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Energy and Resource Management

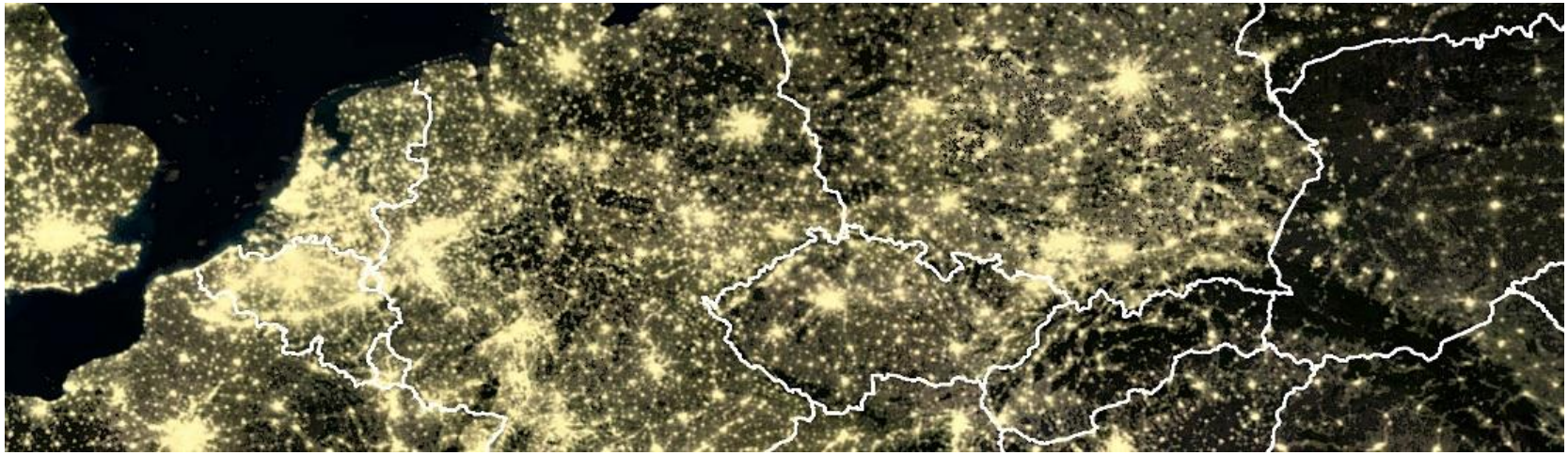


Bild © PlanetObserver

# Development and validation of subsector electricity load profiles

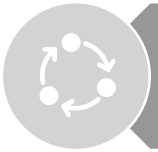
Stephan Seim | ENERDAY 2021 | 09.04.2021

Working paper published in: http://doi.org/10.5281/zenodo.4576494

E&R Energie und Ressourcen

# Agenda

Introduction



Methodology

Results

Validation

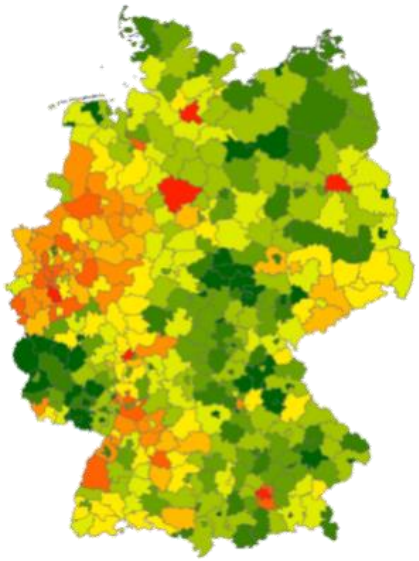
Outlook

# Introduction

DemandRegio: Modelling of final energy consumption in Germany in high regional (county) and temporal ((quarter-)hourly) resolution

## 1. Regionalisation

Annual energy demand based on **# of employees** and **specific demand** per subsector / region



**BLP** – subsector load profiles (Branchenlastprofile)

## 2. Temporal resolution

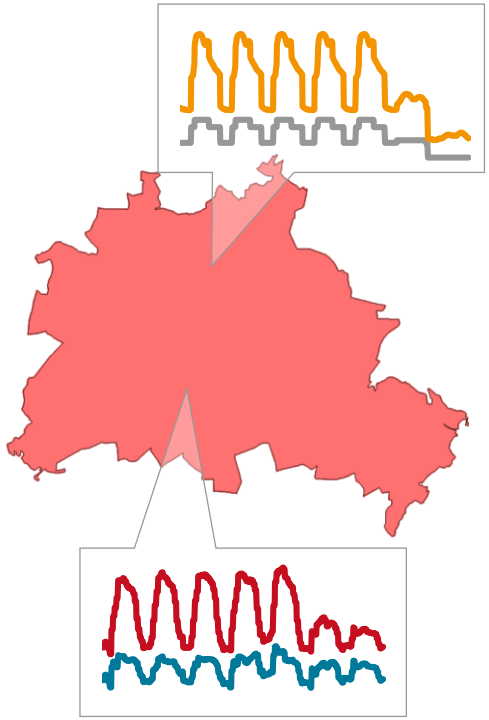
Normalised load profiles for each subsector and region

***Basic approach***: Based on generic and standard load profiles (SLP)

***Extended approach***: Based on newly developed subsector load profiles (BLP)

## 3. Results

Calculation of temporally and regionally resolved energy demand p. subsector and region





Source: Verwiebe, P.; Seim, S. (2019); Own illustration with D-Maps, Administrative boundaries: © GeoBasis-DE / BKG 2017; Generalization: FfE e.V. (edited)

# Introduction

DemandRegio: Modelling of final energy consumption in Germany in high regional (county) and temporal ((quarter-)hourly) resolution

## 1. Regionalisation

Annual energy demand based on **specific demand** and **demand drivers** per subsector and region



**BLP** – subsector load profiles (Branchenlastprofile)

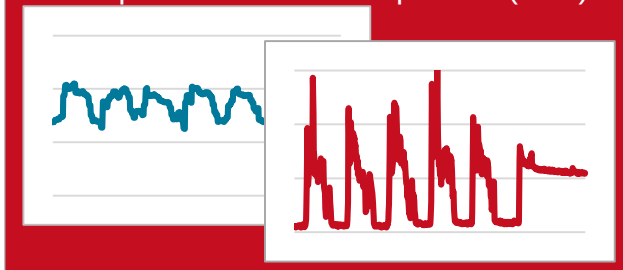
## 2. Temporal resolution

Normalised load profiles for each subsector and region

***Basic approach***: Based on generic and standard load profiles (SLP)



***Extended approach***: Based on newly developed subsector load profiles (BLP)



## 3. Results

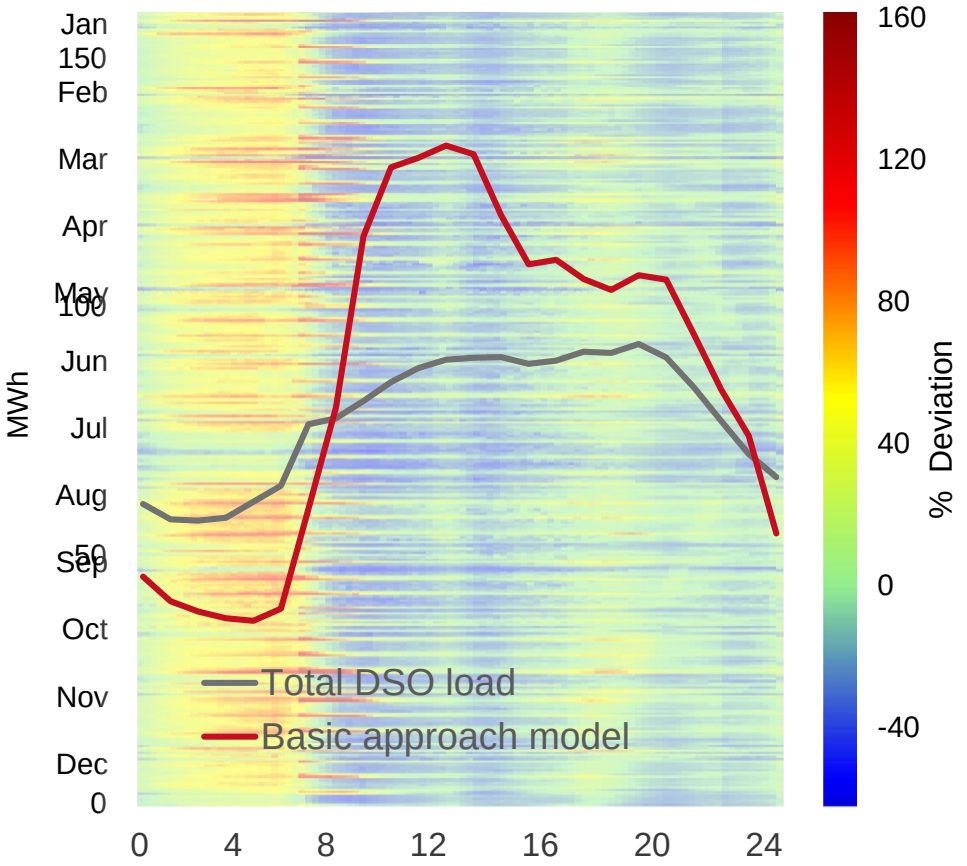




Source: Verwiebe, P.; Seim, S. (2019); Own illustration with D-Maps, Administrative boundaries: © GeoBasis-DE / BKG 2017; Generalization: FfE e.V. (edited)

