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Efficiency Benchmarking for German Municipal Energy Suppliers

Data Envelopment Analysis - Covering the Influences of the German Energy Transition 2005 - 2014

Arne-Steffen Möller

Supervisor: Endre Bjørndal, Mette Helene Bjørndal

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NORWEGIAN SCHOOL OF ECONOMICS

Abstract

Four large companies dominate almost 70 per cent of the German electricity market – RWE, EnBW, E.On and Vattenfall. Their historical advancement was triggered by technical development in the electricity sector towards larger, centralized power plants and connected grids, all requiring high investments. The other 30 per cent of the market are in the hand of more than 1,000 regional energy companies. Moreover, again history repeats: The German energy transition, or 'Energiewende,' again requires massive investments. The only difference is that this time, the trend goes towards renewable, more de-centralized energy power production like wind, photovoltaic or biomass that requires smart grid infrastructure and innovative technologies for energy storage.

This Data Envelopment Analysis analyzes the efficiency of eight German regional energy suppliers in relation to labor and capital allocation over the time span of 2005 – 2014. The aim is to identify best-practice examples of regional energy suppliers that successfully manage their resource allocation and adapt their business models to the requirements of the energy transition.

The efficiency scores reveal that smaller companies can successfully participate in the energy transition, even though their financial power is limited. They need to work closely together with strategic partners in capital-intensive areas, like e.g. wind park investments or smart grid expansion and maintenance. Derived from the insights of this thesis, there are smaller regional energy companies that are following a clear path leading to efficiency improvement, but also a stable base of businesses that could improve their efficiency scores.

Another important aspect of this thesis is to show the practicability of DEA for companies who are willing to benchmark themselves with others, analyze weak points in their business model and identify strategies to counteract those weak points. The willingness of the municipal energy companies to join this research was rather limited and hopefully improves with the results.

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List of Abbreviations

CRS	Constant Returns to Scale
CHP	Combined Heat and Power
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DRS	Deutsche Rechnungslegungsstandards (German Accounting Standards)
GHG	Greenhouse Gas
IAS	International Accounting Standards
KPI	Key Performance Indicator
M&A	Merger and Acquisitions
NGO	Non-Governmental Organization
PV	Photovoltaic
VRS	Variable Returns to Scale

1. Introduction

1.1 Context

The situation of the German energy market is challenging – for years, profit levels are decreasing within most parts of the companies' value chain (Sensfuß, Ragwitz, & Genoese, 2008). The pace of the German energy transition with increasing decentral production puts pressure on businesses that used to operate conventional power plants very profitably. In addition, the increasing demand to invest in the distribution grid through modernization and enhancement requires the distribution system operators to adapt their business models, their financing and sales. All those trends mostly issue from the liberalization of the European energy markets that started in the 90s and a dynamic shift in production towards renewable energies.

The purpose of this thesis is to analyze the efficiency scores in relation to cash and investment figures of selected German municipal energy suppliers from 2005 to 2014. The time frame was chosen to cover a significant period of the German energy transition. The German energy transition was turned into first concrete laws in 1990, but gained momentum during the early 2000s when the Social Democratic Party of Germany (German: Sozialdemokratische Partei Deutschlands) and the Alliance '90/The Greens (German: Bündnis 90/Die Grünen) formed the government of Germany. The aim is to see if the arising changes rather motivated companies to enhance their investment and cash efficiency, or if the challenges put rather more pressure on the companies and their strategic decisions. Increasing or decreasing efficiency scores over time could be the first indicator for this. At this point, it is already important to mention that the individual efficiency scores cannot present a strategic approach on their own, but should rather be taken as an instrument to support management decisions without solely concentrating on past developments (Kerpen, 2016).

The companies that were selected are spread all over Germany. This setup was chosen based on a study carried out by Lenk, Rottmann, Albrecht, and Grüttner (2012), who provide a good overview of installed capacity of renewable energy based on energy sources. Also, companies with strategies favoring renewable energies, as well as businesses that focus rather on conventional business models and production were selected.

1.2 Structure and Research Framework

This thesis firstly describes the historical developments in the German energy market to create a better understanding of the role of the companies described. Also, the chapter tries to raise awareness for the importance of capital investments required in the energy sector. Afterward, to understand the changes in the timeframe between 2005 – 2014, it explains the idea of the so-called German energy transition, which has a major influence on the business model of the municipal energy companies and indicates the reasoning behind the strong concentration of cash- and investment input factors in this thesis. Subsequently, the ideas of efficiency, benchmarking and the data envelopment analysis (DEA) are explained to create an understanding of the decisions made in the next chapter.

Chapter four concentrates on defining the DEA model that is used to generate the DEA efficiency scores. Main decisions on the model formulation are discussed, and the theoretical background is explained in parallel. Chapter five presents the efficiency scores and first overarching interpretations.

In chapter six one of the compared companies will be analyzed in more detail to showcase how certain decisions could have an impact on business performance. Due to the limit of this thesis, this second step analysis will be carried out for only one company. Still, the procedure to analyze the companies can be transferred to the analysis of other businesses as well. The most important aspect is that a company with improving efficiency scores is selected to analyze possible strategic decisions that impacted the increase in efficiency over the period under observation.

2. The German Market for Municipal Energy Suppliers

2.1 Historical Developments

Today, the German market for municipal energy suppliers is still partly dominated by four large corporations: RWE/Innogy, E.On/Uniper, EnBW, and Vattenfall. The constellation is also based on historical developments and the whole origination process of utility companies in Germany. In the late 1880s, the first electric power plants were introduced by the Deutsche Edison-Gesellschaft (later AEG AG). Those power plants were installed locally and were mostly used to electrically illuminate squares, hotels, theaters and train stations in its direct surroundings (Herzig, 1992). Later, whole blocks of buildings were supplied with energy, and private investors mostly owned power plants. The prestigious electric light was first and foremost used within cities, which brought the massive problems of difficult coal supply, and expensive building ground. The technical development made it possible to build larger power plants and supply more customers. At that point, the state came into play when power supply lines needed to interconnect buildings and therefore used public ground. The local authorities often had two possibilities:

- Operate the power plant on their own, or
- Issue licenses to use the public ground for electric power lines.

In many cases, little technical knowledge and financial risk awareness led to the preference of licensing over operating (Löwer, 1992). Later on, the electric street light started to compete increasingly with gas-fired streetlights. The gas light systems were often owned by municipal gas suppliers. Together with the progression of electric lighting and the introduction of electric trains, more and more municipalities started municipal energy businesses, of which many are still existent today. However, also today, more and more municipal energy companies are founded or bought back by municipalities in Germany, as e.g. explained by Alexe (2009), Dordowsky (2013) and Berlo and Wagner (2013).

The "big four" arose due to technical development in long-distance, high-voltage power transmission. They built large power plants and interconnected local grids to use economies of scale and to ensure network stability. Even though the liberalization of energy market required them to unbundle their transmission grids, they kept their large-scale production. In

2014, the “big four” were responsible for approximately 73 percent of the German net energy production (Bundesnetzagentur, 2015). The other approximately 30 percent are often small-scale local production (often combined heat and power plants owned by local municipal energy suppliers), producer communities (e.g. wind farm projects on- and offshore), or other decentral power generation (often biomass and photovoltaic). The market size of those sums up to approximately EUR 70bn. Also, the municipal energy suppliers often own the local distribution grids, which gives them an additional asset in mastering the challenges of the German energy transition.

2.2 The German Energy Transition

The idea of the German energy transition (German: Energiewende) is to base the energy production of the country primarily on renewable energies. The discussions about the transition already started in the 1970s as a result of the 1968s movement in connection with the idea of stopping the unsustainable use of fossil fuels issued by the Club of Rome in the 1970s (von Hirschhausen, 2014). The policy-making process itself started in 1990 with the first introduction of a renewable energy feed-in tariff (Theobald, Nill-Theobald, Templin, & Werk, 2013) and had a planning horizon up to 2050. Based on Joas, Pahle, and Flachsland (2014) and von Hirschhausen (2014), the main focus areas of the German transition are:

- Phasing out nuclear power between 2015 and 2022
- Produce a certain share of electricity from renewable sources (in steps of at least - 2020: 38%, 2030:50%, 2040: 67% and 80% or more in 2050).
- Reduction of GHG emissions compared to 1990 (in steps of at least 2020: 40%, 2030: 55%, 2040: 70%, 2050: 80-95% reduction)
- An implication that is not written down is the fact that more decentral energy production owned by cooperatives and individuals is integrated, e.g. through PV, wind power parks, or biomass

Effects of the various instruments that were introduced are already visible: On May 15, 2016, Germany produced e.g. 100% of its electricity demand for that day via renewable sources, mostly produced by wind power plants (Klaiber, 2016). The following Figure 1 provides a detailed overview on the share of renewable energy production as part of Germany’s gross energy consumption, as well as the total share of renewable energy in percent.

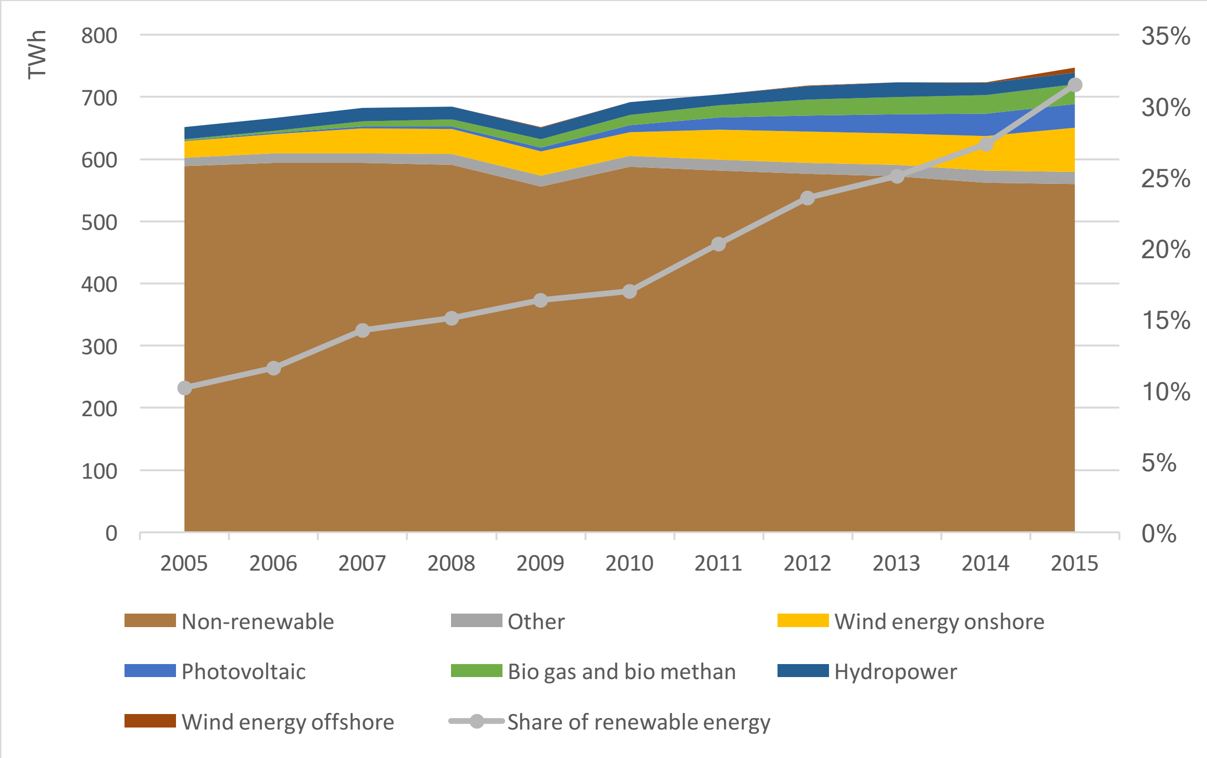

Figure 1: Share of renewable energy in gross electricity consumption in Germany 2005 - 2015, own figure based on (Bundesministerium für Wirtschaft, 2016)

Hydropower has been the major renewable energy source in the German energy mix until 2002. The installed capacity of hydropower in 1990 was 3,982 MW and increased to a maximum of 5,589 MW in 2015. The main reason for this rather slow increase is the topographic situation in Germany that does neither favor conventional hydropower plants, nor pump-storage plants. Also, the potential of new run-of-the-river hydropower developments is exhausted (Anderer, Dumont, Massmann, & Keuneke, 2012).

From 2000 - 2011, also supported by the renewable energy act, onshore wind energy became the largest single source of renewable energy in the German energy mix with around 6 GW installed capacity in 2000 and approx. 28.5 GW installed capacity in 2011. In 2015 onshore wind became the largest single source again, after photovoltaic capacity increased massively in 2012-2014. The first German offshore wind park became operational in 2009, and since then the total installed capacity rose significantly with approximately 93% capacity increase per year on average until 2017 (Bundesministerium für Wirtschaft, 2016). The overall political environment favored future installations of offshore wind energy, but due to a slowdown in the installation of transmission capacity, the expansion targets until 2020 were capped (Hubik, 2016).

The massive introduction of photovoltaic energy production in Germany started in 2004 with tremendous growth rates of up to 86% in the capacity increase. In the years 2009 – 2011 round about 7.5 GW of photovoltaic capacity were installed per year. From 2011, onwards the installation of new capacity dropped dramatically and led to smaller capacity increases of approximately 2GW per year. The major reason for this decline was a change in the German feed-in tariff policy that decreased the guaranteed price for energy produced by photovoltaics by round about 50 per cent within two years. The production cost for solar energy power plants only dropped by around one-fourth at the same time (Windkraft Journal, 2014).

2.3 German Municipal Energy Suppliers' Role in the Energy Transition

The liberalization of the European energy market turned out to be a severe test for German municipal energy suppliers. Especially the rather small municipal energy suppliers had to build up or buy access to knowledge about the liberalization. In the mid-1990s their future was drawn rather bleak. The municipal companies were seen to be too small and to have too little financial reserves to survive the upcoming price competition (Berlo & Wagner, 2012; Kairies-Lamp & Plazek, 2014). This perception led to a sell-out by the municipalities, who were either afraid of upcoming challenges and financial impacts, but also saw the possibility to generate short-term income through the sale (Der Spiegel, 1996). The "big four" utility companies RWE, e.On, Vattenfall and EnBW had enough financial power and were willing to take over their competitors, which led to a strong concentration of market power with the large utility companies (Berlo & Wagner, 2012). Furthermore, it had an adverse impact on the decentralization of energy supplies. The new owners used their stake in the smaller municipal utility companies to shift the business model of the inherited companies from local, small scale production towards a more sales-oriented approach of energy produced in large coal and nuclear facilities of the new owners (Der Spiegel, 1996; Kairies-Lamp & Plazek, 2014).

The energy transition's focus on renewable energy, in connection with a fitting momentum of important political decisions to foster renewable energy on the one side and intensive technical development on the other side, finally offered a chance for the municipal energy suppliers to get back into the game and demonstrate their competitive advantages (Klagge & Brocke, 2013):

- Customer proximity
    - Low transmission and transformation losses due to proximity to the customer.
    - Reduced cost for grid usage, as energy is used close to production, reducing balancing interventions by grid operators and decreases congestion.
- Credibility and local added value
- Know-How of decentral production due to the required integration of decentral energy sources.
- Long-standing relationships with decision-makers (population, politic, local economy), leading to ease of land use and ease of compromises with negatively affected people

But not only the energy transition changed the companies' business models fundamentally. In addition to the increased expansion of decentral and especially renewable energy, triggered by conscious consumers, the digitalization of business processes was another field of action where technology moved faster than many of the smaller municipal energy suppliers could handle (Reiche, 2017).

Taking the requirements of the energy transition into consideration, Euler Hermes Rating GmbH (2014) explicitly outlines the increased need for debt financing for municipal energy suppliers and especially liquidity and liquidity-based figures. The companies need to prove their solvency and liquidity to receive financing support from banks and other stakeholders. A study carried out by Rottmann and Albrecht (2013) identifies the funding requirements of municipal energy companies directly connected to investments in renewable energy and distribution network infrastructure. Also, they identify size-based differences (Rottmann & Albrecht, 2013, p. 11) and limits for debt financing of Energy-Transition-related costs.

3. Benchmarking & DEA

3.1 Benchmarking

Comparing each other has been a constant companion of humanity. Athletes compared themselves during the Olympics, knights during tournaments. However, the methodology that initiated today's understanding of the term benchmarking was first introduced in the business literature by Camp (1989), even though benchmarking itself has been used way before. Camp describes benchmarking projects set up together with the US-American company XEROX, that finally helped the company to survive immense cost pressure in the market. Another outcome of his work was that the term benchmarking and the underlying methodology were widely accepted and used afterward.

In general, benchmarking is the process of collecting data to be able to rationalize behavior and estimate the relationship between inputs and outputs as close as possible. The next step would be to look at a company's current performance and compare it with the ideal performance, which then enables us to gauge the efficiency (Bogetoft & Otto, 2011).

However, as the motivation of benchmarking varies, there is not one benchmarking definition, but rather generic definitions with different focuses (Camp, 1995). A very comprehensive definition of benchmarking that also gives an impression of how a benchmarking process can be established and which process steps need to be considered is:

> *"Benchmarking is the systematic process of measuring one's performance against recognized leaders for the purpose of determining best practices that lead to superior performance when adapted and utilized."*
> *(CII, 1995)*

The aspects mentioned in the definition above are depicted in more detail in

Figure 2 in the so-called formal 10-step benchmarking model first described by Camp (1995). The process of planning, analyzing, integrating and action describes very well the process of this thesis and is therefore also used to structure this thesis.

