Specifying Grid Development Needs in Sample Living Quarters

Siamak Sheykhha, Reinhard Madlener
Chair of Energy Economics and Management,
Institute for Future Energy Consumer Needs and Behavior (FCN),
School of Business and Economics,
RWTH Aachen University, Aachen, Germany

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FCN | Future Energy Consumer Needs and Behavior | E.ON Energy Research Center | RWTH AACHEN UNIVERSITY

Agenda

1. **Introduction**
   Approach and process
2. **Methodology**
   Introduction to the proposed strategy
3. **Insights gained**
   Results, sensitivity analysis, and discussion
4. **Outlook**
   Conclusion and outlook

Siamak Sheykhha, Reinhard Madlener
RWTH Aachen University | Institute for Future Energy Consumer Needs and Behavior (FCN)
Chair of Energy Economics and Management (FCN-ECO)
siamak.sheykhha@eonerc.rwth-aachen.de

Introduction

Motivation

- The need of **creating a decision-making tool** dedicated to systematic and strategic regional grid development, with sample living quarters (“Musterquartiere”) as a conceptual framework, was identified.
- **Specific characteristics** are highlighted and used for **describing such “Musterquartiere**.”
- Availability of **big data** enables the use of new types of (**spatial) analysis**.

Research Goals

1. Analyzing the **concept of “Musterquartiere” as well as its main characteristics**, and its suitability and applicability
2. Defining the **key requirements** for the **development of an algorithm** that can be used for clustering
3. Developing a tool for **Strategic investment planning** of grid operators

Siamak Sheykhha, Reinhard Madlener
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Chair of Energy Economics and Management (FCN-ECO)
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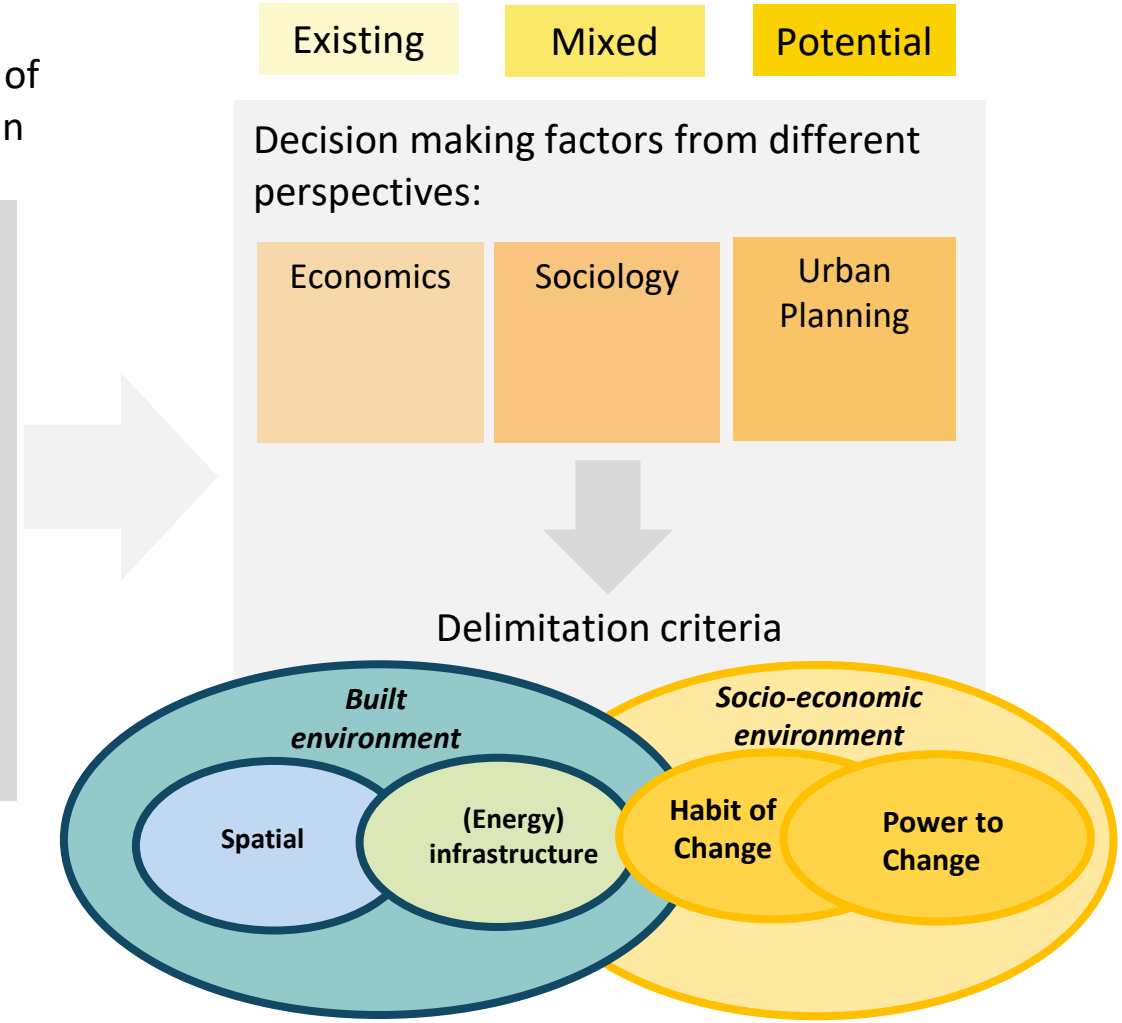
Frameworks for the Classification of Data

Selected approach for the classification of data

Available data: 150 groups of data sets for each building in NRW, Germany

- General information of buildings
- Socio-economic data
- Energy data (e.g., electricity/heat demand, energy technologies)
- Building features (e.g., building use, location,)
- ….



Framework for data classification:

1. Categorization of the given data if relevant for describing the existing situation, or essential for a possible potential, or both
2. Allocation of the available data to the scientific disciplines concerned to describe the decision-making factors
3. Elaboration of four main categories to map the current situation and the possibility of change

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Quarter Identification Strategy: Combining or Clustering?

Sample Quarters as physical entities do not fit per se to the ideal type.

How to "construct" living quarters as meaningful entities?

Classification strategy of data

- Specific strategies
- Our suggestion for a solution ✓

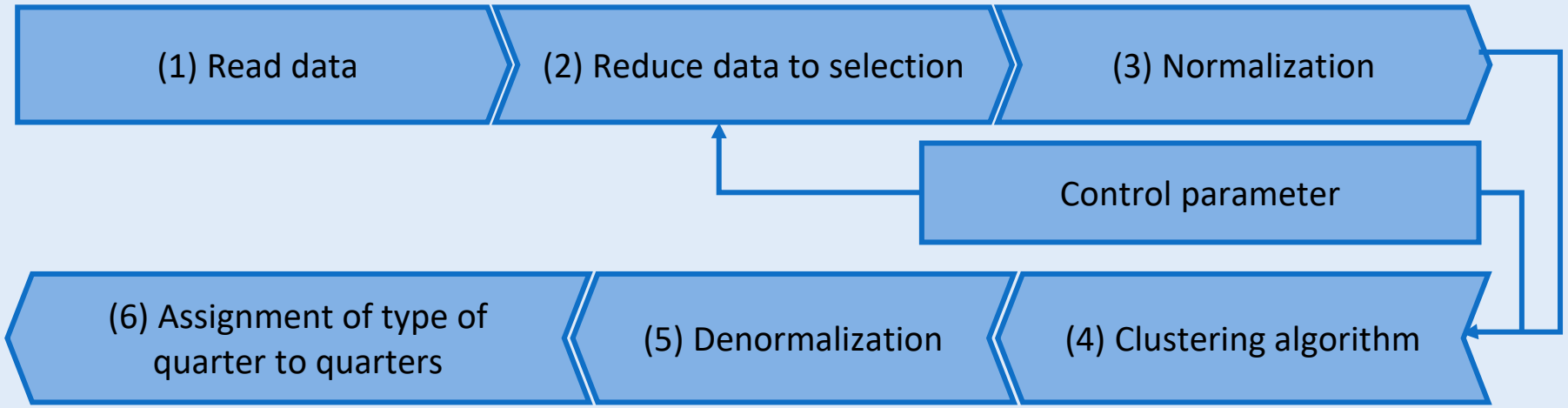
Combination of categories: ✗

- Grouping of Indicators
- Few buildings would be selected

Solution:

