Non-Residential Rooftop PV in Germany - Development and Potential

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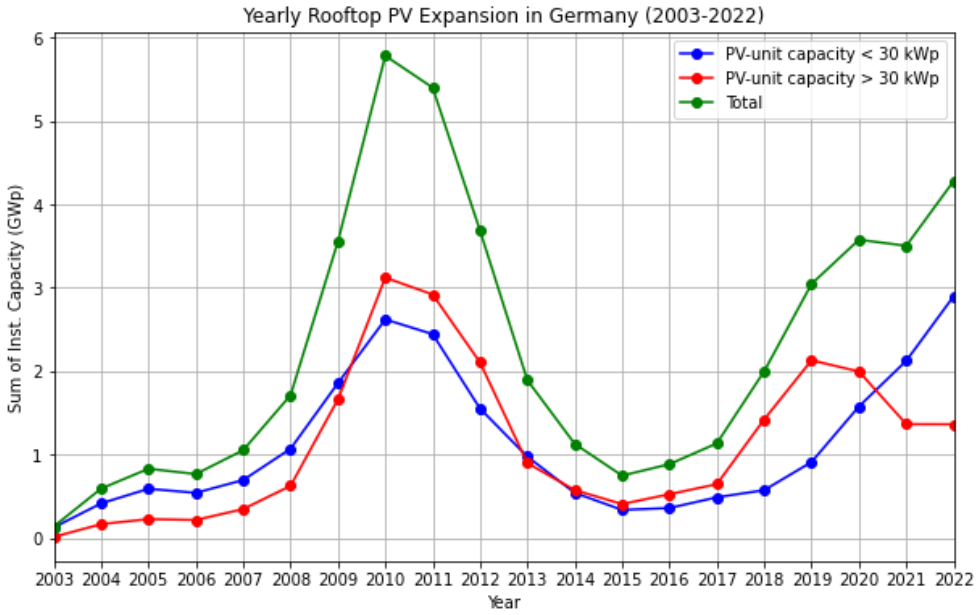
Germany‘s Ambitious Solar Goals

- 2030 governmental plans for Germany:[1]

  Triple current PV capacity from 77 GW to 215 GW
- Rooftop contribution

  11 GW/year expansion post 2026 via rooftop systems



Own illustration, Data: Marktstammdatenregister („MaStR“) – Federal Network Agency

- Current research domains making use of PV-MaStR data[2]:
  - Energy economics
    → Profitability/adoption of (residential) PV/ prosumer
  - Energy system analysis
    → Flexibility (priv. HH) & potential
  - Sustainability studies
    → Land use (ground-mounted PV)
  - Energy Data
    → Aerial image recognition
- Research gap regarding rooftop-PV expansion plans:
  - ➢ Empirical interdependencies between built non-residential PV units, their location and underlying buildings

[1] Federal Ministriy of Economics and Cliimate Action: „Photovoltaik-Strategie Handlungsfelder und Maßnahmen für einen beschleunigten Ausbau der Photovoltaik“

[2] Tepe, D., Kotthoff, F., Muschner, C., Vogt, E., & Hülk, L. (2023). „Improving Data Reliability in Germany's Energy System: A Validation of Unit Locations of the Marktstammdatenregister.“ arXiv preprint arXiv:2304.10581.

Research Questions

- What does empirical data tell about PV unit sizing on non-residential buildings?
- How efficiently is roof space on non-residential buildings exploited for PV installations, and does this vary across industries and regions?

Method and Data

Building the Data Set

1) PV Data from MaStR

Method:
- Filtering and Cleansing:
  - Installed capacity per unit > 30 kWp
  - Unittype: rooftop PV
  - Geo-information present (lat/lon)
- Assign Solar Irradiation (Global Solar Atlas)

Input:
- All PV-units from MaStR
- PV intensity grid (Global Solar Atlas)

Output:
- Dataset „Non-residential PV-units in Germany“

3) Matching Method „PV-Units and Underlying Buildings“

Method:
- “Nearest Neighbor” matching
- “Drawing without replacing”
- Footprint size restriction[3] for matching:
  - Min. Footprint size [m²] >= PV capacity [kWp] / 0.1[kWp/m²]

Input:
- Dataset „Non-residential PV-units in Germany“
- All available building footprints in Germany