# Motivation – Improvement of SLP

- Standard load profiles (SLP) are associated with structural errors
- Data gap of electricity load data in high temporal and regional resolution
- Demand for balancing reserves in balancing groups , partly due to
  - Increased self-consumption
  - changed consumption patterns
  - Insufficient accuracy of the standard load profiles (SLP)
- Weather effects not reflected in electricity SLP

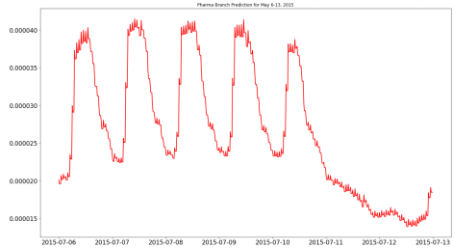



Comparison of the *Basic approach* model with the cumulative load profile of a DSO

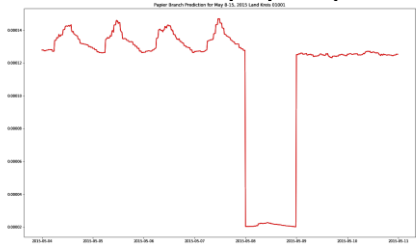

Source: Verwiebe, P.; Seim, S. (2019); Seim, S. et al. (2019); (Beuker (2018), Rykala (2018), Ecke und Kaufmann (2013), Sohns (2015), Hinterstocker et al. (2014)

# Subsector load profiles – overview

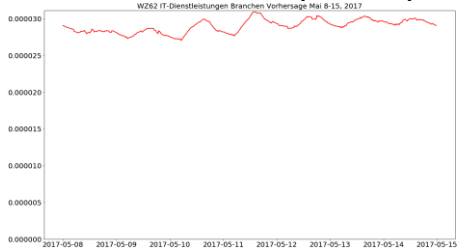
Pharmaceuticals (WZ 21)



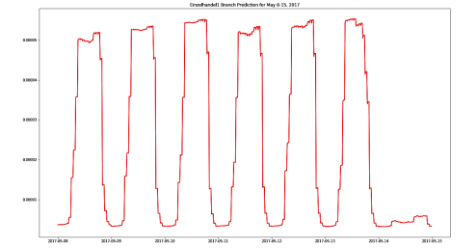
Manufacture of paper (WZ 17)



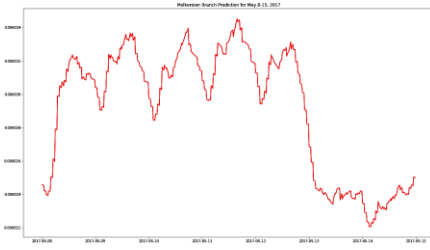
Data centers (WZ 62)



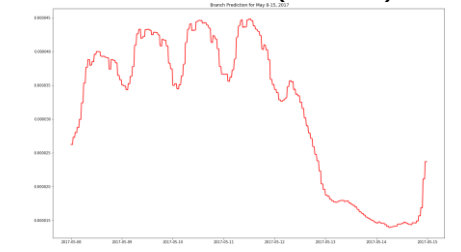
Retail trade non-food (WZ 47)



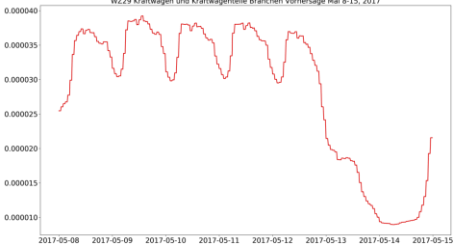
Dairies (WZ 10.5)



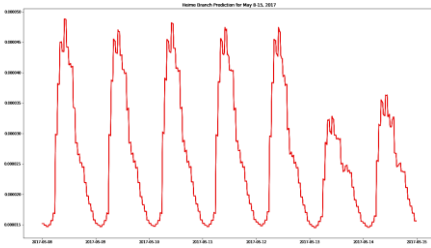
Breweries (WZ 11)



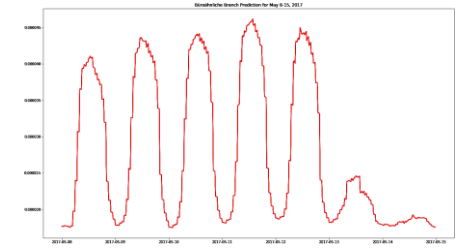
Motor vehicles (WZ 29)



Residential care (WZ 87)



Offices (WZ 64-71)



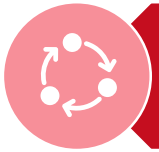
**WZ** – Economic subsector (Wirtschaftszweig), as defined by Destatis

Published under: http://doi.org/10.5281/zenodo.4576494

 Source: Own illustration

# Agenda

Introduction



Methodology

Results

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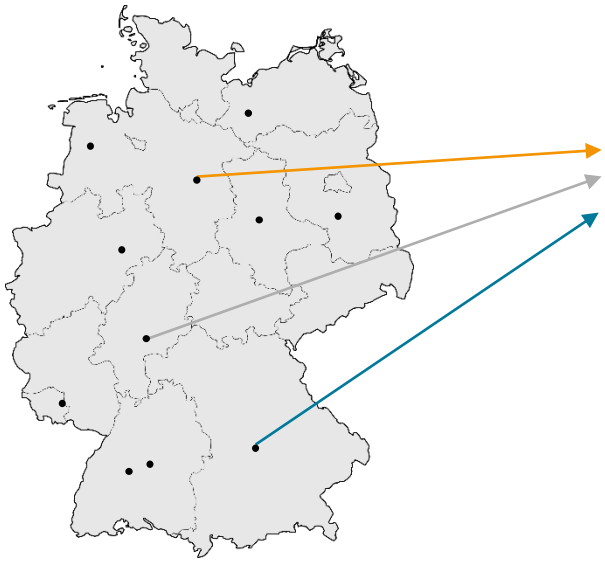
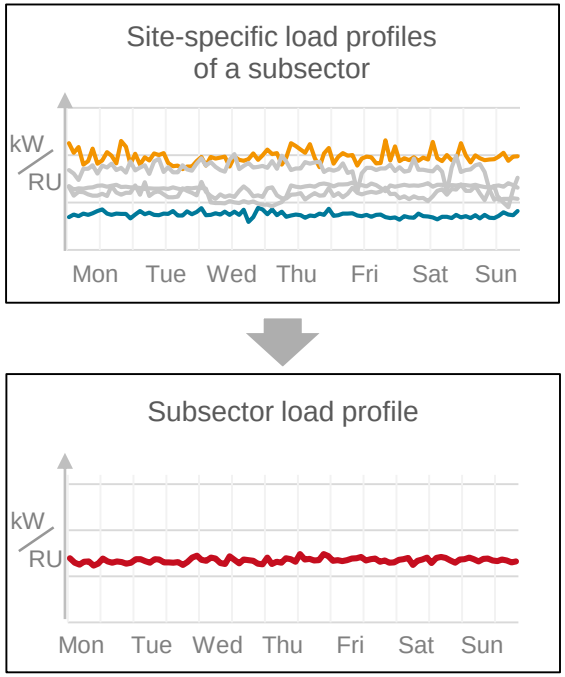
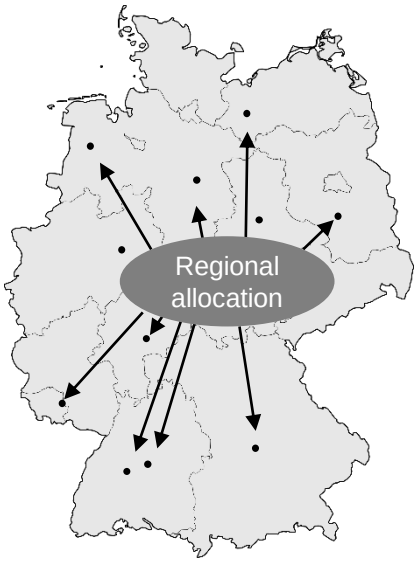
# Methodological approach

| Original data | Modelling | Regionalization |
|---|---|---|
| Load profiles of the companies in an industry over several years<br><br>Site-specific calendar and weather data | 1 Selection of model configuration<br>2 Site-specific regression analysis<br>3 Subsector load profile – Averaging and normalization | Regional allocation based upon<br>• Region-specific statistical reference units (RU) (e.g. employees)<br>• Region-specific calendar and weather data |