- Start from single buildings
- Compute the relative similarity of the buildings around
- If the similarity is too low a boundary of the quarter seems to be approached; some clustering method is needed/useful!

Clustering method



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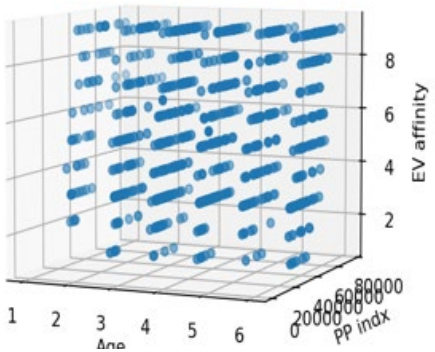
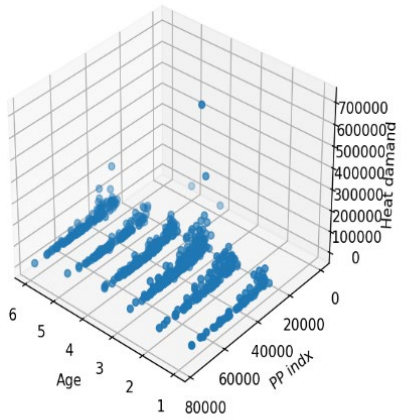
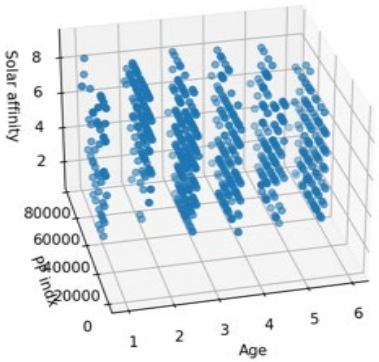
Evaluation of Selected Indicators

Factor analysis:

- Solar affinity is impacted by age group.
- In contrast to the purchasing power, the age group does not influence heat demand.
- Factor analysis can be used for continuous indicators (e.g., density, heat demand, electricity demand, power purchase).







Correlation matrix:

- Two elements of habit of change have a correlation of 0.08 with each other.
- Power to change: PP has a negative correlation with ownership and price sensitivity; ownership and age of inhabitant have correlation of 0.2.

Figure: Thermal image of socio-economic properties

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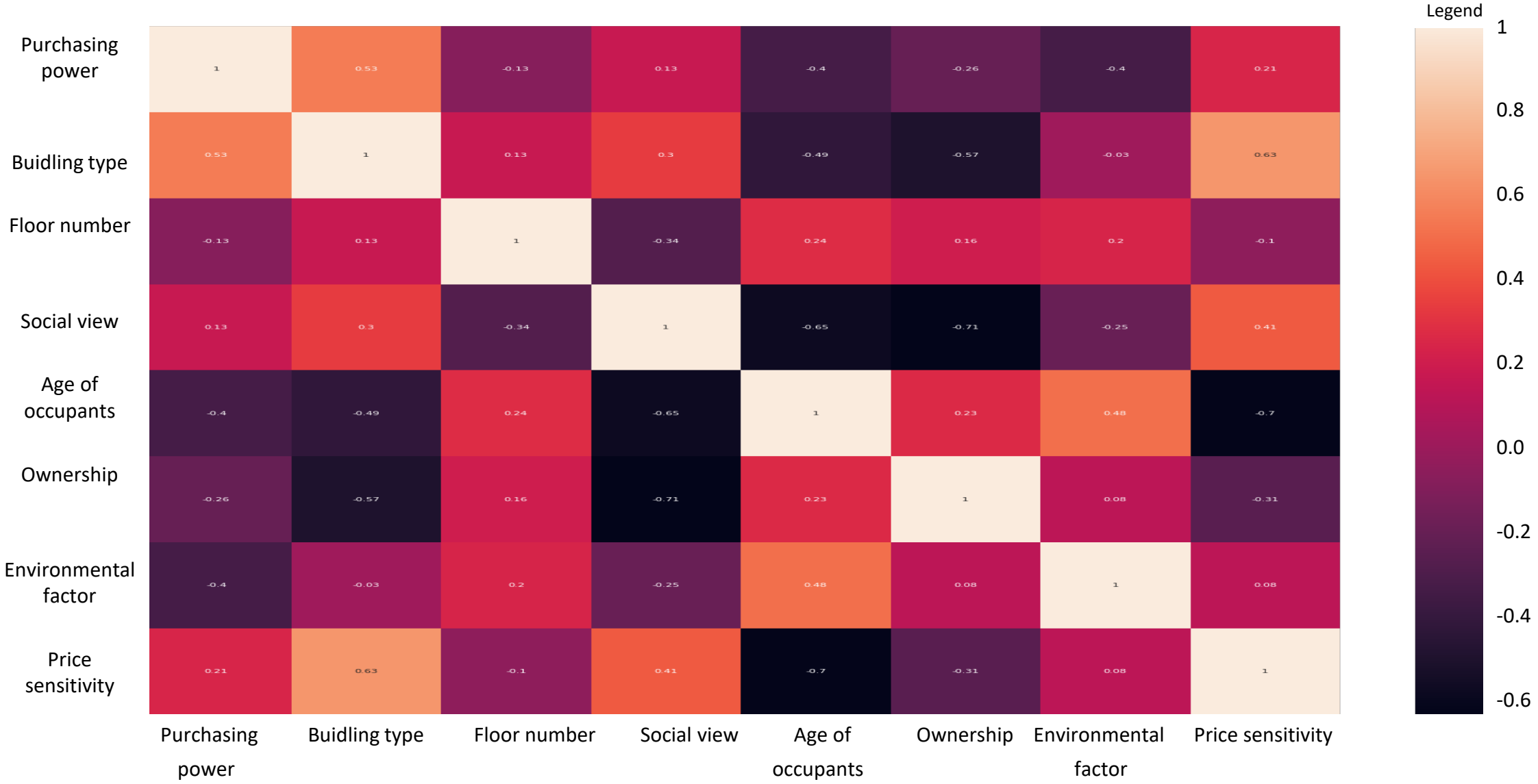

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Indicators

Which building properties are significant for the categorization of a living quarter?

Which social factors of people in a living quarter are significant?