Output:
- Dataset of „Non-residential“ PV-units with assigend buildings and land use in Germany
- List of buildings with no rooftop PV

2) Building Data from OpenStreetMap

Method:
- Filtering and Cleansing:
  - Download all building footprints
  - Compute Footprint size (m²)
  - Filtering footprint size > 300 m²
- Assign land cover and land use of building location (CorineLandCover 5ha)

Input:
- OpenStreetMap Full Data Set Germany
- CorineLandCover data for Germany

Output:
- All available building footprints in Germany > 300 m² with assigned land use

[3]NRW.Energy4Climate – Rooftop PV Manual 2022

What does empirical data tell about PV unit sizing on non-residential buildings?

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Preliminary Results

- Multivariate Linear Regression:
  $Y=\beta_0+\beta_1X_1+\beta_2X_2+\cdots+\beta_kX_k+\epsilon$
- Coefficient Estimation via OLS
- Regression Statistics:
  - $R^2 = 0.452$
  - Observation = 132,172

Dependent Variable	Installed Capacity [kWp]	
	coefficient	t-value
FOOTPRINT SIZE	0.025***	103.473
	[0.000]	
YEAR OF CONSTRUCTION	2.841***	58.665
	[0.048]	
USAGE TYPE (Full Infeed)	11.892***	25.890
	[0.459]	
SOLAR IRRADIATION	-0.038***	-16.001
	[0.002]	
LONGITUDE	0.9554***	10.230
	[0.093]	
LAND COVER	7.181***	19.442
(Industrial/Commercial/Transport)	[0.369]	
LAND COVER	-3.164***	-11.268
(Urban Fabric)	[0.281]	

Note: standard errors in brackets. Significance levels: *** p <0.01, ** p <0.05, * p <0.1.

Regional Rooftop Space Usage Efficiency

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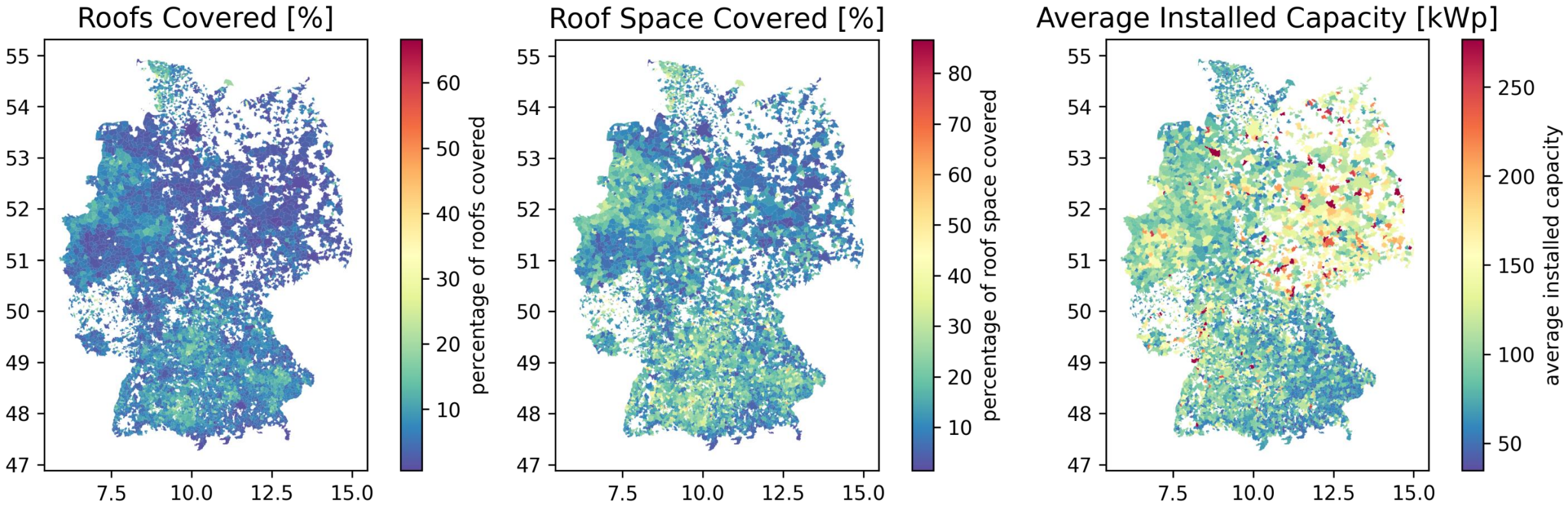
Preliminary Results