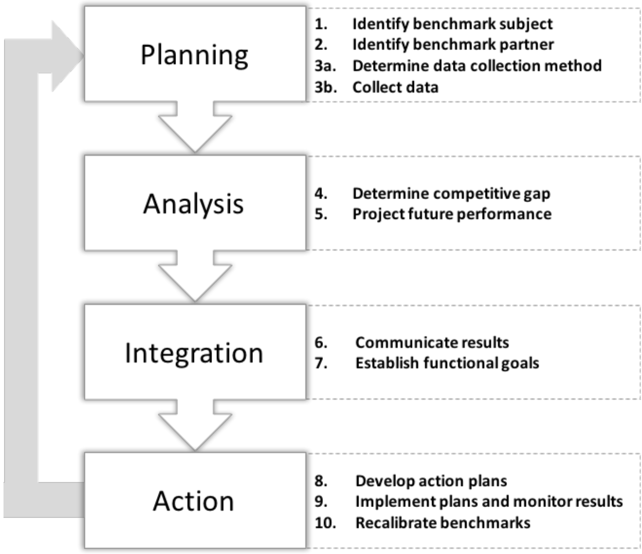

Figure 2: The formal 10-step benchmarking model - based on Camp (1995)

Benchmarking today is not only limited to different companies comparing each other. Intra-company benchmarking between of departments can be carried out as well as benchmarking of NGOs, single products or processes. To ease the reading, companies will be used in the context of this thesis, still comprising all other cases of benchmarking. An example for one use case that is connected to the group of DMUs considered in thesis is the benchmarking of regulated electricity network operators that are benchmarked to estimate their revenue cap/maximal allowed network charges (Elsenbast, Nick, & Boche, 2008).

Besides the process of benchmarking to acquire knowledge from competitors/learning, Bogetoft and Otto (2011) describe two additional objectives to explain why companies could use benchmarking:

- Learning
  In the case of learning, companies are setting up a benchmarking process to identify knowledge improvement opportunities. They either already identified competitive gaps, or will do so during the process. It is important to understand though that the benchmarking itself can only give an indication of action fields but also that "actual operational changes will necessitate in-depth process benchmarking." (Bogetoft & Otto, 2011, p. 3)
- Coordination
  Benchmarking can also be used to coordinate tasks and production plans, or allocate resources with the aim to operate "at optimal cost and performance." (Bogetoft & Otto, 2011, p. 3) The importance of coordination should not be underestimated, as

in some cases it might produce similar effects as successful practice implementation.

- Motivation
  Benchmarking makes it also possible to focus attention on specific performances of employees, managers or companies, by making the performance more visible and identifying changes in performance or by comparison with other elements. Benchmarking in these cases allows e.g. to limit classic incentive problems like moral hazard or adverse selection. (Bogetoft & Otto, 2011; Durand & Vargas, 2003)

The focus of this thesis is clearly on learning from competitors, as one of the main goals is to identify best practice, or rather successful practices of municipal energy companies and challenge one company's strategy or processes to enhance its performance. The distinction of best practice and successful practice is important due to Töpfer (2013), as best practices would need a world- and industry-wide sample for comparison, which can only be established in very few industries, like e.g. the electronic semiconductor industry with very few, international competitors. For this thesis, the term best practice will be used in the same way as successful practice.

3.2 Efficiency

3.2.1 Concept

Efficiency in the case of DEA analysis is based on the production theoretical approach of productivity, which in the easiest case is the ratio of one input factor to one output factor:

$$Productivity = \frac{Output}{Input}$$

While productivity is an absolute figure, an efficiency score relates this figure to a comparative value. Efficiency is therefore defined as an "an economic state that is obtained when a distribution strategy exists where one party's situation cannot be improved without making another party's situation worse" (Investopedia, n.d.-a). This is also known as the Pareto-Optimum. Measuring efficiency like this is based on the maximum principle (with a given input get the maximum output) or minimum principle (get a given output with the least possible input).

Often, efficiency and effectivity are used equally, which is wrong (Kerpen, 2016). While efficiency focuses on the relation of input and output, effectiveness solely focuses on output without taking input into consideration, or as Drucker (2006, p. 147) puts it: "It is fundamentally the confusion between effectiveness and efficiency that stands between doing the right things and doing things right. There is surely nothing quite so useless as doing with great efficiency what should not be done at all."

3.2.2 Efficiency Measurement

Now that the term efficiency is defined, a preliminary clarification of how efficiency can be measured will be carried out. The DEA analysis, which is explained in the following chapter 3.3, is the tool of choice for the calculation of efficiency scores, but certain underlying assumptions and terms connected to efficiency measurement are repeatedly referred to in this thesis, which is why they are explained in this chapter.

The following Figure 3 that we see in a more detailed version again in the discussion of inputs and outputs provides a schematic overview of the transformation of inputs towards outputs. The aim of this transformation, which can also be called production, is to increase the growth of benefits and add additional value (Dyckhoff & Spengler, 2010). This process is carried out by the DMUs.

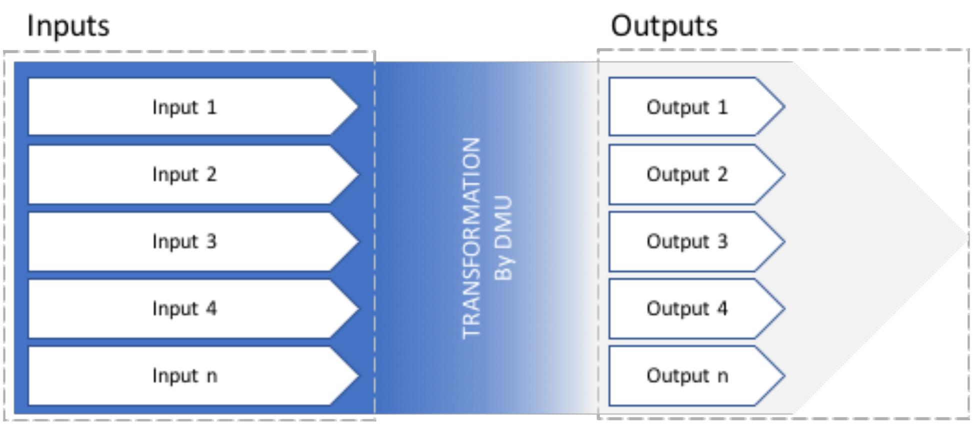

Figure 3: Transformation of inputs, own figure

For a shared understanding of the formulas used to explain the so-called technology area and any other mathematical expressions used in this thesis, the following notation will be used:

DMU_j	Decision Making Unit j, j=1,…,j
h_j	efficiency value for DMU_j
x_{ji}	input i of DMU_j ,
x_j	input vector x of DMU_j $x_j=(x_{j1}, \dots , x_{ji} , \dots , x_{jI})^T$
y_{jr}	output r of DMU_j ,
y_j	output vector y of DMU_j , $y_j = (y_{j1}, \dots , y_{jr} , \dots , y_{jR})^T$
u_{rj}, v_{ij}	coefficient/weight factor for output r and input j of DMU_j

The combination of x_j and y_j creates the production vector (x_j, y_j) = activity (x,y) of DMU_j, which is depicted as an example for the DMUs 1 – 4 in Figure 4. The case is taken out of Rödder and Dellnitz (2011) (as cited in Kerpen, 2016) and will be used to explain further facts over the course of this chapter.

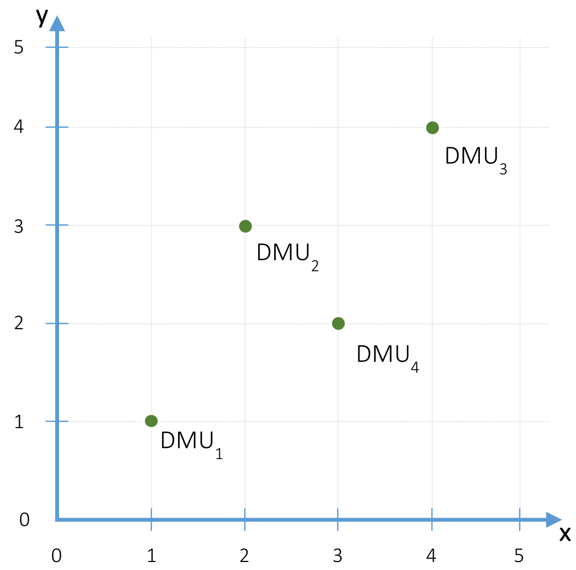

Figure 4: Production of DMUs j = 1, ... , 4 – cf.(Kerpen, 2016, p. 15)

An important term in DEA is the technology T which comprises all possible input and output combinations/production possibilities. In theory, the technology is available to and used by all DMUs considered. The best-practice or efficient production possibilities are located on the so-called production function. This production function can also be called efficient frontier – a term that will be of interest in further explanations, as it forms the basis for the calculation of efficiency scores and to identify the targets of benchmarking. As Bogetoft and Otto (2011, p. 17) put it: “it is often more interesting to learn from the best than to imitate mediocre performances.”

The general assumption of DEA is that the production function is unknown. Otherwise it would be possible to calculate efficient input and output combinations for all companies that produce under this technology (Reucher, Rödder, Lo, & Kopittke, 2008). The activities carried out by the DMUs are therefore important to estimate the technologically possible input- and output combinations of the Technology T based on the empirically collected data. In addition to this, certain assumptions are necessary in order to estimate the technology T. The assumptions are quickly explained in the following paragraphs. As this thesis can only provide a basic insight into the calculation of efficiencies with DEA, please refer to the work of Cooper, Seiford, and Zhu (2011, p. 11 ff.) and Bogetoft and Otto (2011, pp. 23-78) for deeper insights. The general assumptions are:

Integrity Assumption

All activities of DMUs have to be part of the Technology.

$(x_j, y_j) \in T, j = 1, \dots, J$

Possibilities of Inefficiencies (Free Disposability) Assumption

If we assume free disposability, the input can be increased and the output can be decreased without leaving the technology area T. This is also called the "free disposability of input and output" (Bogetoft & Otto, 2011, pp. 60 ff.).

The resulting technology area considering this assumption is depicted in gray in Figure 5. All increases of inputs, e.g. for DMU_1, which produced one output with one input, but could also produce one output with two inputs. The same holds true for the decrease of output: DMU_2 uses two inputs to produce three outputs, but could also only produce any lower number of outputs until zero. The jagged line that evolves from considering various DMUs is widely called free disposable hull. The mathematical description of this assumption would be:

If: $(x, y) \in T$

Then : $(x', y) \in T,\ x' \geq x$

$(x, y') \in T, y' \leq y$

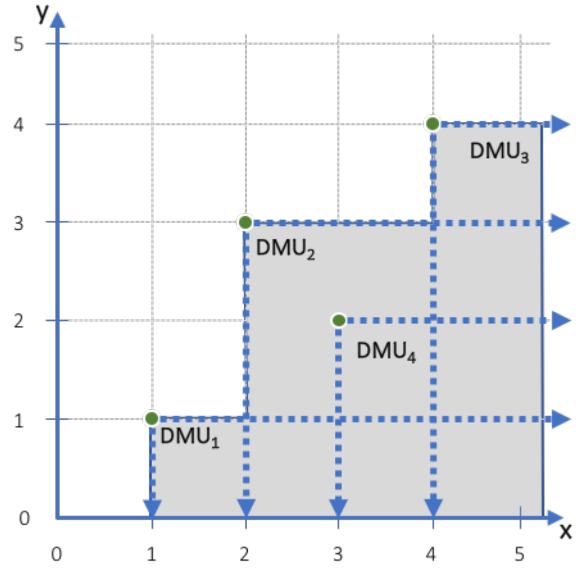

Figure 5: Technology T with free disposability, (Kerpen, 2016, p. 19)

Convexity Assumption

The assumption of convexity implies that all the connecting lines between any observed and all other activities are part of the technology, which can also be mathematically expressed by the formula:

(x', y') and $(x'', y'') \in T$ and $\lambda \in [0,1]$
$\rightarrow \lambda(x', y') + (1 - \lambda)(x'', y'') \in T$

where λ is a factor between 1 and zero that stands for the sum of the weighted average of the two activities which are feasible as well. As Bogetoft and Otto (2011, p. 65) put it: "If we have two feasible production plans, it is often assumed that all weighted averages of the two are also feasible.“

This circumstance is also exemplarily depicted in Figure 6, where the activities (x',y') and (x'', y'') are also part of the technology T, as well as all activities on the line between them. Therefore, the whole gray area in between the DMUs that could be interconnected with lines is considered to be part of the technology.

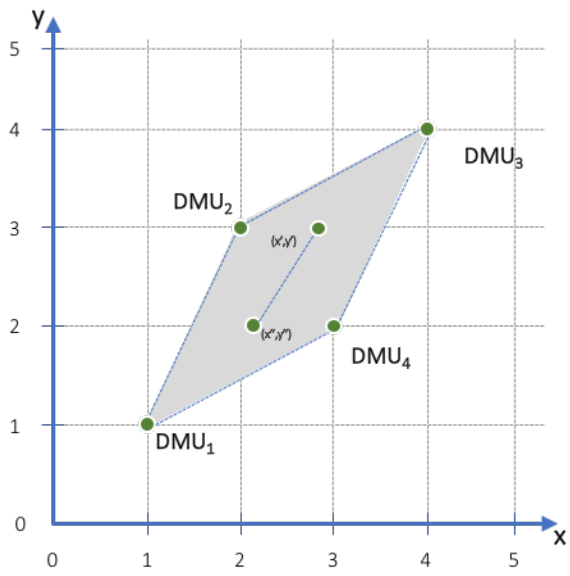

Figure 6: Impact of convexity on technology T, (Kerpen, 2016, p. 20)

When combining the two assumptions of convexity and free disposability, the area of technology T enlarges. This is exemplarily depicted in Figure 7. Kerpen (2016) points out that the areas which are depicted in dark gray are to be seen more as theoretically possible, as there is no evidence for the feasibility in real life.

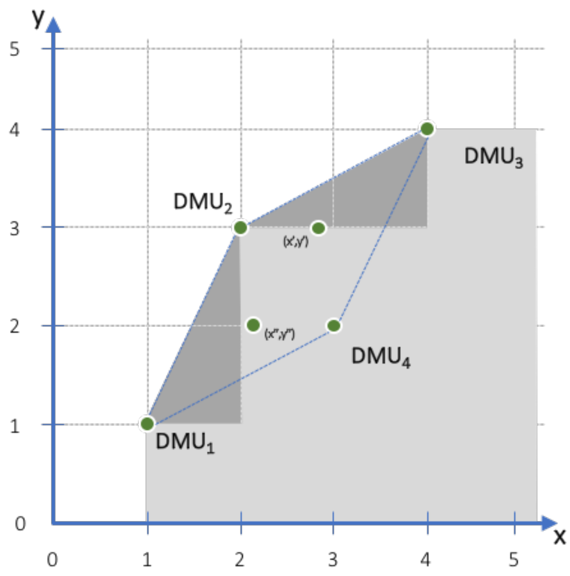

Figure 7: Convexity and free disposability, (Kerpen, 2016, p. 21)

Smallest Set / Convex Hull Assumption

The assumption already indicates that only the smallest area that includes all observations and fulfills the assumptions above is considered as technology T. This fact already has some implications for the following DEA analysis, as a smaller hull automatically leads to larger efficiency scores, as the DMUs move closer to the efficient frontier. This effect can be seen as positive, as the targets set through efficiency scores need to be reachable for all DMUs (Kerpen, 2016).

Returns to Scale Assumption

Another assumption to make concerning efficiency benchmarking is the questions of scaling. This thesis focuses on constant and variable returns to scale, which will be described and depicted in this paragraph. As one of the main decisions for a DEA model is the question of scaling, a more detailed discussion of implications of scaling will be carried out in Chapter 3.3 Background & Development of DEA.

There are several assumptions, e.g. Constant Returns to Scale (CRS), which is the strongest rescaling assumption and Variable Returns to Scale (VRS), which is the weakest. In between, there are decreasing returns to scale and increasing returns to scale (Bogetoft & Otto, 2011). At this point, the question of size comes into play but will be further described at a later stage.

To explain the concepts in more detail, they are depicted in Figure 8. CRS, on the left-hand side, would imply that any activity (x,y) that is on the ray from (0,0) through DMU_2 is possible to be produced. This idea connected with the assumption of free disposability results in a technology T as shown with the gray area (Bogetoft & Otto, 2011). For VRS, depicted on the right-hand side of Figure 8 it becomes clear that the technology T is smaller than for CRS. As an example, DMU3 becomes efficient in a VRS model, even though it would be inefficient in CRS. Kerpen (2016, p. 209 f.) outlines that this is an example of a situation when size-related differences are not corrected so that the DMUs would be compared to the linear CRS efficiency frontier. A VRS model would identify a competitive disadvantage, as the company would be too large to reach the most productive scale size (MPSS). The same holds true for DMU one, which would be too small to reach the maximal productivity.

