Karlsruhe Institute of Technology

JÜLICH FORSCHUNGSZENTRUM

# Energy efficiency in industry

## Analysing the potential by using an agent-based simulation

KoMSO Workshop „Mathematical MSO for Energy Conservation“ | October 9th, 2015
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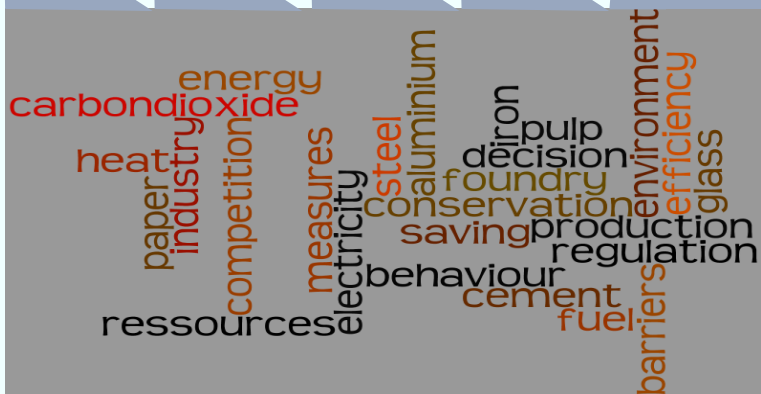
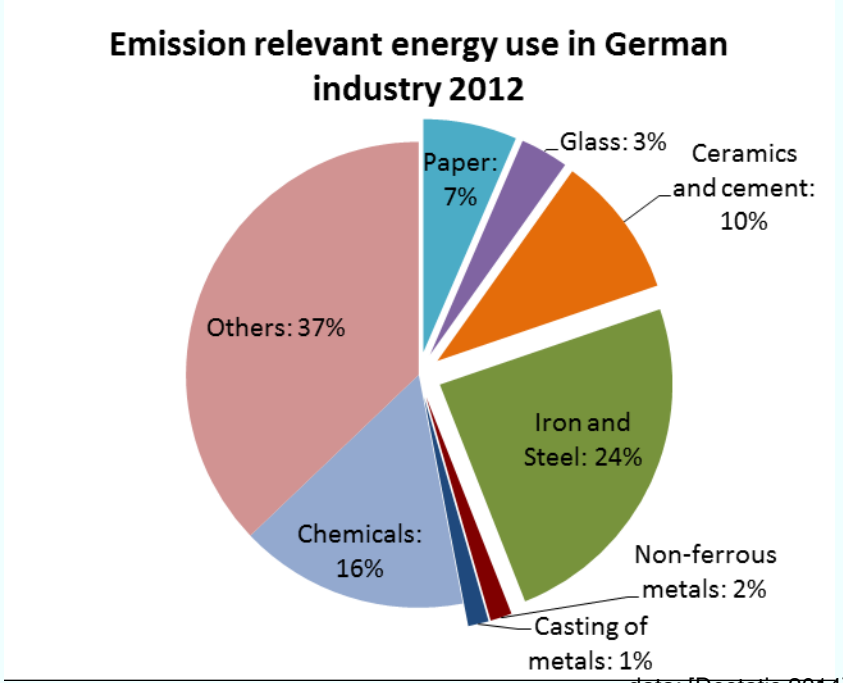
# Outline

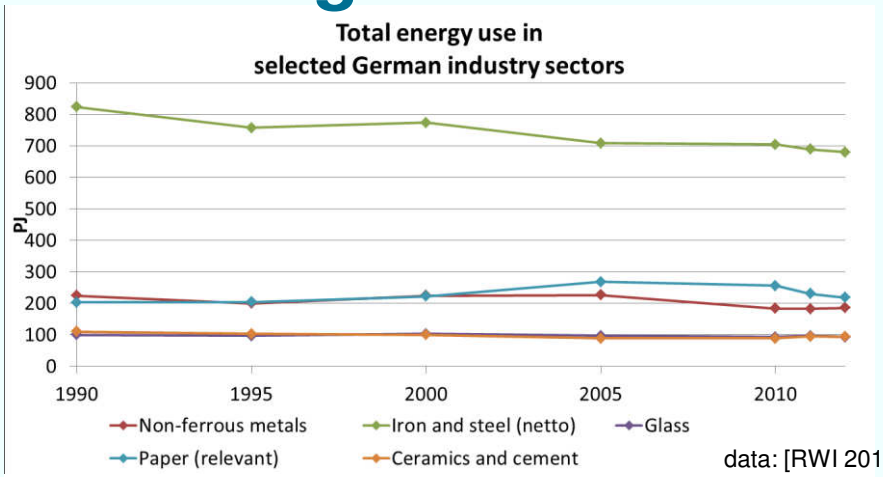
1. **Research Topic**
2. Material and Methods
    1. General approach
    2. Expert interviews, company survey and cluster analysis
    3. Agent-based simulation
3. Discussion and Outlook