Geographical entity: Local Administration Units (LAU) → 5256 from 11007 plotted

Applied Filtering: LAU with 5+ PV units, 99 Percentile of regions plotted, considered only buildings >300 m² footprint size

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Regional Rooftop Space Usage Efficiency per Land Use Category

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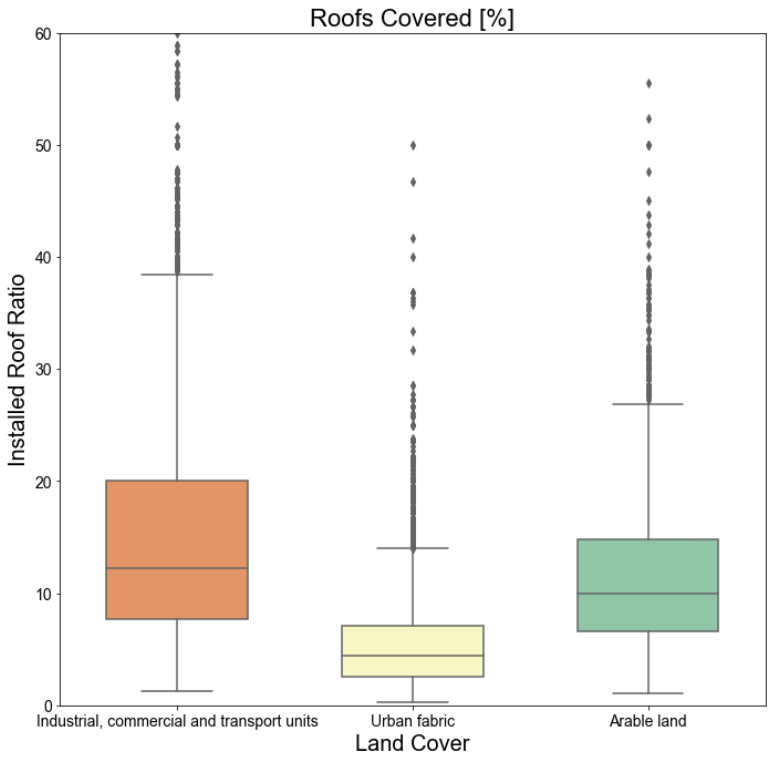
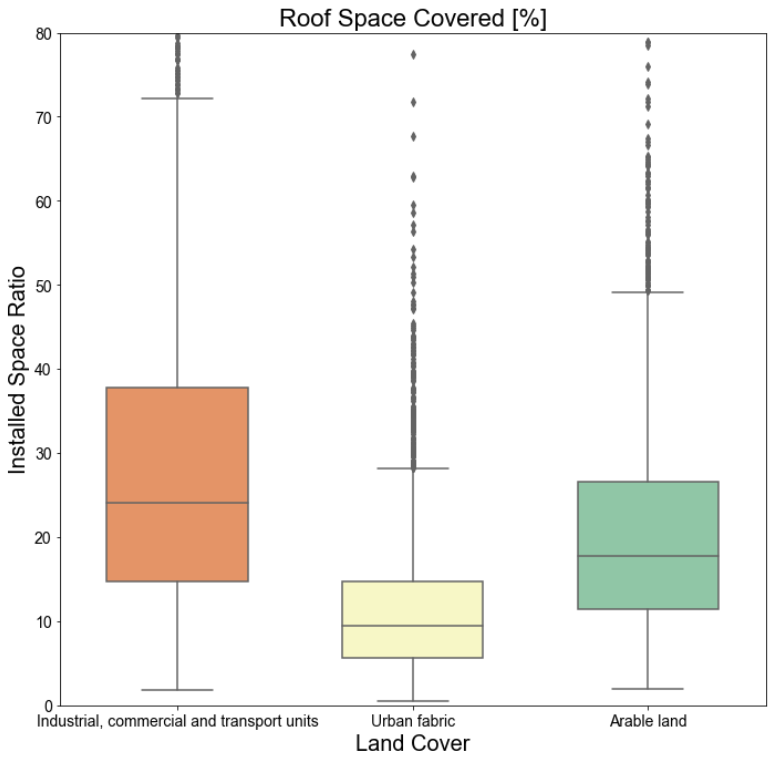
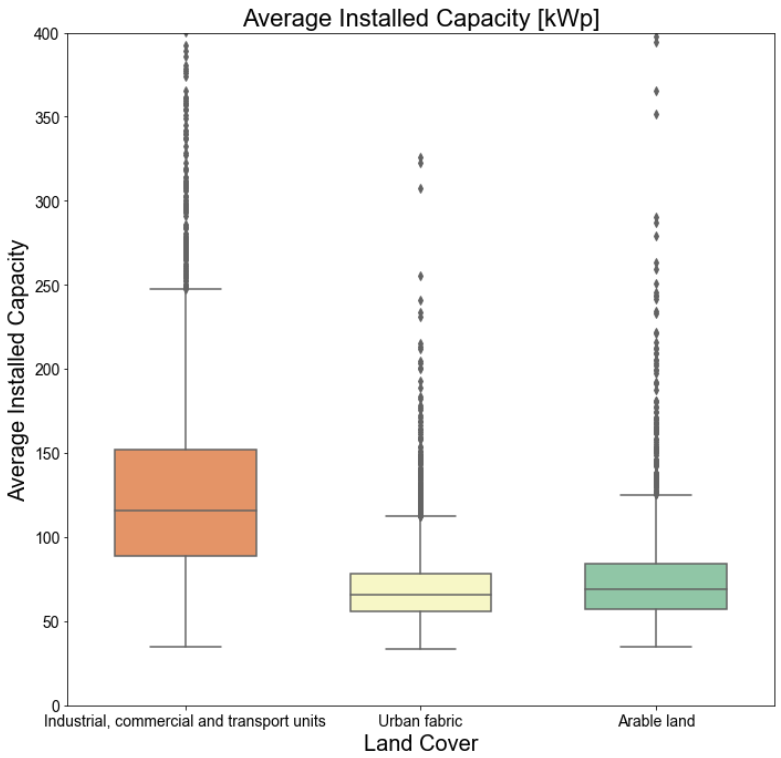
Preliminary Results