Industries that are best described with a VRS model imply economies of scale effects like fix cost degression, volume-based discounts in sourcing, or learning effects,

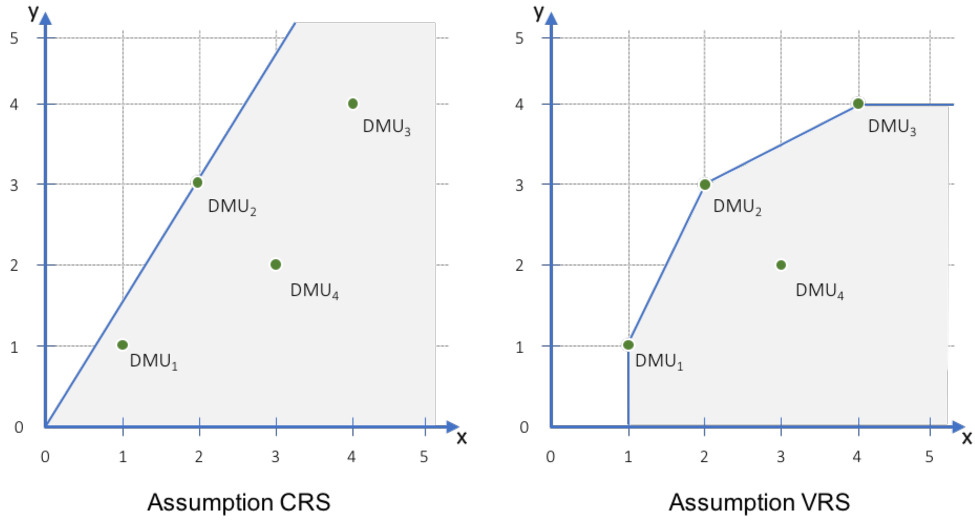

Figure 8: Technology under the assumption of constant and variable returns to scale, (Kerpen, 2016, p. 25)

3.3 Background & Development of DEA

The Data Envelopment Analysis was first introduced by Charnes, Cooper, and Rhodes in 1978. It is a data-oriented performance measurement approach to determine the efficiency of similar, so-called decision-making units (DMU) (Cooper et al., 2011). In economic terms, a DMU would be called a production system, but Charnes, Cooper, and Rhodes (1978) wanted to emphasize the wider application possibilities of DEA aside from purely economic application (Siemens, 2005). In 2008, more than 360 DEA publications (journal, dissertations, or book chapters) were issued – and counting (Emrouznejad, Parker, & Tavares, 2008). Most of these publications develop very specialized, scientific approaches and diverge from developing models with practical adaptability, or as Triantis (2004, pp. 391-392) puts it: "many modelers and performance measurement teams often lose sight of the real world implementation".

The DEA is a non-parametric approach that simultaneously calculates the relative efficiency of DMUs based on multiple inputs and output factors that can be compared without the need to monetize them upfront (Siemens, 2005). The fundamental assumption is that all DMUs share the same technology (production possibilities) which includes technical and organizational knowledge of the DMU (Dyckhoff, 2013). The following Figure 9 illustrates one input – one output production system. While point B and C are within the technology T, point A cannot be considered a possible production output. The production function, therefore, indicates which input is needed to produce a certain output or vice versa determines the maximum output that can be produced with a certain input (Siemens, 2005). A more detailed discussion about the production function and the technology area T has been carried out in the chapter before.

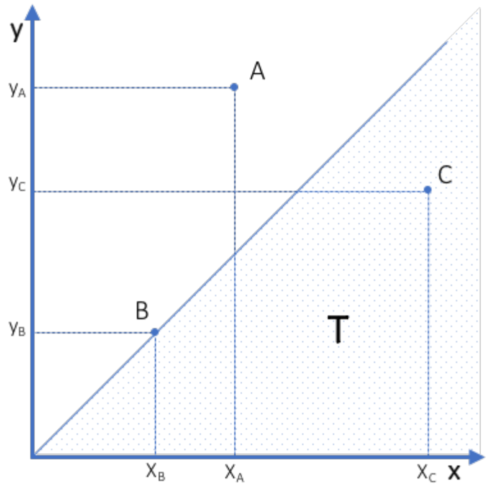

Figure 9: Example of technology T in one input / one output DMU, based on (Dyckhoff, 2013; Siemens, 2005)

Within DEA, the efficient DMUs, or best-practice units, are interconnected via linear functions – the production frontier function (Bauer & Hammerschmidt, 2006). All other DMUs that are not on this production frontier are less productive and enveloped by the production frontier. The area inside the frontier reflects the production possibilities. In the simplified case above, DMU B would be on this efficiency frontier, while C would either have room to improve on the input side (use fewer inputs to produce the same outputs) or output side (produce more outputs with the same input).

Inputs and outputs do not need to be monetarily ratable, nor consistently scalable. Therefore, DEA is widely used in performance analyses e.g. in banks, insurance companies, hospitals, gastronomy, or within non-profit organizations (Cooper et al., 2011). Another example for the universal applicability is the incentive regulation used in regulated markets, like e.g. power and gas markets (Last & Wetzel, 2009), as already mentioned.

The DEA analysis has, compared to single key performance indicators that allows only for unconnected deduction of measures in partial aspects, the big advantage of interconnected and optimally weighted inputs and outputs based on its integrated mathematical approach. Special characteristics of one single industry are considered through the flexibility to adapt to the data used (Bogetoft & Otto, 2011).

3.3.1 CCR – Model

The basic principle of the model developed by Charnes, Cooper, and Rhodes is to calculate efficiency with virtual inputs and outputs which are summed up by adding the single inputs and output factors together with coefficients/weight factors – see also **Fehler! Verweisquelle konnte nicht gefunden werden.**. The coefficients/weight factors were not determined upfront, but are determined by the data itself and are independent of the data's unit (Siemens, 2005).

$$efficiency = \frac{virtual\ output}{virtual\ input} = \frac{u_1 * y_1 + u_2 * y_2 + \ldots + u_n * y_n}{v_1 * x_1 + v_2 * x_2 + \ldots + v_m * x_m}$$

DEA calculates the optimal coefficients/weight factors for each DMU, so that the strengths of each DMU carry more weight than the weaknesses (Backes-Gellner & Zanders, 1989, p. 275), leading to the highest efficiency value that is possible per DMU (Charnes et al., 1978, p. 430) In this input-oriented example for DMU_0 with $r = 1, \ldots, s$ outputs and $i = 1, \ldots, m$ inputs, the aim is to maximize the ratio of all virtual inputs and outputs. The objective function would therefore be:

$$\max_{u_{r0}, v_{i0}} h_0 = \frac{\sum_{r=1}^{s} u_{r0} y_{r0}}{\sum_{i=1}^{m} v_{i0} x_{i0}}$$

By adding the following constraints to the model, the ratio of inputs and outputs per DMU should be maximized but must be equal or less than one and that the coefficient/weight factors must be above 0

$$\max_{u_{r0}, v_{i0}} h_0 = \frac{\sum_{r=1}^{s} u_{r0} y_{r0}}{\sum_{i=1}^{m} v_{i0} x_{i0}}$$

$$s.t.$$

$$h_j = \frac{\sum_{r=1}^{s} u_{r0} y_{rj}}{\sum_{i=1}^{m} v_{i0} x_{ij}} \leq 1 \qquad \forall j = 1, \ldots, J$$

$$u_{r0}, v_{i0} \geq 0$$

where

h_0	efficiency value for DMU_0
y_{r0}	value of input r of DMU_0

x_{i0}	value of output I of DMU_0
u_{r0}, v_{i0}	coefficient/weight factor for output r and input i of DMU_0

The model above would not lead a unique solution (Cooper et al., 2011, p. 8). Therefore, the "Charnes-Cooper" transformation (Charnes & Cooper, 1962) is leading to the model as it is described below, which allows selecting a unique solution. The model is also called the primal, input-oriented CCR model and as it delivers the optimal weight coefficient (multiplier $_r$ and $_i$), it is also known as the so-called multiplier form.

$$\max_{u_{r0},v_{i0}} h_0 = \sum_{r=1}^{s} u_{r0} y_{r0}$$

$$s.t.$$

$$\sum_{r=1}^{s} u_{r0} y_{rj} - \sum_{i=1}^{m} v_{i0} x_{ij} \quad \leq 0 \qquad \forall j = 1, \dots, J$$

$$\sum_{i=1}^{m} v_{i0} x_{i0} = 1$$

$$u_{r0}, v_{i0} \geq 0$$

Based on Allen (2002, p. 65) the linear programming dual input-oriented CCR model for the model above would be:

$$\min_{\lambda_j} \Theta_0$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \quad \geq y_{r0} \qquad \forall\, r = 1, \dots, s$$

$$\theta_0 x_{i0} - \sum_{j=1}^{n} \lambda_j x_{ij} \quad \geq 0 \qquad \forall\, i = 1, \dots, m$$

$$\lambda_j \ \geq 0$$

A company is only strongly efficient, or Pareto/Koopmans efficient, if both input- and output orientation were analyzed and neither input- nor output-slacks exist (Tone & Tsutsui, 2001) for the DMU. In the case of a one-sided observation, Kerpen (2016) notes that only weak efficiency can be assumed or, depending on the orientation input-/output-efficiency (Kleine, 2013).

3.3.2 BCC Model

The CCR model, which was presented in the chapter 3.3.1, is mainly criticized due to its focus on constant returns to scale, which could lead to wrong assumptions, e.g. as presented by Chandra, Cooper, Li, and Rahman (1998) in their study of the Canadian textile industry. Further details on required decisions to be taken for the model selection are provided in chapter

The model developed by Rajiv Dushyant Banker, Charnes, and Cooper (1984) and therefore called BCC – Model, takes variable returns to scale into consideration. Rajiv Dushyant Banker et al. (1984) introduced "a new separate variable […] which makes it possible to determine whether operations were conducted in regions of increasing, constant or decreasing returns to scale".

Looking at Figure 10, displaying a single input, single output model, we can see the CCR model's constant returns to scale marked in with the dashed blue line, and for the BCC model the returns to scale in red that increase first, move along a constant path and finally fall along a number of inputs for the particular DMU (Bogetoft & Otto, 2011). The part with constant returns to scale is also called most productive scale size (MPSS) (Rajiv Dushyant Banker, 1980). The hatched gray area depicts the difference in technology area size that is spanned by the different efficiency frontiers of CCR and BCC – it becomes evident that DMUs tend to be more efficient in BCC models, as they are closer to the production function/efficiency frontier. DMUs that are efficient in CCR will also always be efficient in BCC models (Charnes, Cooper, Lewin, & Seiford, 1997, p. 143).

For a mathematical expression of the model, please see Rajiv D Banker, Cooper, Seiford, Thrall, and Zhu (2004, pp. 346-349)

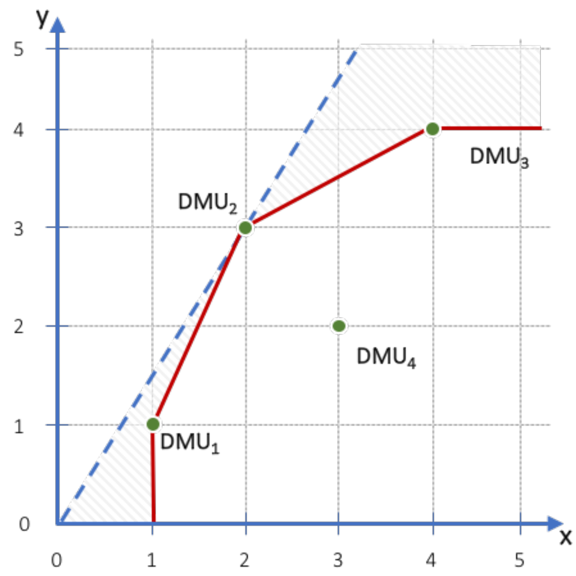

Figure 10: BCC-Model with variable returns to scale, (Bogetoft & Otto, 2011)

3.3.3 Other Models

Bogetoft and Otto (2011) provide an excellent overview of DEA technology sets under different assumptions. Besides the CCR and BCC models, which were discussed already in the chapters before, they also look at models with increasing and decreasing return to scale (DRS, IRS) and the free disposability and free replicability hull (FDH, FRH) assumptions.

For this thesis, those models will not be described in more detail, but further information can be found in (Bogetoft & Otto, 2011, pp. 85-90; Cooper et al., 2011, pp. 7 ff.)

3.4 DEA – Conditions of Application

To run a DEA, several studies mention preconditions for application that need to hold true in addition to the assumptions already referred to in Chapter 3.2 about efficiency measurement.

- Comparability
  Dyckhoff and Spengler (2010) define that DMUs need to be describable with the same inputs and outputs, which also induces that the inputs and outputs themselves need to be determined in the same way and for the same timeframe. This is particularly important when it comes to financial figures, as further explained in chapter 4.2. Another aspect that Dyckhoff and Spengler (2010, p. 141) explain to make DMUs comparable is that they have to "use the same technology to realize their activities".

- Desired Outputs
  Kerpen (2016) outlines that reduced inputs and increased outputs lead to higher efficiency scores in DEA. If undesired outputs exist, "a reduction of this outputs would lead to an increase of efficiency" (Kerpen, 2016, p. 47), which would counteract the understanding of input/output relationship in DEA and therefore has to be considered when setting up the input/output relations.
- Impact of Input and Output
  For DEA, it is important to understand how inputs and outputs are impacting each other to not choose the wrong input-output combinations. In some cases, also for this thesis, it was of great significance to think the consequences through before choosing the inputs/output. A more detailed discussion is provided in 4.2 Selection of input and output factors.

In addition to the factors above, Kerpen (2016) also mentions two more conditions for DEA application: the fact that output can only be generated with input what he calls the "impossibility of paradise" (Kerpen, 2016, p. 47), and the "boundedness of technology" that assumes that a limited number of inputs can only produce a limited number of outputs (Kerpen, 2016, p. 47).

3.5 Dynamisation of DEA

3.5.1 Window Analysis

To analyze the change in DMU's efficiency over several time periods, Charnes, Clark, Cooper, and Golany (1984) introduced the window analysis. The basic idea of the window analysis is to use moving average patterns by treating each year's DMU data as a unique company. The size of the window that is chosen has a strong impact on the results of the DEA analysis (Maidamisa, Ahmad, & Ismail, 2012) and e.g. Webb (2003) has proposed to keep the window width as small as possible to reduce unfairness in comparison of DMUs over a specific time, e.g. due to technical change that could influence over different time periods (Zhang, Cheng, Yuan, & Gao, 2011). Charnes, Cooper, Lewin, and Seiford (2013) suggested a window size of three to four time periods as favorable to keep a balance of informativeness and stability of the efficiency measure.

In this study data of eight German municipal utility companies from 2005 – 2014 is analyzed by using a window size of $w = 3$ to obtain credible efficiency results. The analysis starts with the years 2005 – 2007 as the first window and each year ends up with 3 efficiency measures, except 2005 and 2014, which will have only one, and 2006 and 2013, with two values. The average results of efficiency per year are calculated for each company. The data used to analyze the companies is further displayed in the Appendix A Data Inputs & Output. The results of the DEA will be discussed in Chapter 5.

3.5.2 Malmquist Index

The Malmquist index is another method to analyze efficiency changes over time. The method looks at changes, either a positive or negative, that can arise between two different time periods. It distinguishes between changes arising from general technological improvement from which the company can or cannot participate, and individual, company-specific changes. General shifts in the technology, e.g. cheaper production methods, could make it possible for a company to move closer to the technology frontier, while the internal improvement of the company might not be as strong as desired. Bogetoft and Otto (2011, p. 42) formulate the idea of the Malmquist index with the equation:

$$M^S = \frac{E(t,s)}{E(s,s)}$$

Where M^s stands for the Malmquist Index of one company and E(t,s) shows “the performance […] in period s against the technology in period t”. If the performance in period s is better compared to period t, $E(t,s) \geq E(s,s)$ and the index would therefore be larger than 1. If the company’s performance decreased, the index is smaller than 1.

For this thesis, a broader overview of efficiency over all periods is needed and therefore the window analysis will be used. Further information on the Malmquist Index can be found in Bogetoft and Otto (2011, pp. 41 ff.).

3.6 Influence on data selection and dealing with data irregularities

Sarkis (2007) describes how heavily dependent the outcome of a DEA analysis is on the data set. Besides the logic behind choosing certain inputs and outputs, it is important to select a good number of inputs and outputs. To improve the discriminatory power of inputs and outputs, it is crucial to add only relevant inputs and outputs, as higher varieties in input and output will water down the results and make it hard to "distinguish the high performers from the rest" (Bogetoft & Otto, 2011).

3.6.1 Number of DMUs based on input and output variables

Another important aspect in every DEA analysis is to determine the number DMUs based on input/output factors (Sarkis, 2007). Bogetoft and Otto (2011) add for consideration that the more DMUs are analyzed, the more will have an efficiency score of 1 due to increased homogeneity of the DMUs. On the other hand, there will also be higher probabilities of covering more high performing DMUs, the larger the population is chosen (Sarkis, 2007). In general, it is important to know about the constraining factor of the number of inputs and outputs to choose the right number of DMUs or vice versa. Fulfilling the requirements given in the table below does neither automatically guarantee valid efficiency scores, nor does not following automatically lead to false solutions (Kerpen, 2016, p. 176).