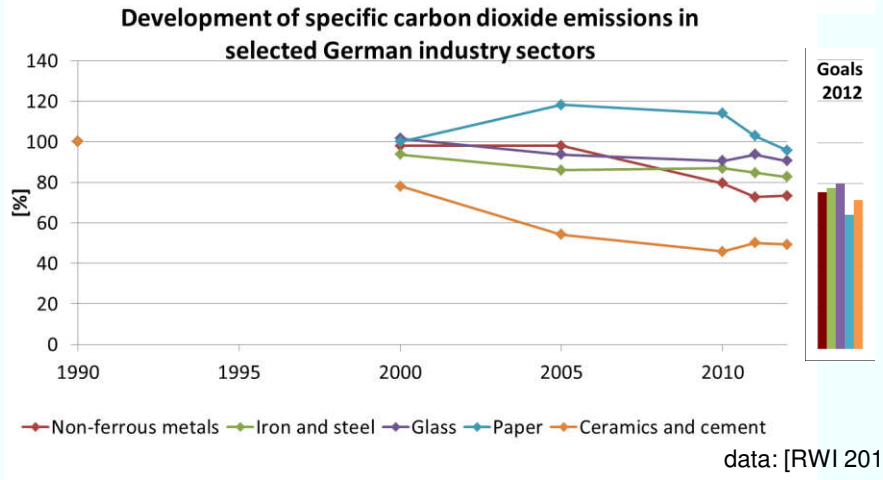
# 1.1 Energy use and greenhouse gas emissions




data: [Destatis 2014]




data: [RWI 2013]




data: [RWI 2013]

- **Criteria for choice of sectors:**
  - Rather homogenous products
  - Specific energy use
  - Size of sector (employees, gross value added, revenues, …)

**Future goals Germany (not industry specific):**

- GHG: 2020: -20%, 2050: -80% (vs. 1990)
- Primary energy use: 2020: -20%, 2050: -50% (vs. 2008)

[BMWi & BMU 2011]

# 1.2 Studies on energy efficiency potentials

| Article/thesis | # Sector | | Focal point | | | Method | | | | | | | Sector insights |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | One sector | More than one sector | Diffusion of energy efficiency technologies | Analysing historical development | Potential of energy efficiency and future carbon dioxide emissions | Bottom-Up | | | | Top-Down | | Hybrid approach | Sophisticated differentiation of companies |
| | | | | | | Optimization | System Dynamics | Simulation | Others | General equilibrium models | Input Output | | |
| [Arens & Worrel 2014] | X | | X | | | | | | X | | | | |
| [Böhringer et al. 2002] | | X | | X | | | | | | X | | | |
| [Breun et al. 2014] | | X | | | X | X | | | | | X | X | |
| [Brunke & Blesl 2014a , b] | X | | X | | X | | | | | | | X | |
| [Fleiter et al., 2013] | | X | | | X | | | | X | | | | |
| [Ilsen, 2011] | | X | | | X | | | X | | | X | X | |
| [Pardo & Moya, 2013] | X | | | | X | | | X | | | | | |
| [Schaffer 2002] | | X | | | | | | | | | X | | |
| [Schneider et al. 2014] | | X | | | X | | | | X | | | | |
| [Seitz 2015] | X | | X | | | | X | | | | | | X |

# 1.3 Objective of research project

- The studies do not (or only to a small extent) differentiate between company types or pay attention to human behaviour
  - → What are behavioural and decision aspects when analysing investments in energy efficient technologies?
- Analysing barriers and drivers and interdependencies for investments in energy efficiency
- Is an agent-based simulation a suitable tool for doing so?