Spatial

1. Location
2. Characteristics
3. Age of building / Construction

Socio-Economic

1. Purchasing power
2. Age of occupants
3. Ownership

Power to change

4. Price sensitivity
5. Environmental concern

Habit of Change

Energy

1. Solar affinity
2. E-Mobility affinity
3. EV stations
4. No. of garages
5. Solar capacity
6. Heating system

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Clustering Strategy: Denormalization of Outputs

- How to elaborate results quantitatively?

Sample

Socio-Economic	Very low power to change Very low habit of change	
Spatial	Local Site, multi family houses	
Energy		
	NOW	FUTURE DEVELOPMENT
PV	Very low	Very low
EV	Very low	Very low
Heat options	Floor heating, central heating	Heat pump

- Output of each indicator is allocated dynamically into five groups:

very low | **low** | **mid** | **high** | **very high**

Power to change: {Age of inhabitant}*{Purchasing power}

Habit of change: {Price sensitivity}*{Environmental concern}*{Home ownership}

PV NOW: Present PV installed capacity
EV NOW: Present No. of EVs

PV Future: {PV affinity}*{Power to change}*{Habit of Change}

EV Future: {EV affinity}*{Power to change}*{Habit of Change}*{No. Of Garages}

Heat options Now: Two technologies with the highest shares
Heat options Future*:

If { District heating share > 5% → District heating
District heating share < 5% → Heat pump }

*Based on scenarios presented in E.ON Energiewende im Wärmesektor

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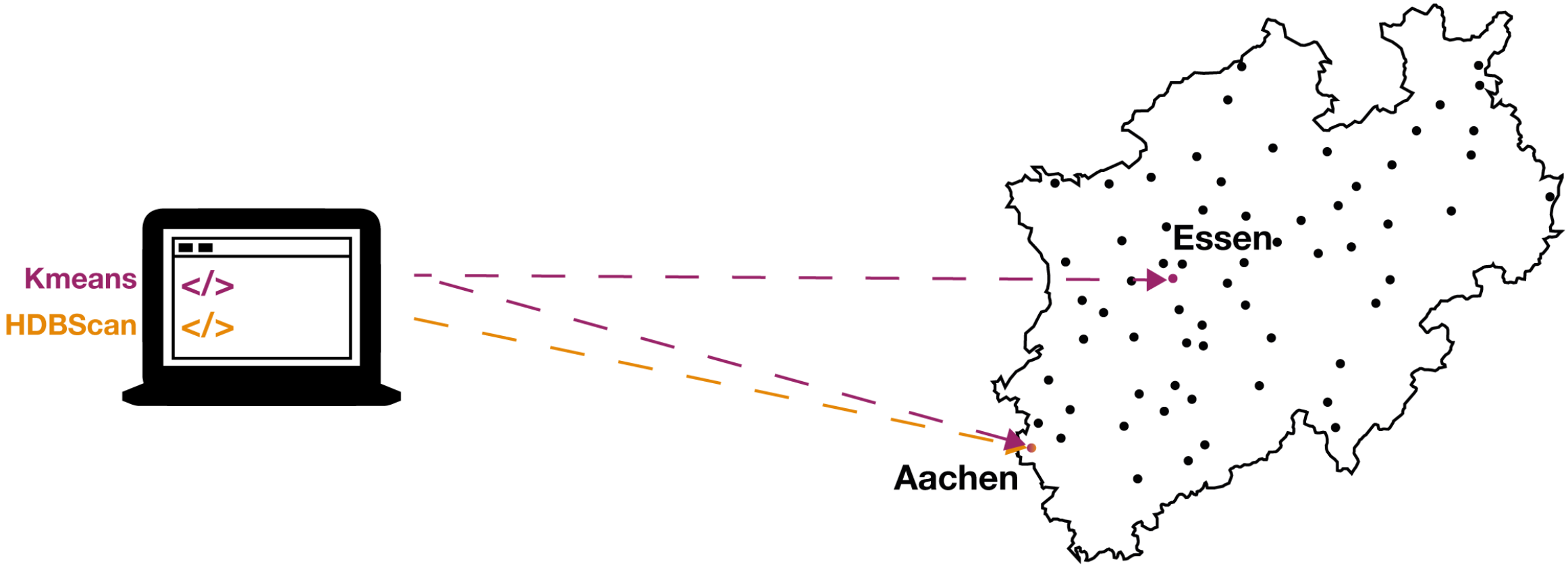
Results

➢ **Implementing one algorithm on two cities (Essen, Aachen)**



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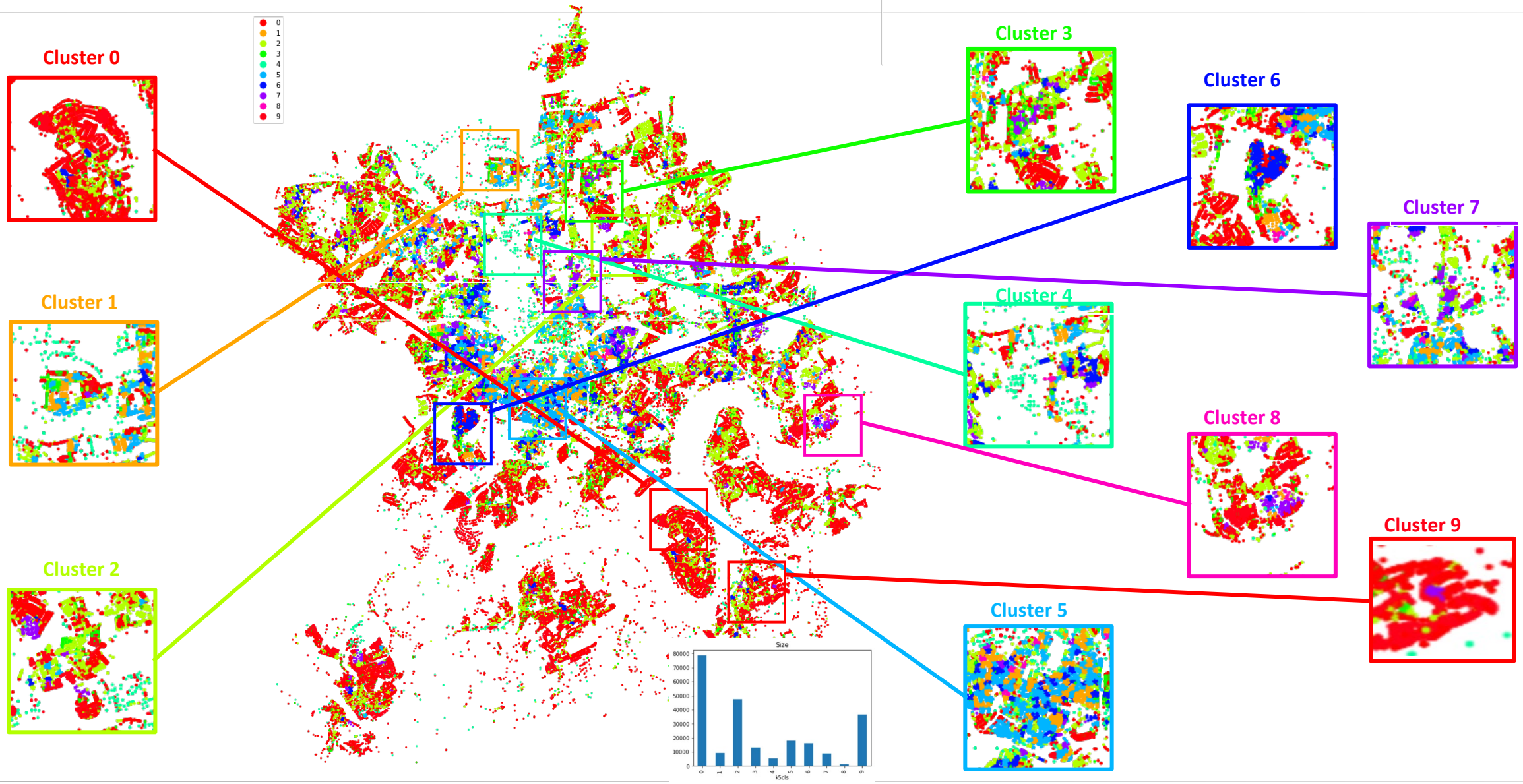
K-means Clustering: Essen