Site distribution of a subsector




Site distribution of a subsector



Source: Verwiebe, P.; Seim, S. (2019)

# Model configuration of multiple regression

Based on $R^2_{adj}$ a suitable model configuration was selected using the example of the offices. This configuration was applied to all other sectors.

$$y = f(X_1, X_2, \dots, X_n) + e \qquad min. \sum_{i=1}^{n} e_i^2$$

Target — Average relationship — error — OLS

| | Model configuration | MAPE* [%] | | $R^2_{adj}$ * | | nRMSE* [%] | | k | Computing time [s] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | y \| log(y) ~ | y | log(y) | y | log(y) | y | log(y) | | y | log(y) |
| 1 | $\beta_0$+holiday+C(month):C(weekday)+C(hour) | 32,4 | 22,0 | 0,71 | 0,79 | 14,8 | 12,7 | 108 | 0,6 | 0,6 |
| 2 | $\beta_0$+holiday+C(month)+C(weekday)+C(quart) | 32,4 | 21,9 | 0,71 | 0,79 | 14,8 | 12,7 | 114 | 0,6 | 0,6 |
| 3 | $\beta_0$+holiday+C(month):C(weekday)+C(quart) | 32,4 | 21,9 | 0,71 | 0,79 | 14,8 | 12,6 | 180 | 0,8 | 0,8 |
| 4 | β | | | | | | | | ,8 | 0,8 |
| 5 | β | | | | | | | | ,9 | 0,9 |
| 6 | β | | | | | | | | ,9 | 0,9 |
| 7 | β | | | | | | | | ,9 | 0,9 |
| 8 | β | | | | | | | | ,3 | 1,3 |
| 9 | $\beta_0$+holiday+C(month)+C(weekday):C(hour)+C(quart)+tp+sr | 9,9 | 8,3 | 0,93 | 0,95 | 7,0 | 6,2 | 277 | 1,3 | 1,4 |
| 10 | $\beta_0$+holiday+C(month):C(hour)+C(weekday) | 32,2 | 21,9 | 0,70 | 0,78 | 14,8 | 12,7 | 295 | 1,3 | 1,3 |
| 11 | $\beta_0$+holiday+C(month)+C(weekday):C(quart) | 9,7 | 8,3 | 0,93 | 0,94 | 7,0 | 6,3 | 684 | 3,3 | 3,3 |
| 12 | $\beta_0$+holiday+C(month):C(quart)+C(weekday) | 33,0 | 22,4 | 0,62 | 0,72 | 15,2 | 13,0 | 1159 | 6,3 | 6,4 |
| 13 | $\beta_0$+holiday+C(month):C(weekday):C(hour) | 9,1 | 8,2 | 0,91 | 0,92 | 6,8 | 6,4 | 2017 | 16,0 | 16,9 |

**Model configuration**

$$\log(y) = \beta_0 + holiday + C(month) + C(weekday):C(hour) + tp + sr$$

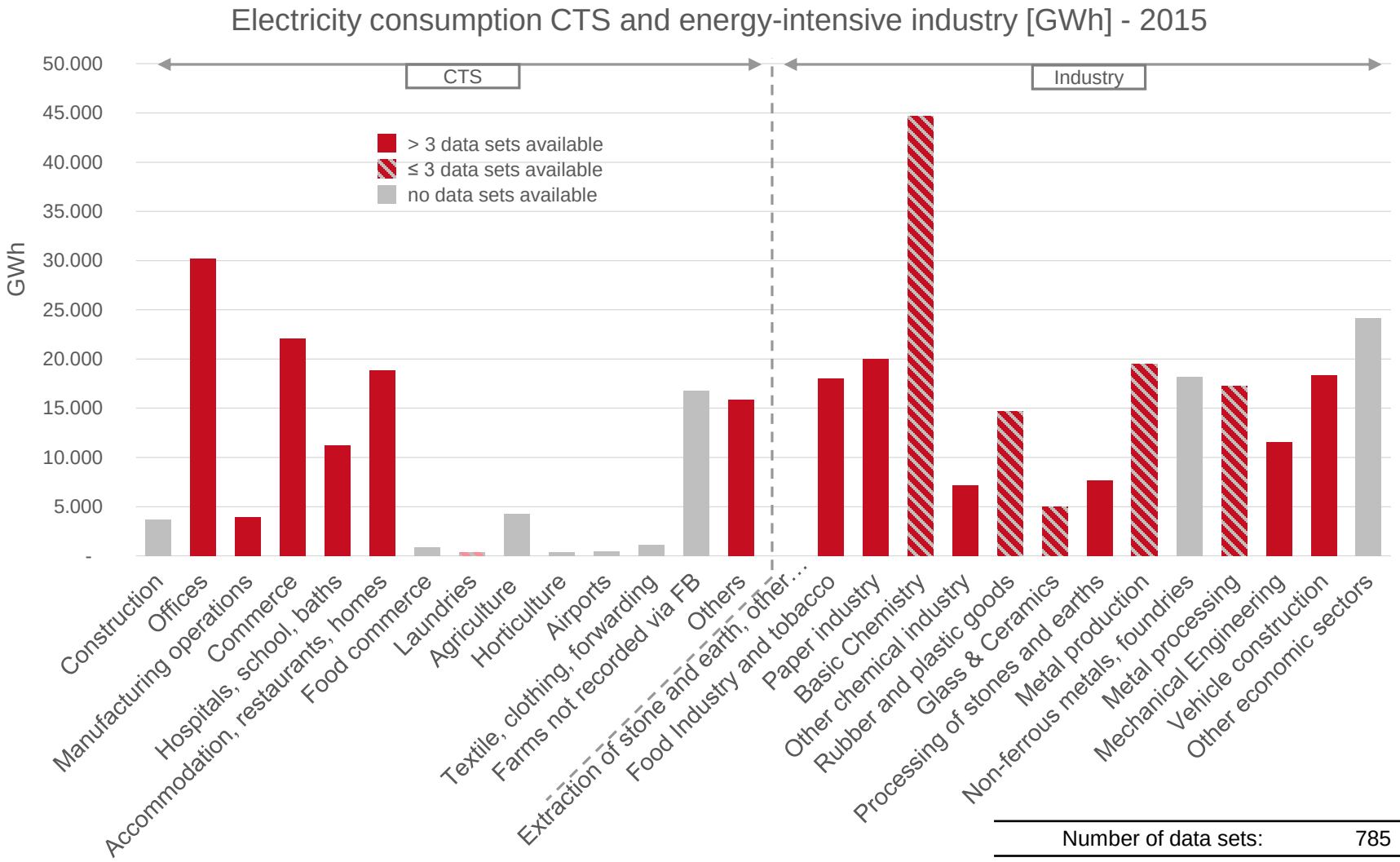
*k – number of independent variables*
*MAPE – Mean absolute percentage error*
*tp – outside temperature*
** determined by cross-validation*
*OLS – Ordinary Least Square*
*sr – solar radiation*

$$MAPE = \frac{1}{T}\sum_{t=1}^{T}\left|\frac{True_t - Pred_t}{True_t}\right|$$

(Details in Backup)


Source: Verwiebe, P.; Seim, S. (2019)