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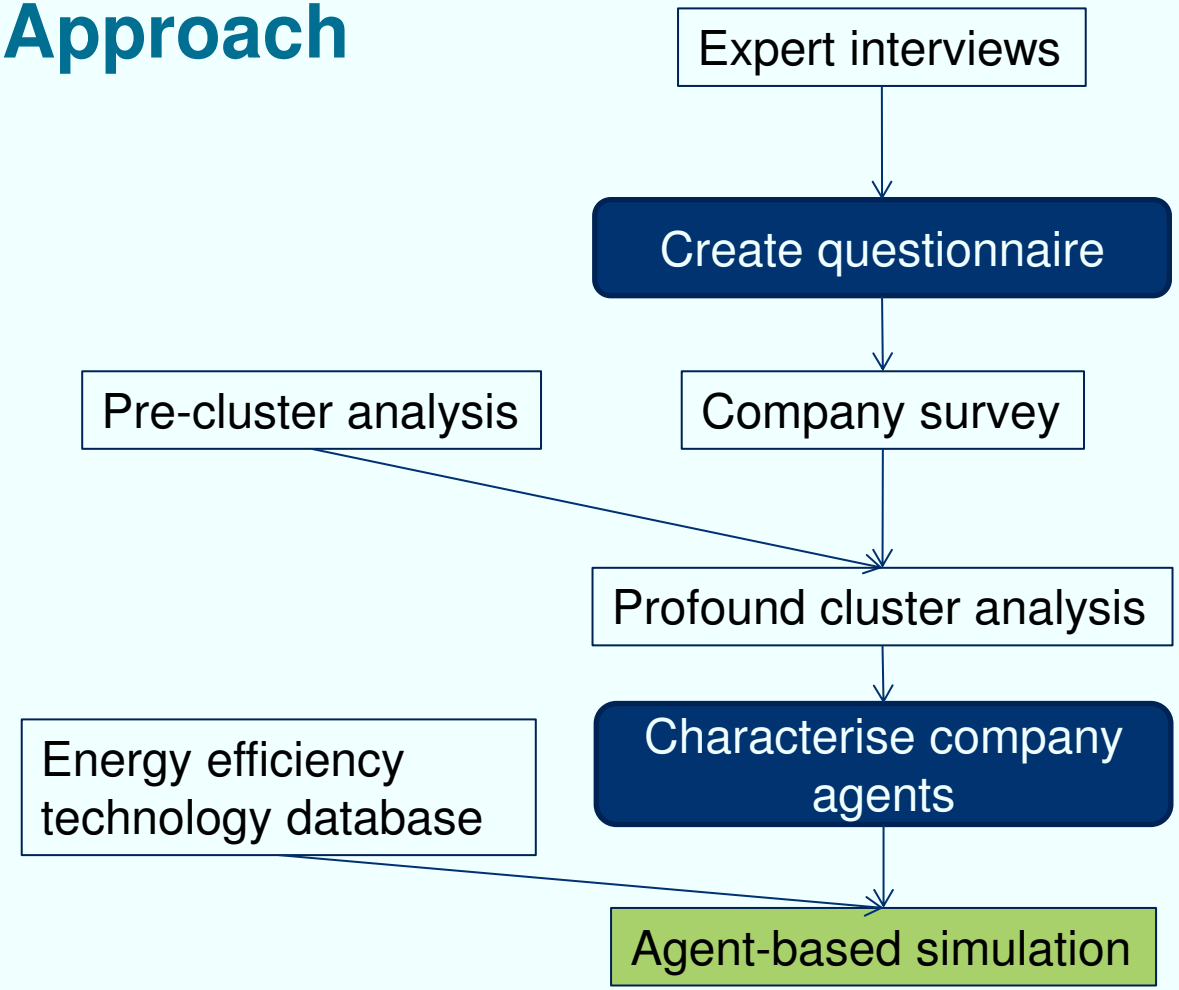
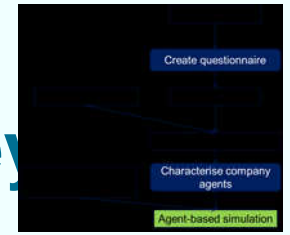
# 2.1 Approach