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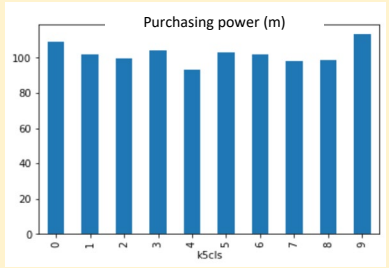
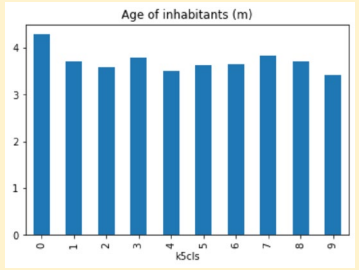
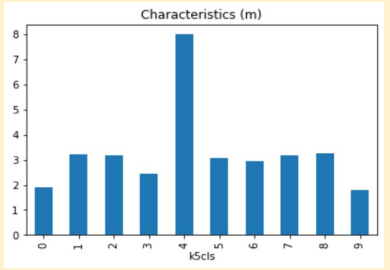
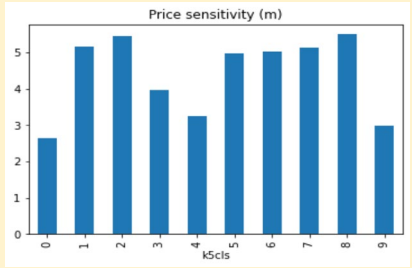
Statistical Analysis of K-means Method: Essen

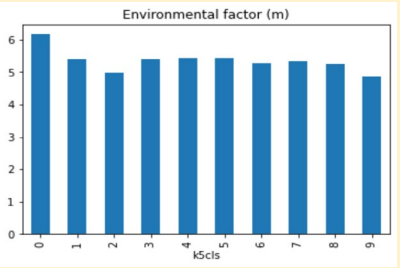
Socio-Economic



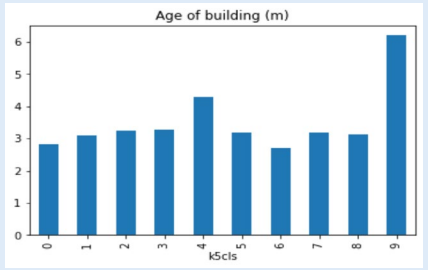


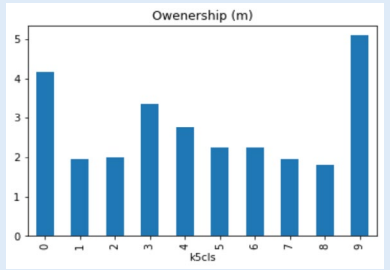


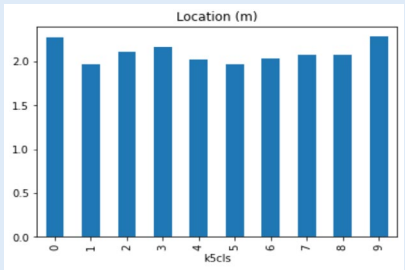




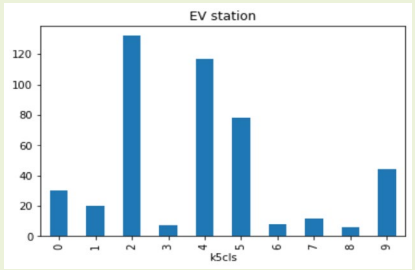
Spatial

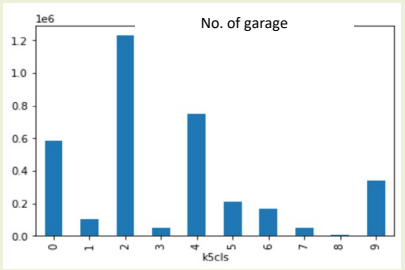


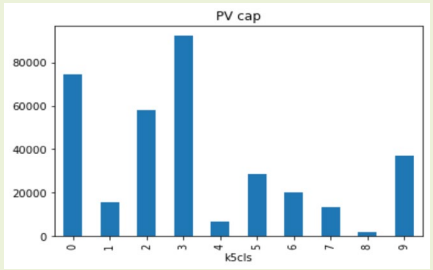


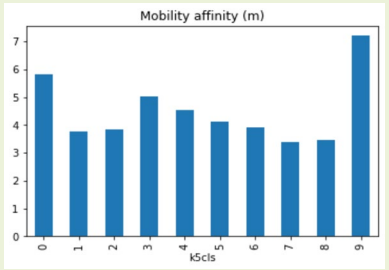


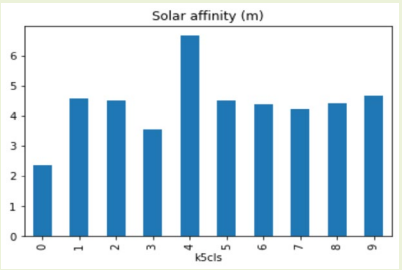
Energy











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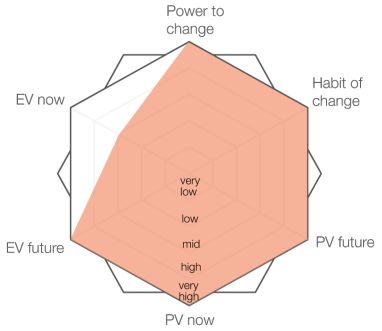
Cluster Profile: Clusters 0-4 (K-means)

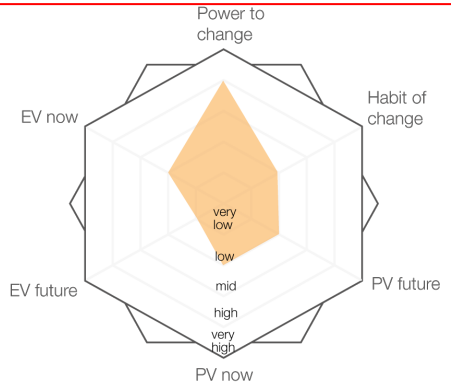
Cluster 0

Socio-Economic	Very high power to change Very high habit of change	
Spatial	Local site, terraced or semi-detached house	
Energy	NOW	FUTURE DEVELOPMENT
PV	Very high	Very high
EV	Mid	Very high
Heat options	Central heating, single multi chamber ovens	Heat pump