# Database according to AGEB (2017)




| Number of data sets: | 785 |
|---|---|

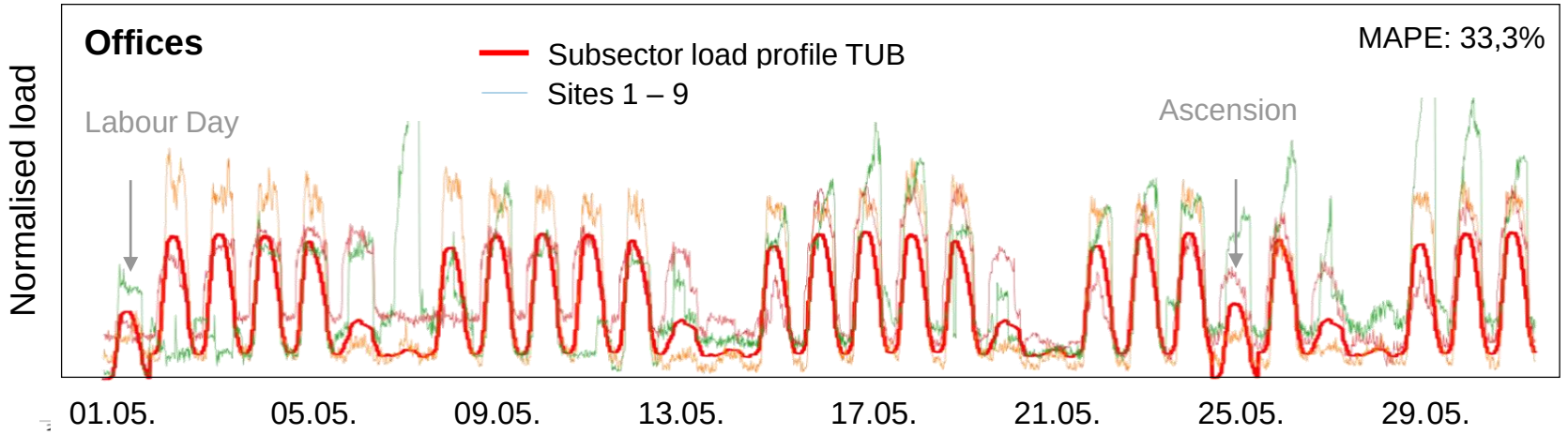
CTS: Commerce, Trade and Services

Note: One data set corresponds to the load profile (electricity) of one year.


Source: AGEB (2017)
22.05.2020

# Agenda

# Subsector load profile – Offices




## Structural features

- Regular weekly structure
- Weekends and public holidays are clearly mapped
- Clear influence of outside temperature, solar radiation and office working hours (S_office)
- Load differences between winter and summer up to 30% in individual sites

| Impact factors | Correlation |
|---|---|
| Holiday | -0,11 |
| Temperature | 0,13 |
| Solar radiation | 0,23 |
| Workday | 0,41 |
| Early | 0,41 |
| Late | 0,06 |
| Night | -0,47 |
| Office | 0,49 |
| Summer | -0,006 |
| Winter | 0,028 |


Source: Own calculations

# Subsector load profiles – overview

## 32 subsectors covered

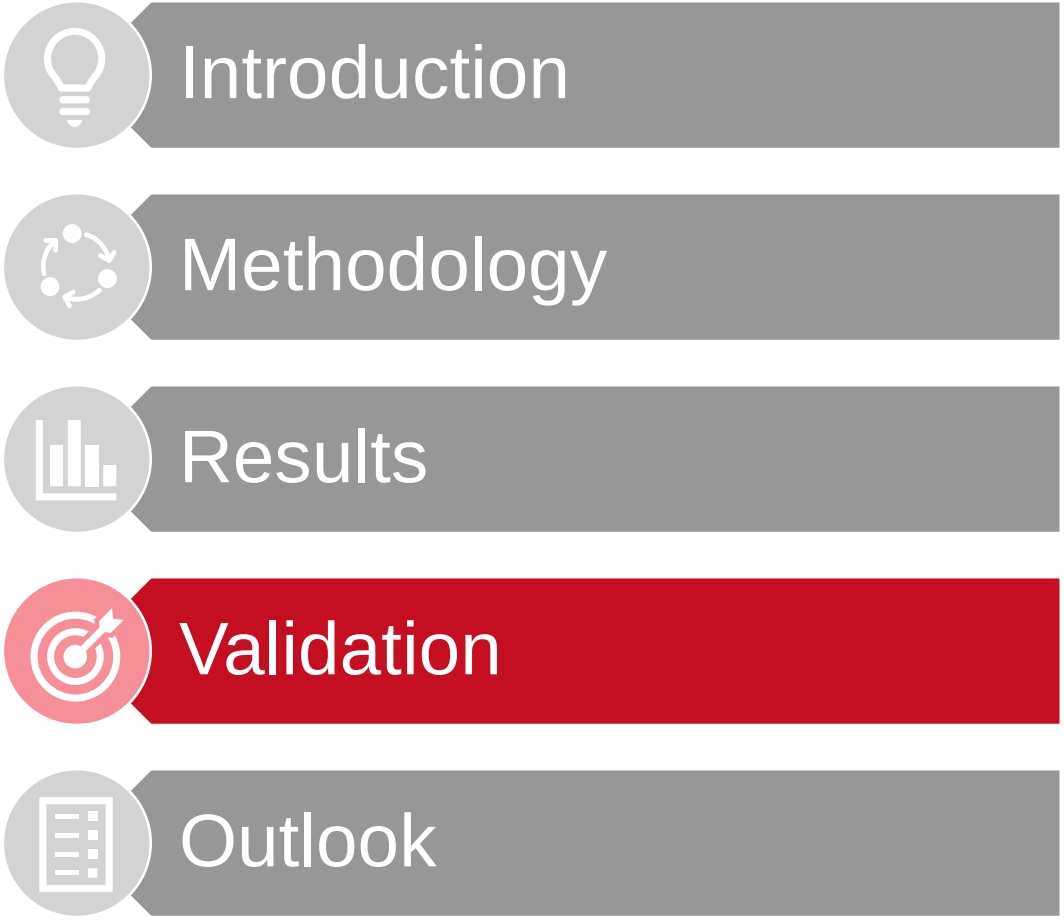
- WZ10: Manufacture of food products
- WZ11: Manufacture of beverages
- WZ12: Manufacture of tobacco products
- WZ17: Manufacture of paper
- WZ21: Manufacture of pharmaceuticals
- WZ22: Manufacture of rubber and plas-tics
- WZ26: Manufacture of computer, electronic and optical products
- WZ28: Manufacture of machinery
- WZ29: Manufacture of motor vehicles
- WZ32: Other manufacturing
- WZ37: Sewerage
- WZ38: Waste collection, treatment and disposal
- WZ41: Construction of buildings
- WZ46: Wholesale trade
- WZ47: Retail trade
- WZ52: Warehousing and support activities for transportation
- WZ55: Accommodation
- WZ62: Computer programming, consultancy
- WZ63: Information service activities
- WZ64-71: Offices
- WZ72: Research and Development
- WZ77: Rental and leasing activities
- WZ82: Office administrative and support activities
- WZ84: Public administration
- WZ85: Education
- WZ86: Human health activities
- WZ87: Residential care activities
- WZ88: Social work activities
- WZ90: Creative, arts and entertainment activities
- WZ91: Libraries, museums and other cultural activities
- WZ93: Sports activities, amusement and recreation activities
- WZ94: Activities of membership organisations

**WZ** – Economic subsector (Wirtschaftszweig), as defined by Destatis

The 32 subsector load profiles are published in: http://doi.org/10.5281/zenodo.4576494

 Source: Seim et al. (2021) 