# 2.2 Expert interviews and company survey

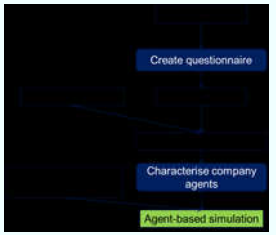
Analysed Sectors according to WZ 2008 [Destatis 2015]:

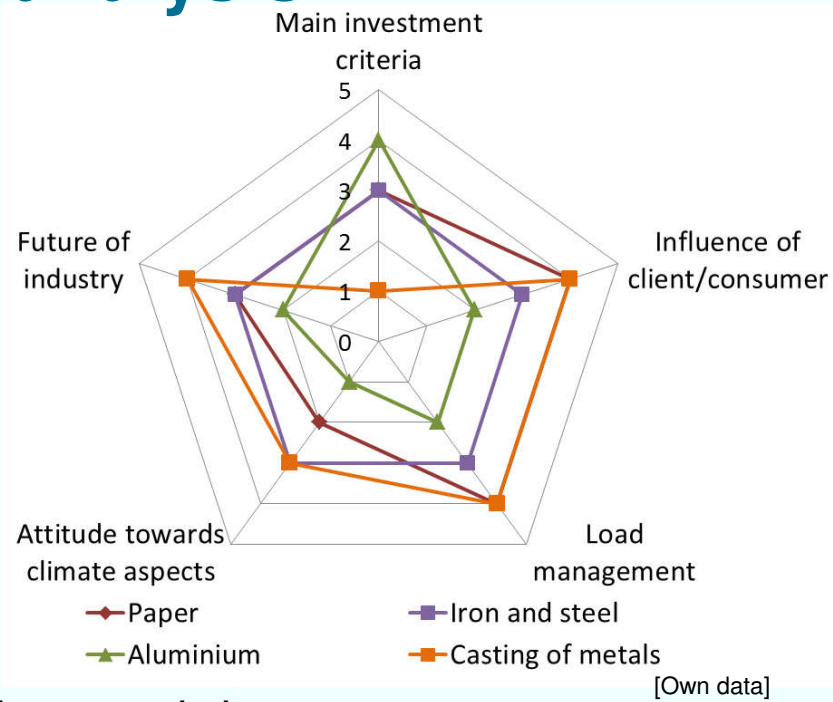
- Manufacture of pulp, paper and paperboard
  - 189 companies (> 9 employees)
- Manufacture of glass and glass products
  - 216 companies (> 9 employees)
- Manufacture of cement
  - 28 companies (> 9 employees)
- Manufacture of basic iron and steel
  - 177 companies (> 9 employees)
- Aluminium production
  - 116 companies (> 9 employees)
- Casting of metals
  - 485 companies (> 9 employees)

1. Interviews with one representative of industry associations and one representative of a company in each analysed sector → 12 interviews.
2. Survey with approx. 200 companies out of 1,211.

**Topics:** energy efficiency technologies, investment parameters, energy policy, future expectations

# 2.2 Expert interviews and pre-cluster analysis

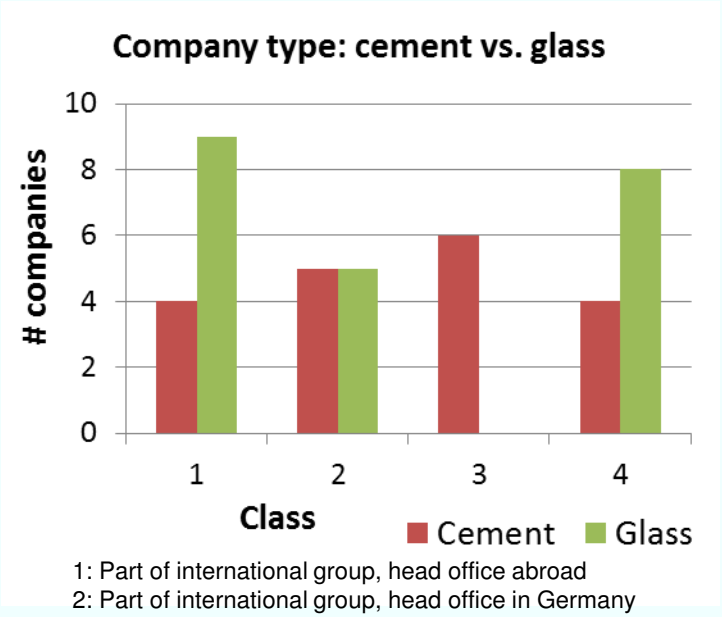



[Own data]