The following table provides a short overview of different approaches to determine the number of needed DMUs and inputs and outputs. As this thesis looks at data from different points in time, treated as separate DMUs, the term DMU will be synonymously used with the term action of each DMU:

Author	**Calculation of DMUs**
Boussofiane, Dyson, and Thanassoulis (1991)	$DMUs = inputs * outputs$
Golany and Roll (1989)	$DMUs = 2 * (inputs + outputs)$
Bowlin (1998); Sinuany-Stern and Friedman (1998)	$DMUs = 3 * (inputs + outputs)$
Dyson et al. (2001)	$DMUs = 2 * (inputs * outputs)$

Table 1: Minimum number of DMUs based on number of input and output, based on (Sarkis, 2007)

For this thesis, the amount of company data that was publicly available for the whole timespan from 2005 – 2014 was limited. A comparably low number of DMUs in relation to the number of inputs and outputs might lead to inefficient companies being declared efficient, which would decrease the information value. To look at the effects of the German energy transition choosing a different time frame would not have been beneficial. Therefore, another option to combine and increase the number of DMUs, while simultaneously analyzing the developments over a certain period was chosen, which was already discussed in chapter 3.5 Dynamisation of DEA. Of course, this was not the predominating influence factor to use window analysis, but the interest in the development of efficiency over time was.

The discriminatory power of DEA does not only depend on the relation of inputs, outputs, and DMUs but notably on the data (Gutierrez, 2005). Therefore, the following Chapter 3.6.2 Data Quality & Correlation will give a brief introduction of the importance of data quality.

3.6.2 Data Quality & Correlation

DEA reacts particularly sensitive to data errors. Therefore, accuracy in data collection is essential, as incorrect data could produce false best-practice DMUs that can falsify the results of the whole analysis (T. J. Coelli, Rao, O'Donnell, & Battese, 2005; Kerpen, 2016; Pham-Phuong, 2004). One advantage of the window analysis that also helped in the preparation of this thesis is the fact that efficiency scores are calculated for each year. Any obvious aberration from the previous year's data contributes to detecting data errors – unfortunately only ex-post.

Another aspect that should be taken into consideration is to analyze the data towards significant dependencies. Scheel (2000) outlines that no positive or negative correlation should exist between inputs and outputs, as this would lead to falsified efficiency scores. The stronger correlation, the stronger the score falsification.

4. The DEA Analysis of German Municipal Energy Suppliers – Model Selection

"The main goal of a DEA is to identify inefficiencies and to enable the search for possibilities to turn off those inefficiencies." (Kerpen, 2016) To select the adequate model for the DEA analysis of German municipal energy suppliers, the author followed the process model for "Selection of Model of Data Envelopment Analysis" developed by Siemens (2005) enriched by the critique of the process by Kerpen (2016, pp. 121 - 122). Kerpen stated that the selection model by Siemens rather helps to identify which models qualify formally, but not which business implications the decisions implies. In general, the model is split into three phases. Phase 1 focuses on formal requirements for DEA. The second phase checks on model-specific requirements to select a model and phase 3 checks for further constraints that are independent of the chosen model.

4.1 Selection of DMUs

A selection of DMUs to carry out a DEA is to some degree a subjective task. On the one hand, DEA requires comparability of DMUs to the extent that they should "use the same resources to pursue the same goals" with differing quantities of inputs and outputs (Scheel, 2000). Kerpen (2016) seconds the opinion that the basic comparability of DMUs is crucial, but also outlines that there are no black or white decisions, but "gradual forms of fulfillment or non-fulfillment" (Kerpen, 2016, p. 156). At the end of the day, it is the idea of the DEA to reveal differences between the DMUs based on their efficiency scores and learn from reference DMUs - which requires differences to a certain extent.

Also, Kerpen (2016) rejects the proposal by Charnes, Cooper, and Rhodes (1981) to make the selection process more tangible by requiring a set of DMUs to come from the same industry. This narrow definition stipulates an "unnecessary and, ultimately non-targeted constraint of the DMU" (Kerpen, 2016, p. 157). An example that supports his observation in the case of energy suppliers would be the increasing need to benchmark with e.g. software companies in the metering and smart home appliance field. Those companies are massively entering the market of regional energy suppliers which must react to keep pace with the new entrants, which are not necessarily from the energy or utility industry.

Therefore, eight German municipal energy companies (subsequently called DMUs) were selected that are geographically distributed throughout Germany. For each of the DMUs, the four inputs and the output were collected and calculated from their publicly available annual financial statements. Therefore, only companies could be selected that offered publicly available information over the whole period from 2005 - 2014.

Also, the companies fulfill all the same basic criteria:

- They produce electricity themselves from varying sources,
- They buy and sell electricity via the German energy exchange, EEX in Leipzig,
- They have a core focus on their regional markets, but also offer nation-wide and provide electricity to special customers, e.g. industry companies,
- They operate the local distribution grid, due to unbundling in a separate company that still belongs to them.

The map in Figure 11 provides an overview of geographical allocation of the eight DMUs. Furthermore, the map is supplemented by the overview of renewable energy production capacity based on a study by Lenk et al. (2012). The big differences between sources of renewable energy generation in Germany are evident. While wind power is prevalent in Western Germany and Northern Germany, hydropower and photovoltaic are predominant in the South, particularly due to geographical preconditions. Even though similar or equal preconditions would enhance the comparability of DMUs, there are only very few examples where this could be achieved (Dyson et al., 2001).

Figure 11: Geographical allocation of DMUs supplemented by installed capacity of renewable energy sources, own graphic based on Lenk et al. (2012)

4.2 Selection of input and output factors

The selection of input and output variables is crucial for DEA analysis. Dyson et al. (2001) provide four criteria that should be considered when selecting the input/output set:

- "it covers the full range of resources used,
- captures all activity levels and performance measures,
- the set of factors are common to all units,
- environmental variation has been assessed and captures if necessary."

A review of the literature revealed that several methods exist to select an appropriate combination of inputs and outputs, as e.g. shown in Luo, Bi, and Liang (2012). The approach chosen for this thesis was heavily dependent on three elements that help narrowing down the different factors:

- **Advice from employees and managers**
  Following the approach of Lall and Teyarachakul (2006), the author conducted an interview with a manager of a municipal energy company to select appropriate input and output factors. A repeated process of alignment with the DEA's stakeholders, as suggested by Hoffmann (2006), could not be established, but the interview already provided manifold insights that helped to structure the analysis. As the interviewee was not part of any examined DMU, there was no need to question the motivation and reasoning behind the answers. As Kerpen (2016, p. 182) outlines: "In principle, it can be assumed that not all participating DMUs are interested in the relentless truth but rather want to 'cut a fine figure' in the investigation results."
- **Focus on investment and cash management**
  As already mentioned, the German energy transition requires strong financial commitment from regional energy suppliers. The ability to cope with that financial burden and develop the business via investments, while still being operationally viable is reflected in using inputs that focus on cash management and investment capability. Reucher et al. (2008) explicitly mention that inputs and or outputs must not be understood as traditional production factors, but as expenditure and performance indicators.
- **Availability of data**
  The amount of publicly available data for the period considered was limited. Only seven out of the eight companies offered online archives with historical financial information. For one company, it was necessary to order printed versions of their annual reports from the company's archive.

As one outcome of the interview and the pre-defined focus on investment and cash management on the one hand and the publicly available data on the contrary, the author first tried to set up a model that uses operational profit (or EBIT) as output factor. Also, the interviewee tended to follow a cost/benefit ratio approach, meaning that they listed several different main cost drivers as inputs and profit as output. This idea is supported by the current perception that municipal companies often must pay out a fixed amount of profit via dividends to their shareholders (municipalities), who are strongly dependent on the cash payout.

Peters (2009) uses the example "profit as output" to explain that interdependencies between inputs and outputs must be avoided. When taking a closer look, it becomes evident that costs and profit are strongly correlated, as $Profit = Revenue - Cost$. This would counteract the free disposability assumption, that was already explained in Chapter 3.2 Efficiency: A reduction of inputs would lead to an increased output, and an increased input would tend to decrease the output. Kerpen (2016) already predicted that challenges arising from the input and output determination could induce major changes in the whole study.

Another aspect that could have been considered besides the companies' financial measurement, which cannot cover all aspects of the companies' value creation, are qualitative factors, like e.g. the amount of renewable energy produced, the level of revenue produced with digital service offerings, like e.g. digital metering, CO_2 generation. As e.g. Grönroos and Ojasalo (2004) describe for the service industry, which utility companies are to a small extent as well, and will become in the following years to an even larger extent, "a new productivity concept geared to the specific characteristics of the service process is needed." This became evident also in the interviews with a manager of an energy company, who identifies a significant shift from pure energy providers to more technology-oriented service providers.

Finally, the main cost influencing factors chosen as inputs are capital and labor, as also defined by Tone and Tsutsui (2009). When looking at the capital-intensive business model of municipal utility companies, this study decided to use the number of employees as the main input when it comes to labor. Also, the investments, e.g. in fixed assets or technology, as well as the availability of capital (operating cash flow), and the short-term financing approach (working capital) are chosen. Revenue is chosen as output factor. Figure 12 provides re-uses the already introduced graphic of input and output transformation and displays the inputs and output that will be further discussed in the following paragraphs.

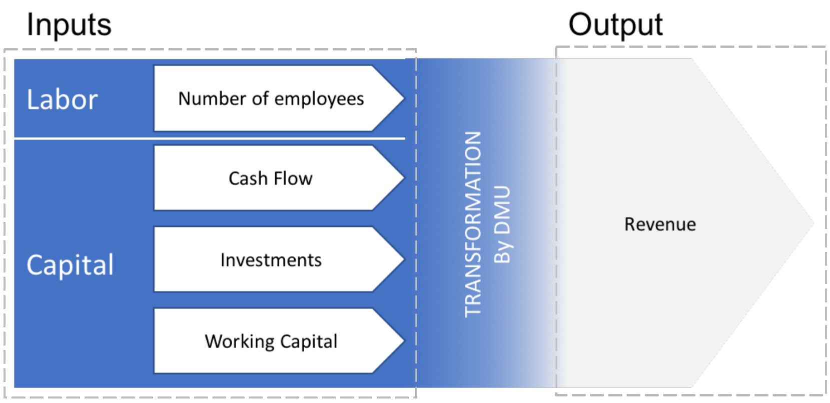

Figure 12: Input and output factors, own figure

Input Factors:

- Number of employees

  The number of employees is a widely-accepted input factor in DEA analysis to cover the aspects of labor input. It comprises all employees that are directly or indirectly concerned with the DMU's production processes and includes all employees in production, supply chain, distribution, and services, as well as everyone in sales, general and administration (SG&A).

  The number of employees also inherits a broad range of included costs e.g. training or recruitment.

  On a side note, the author would like to mention the study of Iribarren and Vázquez-Rowe (2013) which adds the interesting aspect of socio-economic impacts to the use of labor as an input factor. To get an idea, please see Annex C - Socio-Economic Impact of Labor as Input Factor.

- Cash Flow (inverted)

  The cash flow is an important key performance indicator in modern business management to provide transparency on the cash flows of a company. It aims to depict the changes in liquidity over time and the particular root causes. "Cash Flow is a more reliable measure of any organization's financial viability than net income because it is based on cash, not accrual, basis of accounting" (Ozcan & McCue, 1996). As an example for cash flow figures being used in DEA, Luo et al. (2012) even develop their model around the influence of inputs and outputs on the cash performance of a company. For this thesis, the operative cash flow calculation method based on DRS 21 was used, except for enercity who provided their cash flow based on IAS 7 – the differences in calculation up until the operative cash flow level was neglectable. As the Cash Flow should be maximized, the reciprocal of the number has to be used to achieve a maximization (Dyson et al., 2001).

- Net Working Capital

  The net working capital is one KPI to determine the capital efficiency and provides an idea of the underlying operational efficiency of companies in cash collection (Investopedia, n.d.-b, p. 251). The formula to calculate the Working Capital is:

  $Working\ Capital = Current\ Assets - Liabilities\ (short\ term).$

  In addition to the importance of cash flow, Hermann, Kairies-Lamp, and Plazek (2014) outlined the importance of working capital for municipal energy companies when it comes to investment possibilities and liquidity.

  The difference between current assets and short-term liabilities should be positive, which would intend that the currents assets are partly financed by capital with long-term availability. If the working capital is negative, parts of the fixed assets are financed with short-term capital, which is a violation of the golden balance rule (Gabler Wirtschaftslexikon, n.d.). The net working capital should be larger than zero, but should also not be too high. Therefore, minimizing the working capital seems to be a suitable approach.

- Investments (inverted)

  As also outlined in 1.1 Context, investments are considered a major factor for municipal energy companies to cope with the requirements of the German energy transition. Especially investments in renewable energy and heating solutions, as well as infrastructures like transmission and distribution grids, are essential (Blazejczak et al., 2013). Other aspects that require constant investments during the period under observation are the increasing needs for investments in digital infrastructure including data security (Schulte, 2016).

  A number of investments is, therefore, an essential input factor to determine the strength of a municipal energy company during times of constant change and adaptation to changing business models.

  The use of investments as input factor requires additional reasoning regarding the model's orientation. If investments are used, as decided for this thesis, as input factor, more investments should also lead to more revenue. As the input-oriented model tries to minimize the input and takes output as a given, the reciprocal of the investments need to be used for calculation to clarify the context of revenue and investments correctly. Another option would have been to see the possibility to increase investments as a successful result of the company's work and therefore use them as an output – then of course without inverting (Dyson et al., 2001, p. 251).

Output Factor

- Revenue
  As already discussed before, revenue will be used as the only output factor. Revenue in the case of municipal energy suppliers comprises all sales generated revenues, subsidies, as well as revenues generated from further investments. Using revenue is also a figure that is easily comparable and a good indicator of the company size. As energy markets are rather stable in size or even decreasing in Germany, investments are needed to increase the market share and therefore revenue stream.

4.3 Orientation

The overall concept of input, output, or combined orientation was already discussed in Chapter 3.3 Background & Development of DEA. A DMU can either increase its efficiency level through a reduction of inputs with constant outputs (input-oriented model), an increase of outputs with constant inputs (output-oriented model), or a combination of both. The DMU needs to decide if the development of the company should be carried out based on the minimal or maximal principle.

Another important aspect to be considered was already mentioned in the chapter before, the input "investments" could also, as well as other inputs, be used as an output – and vice versa. This interchangeability could lead to a situation where e.g. an influenceable input factor that is used as an output would be taken as a given and would therefore not be part of the optimization (Kerpen, 2016).

Consequently, the decision whether a model is used in input- and output orientation is analyzed from two standpoints: First the possibility of the DMU to influence the input- or output factor and second, the overall industry and market situation.

A literature review carried out by Kerpen (2016) reveals that the possibility to influence the input – respectively output factors is the main rationale for orientation decisions in DEA literature. For this thesis, one focus for the selection of the input factors was the possibility for the companies to influence the inputs. All four inputs, employees, investments, as well as cash flow and working capital, can be influenced as described below:

- Number of Employees
  The number of employees is influenceable by the decision makers of a DMU and implies a variety of follow-up costs and requirements (e.g. HR development, recruiting costs, etc.)
- Investments
  Investments decisions form an important part of strategic decision-making within a company. On a large scale this could involve M&A decisions carried out by the top management, but also decisions on a much smaller or operational scale, e.g. R&D decisions, etc.
- Cash Flow
  Based on Bitz and Terstege (2003), the possibilities to influence the cash flow are manifold and mostly depend on financial management. Areas involved could be:
  - Payments for: wages, resources, taxes, rents or dividends, etc.
  - In-payments for prepayments,
  - Re-organization of payment terms, dunning
  - Etc.
- Working Capital
  The working capital can be influenced via optimized inventory and product offerings, as well as optimized accounts receivable and accounts payable management (Preve & Sarria-Allende, 2010).

The second aspect to the argument for a certain orientation is the general industry and market situation. Badunenko (2009) add for consideration that an increase of outputs might e.g. not be feasible in saturated markets. T. J. Coelli et al. (2005) argument explicitly for energy suppliers that they only have a specific demand to fulfill and very limited possibilities to increase the revenue stream, except e.g. via variation in pricing. Besides the fact that input-oriented models are more as twice as much represented in the literature review sample of Kerpen (2016), his assessment of DEA literature in the energy sector revealed that 80% of the studies are actually input-oriented and the remaining 20% focus on combined input- and output orientation to reflect “the quality of the services provided” (Kerpen, 2016, p. 204).

From a mathematical point of view, the efficiency scores do not vary for the CCR model but do vary from the BCC model, as e.g. shown in T. J. Coelli et al. (2005). Still, they argument that ”an incorrect choice will not have any serious consequences in this instance since the results appear to be quite similar” (T. Coelli & Perelman, 1999, p. 335).

4.4 Returns-to-Scale

Data Envelopment Analysis today is a collective term for a variety of models. The major models used in today’s application of DEA are constant-returns-to-scale models and variable-returns-to-scale-models (Kerpen, 2016). Since Charnes et al. (1978) introduced the CCR model, many different models with different focuses or enhancements were developed (Bogetoft & Otto, 2011; Siemens, 2005).

An important factor where those models often differ, but that is essential to decide upon is the returns-to-scale determination. As already explained in Chapter 3.3 Background & Development of DEA Models different approaches exist to depict the model’s underlying assumptions. However, the definition of which model should be used should be done consciously, as this also has strong influences on the interpretability of the model. The following decision parameters support to understand the implications of the selection of returns-to-scale and will lead to a selection.

Economies of Scale

Based on a study by Henzelmann, Hoyer, Schiereck, and Kammlott (2014), larger regional energy suppliers tend to be more efficient than smaller energy companies. One reason for this could be that economies of scale play a major role in the energy industry. This fact would favor a variable-returns-to-scale model to depict the results observed in the study. As discussed in Chapter 3.3.2 BCC Model, this would allow acknowledging the fact that smaller energy suppliers cannot reach the same efficiency scores as larger suppliers, as they are simply not big enough to leverage on their size.