Geographical entity: Local Administration Units (LAU)

Applied Filtering: LAU with 3+ PV units **of landuse category**, considered only buildings >300 m² footprint size

Number of LAU covered Industrial: 3664 of 5599 / Urban Fabric: 3799 of 7540 / Arable Land: 2437 of 5756

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Conclusion & Outlook

- PV unit sizing depends on hard facts on site:
  - Physical building size available plays crucial role for PV capacity
  - Over time, average PV unit sizing rises
- Strong regional differences in roof space usage → High roof space utilisation with low average installed capacity in the South-East of Germany → Repower Potential
- Strong heterogenity among and within different sectors indicates untapped potential:
  - PV expansion in urban fabric areas still seems to be in its early stages
  - Industrial buildings with strong progress but heterogeneous expansion pattern
- Next Steps:
  - Analyzing local and sectoral repower potential
  - Researching the impact of subsidy scheme on unit sizing over time

Thank you for your attention!

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Backup

(Preliminary) Results

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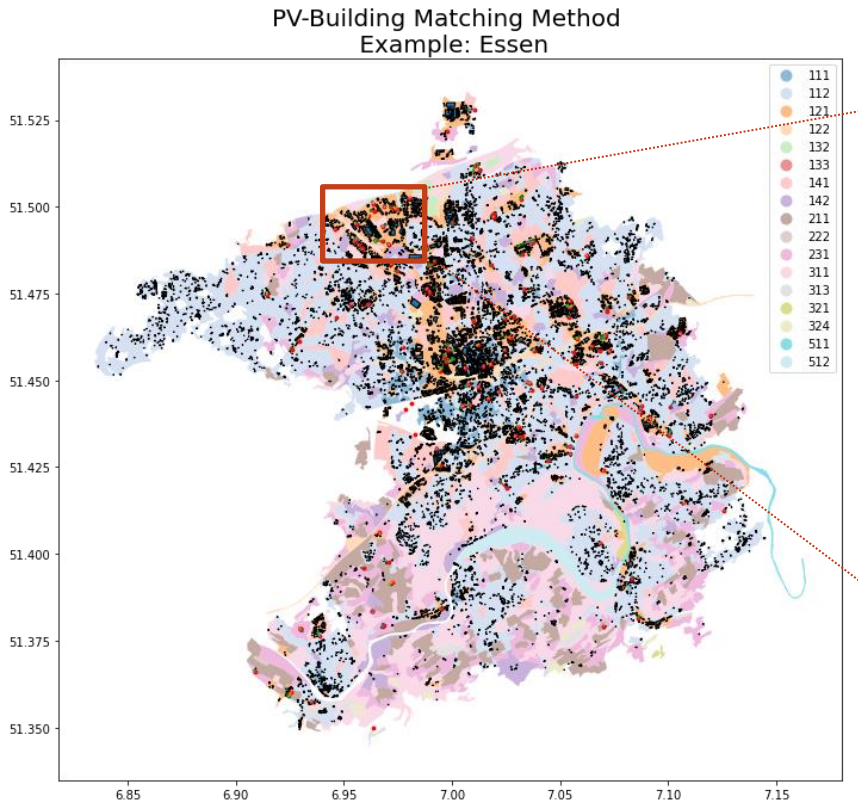
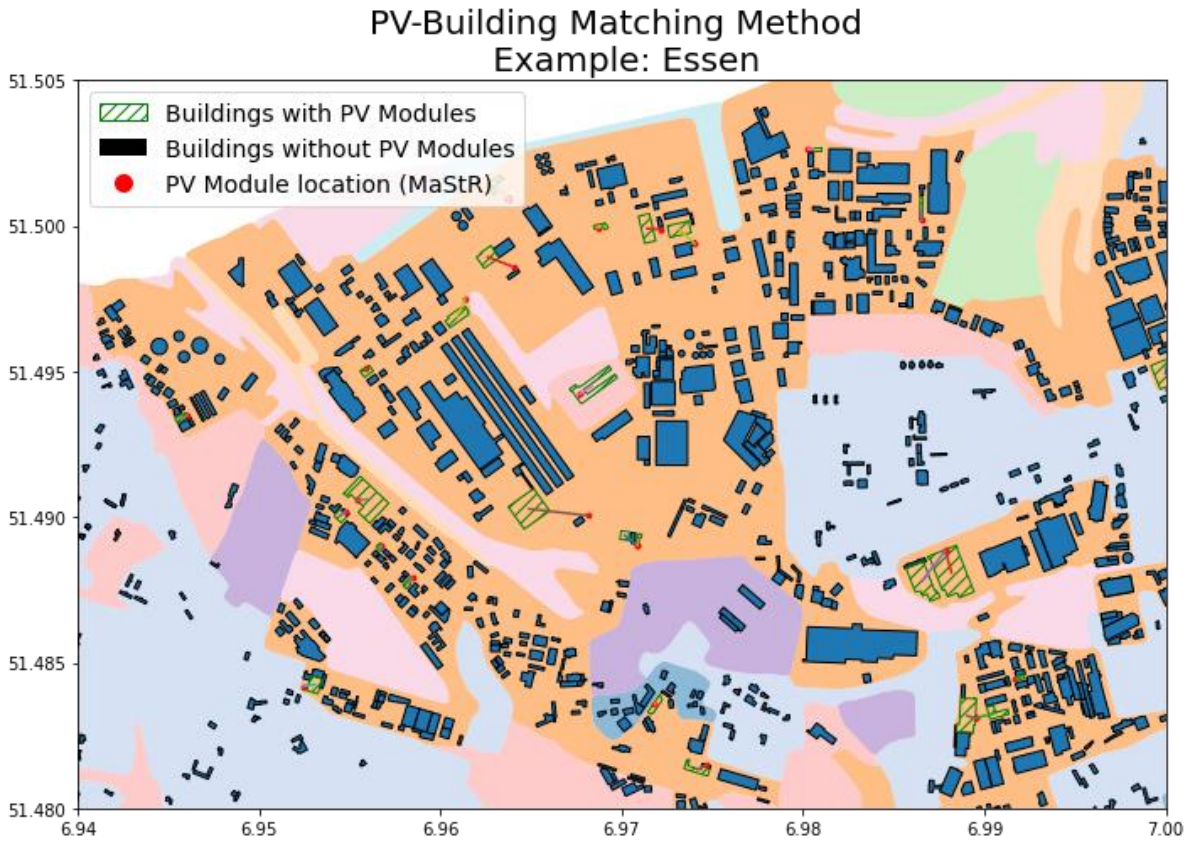
Matching Algorithm & Data Assembly