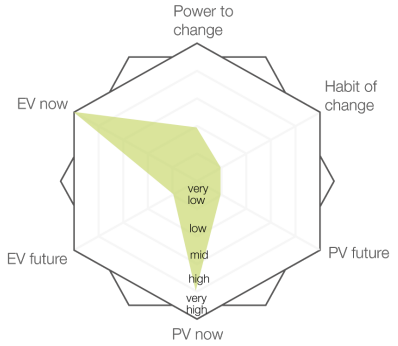
Cluster 1

Socio-Economic	High power to change Low habit of change	
Spatial	Local site, multi-family houses	
Energy	NOW	FUTURE DEVELOPMENT
PV	Low	Low
EV	Mid	Very low
Heat options	District heating, central heating	District heating



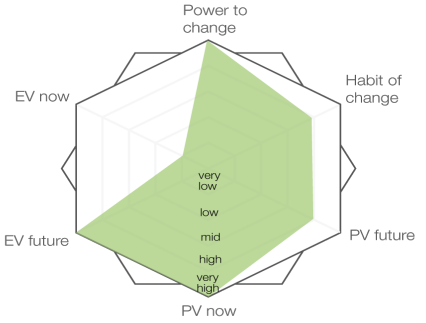
Cluster 2

Socio-Economic	Low power to change Very low habit of change	
Spatial	Local site, multi-family houses	
Energy	NOW	FUTURE DEVELOPMENT
PV	High	Very low
EV	Very high	Very low
Heat options	Central heating, single multi chamber ovens	Heat pump



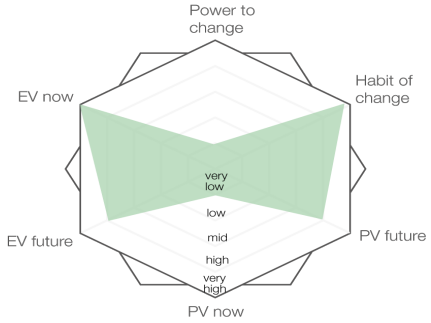
Cluster 3

Socio-Economic	Very high power to change High habit of change	
Spatial	Local site, terraced or semi-detached house	
Energy	NOW	FUTURE DEVELOPMENT
PV	Very high	High
EV	Very low	Very high
Heat options	Central heating, single multi chamber ovens/floor heating	Heat pump



Cluster 4

Socio-Economic	Very low power to change Very high habit of change	
Spatial	Local site, office or other building	
Energy	NOW	FUTURE DEVELOPMENT
PV	Very low	High
EV	Very high	High
Heat options	Central heating, floor heating	District heating



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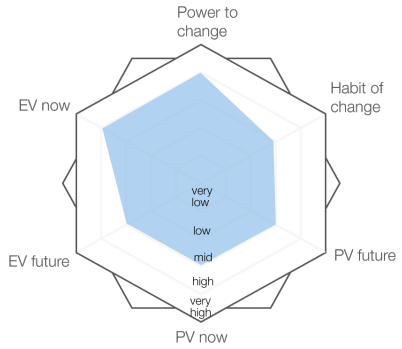
Cluster Profile: Clusters 5-9 (K-means)

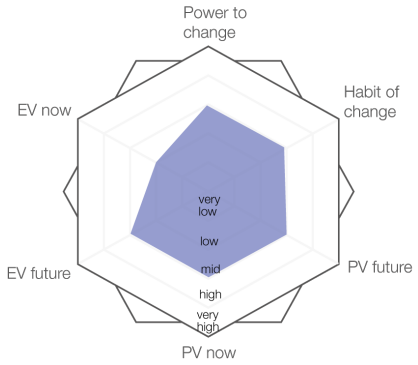
Cluster 5

Socio-Economic	High power to change Mid habit of change	
Spatial	Local site, multi-family houses	
Energy	NOW	FUTURE DEVELOPMENT
PV	Mid	Mid
EV	High	Mid
Heat options	Central heating, district heating	District heating



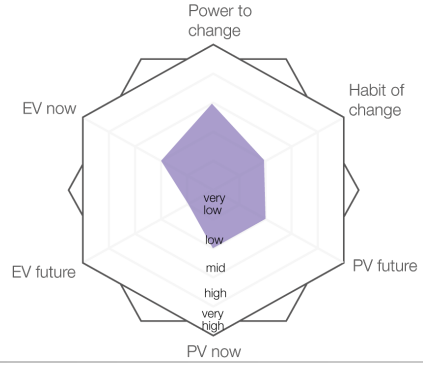
Cluster 6

Socio-Economic	High power to change Mid habit of change	
Spatial	Local site, multi-family houses	
Energy	NOW	FUTURE DEVELOPMENT
PV	Mid	Mid
EV	High	Mid
Heat options	Central heating, district heating	District heating



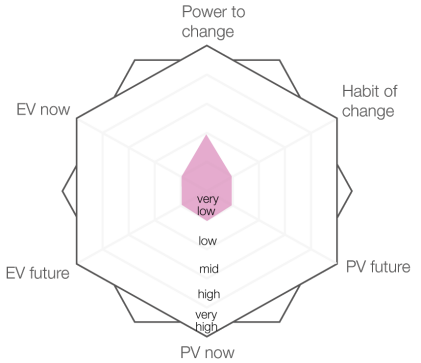
Cluster 7

Socio-Economic	Mid power to change Low habit of change	
Spatial	Local site, multi-family houses	
Energy	NOW	FUTURE DEVELOPMENT
PV	Low	Low
EV	Low	Very low
Heat options	Single multi chamber ovens, central heating	Heat pump



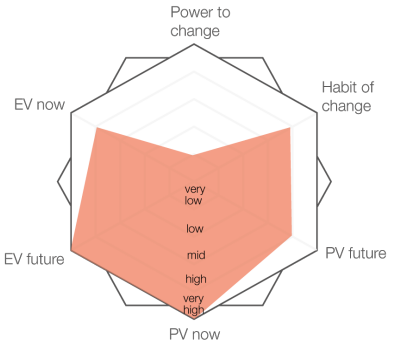
Cluster 8

Socio-Economic	Low power to change Very low habit of change	
Spatial	Local site, multi-family houses	
Energy	NOW	FUTURE DEVELOPMENT
PV	Very low	Very low
EV	Very low	Very low
Heat options	District heating, central heating	District hating



Cluster 9

Socio-Economic	Very low power to change High habit of change	
Spatial	Local site, terraced or semi-detached house	
Energy	NOW	FUTURE DEVELOPMENT
PV	High	Very high
EV	High	Very high
Heat options	Central heating, single multi chamber ovens	Heat pump