The questions that need to be answered in this regard are, therefore: should size effects, like e.g. economies of scale, be represented in the model or not and is the company size a given, or can it change over time. Kerpen (2016) therefore introduces the distinction of Gutenberg (2013, p. 421f.), who takes the company size as a given for a “short period,” but variable over a “long period.” The BCC model, or variable-returns-to-scale, can balance negatively influenced efficiency scores induced by scale effects. In case that a model is oriented towards a short-term observation, this would prevent companies with lower efficiency scores from adapting towards wide-ranging changes of their business model, e.g. through inorganic growth. By applying a model with variable-returns-to-scale, it is therefore important to understand that the strategic dimension of leveraging on growth is lost. Kerpen (2016) proposes to additionally run a CCR model “in order to allow the resulting information to be deliberately incorporated into the process of strategic consideration”.

Industry

It is also important to take a closer look at the industry and the underlying market conditions. Constant-returns-to-scale are observable in industries where upscaling the size of the company does not lead to synergies. Examples can rather be found in the service industry than in e.g. energy companies.

Following the reasoning of Schefczyk (1994), a constant-returns-to-scale model will be applied for this thesis, as the businesses that are observed have the possibility to resize their business, e.g. through organic growth, cooperation, and M&A transactions. An observation of the current market conditions in the German energy supplier industry also revealed that M&A activities, especially for smaller energy suppliers are constantly happening, which can be seen as an indicator that excluding the information of resizing, would undermine the strategic development opportunities for small-scale regional energy suppliers.

5. Efficiency Scores and Discussion

The following Table 2 displays the efficiency scores for all DMUs from 2005 to 2014 calculated with the Benchmarking package for R developed by Peter Bogetoft and Lars Otto in 2015. Each line represents one DEA analysis carried out for all eight companies with data for three years treating the yearly data as if it was independent. The window size is, as already mentioned before, three years. The average efficiency scores per company per year are calculated as the mean of the three different analyses carried out. For example, the DSW score of 2008 is 0.2561. This is the average of the three DEA analyses carried out with DSW's data of 2008:

- 2006-2008: efficiency score for 2008 = 0.2505,
- 2007-2009: efficiency score for 2008 = 0.2577,
- 2008-2010: efficiency score for 2008 = 0.2602.

In addition to these scores, Table 2 also shows the mean of all scores over all the years, as well as the corresponding standard deviation. For the detailed analysis that will be carried out in the next chapter, a company with a higher standard deviation will be chosen to examine the reasons leading to the variances.

	Efficiency Score										Summary Measures	
DMU	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Mean	S.D.
Enercity	*0,2075*	*0,1993*	*0,1575*									
		0,2090	*0,1656*	*0,1420*								
			0,1768	*0,1505*	*0,1847*							
				0,1513	*0,1864*	*0,1671*						
					0,1881	*0,1697*	*0,1373*					
						0,1893	*0,1588*	*0,1708*				
							0,1606	*0,1736*	*0,1877*			
								0,1753	*0,1895*	*0,1735*		
	0,2075	**0,2042**	**0,1666**	**0,1479**	**0,1864**	**0,1754**	**0,1522**	**0,1732**	**0,1886**	**0,1735**	**0,1776**	**0,0187**
DSW	*0,4594*	*0,2760*	*0,2091*									
		0,3072	*0,2286*	*0,2505*								
			0,2386	*0,2577*	*0,3143*							
				0,2602	*0,3182*	*0,2761*						
					0,3189	*0,2776*	*0,2556*					
						0,2884	*0,2666*	*0,1852*				
							0,2810	*0,1903*	*0,2483*			
								0,1933	*0,2576*	*0,2370*		
	0,4594	**0,2916**	**0,2255**	**0,2561**	**0,3171**	**0,2807**	**0,2677**	**0,1896**	**0,2529**	**0,2370**	**0,2778**	**0,0694**
Mainova	*0,3126*	*0,2071*	*0,2966*									
		0,2072	*0,3240*	*0,3174*								
			0,3383	*0,3276*	*0,3144*							
				0,3307	*0,3170*	*0,3476*						
					0,3205	*0,3504*	*0,3222*					
						0,3717	*0,3455*	*0,2621*				
							0,3601	*0,3276*	*0,2730*			
								0,3361	*0,2794*	*0,2808*		
	0,3126	**0,2071**	**0,3196**	**0,3253**	**0,3173**	**0,3566**	**0,3426**	**0,3086**	**0,2762**	**0,2808**	**0,3047**	**0,0399**
Stadtwerke Kiel	*0,6490*	*1,0000*	*0,8998*									
		1,0000	*0,9229*	*0,9173*								
			1,0000	*1,0000*	*0,9959*							
				1,0000	*1,0000*	*0,8350*						
					1,0000	*0,8448*	*0,7652*					
						1,0000	*0,9067*	*1,0000*				
							0,9163	*1,0000*	*0,2677*			
								1,0000	*0,2687*	*0,2843*		
	0,6490	**1,0000**	**0,9409**	**0,9724**	**0,9986**	**0,8933**	**0,8627**	**1,0000**	**0,2682**	**0,2843**	**0,7869**	**0,2741**
Stadtwerke Greifswald	*1,0000*	*0,8769*	*1,0000*									
		0,9893	*1,0000*	*0,9488*								
			1,0000	*0,9488*	*0,9913*							
				1,0000	*1,0000*	*1,0000*						
					1,0000	*1,0000*	*1,0000*					
						1,0000	*1,0000*	*1,0000*				
							1,0000	*1,0000*	*0,7499*			
								1,0000	*0,8356*	*0,8628*		
	1,0000	**0,9331**	**1,0000**	**0,9658**	**0,9971**	**1,0000**	**1,0000**	**1,0000**	**0,7927**	**0,8628**	**0,9552**	**0,0688**
Stadtwerke Gütersloh	*0,5537*	*0,5298*	*0,5392*									
		0,5932	*0,6105*	*0,5502*								
			0,6245	*0,5607*	*0,5769*							
				0,5702	*0,6446*	*0,6546*						
					0,6446	*0,6585*	*0,6953*					
						0,7514	*0,8170*	*0,7281*				
							0,8170	*0,7282*	*0,8306*			
								0,7765	*0,8958*	*0,7480*		
	0,5537	**0,5615**	**0,5914**	**0,5604**	**0,6221**	**0,6882**	**0,7765**	**0,7443**	**0,8632**	**0,7480**	**0,6709**	**0,1031**
N-Ergie	*0,2509*	*0,2312*	*0,2309*									
		0,2466	*0,2512*	*0,2807*								
			0,2629	*0,2892*	*0,1691*							
				0,2920	*0,1700*	*0,1769*						
					0,1729	*0,1797*	*0,1428*					
						0,2002	*0,1668*	*0,1797*				
							0,1681	*0,1841*	*0,1605*			
								0,1867	*0,1623*	*0,1391*		
	0,2509	**0,2389**	**0,2483**	**0,2873**	**0,1706**	**0,1856**	**0,1592**	**0,1835**	**0,1614**	**0,1391**	**0,2025**	**0,0471**
Stadtwerke Magdeburg	*0,3541*	*0,3267*	*0,3549*									
		0,3446	*0,3929*	*0,3118*								
			0,4071	*0,3245*	*0,3788*							
				0,3271	*0,3829*	*0,3090*						
					0,3850	*0,3120*	*0,3378*					
						0,3348	*0,3572*	*0,3185*				
							0,3744	*0,3309*	*0,3224*			
								0,3382	*0,3304*	*0,3335*		
	0,3541	**0,3357**	**0,3850**	**0,3211**	**0,3822**	**0,3186**	**0,3565**	**0,3292**	**0,3264**	**0,3335**	**0,3442**	**0,0230**

Table 2: Results of Data Envelopment Analysis (CRS-I), own table

Before going into the particular details of one company in the following chapter, the overall performance will be analyzed to identify overall trends and correlations. Therefore, relevant topics and characteristics will be identified. Kerpen (2016) proposes to identify those structural sources for differences directly together with the inefficient DMUs, as they know best about their structural disadvantages towards competitors (Kerpen, 2016, p. 231). Also, Kerpen also proposes to balance structural differences by correcting the efficiency values, which will not be carried out in this thesis. Further information on the approach of balancing structural differences can be found in Kerpen (2016, pp. 231 ff.)

To ease the overview of the development of efficiency scores, the line diagram in Figure 13 shows the average efficiency scores per year per company. By just looking at the diagram it seems already obvious that most companies are developing very stable over time, except a few, which will be examined in more detail in the following chapter for the Stadtwerke Gütersloh, who show an overall positive trend – which raises the question if there were particular influencing factors leading to this development.

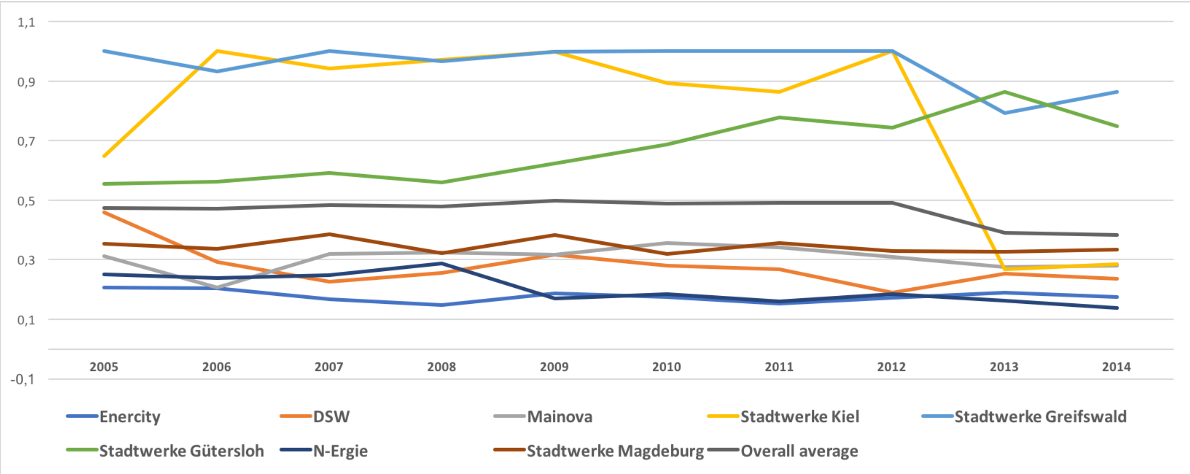

Figure 13: Visualization of average DEA efficiency scores per company, own graphic

A comparison between mean efficiency scores and their standard deviation presents a medium correlation with a correlation coefficient of 0.6014. Practically, this would mean that fluctuation in efficiency scores of the energy companies rises with average efficiency indicated by the correlation coefficient. This effect is also visible in Figure 14. One should not forget though, that especially the drop of efficiency of Stadtwerke Kiel in 2013 has some influence on this. The results of the first window analysis by Charnes et al. (1984) carried out for maintenance units of the US Air Force showed right opposite results – a low mean efficiency score often came across with a stronger variance in the results.

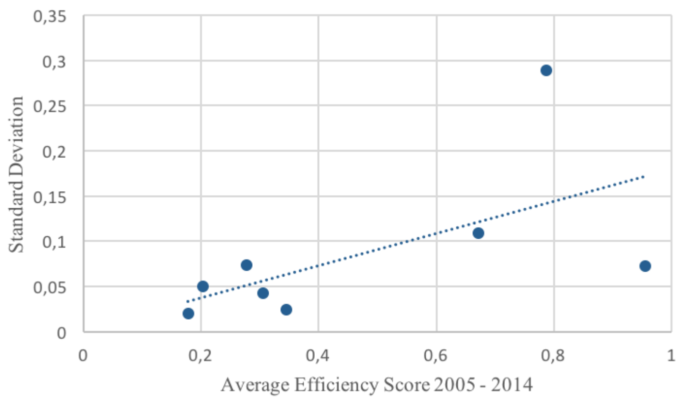

Figure 14: Mean efficiency scores and standard deviation, own graphic

To continue with the analysis for all companies, three more likely influence factors will be reflected upon:

- Influence of company size based on revenue
- Geographical disposition
- The overall amount of energy sold in Germany

Company Size

As already indicated before, Henzelmann et al. (2014) found that larger energy companies tend to be more efficient than smaller energy companies. The following Table 3 provides an overview of DMUs clustered by revenue.

	DMU	Efficiency Score
Revenue < 150 m€	• Stadtwerke Greifswald • Stadtwerke Gütersloh	0,9552 0,6709
Revenue < 500 m€	• Stadtwerke Kiel • Stadtwerke Magdeburg	0,7869 0,3442
Revenue < 1.500 m€	• DSW	0,2778
Revenue ≧ 1.500 m€	• Enercity • Mainova • N-Ergie	0,1776 0,3047 0,2025

Table 3: DMU mean efficiency scores clustered by revenue, own graphic

The correlation coefficient of -0.8051 supports what the table already indicates. For their investment and cash performance, smaller DMUs tend to be more efficient than larger companies, based on the overall revenue. This is additionally depicted in the graphic below:

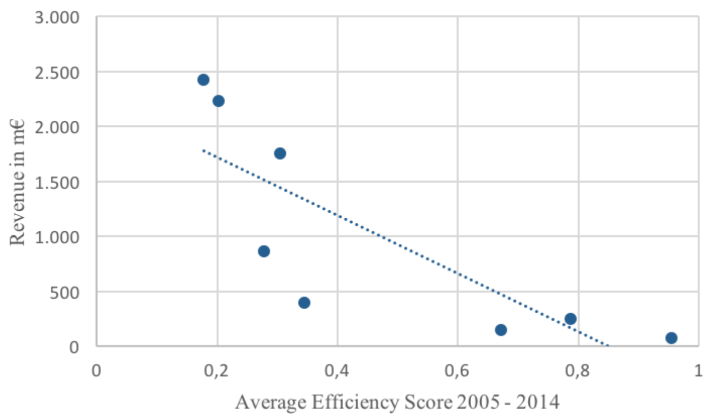

Figure 15: Average revenue in m€ vs. average efficiency scores 2005 – 2014, own graphic

Geographical Disposition

One influence factor that should be considered for the overall analysis is the geographical disposition of the companies. As already outlined in the Chapter 4.1 Selection of DMUs, companies are presented with different geographical influence factors that favor or disfavor certain technologies, e.g. in the renewable sector, e.g. the wind in the North of Germany vs. solar in the South. The following Table 4 shows the mean efficiency scores for all companies clustered by German region where they have their main area of operation. Even though the average efficiency scores for companies in the North are the highest with 0,5660, while the respective average scores for Middle Germany and South Germany are 0,4178 and 0,2025, it requires a deeper analysis of the underlying factors.

	DMU	Efficiency Score
Northern Germany	Stadtwerke Greifswald	0,9552
	Stadtwerke Kiel	0,7869
	Stadtwerke Magdeburg	0,3442
	Enercity	0,1776
Middle Germany	Stadtwerke Gütersloh	0,6709
	Mainova	0,3047
	DSW	0,2778
South Germany	N-Ergie	0,2025

Table 4: Mean DMU Efficiency scores clustered by geographical disposition, own graphic

Amount of Energy Sold in Germany

The relative size or market share, other than revenue, is another interesting aspect to look at when considering structural correlations. The Table below provides an overview of the company’s proportion of Germany’s gross energy consumption per year. The amount of energy sold was collected via the company’s annual reports.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Enercity	3,861%	3,191%	3,173%	3,706%	4,171%	3,495%	3,914%	3,365%	2,710%	2,616%
DSW	0,390%	0,396%	0,349%	0,353%	0,353%	0,329%	0,380%	0,536%	0,575%	0,564%
Mainova	0,827%	1,030%	1,142%	1,028%	1,310%	1,401%	1,637%	1,672%	1,825%	1,836%
Stadtwerke Kiel	0,156%	0,177%	0,181%	0,196%	0,234%	0,224%	0,206%	0,194%	0,195%	0,189%
Stadtwerke Greifswald	0,027%	0,028%	0,028%	0,029%	0,031%	0,032%	0,033%	0,033%	0,033%	0,033%
Stadtwerke Gütersloh	0,108%	0,098%	0,107%	0,127%	0,104%	0,086%	0,091%	0,084%	0,078%	0,071%
N-Ergie	2,365%	1,498%	1,576%	1,603%	1,992%	1,615%	1,651%	1,818%	2,267%	2,617%
Stadtwerke Magdeburg	0,137%	0,135%	0,138%	0,124%	0,130%	0,135%	0,303%	0,324%	0,346%	0,390%

Table 5: Share of DMU's energy production based on German gross energy consumption per year, own graphic based on own data and (BMWi, 2015)

The correlation coefficient for the means of this dataset is -0,62 and therefore a medium indicator that companies with smaller shares of energy production in Germany tend to have higher efficiency scores, which is also depicted in the figure below:

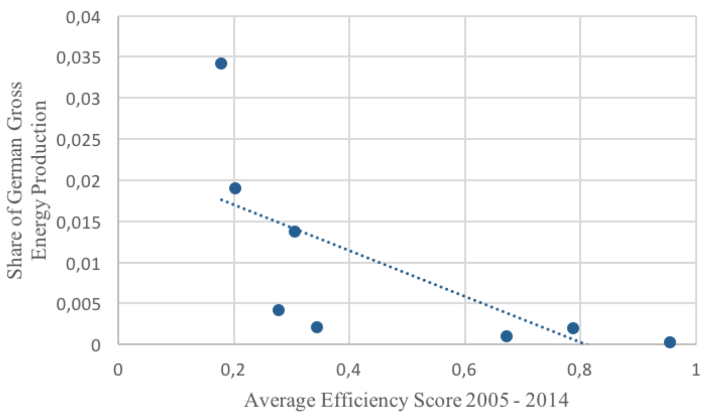

Figure 16: Share of Germany's gross energy production vs. mean efficiency scores 2005 – 2014, own graphic

6. Analysis Stadtwerke Gütersloh

The aim of this thesis is to analyze the efficiency scores relating to cash management and investments of eight German municipal energy suppliers over the time span of 2005 – 2014. In chapter five, a general overview of the development has already been performed, and some basic assumptions about correlations have been made. To make the results even more tangible, the focus of this chapter will now be even more detailed, as the underlying developments for the development of one single DMU, Stadtwerke Gütersloh, will be looked at in more detail. The aim is to provide an overview of the actions performed by the Stadtwerke Gütersloh. These actions could then be used for other companies to compare their actions during that time.

