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Decision making models in energy projects: Impact of OPEX on results of Life Cycle Cost Analysis in feasibility studies

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Abstract

Long-term strategic investment decisions are associated with high costs and risks. The decision-makers need a solid foundation to judge the best alternative for an investment project. In every sector of business, strategic decisions are taken. The natural gas industry in Germany has made considerable expenditures in gas infrastructure and will continue in future. A considerable part of the investment goes into compressor capacity. To avoid misallocation of funds the optimal alternative for compressors must be identified.

Gas suppliers employ a decision-making methodology based on Life Cycle Cost (LCC) analysis in conjunction with the NPV technique to choose the best compressor option. In feasibility studies, several options are evaluated in this way.

In this publication seven feasibility studies have been examined. The goal of these studies is to determine the optimum alternative for an investment project in the natural gas industry. The ranking is determined by the calculated NPVs which is based on relevant input data.

The quality of input data and its forecasting have a significant impact on the results and can even change the ranking of the options.

This publication examines the question of how reliable the results in the feasibility studies are.

First, the model calculations are reproduced, and the model verified. In the second step, the applied input data are replaced by real historical input data in the model in order to assess the effects on the calculation of the NPV.

Sensitivity analysis is applied on relevant input data. Measures for risk mitigation are proposed.

Keywords: Life Cycle Cost Analysis, Net Present Value Method, Operating expenditure, Cost drivers, Feasibility studies, Sensitivity analysis

JEL codes: C82, D81, G11

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1. Introduction

Long-term strategic decisions are accompanied by significant costs and risks (Crundwell, 2008). The decision-makers need a solid foundation on to base their judgement on the best alternative for an investment project.
This broad term also refers to significant investments in natural gas infrastructure in Germany.
By 2028, Germany's gas suppliers will have invested over €7 billion. On March 20, 2019, Gas Transmission System Operators (FNB) released a press statement announcing the news. (FNB, 2019)
Compressor station investments account for a significant share of the total, which frequently exceeds €100 million. Being the primary components, compressors contribute to around 20-30% of that total.
For picking the correct option for compressors, gas suppliers use a decision-making model built on Life Cycle Cost (LCC) study in conjunction with the NPV.
NPV is an often-used tool for making a stable base for decision-making for significant investments. Mackevičius and Tomaševič (2010) states that IRR and NPV are most commonly employed in appraising investment tasks built on discounted cash flow. The prevalence of these approaches in practice differs from 70% - 100%, and Scholleová et al. (2010) comes to a similar result.
LCC analysis is widely used in some business areas, i.e., in the hydrocarbon industry and thus in the natural gas industry.
Life Cycle Cost analysis is established in some codes and standards such as ISO 15663 "Petroleum and natural gas industries – Life Cycle Costing" or NORSOK O-CR-001/002 "Life Cycle Cost for systems and equipment" (001) and Life Cycle Cost for facilities" (002). Both NORSOK standards are withdrawn, and ISO 15663 remains as a relevant standard. NPV is implemented in this analysis process.
Korpi and Ala-Risku (2008) reviewed LCC cases stated in theoretical, and practitioner works. They found that most of the stated LCC cases were far from ideal, and the review highlights the difficulty of conducting reliable LCC analysis.
In the literature, feasibility studies on the appraisal of significant investment projects are rarely available. It also applies to feasibility studies conducted after LCC for gas infrastructure investment proposals in Germany.
In terms of analysing the dependability of results and risk assessment, there is no systematic examination of feasibility studies based on LCC in Germany's gas infrastructure in the literature.
LCC analyses energy and maintenance expenses as part of an investment's operating costs (OPEX). Valid input data is essential but predicting how to input data will evolve in the future is much more difficult.
The result and recommendation for the best suitable option depend upon the quality of input data and their development prediction.
Six feasibility studies prepared by experts from consulting companies and one case study published in a scientific journal were examined.
The goal of the feasibility studies is to determine the optimum choice for a particular operational scenario. The veracity of the chosen input data was investigated in the feasibility studies. To this end, the assumptions made in these studies on energy prices and their evolution are compared to actual, historical data on energy costs from today's perspective. The study's mathematical models are recreated for this purpose, and actual energy costs are utilised as input values. It is feasible to analyse the ranking of the choices in feasibility studies using this technique. The applicable energy costs and evolution

heavily influence the best option or the sequence in which the options are presented. In addition, although maintenance expenditures are not the cost driver, they are incorporated in the analysis.