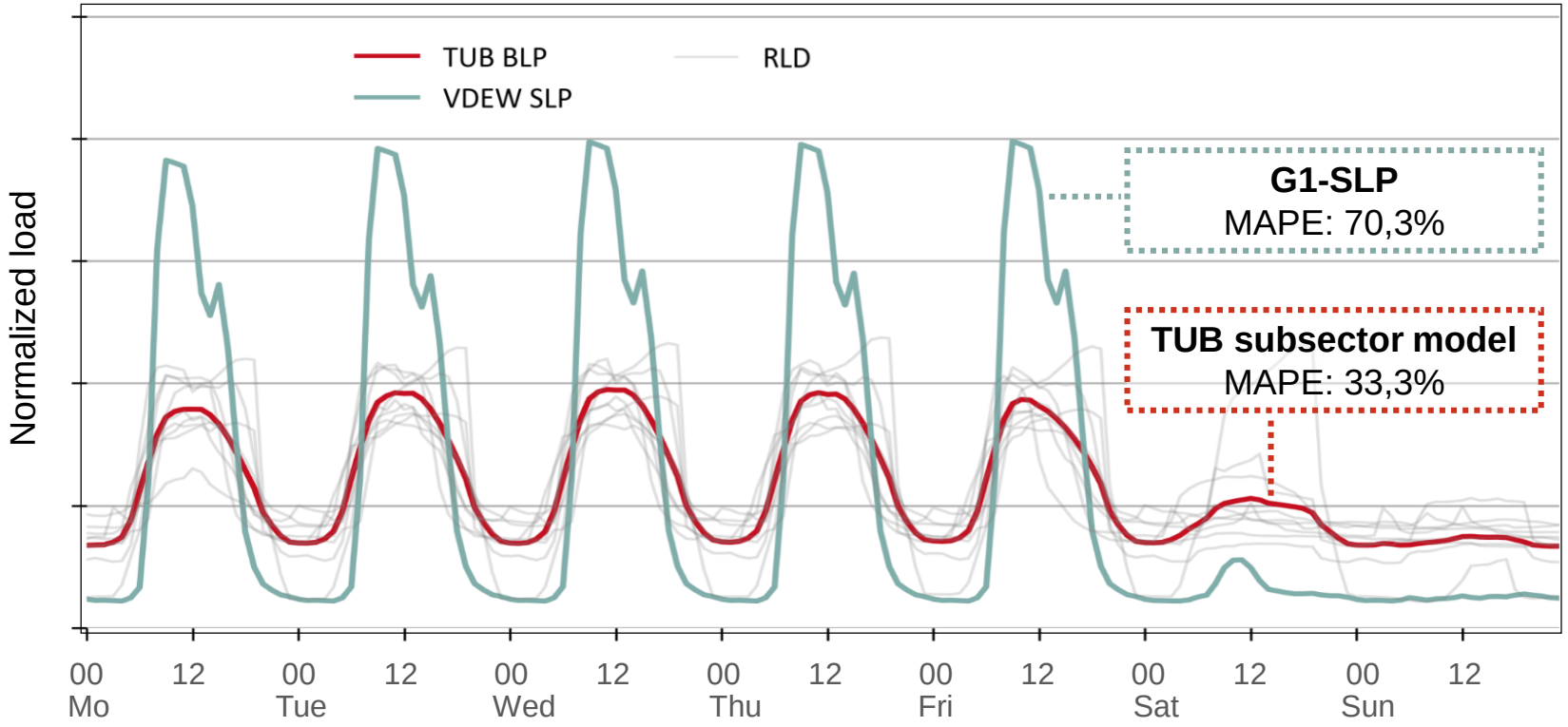
# Agenda



# Validation of subsector load profiles

## 1) Comparison with individual VDEW Standard load profiles

Comparison between G1-SLP and the TUB subsector model for offices (WZ 64 – 71)
Average week (2017)

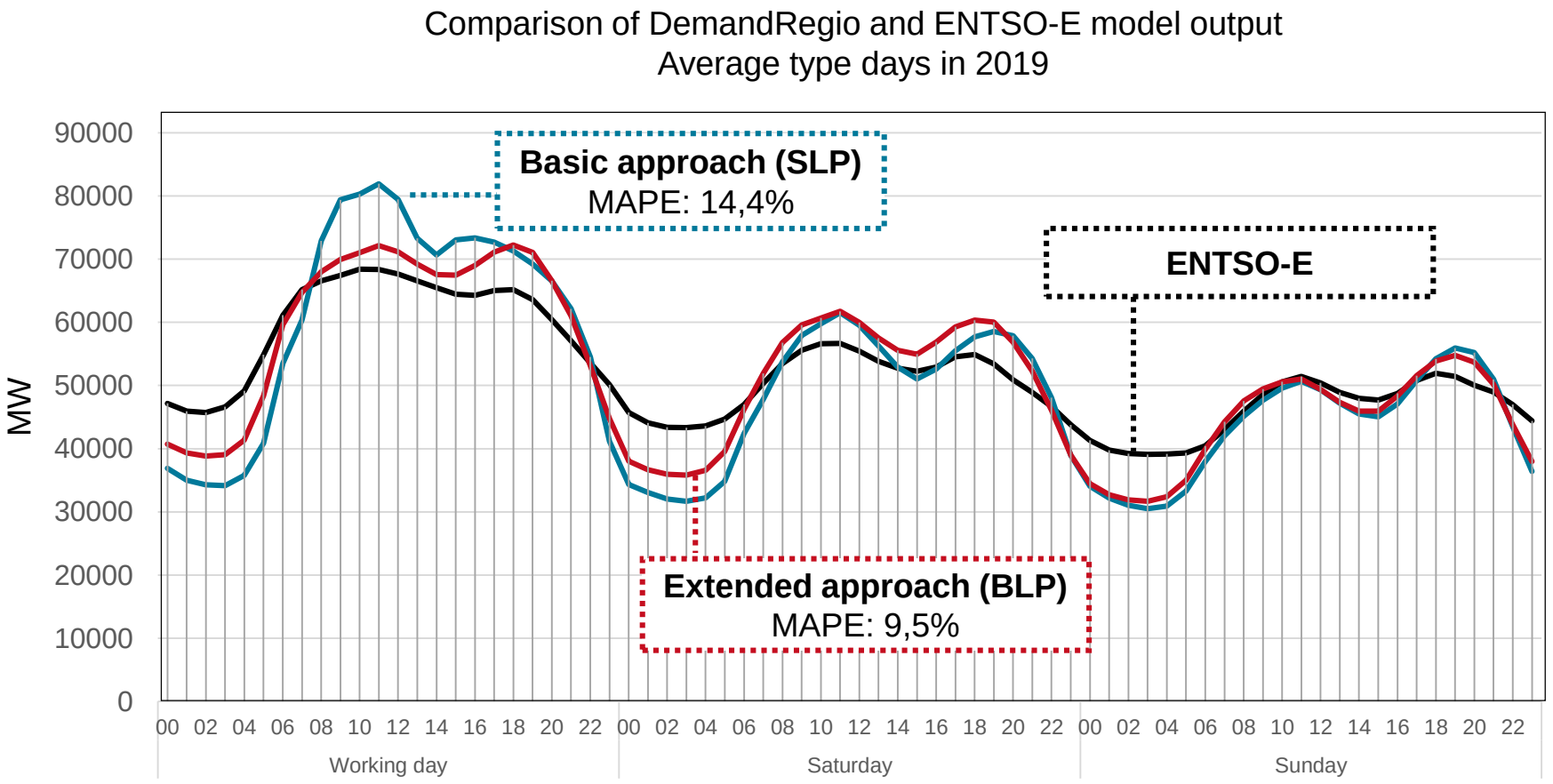




Source: Rüdt, D. (2020); Seim, S. et al. (2021); Bitterer, R.; Schieferdecker, B. (1999)

# Validation of subsector load profiles

## 2) Validation with ENTSO-E total load




 Source: Gotzens, F. et al. (2020); Seim, S. et al. (2021) 22.05.2020

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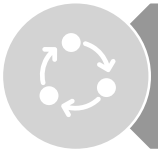

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# Outlook

## Challenges

- Representativeness
- Heterogeneous economic subsectors
- Stochastic influences difficult to map
- Unknown production schedules / company holidays for industrial enterprises
- Future influence of load management

## Future applications

- Determination of the spatially and temporally resolved residual load in connection with RE generation
- Further enhancement of the data basis
- Improve residential load profile
- Projection of load profiles based on efficiency gains
- Identification of subsector-specific load shifting potential


Hong, Tao; Fan Shu (2016)

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# Development of subsector load profiles (BLP)

## Modelling

**Model selection**
- Test different model configurations
- Selection based on $R^2_{adj.}$

Cross validation

**Data preparation**
- Checking the raw data
- Normalization and visualization

**Individual sites**
- Company-specific regression analyses and correlation analyses

**Subsector load profile**
- Subsector load profiles from individual companies
- Quantile regression prediction intervals

**Evaluation**
- Determination of MAPE and $R^2_{adj.}$ of the subsector load profiles

Cross validation

## Output

### Subsector load profile

- Load profile per county, subsector and year
- 10 Weather years (2009 – 2018)
- 32 subsectors (electricity)
- Prediction intervals
- Forecast quality MAPE and $R^2_{adj.}$
- Correlation analysis matrix


Source: Verwiebe, P.; Seim, S. (2019)

# Averaging and regionalisation

**Averaging** of regression coefficients

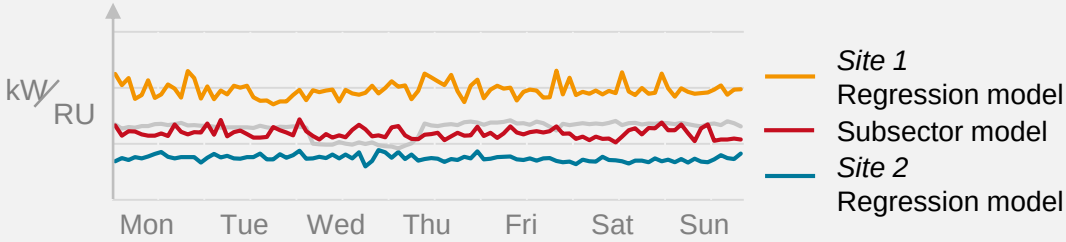
Site 1: $f(x)_{0-1} = 0{,}4 \cdot x_1 - 0{,}09 \cdot x_2$