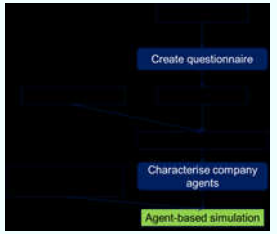
- **Investment criteria:**
  1: monetary, 2: monetary + image, 3: monetary + quality,
  4: environment + monetary, 5: environment + image
- **Influence:**
  1: very high,…, 5: very low
- **Load management:**
  1: very high potential,…, 5: very low potential
- **Attitude and future:**
  1: very positive,…, 5: very negative

- **Source:** annual financial statements, company information (homepage,…)
- **Parameters:** company type, #facilities, own electricity generation, products, #employees, revenue, fixed capital, environmental affinity
- **Method:** distance and similarity measures



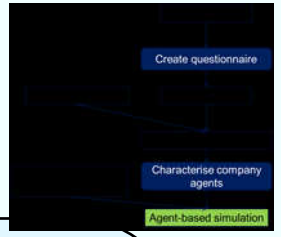

1: Part of international group, head office abroad
2: Part of international group, head office in Germany
3: German group, only German sites
4: Single company with one site

data: [Bundesanzeiger 2015]

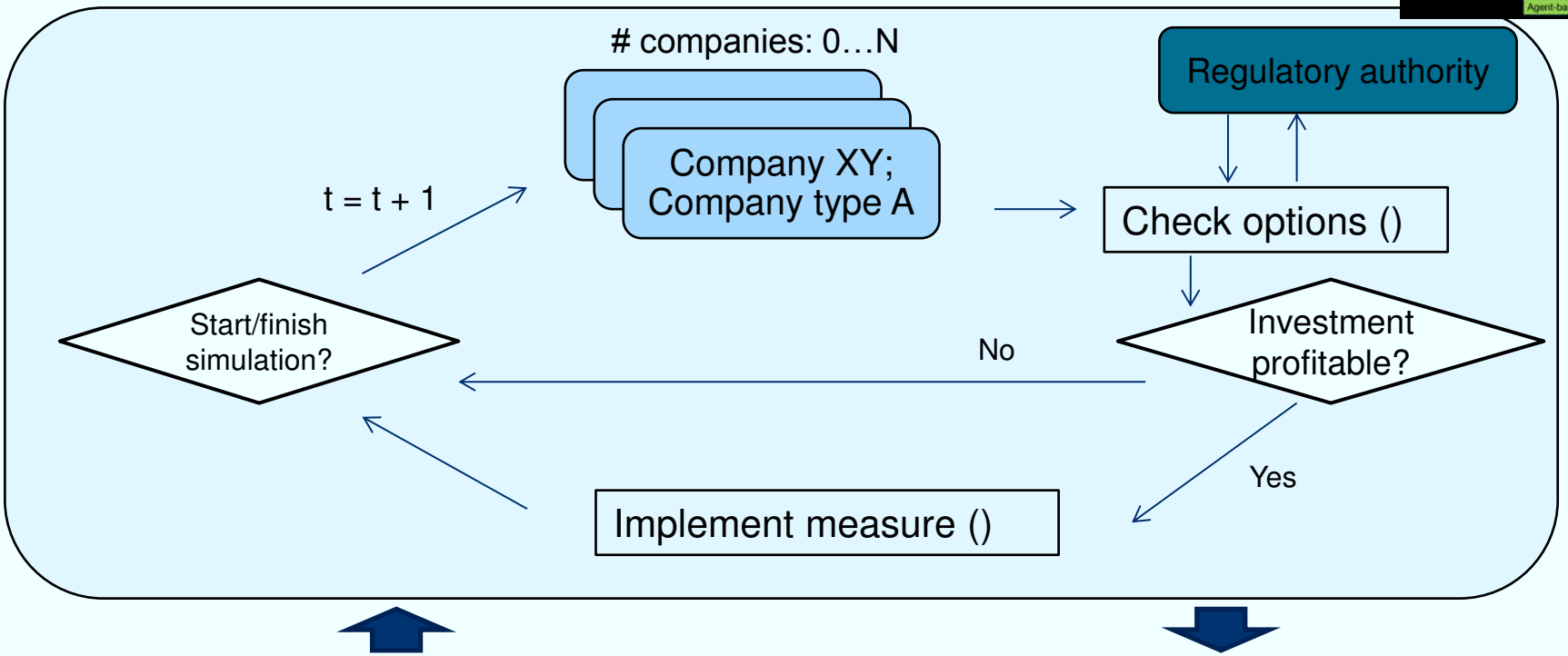



# 2.3 Agent-based simulation (ABS)

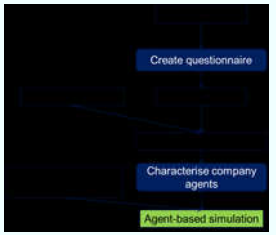
- **Explanation:**
  - Simulation to explain and understand complex systems
  - Each agent interacts with its environment (Agent is a representation of a distributed and autonomous entity)
  - The sum of the actions of each single agent determines the system behaviour
- **Advantages:**
  - Different entities (companies, regulatory authority, distributer of technologies,…) can be represented
  - Agents can be modelled with different character and behaviour