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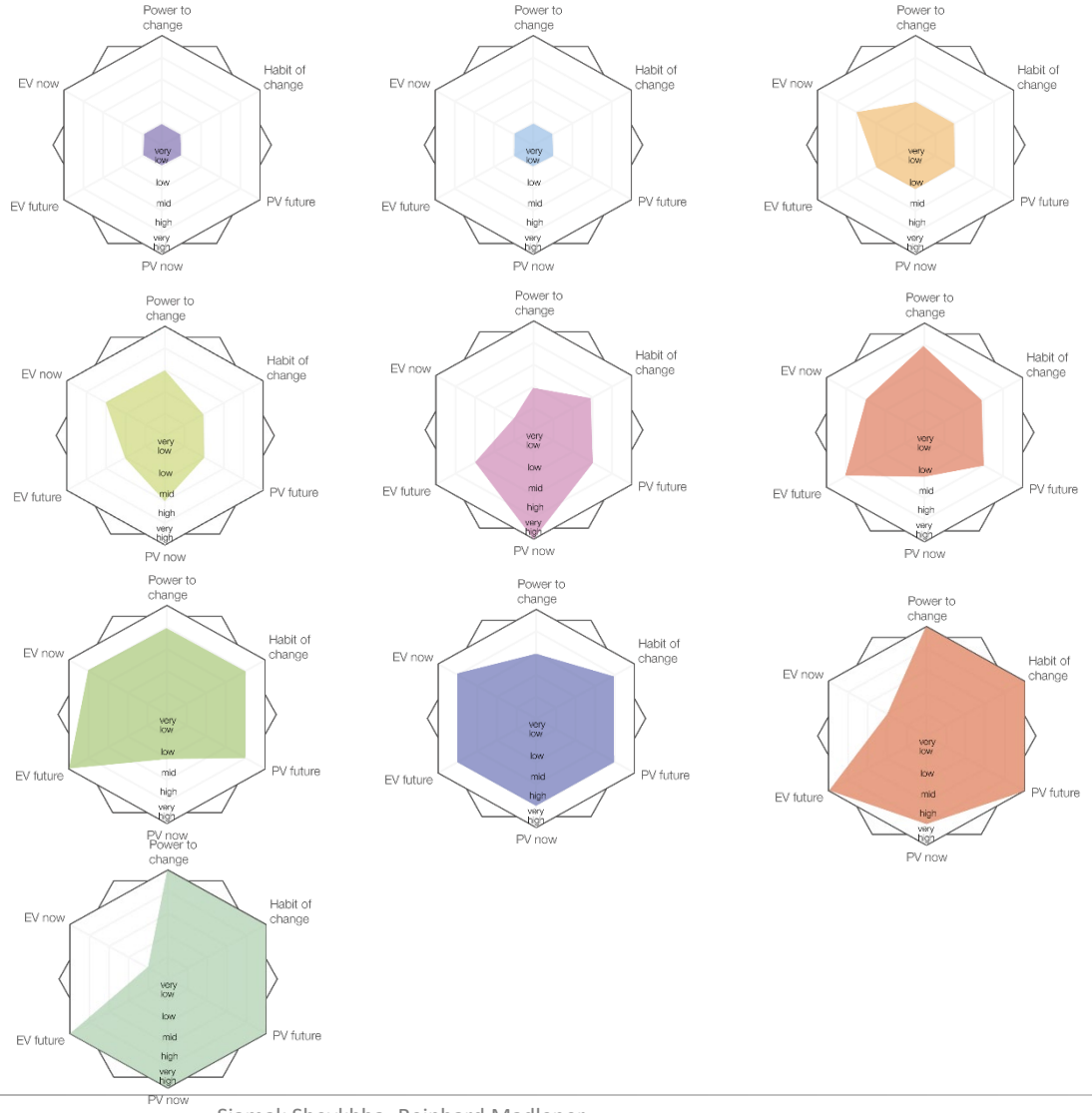
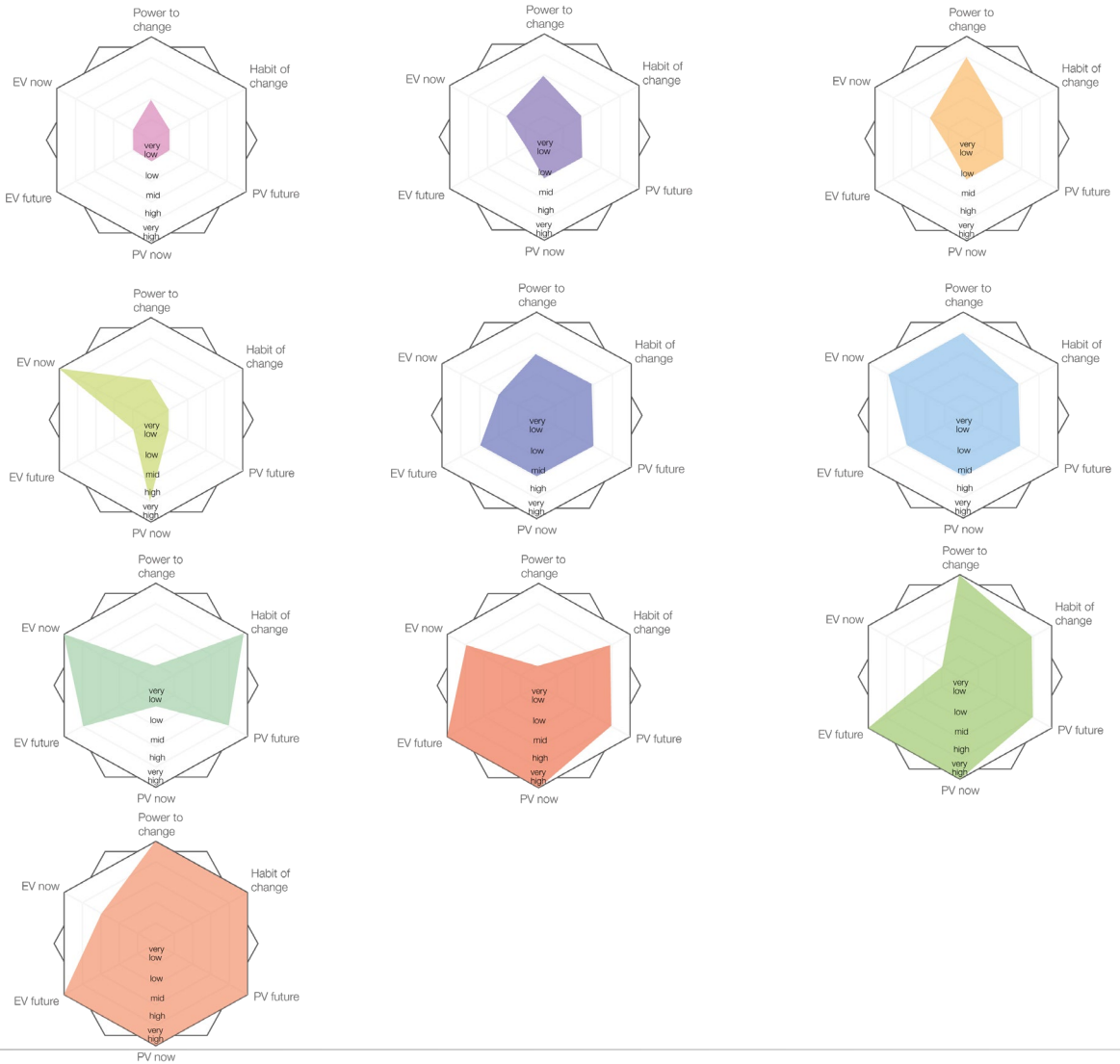
Sensitivity Analysis: Comparing Clusters of Aachen and Essen