Site 2: $g(x)_{0-1} = 0{,}6 \cdot x_1 - 0{,}05 \cdot x_2$

Subsector: $h(x)_{0-1} = 0{,}5 \cdot x_1 - 0{,}07 \cdot x_2$

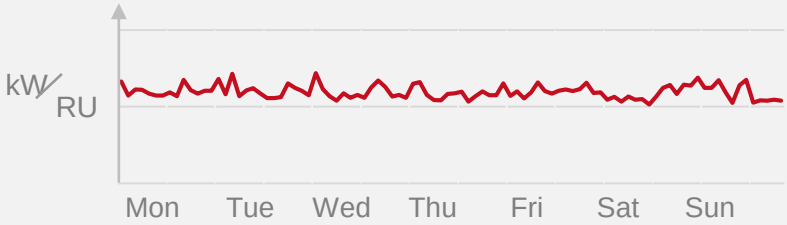
$x_1$ – *Outdoor temperature* [°C]

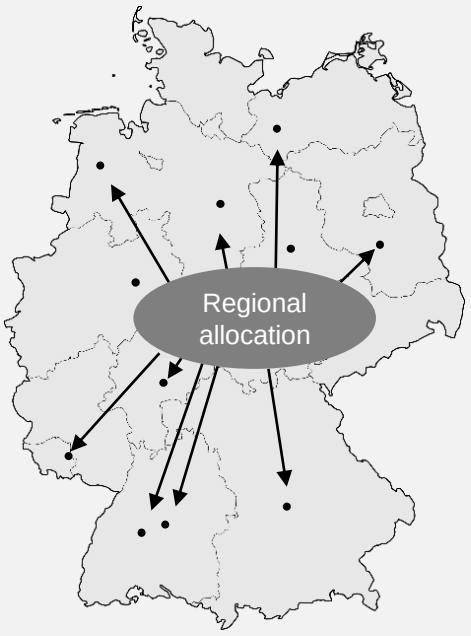
$x_2$ – *Solar radiation* $[\frac{W}{m^2}]$




**Regionalization** of the subsector load profile by appropriate scaling with reference units (RU).

- Employees (alternatively: site area, production volume)





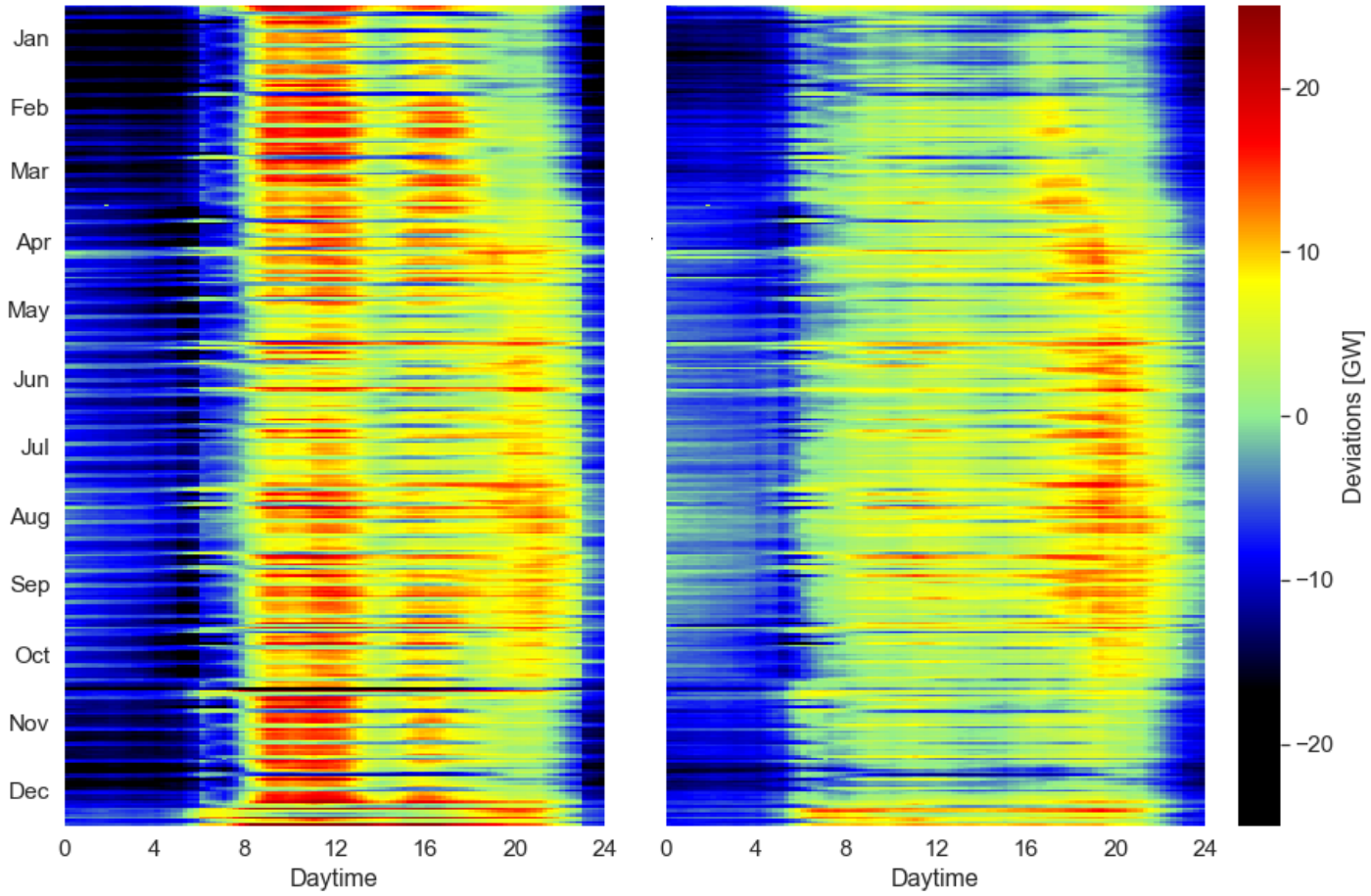
Source: Source: Verwiebe, P.; Seim, S. (2019) Administrative boundaries: © GeoBasis-DE / BKG 2017; Generalization: FfE e.V. (edited)