In Figure 17, the results of the eight DEA windows analyses for the Stadtwerke Gütersloh are displayed with 3 data points per analysis representing the efficiency scores per analysis per year for the Stadtwerke Gütersloh. Also, the gray dashed line shows the mean for the three data points per year – except for 2005 and 2014 with one data point each and 2006 and 2013 with two data points each.

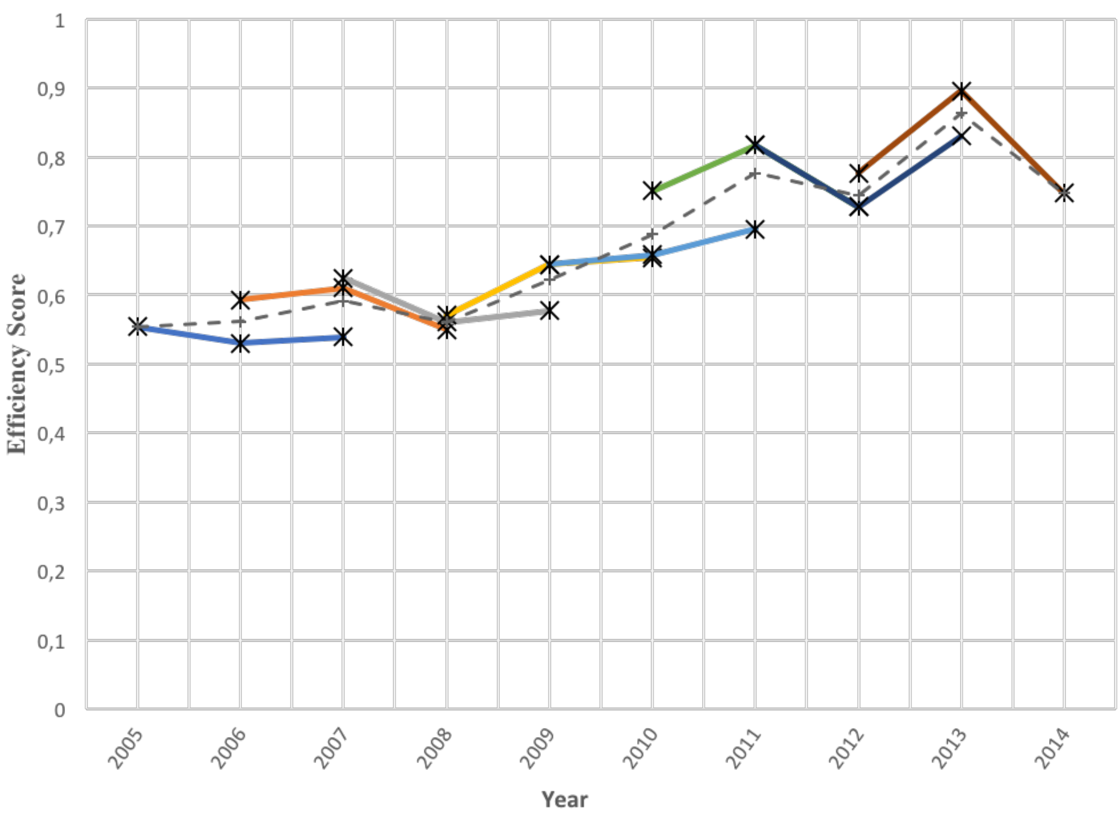

Figure 17: CRS efficiency scores of Stadtwerke Gütersloh, 3-year window and average per year, own graphic

The positive trend is also visible from Table 6 below – starting with an efficiency score of 0.5537 in 2005 with a constant increase until 2011, followed by a more volatile development until 2014, but still with an overall positive trend.

	Efficiency Score										Summary Measures	
DMU	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Mean	S.D.
Stadtwerke Gütersloh	*0,5537*	*0,5298*	*0,5392*									
		0,5932	*0,6105*	*0,5502*								
			0,6245	*0,5607*	*0,5769*							
				0,5702	*0,6446*	*0,6546*						
					0,6446	*0,6585*	*0,6953*					
						0,7514	*0,8170*	*0,7281*				
							0,8170	*0,7282*	*0,8306*			
								0,7765	*0,8958*	*0,7480*		
	0,5537	**0,5615**	**0,5914**	**0,5604**	**0,6221**	**0,6882**	**0,7765**	**0,7443**	**0,8632**	**0,7480**	**0,6709**	**0,1031**

Table 6: Efficiency scores for Stadtwerke Gütersloh 2005 – 2014, own table

The question which actions have helped the company to develop itself and follow a positive trend in efficiency scores will be analyzed with the help of the DEA in business context – model developed by (Kerpen, 2016, p. 230).

As it is not known whether the Stadtwerke Gütersloh used any benchmarking in the analyzed time frame, the focus will more be on strategy process and strategic decisions that could have had an influence on the analyzed input factors. Therefore, the annual reports and other sources of information, like regional newspapers, about the Stadtwerke Gütersloh will be used. Also, factors like geographic disposition will be looked at in more detail and compared with a peer company in the DEA analysis.

In Annex D an overview of the highlighted priorities and challenges of the Stadtwerke Gütersloh for the timeframe from 2005 – 2014 is presented. It becomes obvious that the management of the Stadtwerke was very well aware, already in 2005, that the energy transition would result in the strong decentralization of energy sources, which would require additional investments. Still, the main concern, especially in the years 2005 and 2006 and beyond were the structural changes in the German energy landscape induced by required unbundling activities.

The following paragraphs will highlight some of the major actions taken by the Stadtwerke Gütersloh and, where possible, compare it to actions of other competitors that either performed better or worse in the analyzed time frame. The strategies of both companies concerning this issue will then be compared.

Strategic partnerships and cooperation

The Stadtwerke Gütersloh made one move that has been a constant recommendation in several studies, e.g. (Edelmann, 2015; Kurtz, Fecht, & Butler, 2009; Theurl & Sander, 2011). They started aligning with strategic partners in their regional area to bundle activities and reduce the investment requirements. A different approach to this was carried out by the Stadtwerke Magdeburg (see Annex D), who have the Stadtwerke Gütersloh as one of their main peer DMUs. The Stadtwerke Magdeburg started nationwide sales push program in 2007 to profit from the new discrimination-free and competitive market environment all on their own. The aim of this action was to increase the sales territory (therefore a rather output-oriented approach in DEA terms) and become visible as one of the first regional energy suppliers to enter the nationwide competition (Städtische Werke Magdeburg, 2007, p. 4). The time for this sales initiative came along with a positive market environment and strong energy spot price developments from 2007 – 2009, as can be seen in Figure 18. This already led the Stadtwerke Magdeburg to the conclusion that this initiative heavily relies on the "quality of sourcing conditions, efficiency of sales channels and marketing activities, as well as cost reduction in customer management" (Städtische Werke Magdeburg, 2007, p. 4). In 2010, the Stadtwerke Magdeburg, for the first time, highly emphasized the need for investments in order to have a successful energy transition in their strategic outline at the beginning of the annual report, but at that time the efficiency was still way below those of Stadtwerke Gütersloh (Städtische Werke Magdeburg, 2010, p. 11).

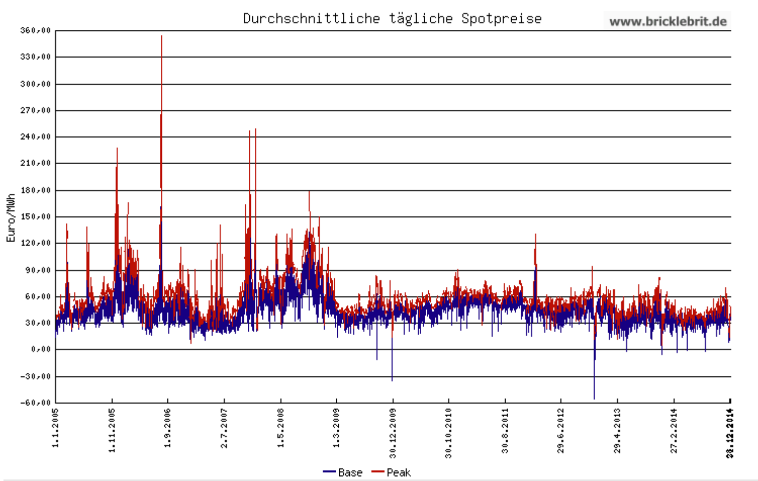

Figure 18: Daily energy spot prices Germany 2005 - 2014 for base and peak load, (Bricklebrit.com, 2017)

Strategic Investments in Renewable Energy

The Stadtwerke Gütersloh's approach to investing in renewable energy production was rather careful. They ascribed importance to the development of renewables already in 2007, but their first wind power project was e.g. taken into operation in 2011. One reason for this rather conservative approach is that the Stadtwerke Gütersloh incorporated a cooperative venture together with four other regional energy suppliers in the area to identify the best areas for wind power, supervise the building process and hand over the turnkey power plant. The shared risk, as well as the shared need for investment, have helped the Stadtwerke to come through a difficult phase of volatile energy prices with an improving cash and investment efficiency.

Also, the Stadtwerke Gütersloh implemented an initiative that could best be described as "crowd funding" in today's terms. Since 2011, inhabitants, companies, cities or municipalities can invest in the GrünEnergie eG, a cooperative that solely invests in renewable energy projects (Stadtwerke Gütersloh, 2014).

Geographical disposition and political influence

The municipality of Gütersloh has a strong focus on renewable energy, knowing that the geographical disposition is somehow unfavorable for large-scale wind energy production. Still, the amount of bioenergy and smaller wind projects is high as can be seen in the map below (Figure 19). Already in 2002, 18 percent of the energy fed-in the electricity grid of Gütersloh came from renewable energy sources (Stadt Gütersloh, 2015).

The main energy sources in Gütersloh contributing to this trend in ascending order based on energy fed-in in 2002 were:

- Biomass and sewage gas
  In the municipal area of Gütersloh, biomass energy production is rather significant. Already in 2002, two CHP power plants with a capacity of approximately 16MW mostly operated with sewage gas and wood were existent (Stadt Gütersloh, 2015).
- Wind power
  Installed capacity of onshore wind power more than doubled from 2002 until 2009 up to 10MW installed capacity in 2009 (Stadt Gütersloh, 2015) and the city of Gütersloh

aims to increase the installed capacity even further, e.g. by declaring new available areas for the construction of wind power plants (Stadt Gütersloh, 2016).

- Photovoltaic

  Gütersloh is one of the mid-sized German cities with the upper third most installed photovoltaic capacity (last update 2015). In total, the installed capacity per inhabitant increased from 14W per inhabitant in 2003 to 270W in 2015 (Stadt Gütersloh, 2015). The city of Gütersloh provided roof areas on schools and other public buildings to promote solar energy installation. Also, renewable energy production, especially from PV is integrated into the curriculum of the schools in the area to

- Geothermal energy

  So far only smaller geothermal heating projects were implemented. Based on information provided by the Stadt Gütersloh (2015) the potential of geothermal energy could cover up to 69.8 percent of the required heating energy. Usage for electricity generation is rather limited, as Gütersloh is rather qualified for close-to-surface geothermal energy. This trend is also observable all over Germany with nine installed projects with 36.9 MW capacity in 2016 (Bundesverband Geothermie, 2016). The main time frame of installation was 2004 – 2009 (Stadt Gütersloh, 2015).

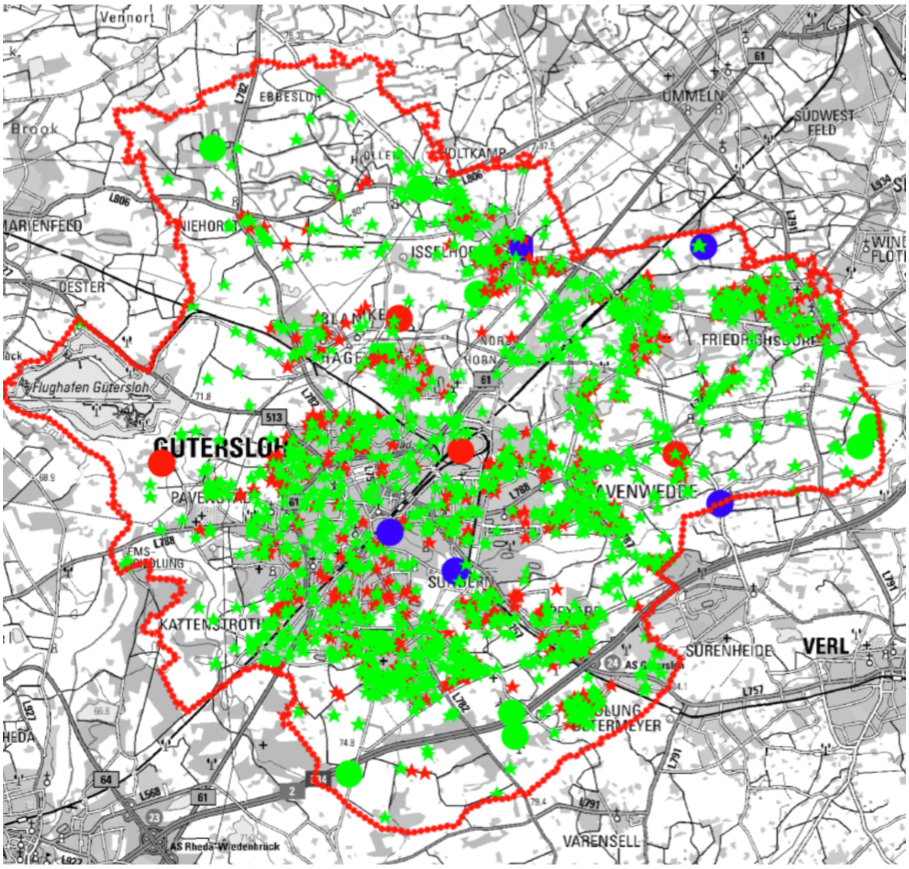

Figure 19: Renewable energy facilities in the municipal area of Gütersloh, (Kreis Gütersloh, 2015)

Another politically influenced aspect that cannot be analyzed in more detail, also due to a lack of publicly available data, is the geographical disposition in regards to former East and West Germany. After the German reunification in 1990, the investment bottleneck in former East Germany, especially for energy production and distribution was severe and therefore companies needed to prioritize differently than in former West Germany.

From the different strategic focuses and influencing factors, we can assume that the Stadtwerke Gütersloh were in a good position to answer the upcoming challenges of the German energy transition. Not only was the overall trend to support renewable energy much more pronounced than in other areas, but also, the trend was strongly supported by the political decision makers. Also, the customers were willing to support the trend by investing their money in the cooperative to support regional renewable energy, which lowered the financing needs of the Stadtwerke. Again, it is important that some of the factors displayed here in more detail are specific for the Stadtwerke Gütersloh. Still, this DEA is setup to compare one company with a relative better company based on the efficiency scores. Therefore it is important to understand which companies did relatively better and are therefore worth to be analyzed and worth to compare another company with.

7. Conclusion

One of the main difficulties while developing the benchmarking model of this thesis was to collect the available data from all participating companies. All businesses are bound to the disclosure requirements by the German Commercial Code – depending on their form of organization. This fact allows collecting a minimum number of comparable figures. For a deeper analysis, it would be beneficial to get access to more data sources, e.g. through direct collaboration with the companies. This would one the one hand increase the reliability of the study and provide more best practices, on the other hand, it would also increase the efforts needed to process the data and make sure it is comparable.

Another aspect that should be mentioned is that this DEA delivered different results, as e.g. a study by Henzelmann et al. (2014) who included the amount of material used in the production process, which revealed a strong effect of economies of scale, e.g. through sourcing advantages. The focus of this thesis was deliberately on investments and cash figures, as this is strongly connected to the capital needs of the German energy transition.

Also, it is important to realize that all the information that is provided in this thesis is backward-looking. Analyzing a historical trend helps to understand the developments in the past and, to some degree, also provide strategic advice for future decisions. Moreover, this thesis showed that DEA is a legit tool that can be used by companies to benchmark themselves with others, identify a peer company and compare one's strategy with the competitors'.