Aachen



Essen



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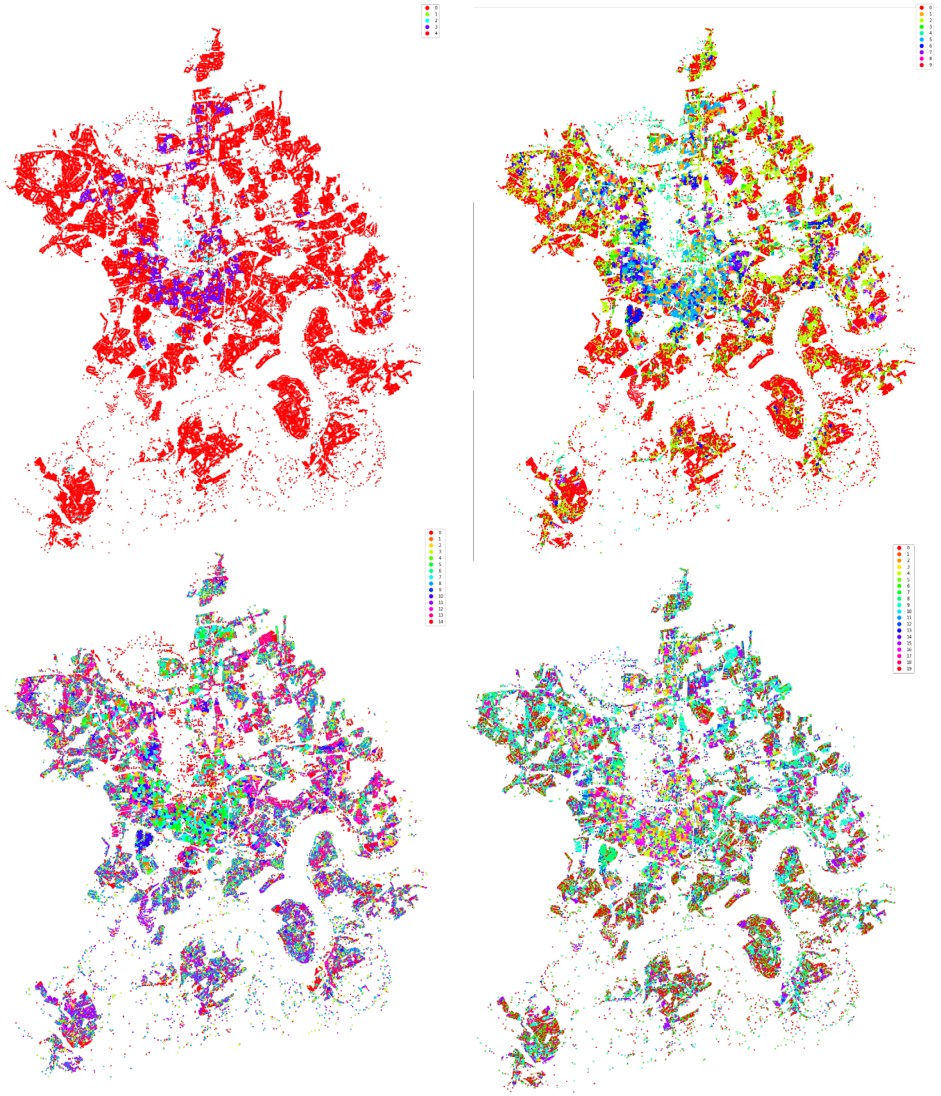
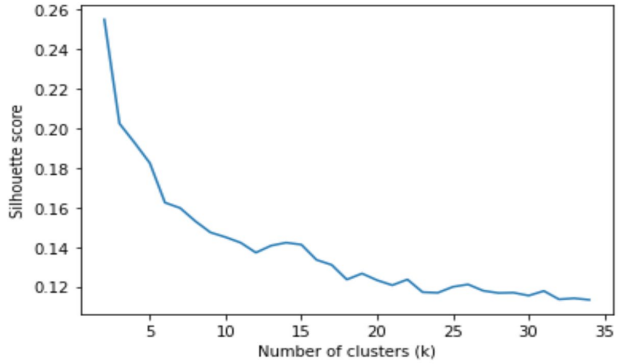
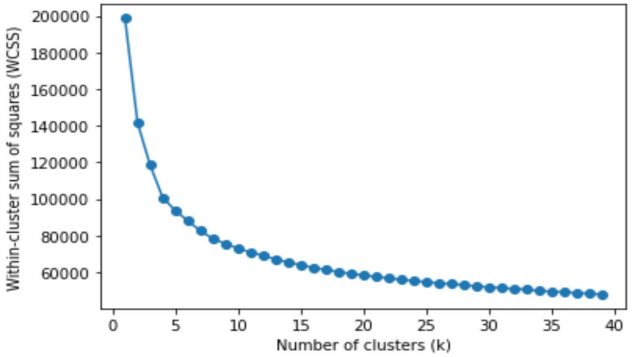
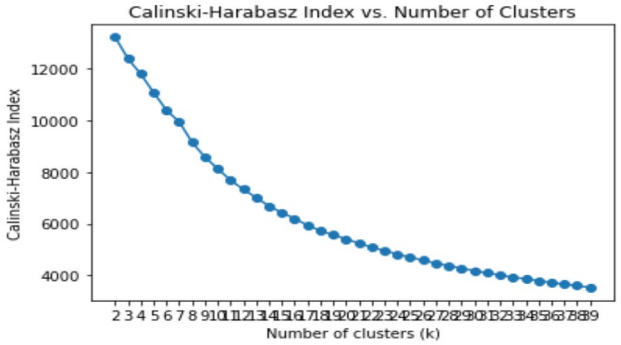
Sensitivity Analysis: K-means Method









Sensitivity analysis approaches:

- Cluster numbers between 10 and 20 seem a good choice.
- Impact of an increasing number of clusters on the quality of the outputs:
  - Increases the noise (outliers) in the outputs.
  - Creates subclusters that can have trivial differences with other clusters.
  - Lower visualized quality
  - Worse statistical index (e.g., WCSS, Silhouette score)

Siamak Sheykhha, Reinhard Madlener
RWTH Aachen University | Institute for Future Energy Consumer Needs and Behavior (FCN)
Chair of Energy Economics and Management (FCN-ECO)
siamak.sheykhha@eonerc.rwth-aachen.de

Discussion of key results

- High ownership
- Low price sensitivity
- Highest environmental concern
- Few EV stations
- High E-mobility affinity
- Medium solar capacity

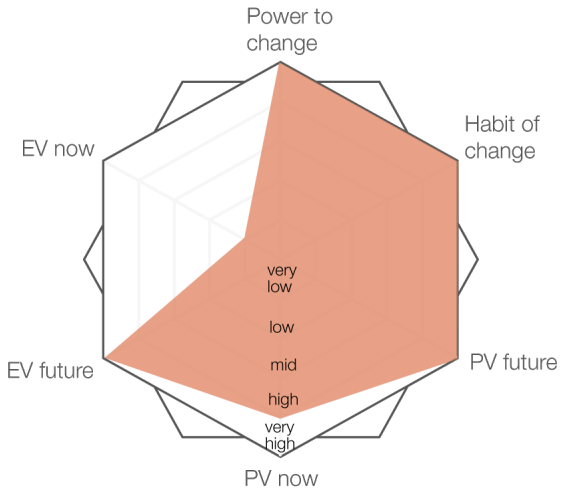
➢ Future development on the part of residents high

➢ Inhabitants do have the power and the means to create change

➢ Change potential

➢ Provide concentrated energy (EV, PV)

Socio-Economic	Very high power to change Very high habit of change	
Spatial	Local site, Terraced or semi-detached house	
Energy	NOW	FUTURE DEVELOPMENT
PV	High	Very high
EV	Low	Very high
Heat options	Central heating, floor heating	Heat pump



