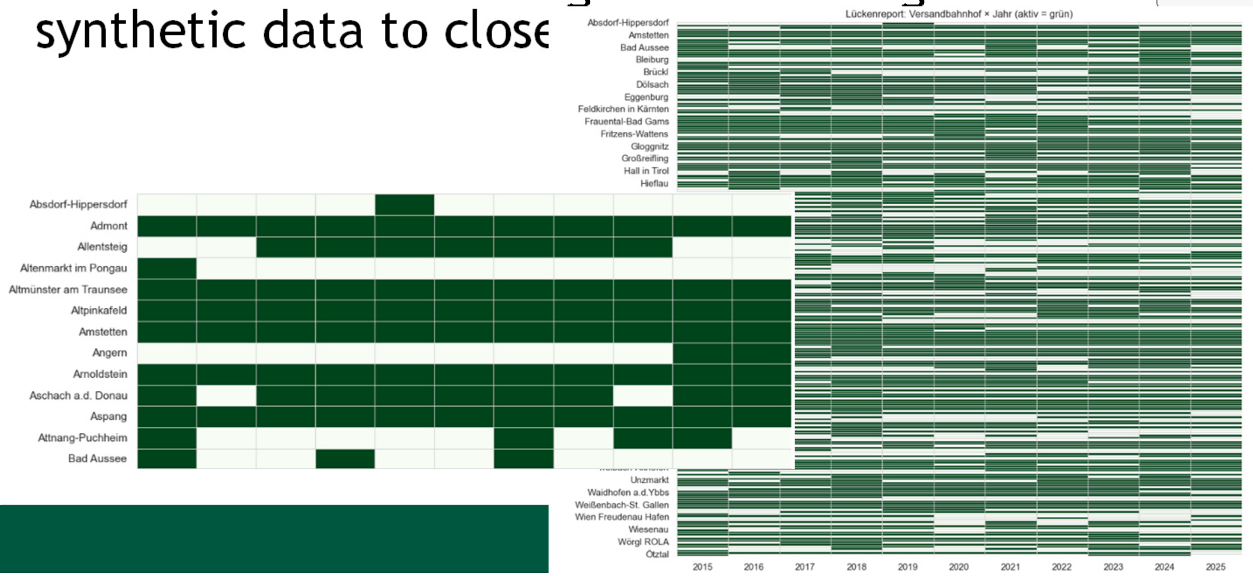
- The project develops cooperative, AI-driven strategies to shift wood transport toward climate-friendly rail logistics, improving resilience and sustainability in Austria's regional supply chains.
- ST-GNNs based on a graph-based representation of the data
- Identification of missing data and usage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

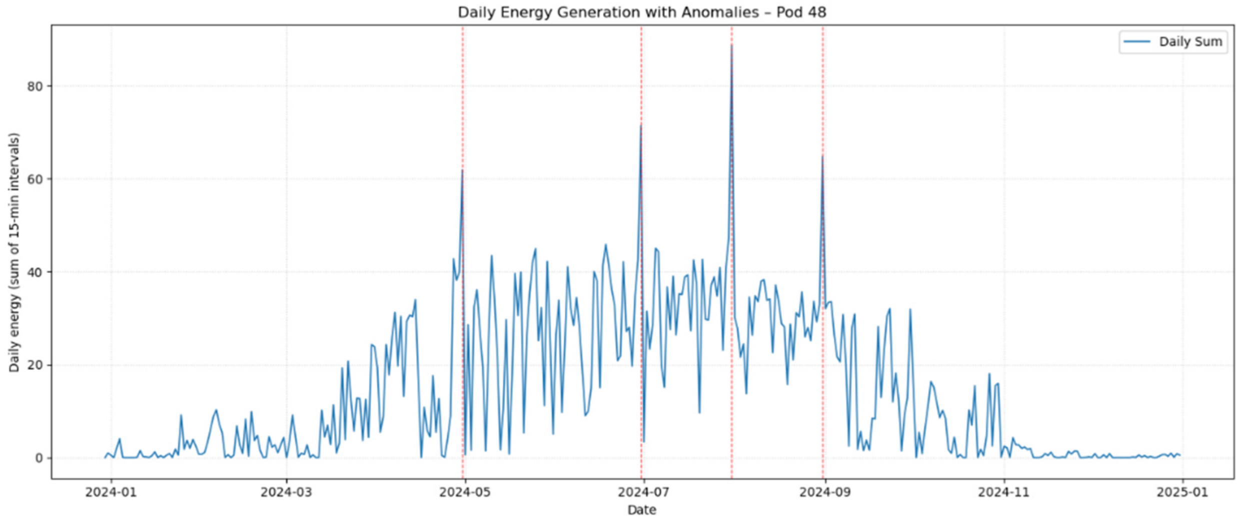


# iKlimEt

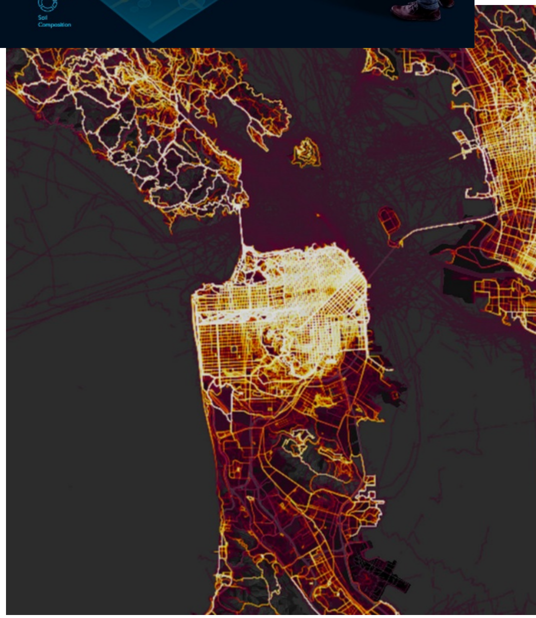
- The iKlimEt project develops AI-driven simulation tools for integrated, climate-resilient energy system planning, focusing on sector-coupled optimization and validating them through a case study in Styria to support Austria's 2040 climate neutrality goals.

- 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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