# Validation of subsector load profiles

## 2) Validation with ENTSO-E total loads

*Basic approach* residuals

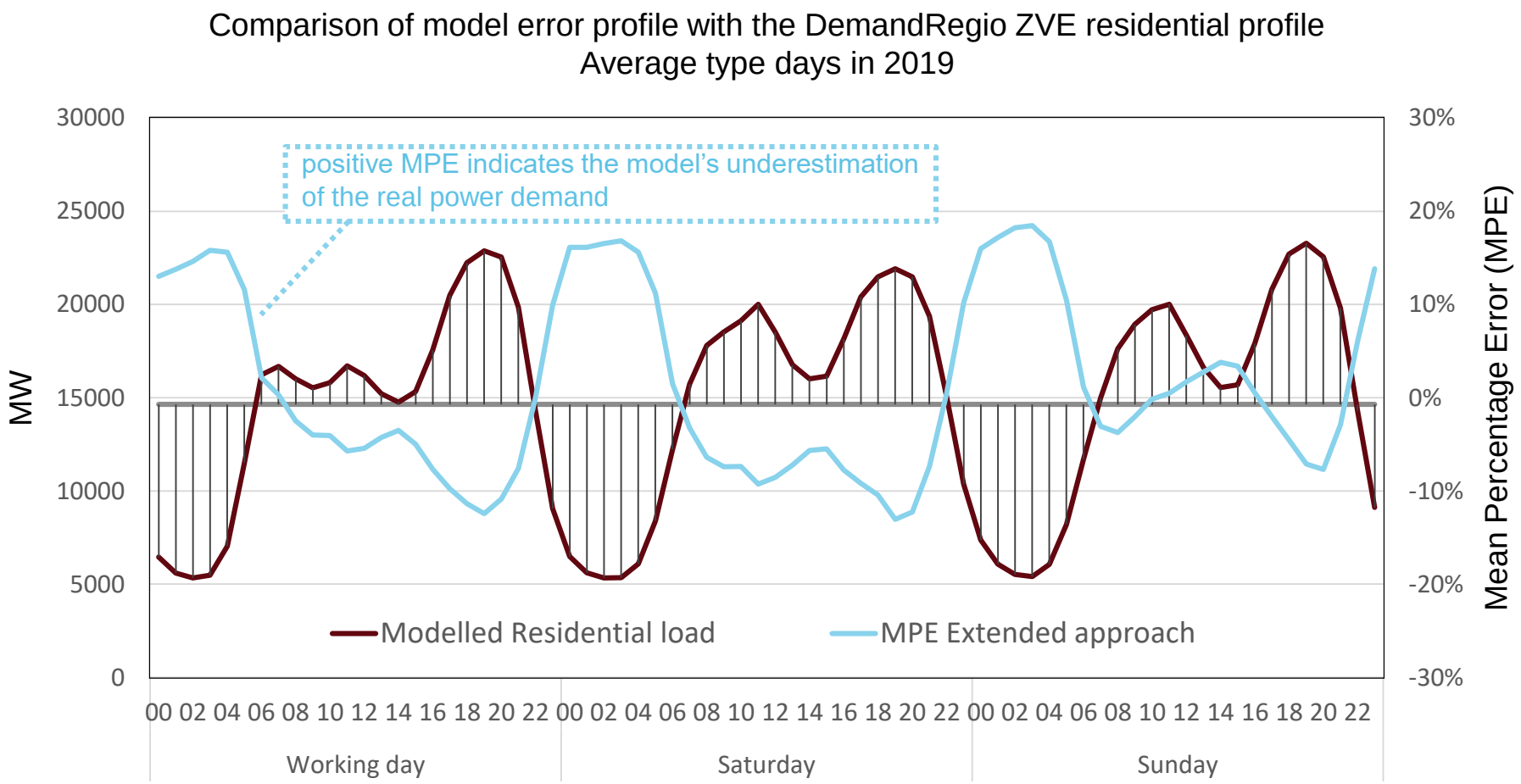
*Extended approach* residuals




Heatmap figures:
Residuals of the ENTSO-E load forecast of 2019, using SLP (left) and subsector load profiles (BLP) (right)

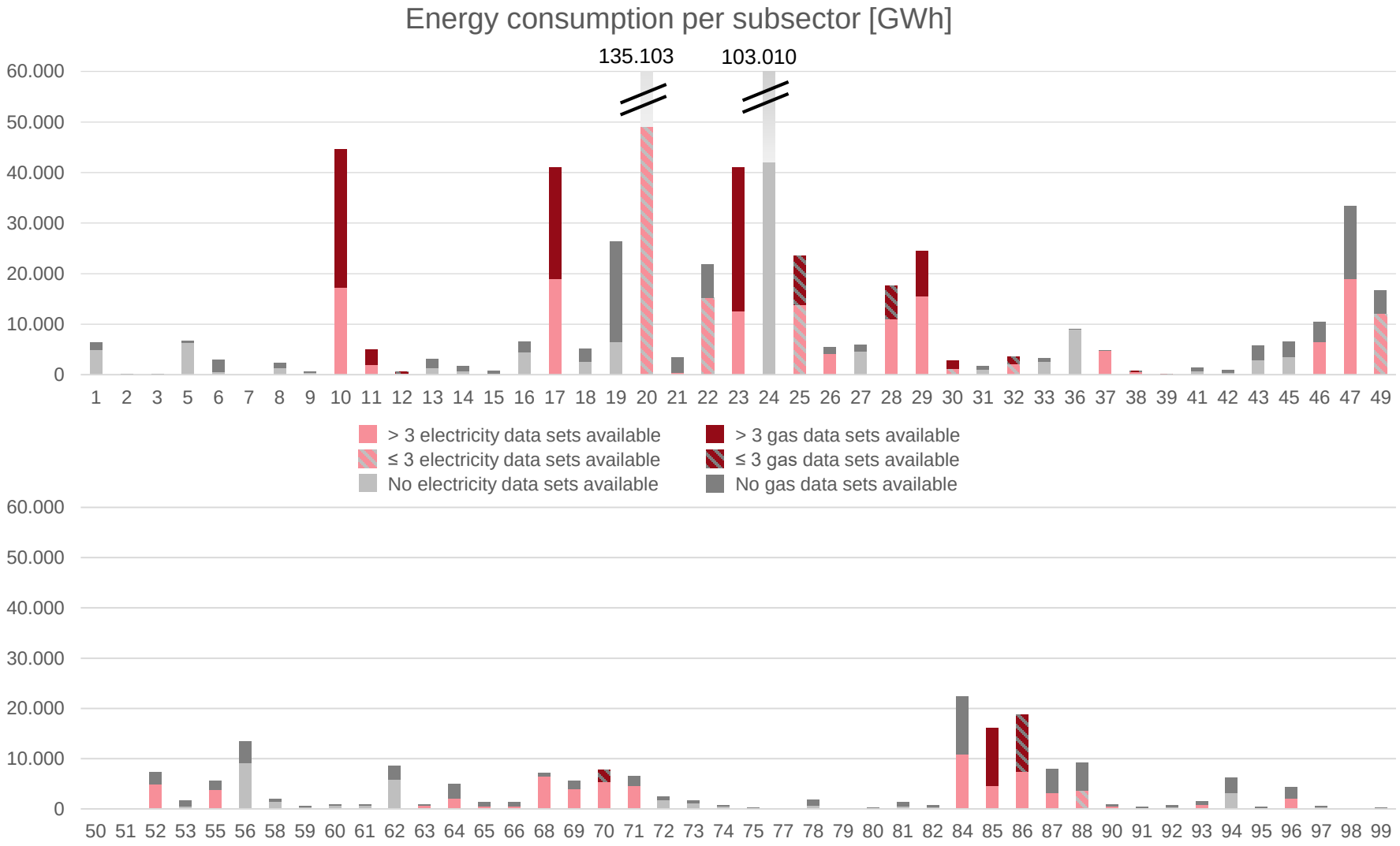
 Source: Seim, S. et al. (2021); Held, M (2020)

# Analysis of remaining error profile




 Source: Gotzens, F. et al. (2020)

# Data base according to WZ 2008




Note: One data set corresponds to the load profile of one year.

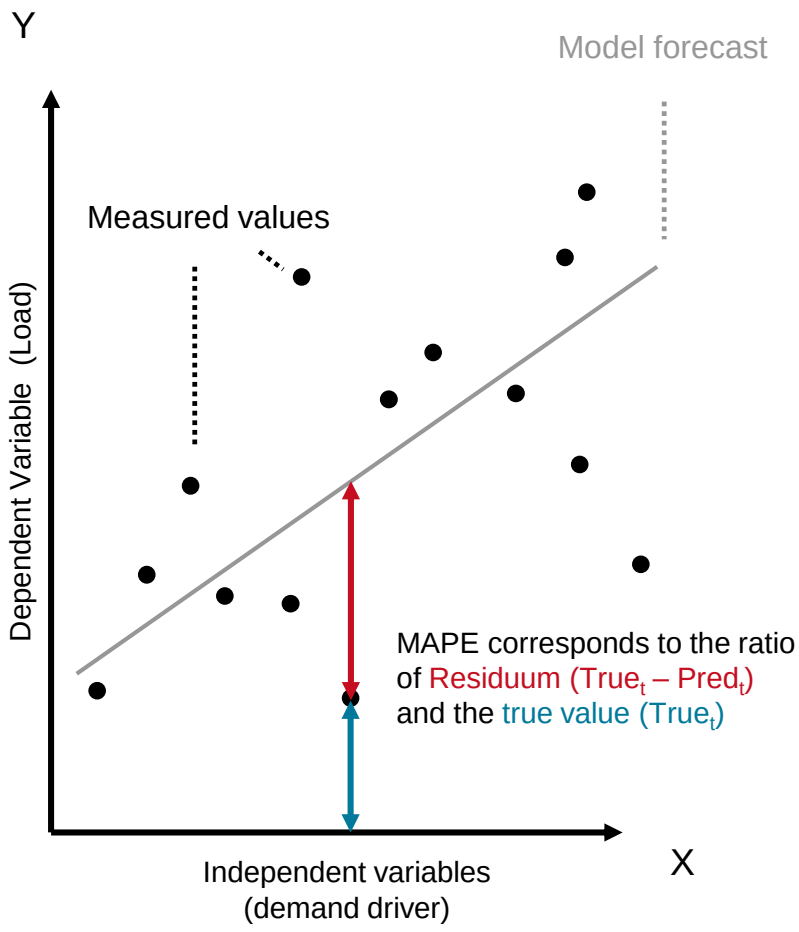
 Source: Own calculation

# Forecast quality - MAPE

## MAPE - Mean Absolute Percentage Error

- One of the most widely used quality criteria for evaluating energy demand forecasts
  → enables comparability across a large number of studies
- Simple and transparent concept
- Weaknesses of the MAPE lie in application cases that have very small values as well as "zero" values in the denominator, due to which the MAPE can be distorted

$$\mathrm{MAPE} = \frac{1}{T}\sum_{t=1}^{T}\left|\frac{\mathrm{True}_t - \mathrm{Pred}_t}{\mathrm{True}_t}\right|$$