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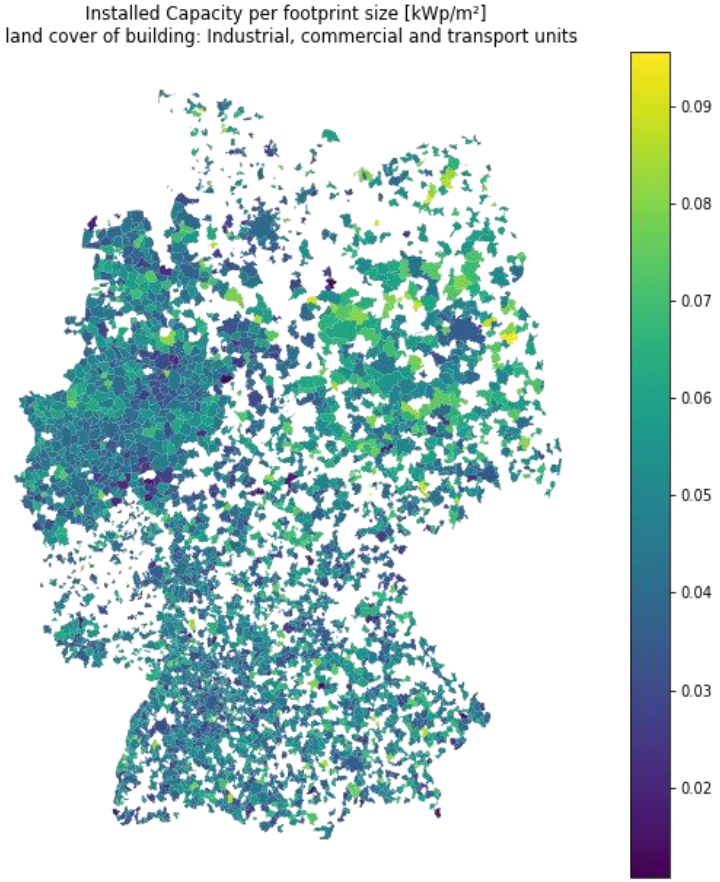
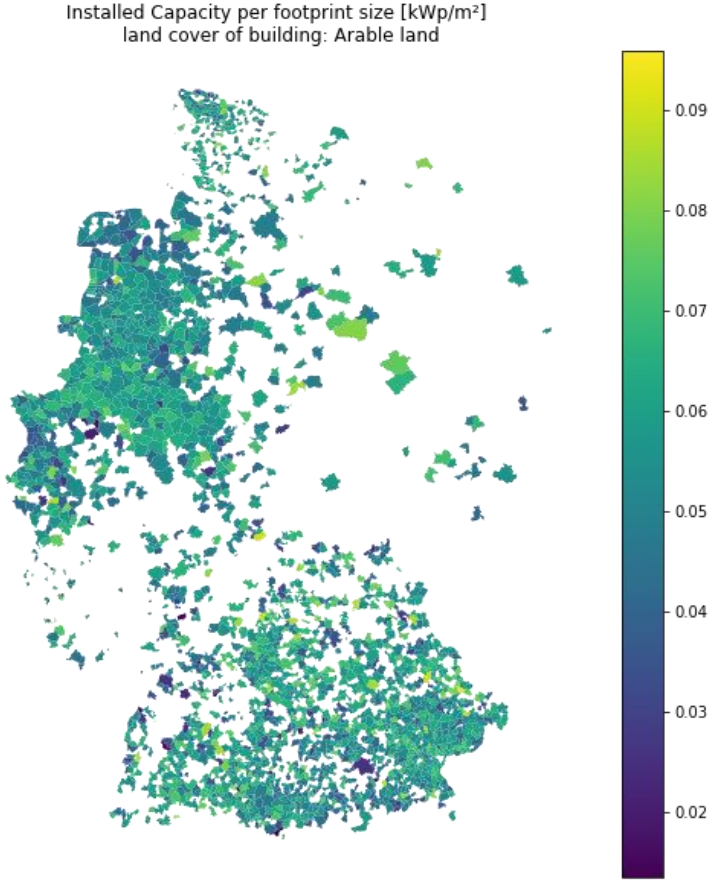
Installed Capacity per Rooftop Space available