Even though this study was focused on benchmarking similar DMUs, it might in the future also become interesting to single out certain functional areas of companies. This would allow benchmarking this single part with e.g. more innovative or dynamic businesses or parts of companies on the market. The knowledge obtained through this benchmarking could be internalized, leading to higher efficiency scores compared to competitors who do not have the necessary knowledge. An example in the area of German municipal energy companies would be the participation in the growth of so-called smart home devices – an area that is connected to the administration of electricity measurement points. Until now, the regional energy suppliers have a monopoly on the administration of this electricity measurement points in Germany, but competitors are pushing into the market with highly developed products, and the whole technique will become even more attractive for competitors in connection with smart grids.

For this thesis, constant returns to scale were used to be able to also show structural and more long-term development potential, like e.g. size-dependent. In Annex F the analysis was carried out again with variable returns to scale, also input oriented. As outlined before, the efficiency scores are higher compared to the CCR analysis for several reasons, and a comparison could reveal more potential explanations for the strategic development of the German municipal energy suppliers. Also, it becomes obvious that the overall efficiency scores could also show that, depending on the size of the companies, they are performing well. Still, this thesis would like to emphasize the fact that a strategic direction could also include mergers & acquisitions, as well as cooperation. This strategic indicator is lost when looking at the figures in Annex F.

Finally, Another interesting aspect that would enhance the research carried out in this thesis would be to integrate unwanted outputs in the analysis. Examples would be e.g. CO_2 emissions during the production process, that should, of course, be on the input side in the case of this research, as they should be minimized. Unfortunately, only enercity provided the CO_2 for the required timeframe.

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Appendix

A. Data Inputs & Output

The data for this thesis is mainly taken out of or calculated with the help of the companies' annual reports. For the sake of completeness, the annual reports are included in the references, but will not be displayed below each table. Please note that for calculatory reasons, some of the data has been inverted, as described in Chapter 4.2.

2005 – 2007

	Output	Inputs			
Company	**Revenue (in m€)**	**Employees**	**Working Capital (in m€)**	**Cash Flow (in m€)**	**Investments (in m€)**
enercity_2005	1754,0000	2814,0000	124,1200	194,0200	46,5000
enercity_2006	1803,0000	2758,0000	127,2400	104,2000	51,6000
enercity_2007	2277,0000	2731,0000	132,0400	187,2600	59,8000
dsw_2005	633,8000	1902,0000	179,2730	133,4840	41,5000
dsw_2006	692,2000	1132,0000	144,2150	85,9970	28,8000
dsw_2007	792,6000	1070,0000	104,9300	159,9940	29,8000
mainova_2005	1375,6000	3009,0000	219,0860	147,2680	130,3790
mainova_2006	1583,7350	2950,0000	17,1110	243,6920	87,7780
mainova_2007	1497,7130	2884,0000	277,6680	82,7400	76,0660
kiel_2005	224,9140	1288,0000	13,2550	29,7440	17,2000
kiel_2006	139,6390	1258,0000	6,8380	59,3410	25,6000
kiel_2007	152,1170	1137,0000	28,6850	186,4320	25,8000
greifswald_2005	56,6404	238,0000	65,0740	7,1400	4,9000
greifswald_2006	61,0911	226,0000	49,4529	7,4870	5,2000
greifswald_2007	62,9704	221,0000	62,2084	1,0730	4,8000
guetherloh_2005	132,8919	425,0000	58,0374	15,7738	7,0000
guetherloh_2006	140,4070	427,0000	59,2809	19,2055	5,9000
guetherloh_2007	142,6339	415,0000	67,3461	17,1646	14,3000
nergie_2005	1390,9580	2848,0000	84,9530	147,3000	101,5080
nergie_2006	1679,2630	2791,0000	180,7010	189,2000	80,5120
nergie_2007	1768,4670	2696,0000	244,8210	195,8280	81,7950
magdeburg_2005	262,1850	718,0000	31,6480	58,3000	22,1000
magdeburg_2006	298,8850	733,0000	38,3340	67,0000	18,6000
magdeburg_2007	337,1310	728,0000	85,9440	58,0220	31,7430

2006 – 2008

	Output	**Inputs**			
Company	**Revenue (in m€)**	**Employees**	**Working Capital (in m€)**	**Cash Flow (in m€)**	**Investments (in m€)**
enercity_2006	1.803,00	2.758,00	127,24	104,20	51,60
enercity_2007	2.277,00	2.731,00	132,04	187,26	59,80
enercity_2008	2.844,00	2.741,00	172,91	34,26	61,00
dsw_2006	692,20	1.132,00	144,215	86,00	28,80
dsw_2007	792,60	1.070,00	104,93	159,99	29,80
dsw_2008	855,00	1.089,00	153,983	63,44	24,90
mainova_2006	1.583,74	2.950,00	17,111	243,69	87,78
mainova_2007	1.497,71	2.884,00	277,668	82,74	76,07
mainova_2008	1.715,20	2.874,00	373,379	190,79	91,50
kiel_2006	139,64	1.258,00	6,838	59,34	25,60
kiel_2007	152,12	1.137,00	28,685	186,43	25,80
kiel_2008	142,93	1.100,00	20,269	33,10	35,50
greifswald_2006	61,09	226,00	49,45286061	7,49	5,20
greifswald_2007	62,97	221,00	62,20838187	1,07	4,80
greifswald_2008	70,43	216,00	66,01645248	6,07	5,70
guetherloh_2006	140,41	427,00	59,280915	19,21	5,90
guetherloh_2007	142,63	415,00	67,34609317	17,16	14,30
guetherloh_2008	163,99	411,00	73,01858984	24,73	11,40
nergie_2006	1679,26	2791,00	180,701	189,20	80,51
nergie_2007	1768,47	2696,00	244,821	195,83	81,80
nergie_2008	1816,89	2637,00	359,341	152,04	83,70
magdeburg_2006	298,89	733,00	38,334	67,00	18,60
magdeburg_2007	337,13	728,00	85,944	58,02	31,74
magdeburg_2008	393,08	704,00	74,309	66,17	32,43

2007 – 2009

	Output	Inputs			
Company	Revenue (in m€)	Employees	Working Capital (in m€)	Cash Flow (in m€)	Investments (in m€)
enercity_2007	2277,0000	2731,0000	132,0400	187,2600	59,8000
enercity_2008	2844,0000	2741,0000	172,9100	34,2600	61,0000
enercity_2009	2815,0000	2705,0000	336,0700	238,8100	98,1000
dsw_2007	792,6000	1070,0000	104,9300	159,9940	29,8000
dsw_2008	855,0000	1089,0000	153,9830	63,4380	24,9000
dsw_2009	833,1000	1079,0000	226,3700	81,3000	41,0000
mainova_2007	1497,7130	2884,0000	277,6680	82,7400	76,0660
mainova_2008	1715,2000	2874,0000	373,3790	190,7880	91,5000
mainova_2009	1661,0000	2859,0000	308,9800	330,0350	97,9000
kiel_2007	152,1170	1137,0000	28,6850	186,4320	25,8000
kiel_2008	142,9290	1100,0000	20,2690	33,1000	35,5000
kiel_2009	145,1800	1103,0000	17,2800	32,9000	27,9000
greifswald_2007	62,9704	221,0000	62,2084	1,0730	4,8000
greifswald_2008	70,4338	216,0000	66,0165	6,0710	5,7000
greifswald_2009	69,8111	214,0000	68,3642	6,2000	5,7000
guetherloh_2007	142,6339	415,0000	67,3461	17,1646	14,3000
guetherloh_2008	163,9859	411,0000	73,0186	24,7274	11,4000
guetherloh_2009	159,4533	415,0000	72,3051	14,1493	4,8000
nergie_2007	1768,4670	2696,0000	244,8210	195,8280	81,7950
nergie_2008	1816,8890	2637,0000	359,3410	152,0350	83,7030
nergie_2009	2394,4880	2580,0000	166,3020	209,0580	83,5510
magdeburg_2007	337,1310	728,0000	85,9440	58,0220	31,7430
magdeburg_2008	393,0750	704,0000	74,3090	66,1730	32,4260
magdeburg_2009	398,2880	695,0000	115,6540	59,9000	26,0000

2008 – 2010

	Output	Inputs			
Company	**Revenue (in m€)**	**Employees**	**Working Capital (in m€)**	**Cash Flow (in m€)**	**Investments (in m€)**
enercity_2008	2844,0000	2741,0000	172,9100	34,2600	61,0000
enercity_2009	2815,0000	2705,0000	336,0700	238,8100	98,1000
enercity_2010	2578,0000	2642,0000	193,3200	163,2000	83,0000
dsw_2008	855,0000	1089,0000	153,9830	63,4380	24,9000
dsw_2009	833,1000	1079,0000	226,3700	81,3000	41,0000
dsw_2010	844,9000	1052,0000	179,1570	110,3000	49,1000
mainova_2008	1715,2000	2874,0000	373,3790	190,7880	91,5000
mainova_2009	1661,0000	2859,0000	308,9800	330,0350	97,9000
mainova_2010	1670,6000	2884,0000	393,6760	146,2220	110,3000
kiel_2008	142,9290	1100,0000	20,2690	33,1000	35,5000
kiel_2009	145,1800	1103,0000	17,2800	32,9000	27,9000
kiel_2010	170,4550	1094,0000	14,5420	61,5000	34,7000
greifswald_2008	70,4338	216,0000	66,0165	6,0710	5,7000
greifswald_2009	69,8111	214,0000	68,3642	6,2000	5,7000
greifswald_2010	77,0689	285,0000	71,4545	12,3000	15,3000
guetherloh_2008	163,9859	411,0000	73,0186	24,7274	11,4000
guetherloh_2009	159,4533	415,0000	72,3051	14,1493	4,8000
guetherloh_2010	154,1195	453,0000	75,1875	25,2788	7,7000
nergie_2008	1816,8890	2637,0000	359,3410	152,0350	83,7030
nergie_2009	2394,4880	2580,0000	166,3020	209,0580	83,5510
nergie_2010	2383,2070	2574,0000	191,6550	187,6190	108,7770
magdeburg_2008	393,0750	704,0000	74,3090	66,1730	32,4260
magdeburg_2009	398,2880	695,0000	115,6540	59,9000	26,0000
magdeburg_2010	410,0690	662,0000	79,5050	61,9000	23,0000

2009 – 2011

	Output	Inputs			
Company	Revenue (in m€)	Employees	Working Capital (in m€)	Cash Flow (in m€)	Investments (in m€)
enercity_2009	2815,0000	2705,0000	336,0700	238,8100	98,1000
enercity_2010	2578,0000	2642,0000	193,3200	163,2000	83,0000
enercity_2011	2744,0000	2587,0000	101,9300	183,1700	63,5000
dsw_2009	833,1000	1079,0000	226,3700	81,3000	41,0000
dsw_2010	844,9000	1052,0000	179,1570	110,3000	49,1000
dsw_2011	897,2000	1047,0000	171,4010	184,5630	35,0000
mainova_2009	1661,0000	2859,0000	308,9800	330,0350	97,9000
mainova_2010	1670,6000	2884,0000	393,6760	146,2220	110,3000
mainova_2011	1785,5000	2970,0000	358,6460	196,5060	134,7000
kiel_2009	145,1800	1103,0000	17,2800	32,9000	27,9000
kiel_2010	170,4550	1094,0000	14,5420	61,5000	34,7000
kiel_2011	175,4540	1020,0000	13,7070	50,0680	45,6630
greifswald_2009	69,8111	214,0000	68,3642	6,2000	5,7000
greifswald_2010	77,0689	285,0000	71,4545	12,3000	15,3000
greifswald_2011	75,3300	231,0000	72,5980	13,9000	9,2000
guetherloh_2009	159,4533	415,0000	72,3051	14,1493	4,8000
guetherloh_2010	154,1195	453,0000	75,1875	25,2788	7,7000
guetherloh_2011	148,9571	460,0000	76,9025	8,7690	7,2000
nergie_2009	2394,4880	2580,0000	166,3020	209,0580	83,5510
nergie_2010	2383,2070	2574,0000	191,6550	187,6190	108,7770
nergie_2011	2524,7870	2562,0000	79,5780	167,1800	118,0830
magdeburg_2009	398,2880	695,0000	115,6540	59,9000	26,0000
magdeburg_2010	410,0690	662,0000	79,5050	61,9000	23,0000
magdeburg_2011	419,9000	689,0000	97,4310	80,7100	31,6000

2010 – 2012

	Output	Inputs			
Company	**Revenue (in m€)**	**Employees**	**Working Capital (in m€)**	**Cash Flow (in m€)**	**Investments (in m€)**
enercity_2010	2.578,00	2.642,00	193,32	163,20	83,00
enercity_2011	2.744,00	2.587,00	101,93	183,17	63,50
enercity_2012	2.641,00	2.593,00	131,78	106,08	49,30
dsw_2010	844,90	1.052,00	179,16	110,30	49,10
dsw_2011	897,20	1.047,00	171,40	184,56	35,00
dsw_2012	1.033,00	1.024,00	79,46	150,50	35,70
mainova_2010	1.670,60	2.884,00	393,68	146,22	110,30
mainova_2011	1.785,50	2.970,00	358,65	196,51	134,70
mainova_2012	2.211,20	2.810,00	331,05	216,44	119,50
kiel_2010	170,46	1.094,00	14,54	61,50	34,70
kiel_2011	175,45	1.020,00	13,71	50,07	45,66
kiel_2012	163,92	1.040,00	17,56	13,24	31,12
greifswald_2010	77,07	285,00	71,45	12,30	15,30
greifswald_2011	75,33	231,00	72,60	13,90	9,20
greifswald_2012	85,49	289,00	69,67	8,00	10,30
guetherloh_2010	154,12	453,00	75,19	25,28	7,70
guetherloh_2011	148,96	460,00	76,90	8,77	7,20
guetherloh_2012	157,69	463,00	64,61	13,24	8,10
nergie_2010	2383,21	2574,00	191,66	187,62	108,78
nergie_2011	2524,79	2562,00	79,58	167,18	118,08
nergie_2012	2587,06	2542,00	176,52	129,39	123,39
magdeburg_2010	410,07	662,00	79,51	61,90	23,00
magdeburg_2011	419,90	689,00	97,43	80,71	31,60
magdeburg_2012	439,60	692,00	75,90	59,97	37,00

2011 – 2013

	Output	Inputs			
Company	**Revenue (in m€)**	**Employees**	**Working Capital (in m€)**	**Cash Flow (in m€)**	**Investments (in m€)**
enercity_2011	2744,0000	2587,0000	101,9300	183,1700	63,5000
enercity_2012	2641,0000	2593,0000	131,7800	106,0800	49,3000
enercity_2013	2450,0000	2591,0000	134,4900	227,9900	48,5000
dsw_2011	897,2000	1047,0000	171,4010	184,5630	35,0000
dsw_2012	1033,0000	1024,0000	79,4550	150,5030	35,7000
dsw_2013	1103,2000	997,0000	222,9080	175,9020	37,9000
mainova_2011	1785,5000	2970,0000	358,6460	196,5060	134,7000
mainova_2012	2009,2000	2943,0000	392,6280	137,4430	127,5000
mainova_2013	2211,2000	2810,0000	331,0540	216,4420	119,5000
kiel_2011	175,4540	1020,0000	13,7070	50,0680	45,6630
kiel_2012	163,9240	1040,0000	17,5640	13,2350	31,1180
kiel_2013	632,1510	1052,0000	18,3440	52,5310	24,1470
greifswald_2011	75,3300	231,0000	72,5980	13,9000	9,2000
greifswald_2012	85,4940	289,0000	69,6735	8,0000	10,3000
greifswald_2013	94,9373	232,0000	63,9239	13,3181	11,1000
guetherloh_2011	148,9571	460,0000	76,9025	8,7690	7,2000
guetherloh_2012	157,6851	463,0000	64,6063	13,2400	8,1000
guetherloh_2013	151,1678	457,0000	75,2706	13,8030	6,5000
nergie_2011	2524,7870	2562,0000	79,5780	167,1800	118,0830
nergie_2012	2587,0610	2542,0000	176,5190	129,3910	123,3860
nergie_2013	2873,9050	2534,0000	151,7540	198,7700	179,3480
magdeburg_2011	419,9000	689,0000	97,4310	80,7100	31,6000
magdeburg_2012	439,6000	692,0000	75,9040	59,9660	37,0000
magdeburg_2013	483,5000	709,0000	89,8250	102,4650	28,1000

2012 – 2014

	Output	Inputs			
Company	**Revenue (in m€)**	**Employees**	**Working Capital (in m€)**	**Cash Flow (in m€)**	**Investments (in m€)**
enercity_2012	2641,0000	2593,0000	131,7800	106,0800	49,3000
enercity_2013	2450,0000	2591,0000	134,4900	227,9900	48,5000
enercity_2014	2367,0000	2540,0000	59,7800	161,8600	49,1000
dsw_2012	1033,0000	1024,0000	79,4550	150,5030	35,7000
dsw_2013	1103,2000	997,0000	222,9080	175,9020	37,9000
dsw_2014	962,0000	1007,0000	129,3890	103,5830	34,7000
mainova_2012	2009,2000	2943,0000	392,6280	137,4430	127,5000
mainova_2013	2211,2000	2810,0000	331,0540	216,4420	119,5000
mainova_2014	2036,7000	2765,0000	267,4840	208,1280	95,9000
kiel_2012	163,9240	1040,0000	17,5640	13,2350	31,1180
kiel_2013	632,1510	1052,0000	18,3440	52,5310	24,1470
kiel_2014	579,3100	1045,0000	3,9530	43,2040	38,9460
greifswald_2012	85,4940	289,0000	69,6735	8,0000	10,3000
greifswald_2013	94,9373	232,0000	63,9239	13,3181	11,1000
greifswald_2014	99,6945	237,0000	70,0965	11,2000	12,2000
guetherloh_2012	157,6851	463,0000	64,6063	13,2400	8,1000
guetherloh_2013	151,1678	457,0000	75,2706	13,8030	6,5000
guetherloh_2014	148,0645	454,0000	71,2529	13,9190	10,6000
nergie_2012	2587,0610	2542,0000	176,5190	129,3910	123,3860
nergie_2013	2873,9050	2534,0000	151,7540	198,7700	179,3480
nergie_2014	2879,2970	2418,0000	72,2340	216,1330	108,7770
magdeburg_2012	439,6000	692,0000	75,9040	59,9660	37,0000
magdeburg_2013	483,5000	709,0000	89,8250	102,4650	28,1000
magdeburg_2014	493,1000	706,0000	98,1570	89,3940	41,9000

B. Interview – Company Executive Manager

The head of operations of a smaller municipal energy supplier < EUR 50m agreed to answer some questions regarding the setup of the DEA model. It was his wish to stay anonymous in any published version. In the case of questions, the author of this thesis happily arranges a contact.