Hong, T.; Fan S. (2016)

# Quantile Regression - Theory

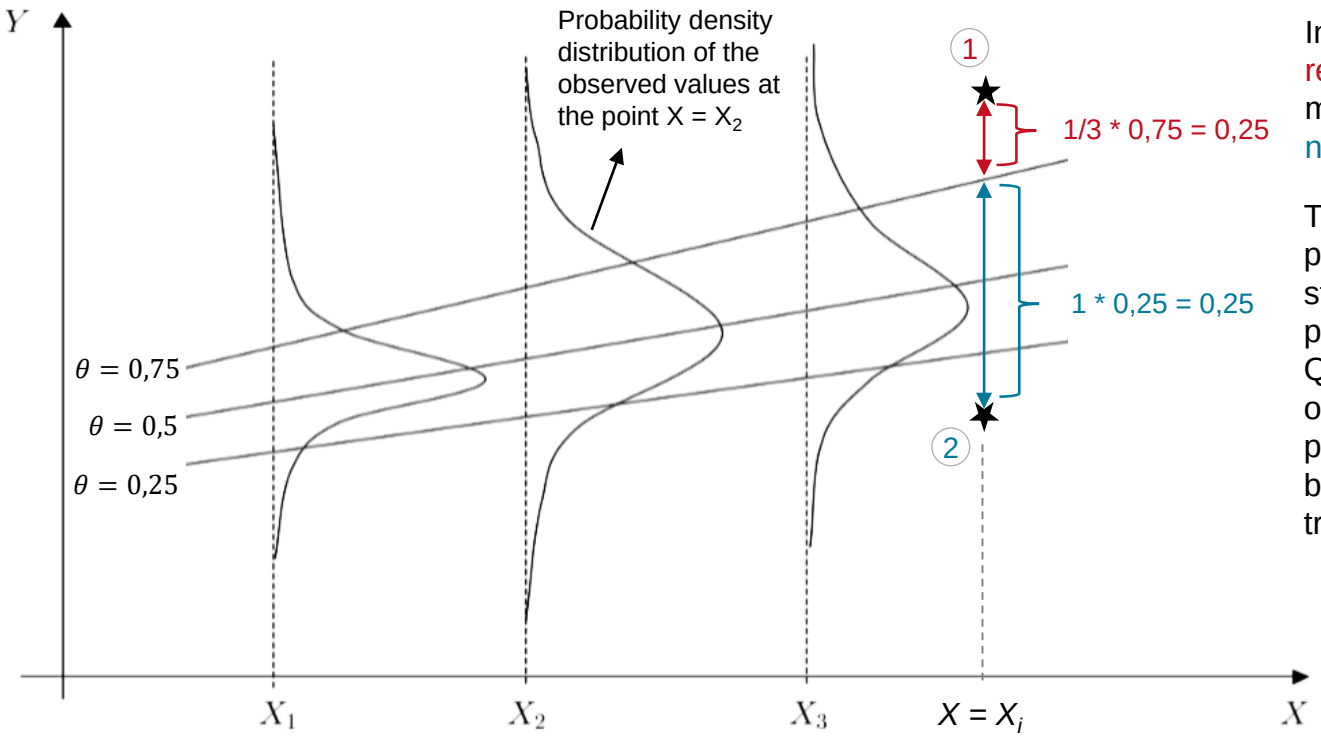
**Optimisation criterion**

Residuals are positiv

Residuals are negativ

$$\widehat{\beta_\theta} = \underset{\theta}{argmin} \sum_{i=1}^{N} [\theta * I(y_i > x_i'\beta_\theta) + (1-\theta) * I(y_i < x_i'\beta_\theta)] * |y_i - x_i'\beta_\theta|$$

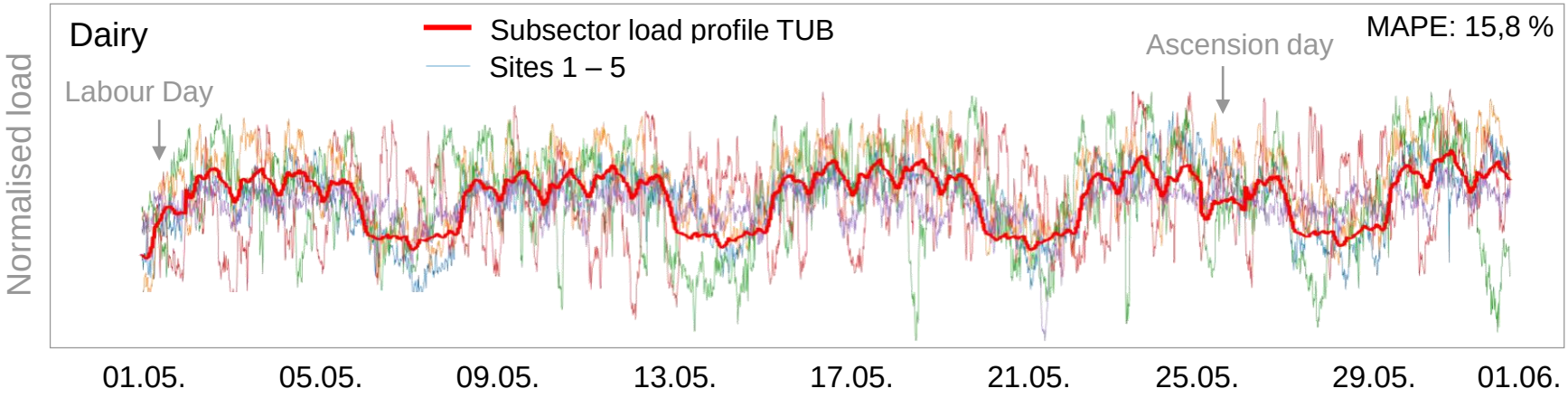
0,75 Indicator function 0,25 Absolute deviation




Intuition: If $\theta$ = 0,75, positive residuals (1) will be weighted more strongly (0,75) than negative residuals (2) (0,25)

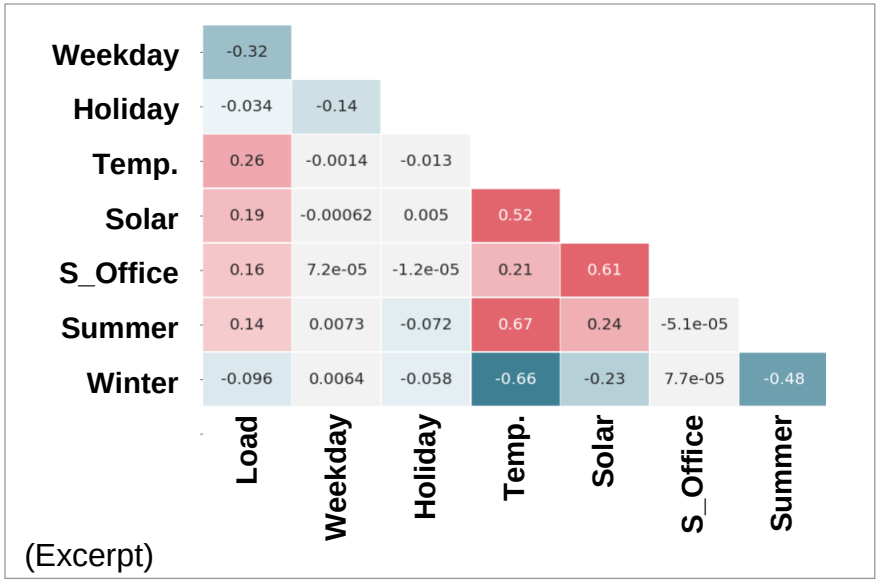
The example shows, that point (1) is weighted more strongly as compared to point (2) for the 0.75 Quantile of y at the position of X =$X_i$ . In the minimisation process, the residuals must be equal after the transformation.

# Subsector load profile – Dairy




## Structural features

- Regular weekly structure
- Weekends are clearly depicted, holidays appear pretty normal, however.
- Significant influence of the outside temperature




(Excerpt)


Source: Own calculations