LAU with >3 units per Land Use Sector

Data

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Descriptive Statistics

Variable	N	Mean	SD	Min	Max	unit
INSTALLED CAPACITY	132,180	89.185	76.829	30.005	690.165	kWp
FOOTPRINT SIZE	132,180	1832.273	1863.562	302.120	14558.261	m²
YEAR OF CONSTRUCTION	132,180	2012.723	4.706	2004	2023	Years
SOLAR IRRADIATION	132,180	1304.284	72.590	1019.413	1487.663	kWh/kWp
LONGITUDE	132,180	9.735	1.969	5.884	15.025	
USAGE TYPE	132,180	Part. Self consuming		Full grid infeed		Binary
CLC LEVEL	132,180	Arable Land	Urban Fabric	Industrial/Commercial/Transport units		categorical

Global Solar Atlas

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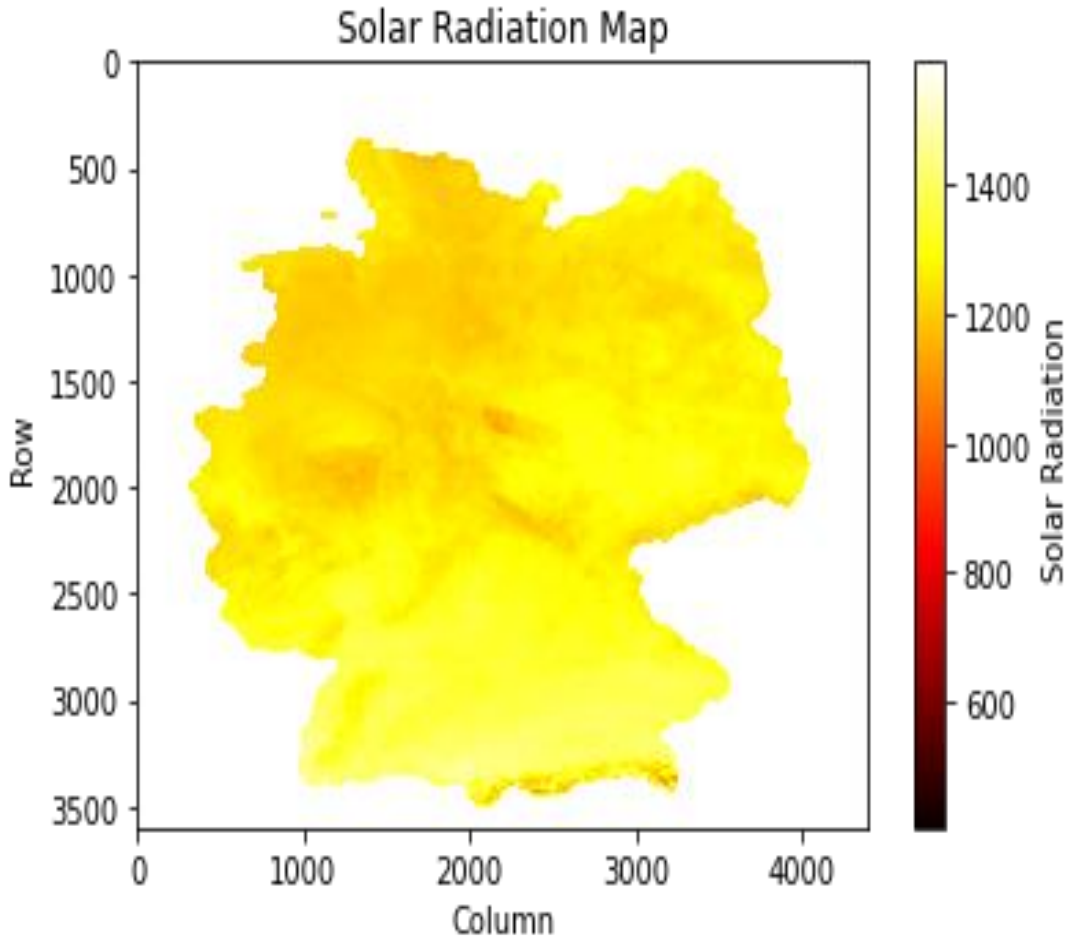
Average Radiation Intensity last 30 years



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