2. Literature review

2.1. Decision making

Decision-making is an essential aspect of practically every situation, and decisions must be taken in all corporate processes and at every management level of an organisation. In an organisation, making a choice is a complicated combination of personal psychology, group dynamics, context, information availability, and self-interest. These judgments are either pre-programmed or not. (Crundwell, 2008).
The meaning of programmed is that a procedure for decision-making is incorporated in the organisation.
Scholleova et al (2010) has carried out an empirical research on investment decision making in Chech Republic in a form of questionnaire investigation. They outline that criteria of evaluating capital projects can be divided in two groups – static and dynamic criteria. The responds of 252 questionnaires we evaluated with the result that 75% use static criterion only. Only 22% use dynamic criterions. Comparison with the results of foreign countries (US, GB, Sweden, Finland) reflects a considerable higher rate of dynamic criterions in those countries. However, the research shows that the choice of criterion is beside others affected by the size of the company. But also, other characteristics may affect the use of dynamic criteria.

In the natural gas business of Germany, the decisions on major investment projects are based on feasibility studies (Homann, 2017), and experts prepare these feasibility studies for experts. In consequence, the natural gas industry in Germany makes decisions on structured models comprising economic and technical criteria and by following LCC and NPV as the commonly used discounted cash flow method.

2.2. Discounted cash flow in investment projects

NPV is the prime instrument for creating a firm basis for decision making for major investments. In many articles it is compared to other methods of dynamic investment methods such as IRR (Internal Rate of Return). Also, sensibility analysis are state of the art. In practice the prevalence of this methods varies from 70% to 100% (Mackevičius and Tomaševič, 2010) what demonstrates the importance and common acceptance.
NPV embedded in life cycle costing provides a structured approach for decision making in investment projects.

2.3. Life cycle cost analysis (LCCA)

“The idea behind life-cycle cost analysis (LCCA) is that capital investment decisions should be based on costs over lifetime of the investment, including operations and maintenance, and not just on initial capital cost. The lowest long-run cost is not necessarily achieved by the lowest initial capital expenditure, even when future costs are discounted. (Lee, 2002)

Life Cycle Cost analysis is established in codes and standards such as ISO 15663 “Petroleum and natural gas industries – Life Cycle Costing” part 1 -3 as an international standard. The German standard VDI 6025 “Betriebswirtschaftliche Berechnungen für Investitionsgüter und Anlagen” is a comparable approach to ISO 15663.
LCC is relevant for decision making in strategic management in general and is used to answer a broad set of questions in production processes. LCC is used in particular to find the best option for an investment project.
Life cycle cost analysis (LCCA) shall not be mixed with life cycle assessment (LCA). LCCA has an economic approach. LCA, as one of the techniques of environmental management, is recognized and recommended as a tool for assessing environmental projects (Kulczycka and Smol, 2016)
LCCA is based on codes as mentioned above and LCA follows i.e EN ISO 14040.

2.4. Case studies

In many companies decision making follows established procedures. Most companies apply discounted cash flow methods and LCCA. Reviews of academic and practitioner literature (Korpi et al, 2008) revealed that most LCC cases were far from ideal and difficulties in conducting reliable LCC cases were found.
In general, case studies which are prepared by experts are assigned by companies, in this case by the owners the gas infrastructure. The case studies are prepared by consulting firms. These case studies are not publicly available.
This may be the reason why the assessment of case studies about the evaluation of major investment projects in Germany`s infrastructure could not be found in literature.
A systematic evaluation of case studies which are based on LCC in Germany`s gas infrastructure in terms of examining the reliability of results and risk assessment is not provided in literature.
In this paper, conducted case studies are examined in the above-mentioned respect. The results and findings can apply not only to German gas infrastructure, but to energy projects in general. Authors of feasibility or case studies for other business fields face the same difficulties as the authors of the case studies analyzed in this work.

2.5. Terms, definitions, and abbreviations

Various terms, definitions and abbreviations are used in this paper. These are explained in the following.

LCC
Life Cycle Cost (LCC) is defined rather broadly as “an economic method for assessing all (direct; indirect, internal, and external costs) and revenues (cash flows) arising within a defined life cycle considered important to the investment decision and project evaluation (Ilg et al., 2017).
A brief definition of LCC is provided in EN ISO 15663-1: discounted cumulative total of all costs incurred by a specified function or item of equipment over its life cycle

NPV
Net present value (NPV) presents the sum of net cash flows of an investment project reduced to the present value by discounting (Rosenzweig and Volarevic, 2010)

A brief definition of LCC is provided in EN ISO 15663-1: sum of the total discounted costs and revenues

DCE

Discounted cumulated expenditure (DCE) represents the NPV based on CAPEX and OPEX. Revenues are not considered, as they are the same for all candidate options for the defined operating cases.

DCE can be considered as total cost of ownership (TCO) comprising CAPEX and OPEX.

Discount rate

OPEX (Operational expenditure)

OPEX is the operational expenditure that is spent to operate the system during the life span of the chain (Kim et al., 2016)

A brief definition of OPEX is provided in EN ISO 15663-1: money used for operation and maintenance, including associated costs such as logistics and spare.