  - Agent can adapt its behaviour (learning effect, interaction)
- **Disadvantages:**
  - High effort for calibration and validation
  - No sufficing possibility for induction → Which agent is responsible for system behaviour?




# 2.3 ABS – basic model




**Database (different often inhomogeneous and ill-matched data):**
**Company details:** size, costs, age of facilities, …
**Energy efficiency measures:** performance, price, …
**Economic development:** prices of commodities, development of production, …
**Political instruments:** taxes, emission trading, penalties, guidelines,…
…




# 2.3 ABS – basic model

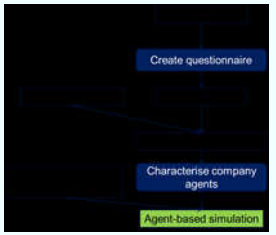
**Indirect interaction of agents (not yet implemented):**

- Characteristics of efficiency measures can change according to the number of companies implementing this measure
- Share of production for companies can change according to behaviour of other companies
- Interaction with regulatory authority that can change the rules of the game

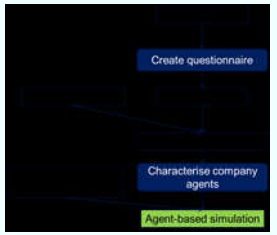
**Methods:**

- Check options ():
  - Evaluation of different possible measures by using the set investment calculation methods
  - Choice of measure that fulfils the conditions the best
- Implement measure ():
  - Update characteristics of facility (remove data of old machine/measure and adjust data for energy use, emissions, productivity,…)
  - Update production costs of facility

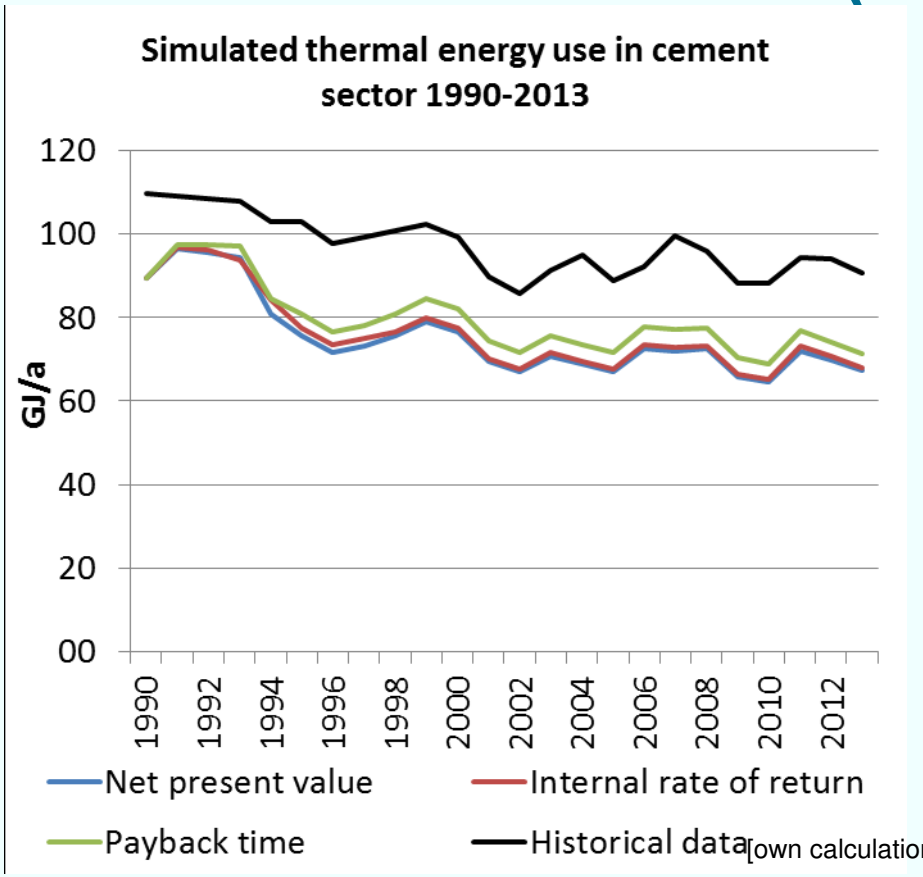
# 2.3 ABS – evaluation of efficiency measures:




1. **Check age of machine/facility**
   - For each company {
     For each facility/machine {
     If AgeOfFacility/machine == 1 {
     then checkRestrictionsOfMeasures () }}};
2. **Check type of machine/facility**
   - Company X: For each measure {
     requirements ok ();
     conflicts ok ()};
3. **Calculate the net present value of possible measures and chose the measure with the highest value**
   - Company X and measures type Y:
     Chose max (NPV $Y_1$, NPV $Y_2$, …, NPV $Y_n$)
     NPV: $C_0(i) = \sum_{t=0}^{T} \frac{Z_t}{(1+i)^t}$ , $C_0$: net present value at time t=0, i: interest rate, T: periods, $Z_t$: Cash flow in period t




# 2.3 ABS – first results (calibration)




[own calculation]

Interest 15%, different investment calculation rules for replacement investments, payback time is used for additional investments (within the life cycle of machine)

- No consideration of financing aspects
- Deterministic development of production and prices
- All companies use the same calculation method for investment decisions
- Constant supply of measures with constant characteristics (performance, price)

- **Thermal energy use**, **electricity use** and **carbon dioxide emissions** are examined

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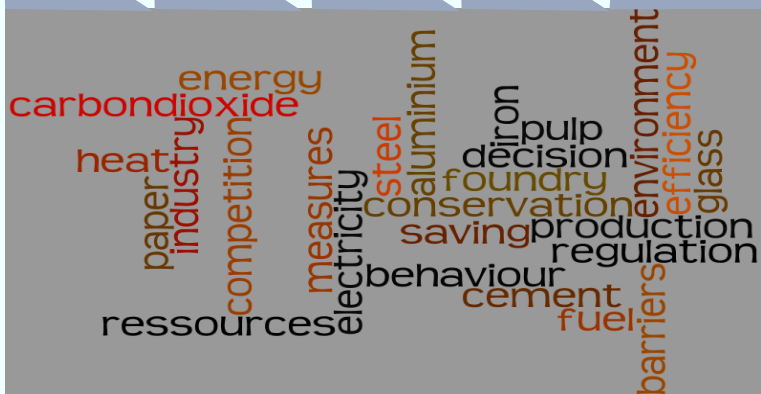

# 3 Discussion

- Will the outcome of the company survey be sufficient to identify different company types and strategies to implement different investment behaviour?
- Will the data about energy efficiency measures be adequately detailed (performance, price, complexity)?
- Are the most important parameters and barriers identified for the purpose of the study?
- Is agent-based simulation a suitable method for this subject?

# 3 Outlook

- run different scenarios up to 2050

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# Thank you very much for your attention!

# References


[Arens & Worrell, 2014] ARENS, M. & WORRELL, E. (2014) Diffusion of energy efficient technologies in the German steel industry and their impact on energy consumption. *Energy,* 73:0**,** 968-977.

[BMWI & BMU 2011] BMWI & BMU (2011) *Energiekonzept für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung.* Berlin.