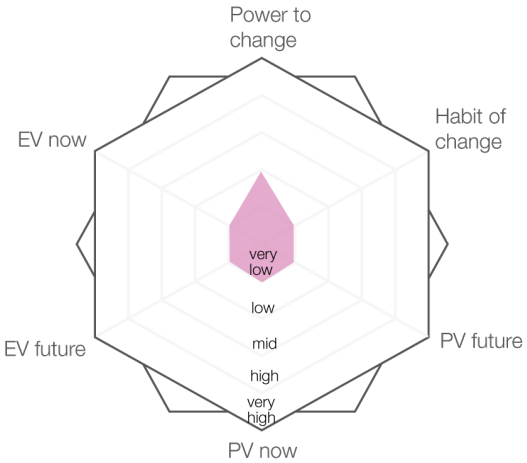
- Low ownership
- Highest price sensitivity
- Medium environmental concern
- No EV stations
- Lower E-mobility affinity
- Very low solar capacity

➢ Future development on the part of residents low

➢ Inhabitants do not have the power and the means to create change

➢ Other actors (like the landlord) or institutions (like the city municipality) could create change in this area

Socio-Economic	Low power to change Very low habit of change	
Spatial	Local site, multi-family houses	
Energy	NOW	FUTURE DEVELOPMENT
PV	Very low	Very low
EV	Very low	Very low
Heat options	Central heating, floor heating	Heat pump



Siamak Sheykhha, Reinhard Madlener
RWTH Aachen University | Institute for Future Energy Consumer Needs and Behavior (FCN)
Chair of Energy Economics and Management (FCN-ECO)
siamak.sheykhha@eonerc.rwth-aachen.de

Agenda

1. **Project aim & scope**
   Approach and process
2. **Methodology**
   Introduction to the proposed strategy
3. **Insights gained**
   Results, sensitivity analysis, and discussion
4. **Outlook**
   Conclusion and outlook

Siamak Sheykhha, Reinhard Madlener
RWTH Aachen University | Institute for Future Energy Consumer Needs and Behavior (FCN)
Chair of Energy Economics and Management (FCN-ECO)
siamak.sheykhha@eonerc.rwth-aachen.de

Conclusion

Conclusion:

- The optimal number of clusters depends on several parameters: indicators, clustering algorithm, aims of clustering, number of key outputs.
- There is **no single optimal number** of clusters in all cities/regions. However, the proposed heuristics can help us to find the optimal number of clusters for any region.
- We determined energy characteristics of clusters for the **current** and the **future** status.
- We found **10** meaningful clusters for city of Essen, Germany.
- For EVs, solar PV, heating systems, socio-economic factors and building types, the proposed **clustering algorithm** works.

Outlook:

- Exploring contrasting situations like rural areas or ones that are of a suburban structure.
- Investigate whether clusters can also be described with existing planning instruments (such as the land use plan and regional planning).
- Carbon emissions and mitigation costs analysis.
- **Scalability** of the algorithm: Using other clustering algorithms (e.g., HDBSCAN)
- Explicit consideration of spatial dependencies (e.g., **contiguity**).

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RWTH Aachen University | Institute for Future Energy Consumer Needs and Behavior (FCN)
Chair of Energy Economics and Management (FCN-ECO)
siamak.sheykhha@eonerc.rwth-aachen.de

Thank you for your attention!

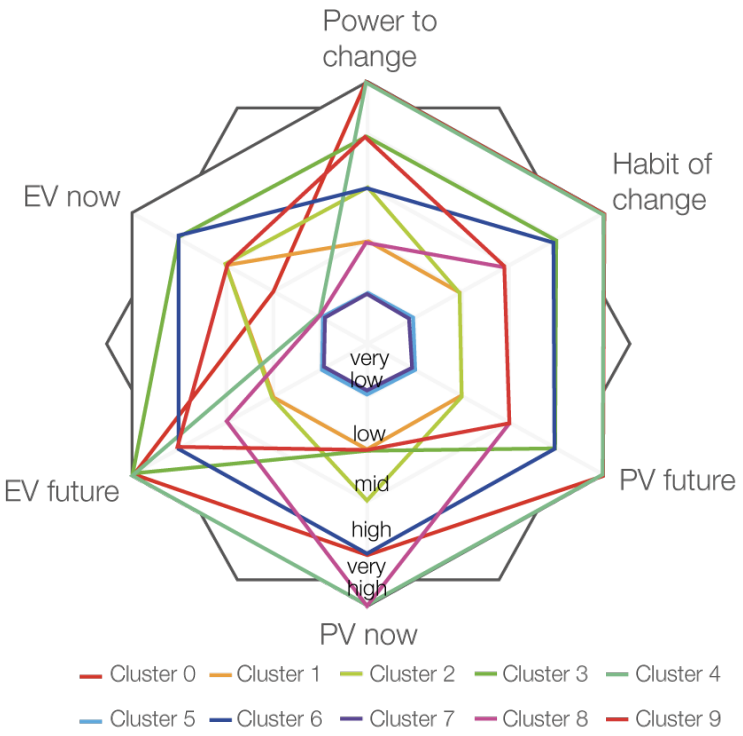
Questions?

Contact

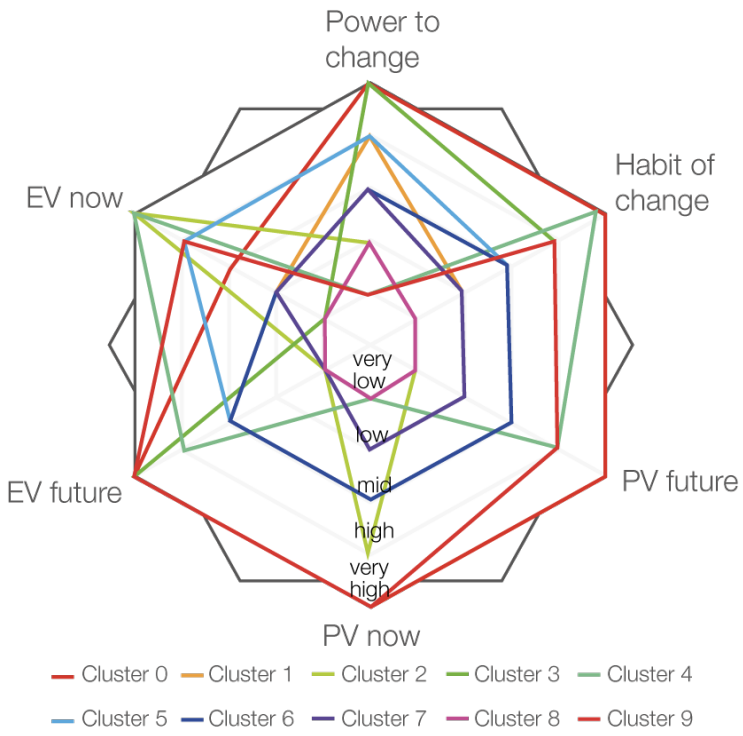
E.ON Energy Research Center
Mathieustraße 10
52074 Aachen
Germany
http://www.eonerc.rwth-aachen.de

Siamak Sheykhha, Reinhard Madlener
T +49 241 80 49841
Firstname.Surname@eonerc.rwth-aachen.de
www.fcn.eonerc.rwth-aachen.de

Summary of Clusters Profile: Aachen vs. Essen



Aachen



Essen

- Differences can be attributed to different types of features in cities. For example, Essen has a higher EV potential than Aachen. However, both have a relatively similar EV future.
- In Essen, there is a positive correlation between EV and PV potential for the future in clusters.
- In clusters where the share of multi-family houses is high, the expected future solar PV and e-vehicle (EV) potential is low.
- Terraced or semi-detached houses has the highest PV and EV potential.

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