Question	**Answer**
What is your position	• Head of operations at municipal energy supplier.
What do you do in your daily work?	• Planning of everyday business • Work with colleagues from different departments to improve day-to-day business processes • Gather information to plan business long-term
Benchmarking is the process of comparing own processes with those of other companies. Did you ever use benchmarking in your job or could this be of interest in the future for you?	• Owner of distribution grid for electricity and gas, even though separated from main company – therefore benchmarking known due to regulatory necessities • No operational benchmarking used • No plans to do so in the future
Did you ever hear about the efficiency analysis tool called DEA?	• Knowledge about DEA being one of the techniques used by the Bundesnetzagentur to benchmark distribution system operators.
Imagine that DEA gives you a figure that condenses any number of input/output-related efficiency benchmark. What would you think should be legitimate input and	• Our main KPI is profit – due to public ownership structure – 100% public ownership. Yearly targets for transfer of profits.

output factors to depict the processes of your company?	• To increase profits, mostly cost-focused. • Qualitative factors are also important, like e.g. network stability.
Can you elaborate a little more on the cost perspective?	• Most of our costs are incurred for raw materials, HR, but also investments in new production resources, like e.g. wind parks → decrease of importance of materials, but rather constant revenue stream/financing costs

C. Socio-Economic Impact of Labor as Input Factor

A topic which is not part of this thesis, but becomes obvious to think about when looking at the number of employees from 2004 – 2014 is the socio-economic impact of selecting the number of employees as an input value. The idea was also described in a paper written by Iribarren and Vázquez-Rowe (2013). In Figure 20, the effect also becomes visible when running a linear regression on the total number of employees of the eight energy companies looked at:

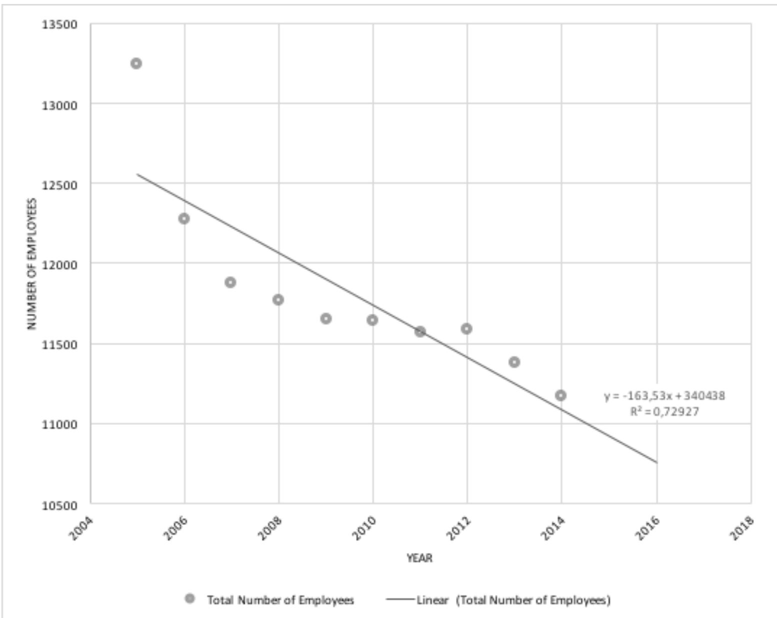

Figure 20: Linear regression of number of employees for all companies, own graphic

The linear regression shows that around 160 jobs were cut on average per year at all companies that were part of the DEA of this thesis and in turn. As DEA explicitly looks at lowering the input and higher the output, the better the efficiency value. Therefore, Iribarren and Vázquez-Rowe (2013) add a socio-economic value when labor is used as a DEA input: “all actors should understand labor minimization as a virtual means toward the redefinition of tasks with socioeconomic growing purposes, but not as a tool for the identification of useless job positions.” A deeper understanding of why those jobs were cut would need to be developed though.

D. Strategic Focus Analysis

a. Stadtwerke Gütersloh

Stadtwerke Gütersloh - Strategic Focus Areas 2005 - 2015

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Supervisory Board											
- Price increase in Sourcing leading to new pricing startegy	x	x		x	x	x	x	x		x	8
- Energy Politics, environment and climate protection focus			x	x	x	x					4
- Cooperation with same size regional competitors / Strategic partnerships			x	x	x		x	x		x	6
Unbundling activities					x						1
Investment in wind energy parks							x				1
Incorporation of wind energy subsidiary								x		x	2
Managing Board											
Challenges arising from different German energy law adaptations - unbundling, renewable energy, etc.	x	x	x	x	x	x	x	x	x	x	10
Customer proximity, customer service quality	x			x	x	x	x	x	x	x	8
Decentralization of Energy Supply	x				x	x		x	x	x	6
Focus on strategic partnerships, especially in distribution network and renewable energy			x					x	x	x	4
Climate Change		x					x	x	x	x	5
Energy Efficiency program promotion				x		x		x		x	4
Regional Renewable Energy Projects and cooperative investment in wind parks / bio energy / bio gas etc.							x	x	x	x	4
Combined heat and power challenges					x		x			x	3
Strategic Partnership for investment opportunities in renewable energy for customers in Gütersloh together with regional banks			x					x	x		3
Price development			x		x			x			3
Innovative, customized contract opportunities for customers									x	x	2
Investments in distribution grids	x						x				2
Smart Grids						x			x		2
E-mobility						x	x				2
Reconciliation of investments in power plants	x										1
Strategy of reasonable growth		x									1
Setup of strategic climate change program (25% of total investments per year directed towards renewable energy)						x					1
Introduction of renewanle energy tariff							x				1
Limited investment possibilities due to lack of financial resources									x		1
Innovation / H-Cell										x	1

Table 7: Strategic focus areas of the Stadtwerke Gütersloh 2005 – 2014, own table

The information in the table above was collected from all annual reports of the Stadtwerke Gütersloh and therein especially from the statements of the managing and supervisory board (Stadtwerke Gütersloh, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014).

b. Stadtwerke Magdeburg

Stadtwerke Magdeburg - Strategic Focus Areas 2005 - 2014

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Managing Board											
Customer proximity, customer service quality	x	x	x	x	x	x	x		x		8
Challenges arising from different German energy law adaptations - unbundling, renewable energy, stronger competition	x	x	x	x	x	x					6
Ongoing Market expansion and customer acquise with new products				x	x	x	x				4
Sales area expansion							x	x	x		3
Increase of investments							x	x	x		3
Intensification and adaptation of of sales processes in order to participate in more dynamic market environment			x		x						2
Strengthening of nationwide sales opportunities			x					x			2
Incorporation of renewable energy investment						x	x				2
Introduction of renewanle energy tariff			x								1
Challenging market environment				x							1
Limited investment possibilities due to lack of financial resources							x				1
Cost awareness							x				1
Shift of target group focus - from city to region							x				1
Supplier management							x				1
Regional responsibility							x				1
Increased competition								x			1
Energy transition as cost driver								x			1
Exceptional charges due to elbe river flood									x		1
employer Branding										x	1
Employability of Staff										x	1
Support of City of Magdeburg's Energy and Climate Management program										x	1

Table 8: Strategic focus areas of the Städtische Werke Magdeburg 2005 – 2014, own table

The information in the table above was collected from all annual reports of the Städtische Werke Magdeburg and therein especially from the statements of the managing board: (Städtische Werke Magdeburg, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014)

E. Stadtwerke Greifswald – Super Efficiency Analysis

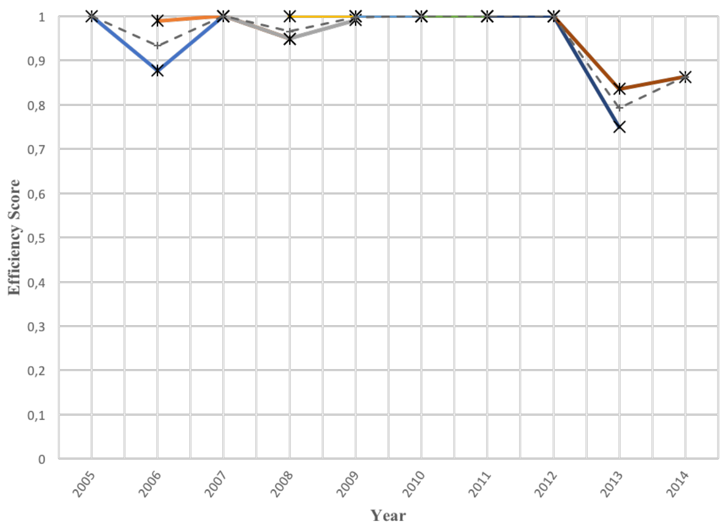

Figure 21: CRS efficiency scores of Stadtwerke Gütersloh, 3-year window and average per year, own graphic

For the case of the Stadtwerke Greifswald, with very high efficiency scores, it is rather difficult to formulate interpretations. Especially in the case of efficiency scores of one, for a consecutive period. One concept to counteract this is the so-called super-efficiency, which is explained in more detail by Bogetoft and Otto (2011, pp. 115 ff.) or Cooper, Seiford, and Tone (2006, pp. 301 ff.).

F. Variable Returns to Scale Analysis

	Efficiency Score										Summary Measures	
DMU	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Mean	S.D.
Enercity	*0,9325*	*0,8950*	*1,0000*									
		0,8889	*1,0000*	*1,0000*								
			1,0000	*1,0000*	*1,0000*							
				1,0000	*1,0000*	*1,0000*						
					1,0000	*0,9567*	*1,0000*					
						0,9596	*1,0000*	*0,9614*				
							1,0000	*0,9310*	*1,0000*			
								0,8590	*1,0000*	*1,0000*		
	0,9325	**0,8920**	**1,0000**	**1,0000**	**1,0000**	**0,9721**	**1,0000**	**0,9171**	**1,0000**	**1,0000**	**0,9714**	**0,0396**
DSW	*0,9529*	*0,9127*	*1,0000*									
		0,8920	*1,0000*	*1,0000*								
			1,0000	*0,9834*	*1,0000*							
				0,9534	*0,9604*	*1,0000*						
					0,9534	*1,0000*	*1,0000*					
						1,0000	*1,0000*	*1,0000*				
							1,0000	*1,0000*	*1,0000*			
								1,0000	*1,0000*	*0,9535*		
	0,9529	**0,9023**	**1,0000**	**0,9789**	**0,9712**	**1,0000**	**1,0000**	**1,0000**	**1,0000**	**0,9535**	**0,9759**	**0,0306**
Mainova	*1,0000*	*1,0000*	*0,9203*									
		1,0000	*0,9294*	*1,0000*								
			0,8925	*0,9396*	*1,0000*							
				0,9079	*1,0000*	*1,0000*						
					1,0000	*0,9130*	*1,0000*					
						0,8883	*1,0000*	*1,0000*				
							0,9420	*0,8328*	*1,0000*			
								0,8311	*1,0000*	*0,9542*		
	1,0000	**1,0000**	**0,9141**	**0,9492**	**1,0000**	**0,9338**	**0,9807**	**0,8879**	**1,0000**	**0,9542**	**0,9620**	**0,0386**
Stadtwerke Kiel	*0,9424*	*1,0000*	*1,0000*									
		1,0000	*1,0000*	*1,0000*								
			1,0000	*1,0000*	*1,0000*							
				1,0000	*0,9604*	*1,0000*						
					0,9001	*1,0000*	*1,0000*					
						1,0000	*1,0000*	*0,9438*				
							1,0000	*0,9388*	*1,0000*			
								0,9176	*1,0000*	*1,0000*		
	0,9424	**1,0000**	**1,0000**	**1,0000**	**0,9535**	**1,0000**	**1,0000**	**0,9334**	**1,0000**	**1,0000**	**0,9829**	**0,0265**
Stadtwerke Greifswald	*0,9520*	*1,0000*	*1,0000*									
		1,0000	*0,9896*	*1,0000*								
			1,0000	*1,0000*	*1,0000*							
				1,0000	*1,0000*	*1,0000*						
					1,0000	*1,0000*	*1,0000*					
						1,0000	*1,0000*	*0,9933*				
							1,0000	*0,8997*	*1,0000*			
								0,8977	*1,0000*	*1,0000*		
	0,9520	**1,0000**	**0,9965**	**1,0000**	**1,0000**	**1,0000**	**1,0000**	**0,9302**	**1,0000**	**1,0000**	**0,9879**	**0,0239**
Stadtwerke Gütersloh	*0,9864*	*1,0000*	*1,0000*									
		1,0000	*1,0000*	*1,0000*								
			1,0000	*1,0000*	*0,9662*							
				1,0000	*0,9686*	*0,9671*						
					0,9223	*1,0000*	*0,8342*					
						1,0000	*0,8448*	*0,9494*				
							0,7469	*0,8461*	*0,8280*			
								0,8426	*0,8279*	*0,8451*		
	0,9864	**1,0000**	**1,0000**	**1,0000**	**0,9524**	**0,9890**	**0,8086**	**0,8794**	**0,8280**	**0,8451**	**0,9289**	**0,0753**
N-Ergie	*1,0000*	*0,9805*	*1,0000*									
		0,9828	*1,0000*	*1,0000*								
			0,9577	*0,9683*	*1,0000*							
				0,8989	*1,0000*	*1,0000*						
					1,0000	*1,0000*	*1,0000*					
						1,0000	*1,0000*	*1,0000*				
							1,0000	*0,9283*	*1,0000*			
								0,9231	*1,0000*	*1,0000*		
	1,0000	**0,9817**	**0,9859**	**0,9558**	**1,0000**	**1,0000**	**1,0000**	**0,9505**	**1,0000**	**1,0000**	**0,9874**	**0,0183**
Stadtwerke Magdeburg	*1,0000*	*1,0000*	*1,0000*									
		1,0000	*0,9767*	*1,0000*								
			0,9747	*1,0000*	*1,0000*							
				1,0000	*0,9763*	*1,0000*						
					0,9523	*1,0000*	*1,0000*					
						1,0000	*1,0000*	*1,0000*				
							1,0000	*1,0000*	*1,0000*			
								1,0000	*1,0000*	*1,0000*		
	1,0000	**1,0000**	**0,9838**	**1,0000**	**0,9762**	**1,0000**	**1,0000**	**1,0000**	**1,0000**	**1,0000**	**0,9960**	**0,0082**

Table 9: Results of data envelopment analysis (VRS-I), own table

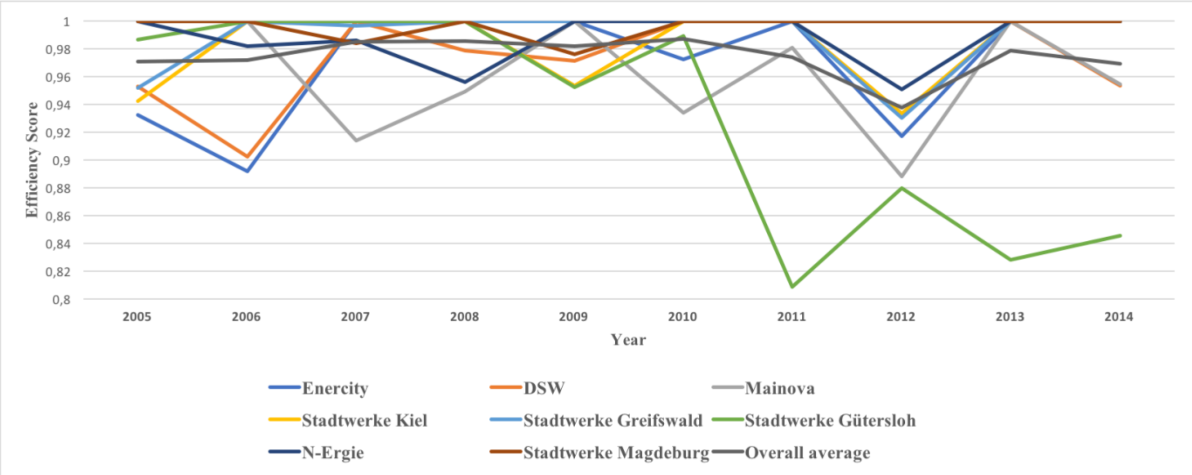

Figure 22: Visualization of average DEA efficiency scores (VRS-I) per company, own graphic