[Böhringer et al., 2002] BÖHRINGER, C., LÖSCHEL, A. & ROHDE, A. (2002) PACE - Policy analysis based on computable equilibrium. *Forum für Energiemodelle und Energiewirtschaftliche Systemanalysen in Deutschland: Energiemodelle zum Kernenergieausstieg in Deutschland - Effekte und Wirkungen eines Verzichts auf Strom aus Kernkraftwerken.*119-142, Heidelberg, Physica-Verlag.

[Breun et al., 2014] BREUN, P., FRÖHLING, M. & SCHULTMANN, F. (2013) A hybrid model to evaluate climate policies with regard to resource intensive industries. *Joint 11th socio-economic Metabolism Conference and 4th ISIE Asia-Pacific Conference*, November 17-19, 2014, Melbourne, Australia

[Brunke & Blesl, 2014a] BRUNKE, J.-C. & BLESL, M. (2014a) Energy conservation measures for the German cement industry and their ability to compensate for rising energy-related production costs. *Journal of Cleaner Production,* 82:0**,** 94-111.

[Brunke & Blesl 2014b] BRUNKE, J.-C. & BLESL, M. (2014b) A plant-specific bottom-up approach for assessing the cost-effective energy conservation potential and its ability to compensate rising energy-related costs in the German iron and steel industry. *Energy Policy*: 67:0, 431-446.

[Bundesanzeiger 2015] BUNDESANZEIGER (2015a) *Jahresabschlüsse zum Geschäftsjahr 2013, Rechnungslegung/Finanzberichte.* Berlin, Bundesanzeiger Verlag, www.bundesanzeiger.de (last access: 10/06/2015).

[Destatis 2014] DESTATIS (2014) *Tabellen zu den Umweltökonomischen Gesamtrechnungen, Teil 2: Vorbericht Energie, Berichtszeitraum 1995 - 2013*. Statistisches Bundesamt, Wiesbaden.

[Destatis 2015] DESTATIS (2015) *Statistisches Unternehmensregister – Unternehmen nach Wirtschaftsgruppen und Größenklassen der sozialversicherungspflichtig Beschäftigten im Berichtsjahr 2012,* Registerstand: 30.05.2014, Statistisches Bundesamt, Wiesbaden.

[Fleiter et al. 2013] FLEITER, T., SCHLOMANN, B. & EICHHAMMER, W. (2013) *Energieverbrauch und CO2-Emissionen industrieller Prozesstechnologien - Einsparpotenziale, Hemmnisse und Instrumente.* Karlsruhe, Fraunhofer Verlag.

[Ilsen, 2011] ILSEN, R. (2011) *Ein Beitrag zur modellgestützten Analyse umweltpolitischer Instrumente in den Bereichen Luftreinhaltung und Klimawandel*. Deutsch Französisches Institut für Umweltforschung (DFIU), Karlsruhe, KIT.

[Pardo & Moya, 2013] PARDO, N. & MOYA, J. A. (2013) Prospective scenarios on energy efficiency and CO2 emissions in the European Iron & Steel industry. *Energy,* 54:0**,** 113-128.

[RWI 2013] FRONDEL, M., JANßEN-TIMMEN, R. & RITTER, N. (2013) *Die Klimavorsorgeverpflichtung der deutschen Wirtschaft – Monitoringbericht 2011 und 2012*. Rheinisch-Westfälisches Institut für Wirtschaftsforschung (rwi), Essen.

[Schaffer, 2002] SCHAFFER, A. (2002) *Ecological input-output analysis : ECOLIO - a model for conventional and ecological key sector analyses in Germany*. Wirtschaftswissenschaften, Karlsruhe, Universität Karlsruhe.

[Schneider et al., 2014] SCHNEIDER, C., LECHTENBÖHMER, S. & S., H. (2014) *Re-industrialisation and low carbon economy – can they go together? Results from transdisciplinary scenarios for energy intensive industries*. ECEEE 2014 INDUSTRIAL SUMMER STUDY – RETOOL FOR A COMPETITIVE AND SUSTAINABLE INDUSTRY, Arnhem.

[Seitz, 2015] SEITZ, C. (2015) *Diffusion innovativer Antriebstechnologien zur CO2-Reduktion von Nutzfahrzeugen – Empirische Untersuchung des organisationalen Adoptionsverhaltens und systemdynamische Prognose für den deutschen Automobilmarkt*. Fakultät für Wirtschaftswissenschaften, Karlsruhe, Karlsruher Institut für Technologie.