Energy costs are the cost drivers in the feasibility studies, followed by maintenance costs.

CAPEX (Capital expenditure)

A brief definition of CAPEX is provided in EN ISO 15663-1: money used for purchase, install and commission a capital asset.

The time frame for purchase, installation and commissioning is over several years and CAPEX is subject to discounting.

Interest Rate or discount rate

The interest rate is usually given as a percentage per time period. It is used in the NPV method to discount all of the payments. For simplicity, it is assumed that payments are made at the end of the relevant year

Escalation factor

The escalation factor is a percentage factor per time period (i.e. per year). The expression is used as a synonym for inflation rate.

The inflation rate is calculated from the increase in the price of certain goods and services on which an average end consumer spends money over the course of the year (de.statista.com). In the feasibility studies it is used to forecast the development of OPEX.

2.6. Compressors and drivers

Compressors are the centerpieces within gas supply systems. Their main task is to build up the required pressure level to compensate for dropping pressure due to pipe friction losses.

Depending on the task, turbocompressors or reciprocating compressors are used. In the transmission system, turbocompressors are usually used because of moderate compression ratios (about 1.2 to 1.5) and large transport volumes (Glas et al. 2019).

Either gas turbine or electric motors can be used to drive turbocompressors. Gas turbines are fired with natural gas, which they take directly from the pipeline system. Electric motors are supplied with electrical energy.

Because of different speeds, a gearbox is installed between the turbo compressor and electric motor. This is usually not the case with the turbo compressor/gas turbine combination because of matching speed.

A special form of the turbo compressor/electric motor combination is a high-speed, hermetically sealed turbo compressor with an electric motor, which are integrated in one housing. The magnetic bearing of the shaft allows high speeds.
Manufacturer names for this special form are HOFIM, MoPiCo or HighSpeed Electric Moto-Compressor.
Reciprocating compressors (recips) are not driven by gas turbines because of their low speed, but with gas engines, if natural gas is used as the energy.
However, reciprocating compressors can also be combined with electric motors if electric power is used as energy. Due to the high-pressure ratio that reciprocating compressors can build up, they are mainly used in underground natural gas storage facilities.
For the above technical reasons, the following compressor/drive combinations are typically investigated in the feasibility studies:

- TC+GT: Turbocompressor + Gasturbine
- TC+EM Turbocompressor + electric motor, conventionel
- Recip +GM reciprocating compressor + Gas engine
- Recip+EM reciprocating compressor + electric motor
- HOFIM/MoPiCo High Speed Turbocompressor with electric motor and magnetic bearing.

These combinations are assessed in the feasibility studies and thus in this paper.

3. Material and Methods

3.1. Archival Analysis

The approach of gathering and interpreting empirical data is known as archival analysis (Doering, 2016). Extant documents as well as one research-generated document will be examined in this paper. Six (6) unpublished feasibility studies are extant documents. One publication that focuses on compressor driver selection is subject to analysis and is based on LCC and NPV.
The feasibility studies and the publication are aimed at determining the optimum investment project alternative. They proceed in the order of LCC and NPV calculations.
Quantitative data analysis will be used to examine the influence of the input data quality on the results of the feasibility studies.

3.2. Material

Table 1: Studies, consultants, and compressor stations

Study	Year	Consultant 1	Consultant 2	Consultant 3	Consultant 4	Author
1	2008	CS 1				
2	2012		CS 2			
3	2014		No LCC conducted			
4	2015			CS 4		
5	2015			CS 5		
6	2015				CS 5	
7	2005			CS 6		
8 Paper	2001					CS 7

The investment in compressors is a long-term investment and is associated with considerable monetary resources. In the decision-making process, the gas suppliers rely on feasibility studies. Most studies follow Life Cycle Calculation (LCC) as outlined in ISO 15663. LCC analysis aims to find the best option for an investment project.
The influence of input data quality on the outcome of an LCC analysis in feasibility studies is investigated in this study.
Experts from consulting firms conducted the feasibility studies, which were then reviewed by experts from natural gas suppliers. These feasibility studies represent expert opinions.
In the analysis, one article on the same subject published in a scientific journal is included. The six studies that were assessed were completed between 2005 and 2015. In addition, one article from 2001 is being scrutinized. Seven (7) studies were evaluated in total.
Five (5) different consultants prepared the studies for seven (7) compressor gas stations in Germany.

It should be noted that,

- Consultant two has executed two studies for two different compressor stations in 2012 and 2014. Therefore, study 3 does not include an LCC analysis in conjunction with NPV calculation and is not subject to the assessment.
- Consultant 3 has executed three studies for three different compressor stations in 2005 and 2015.
- One gas supplier has asked two consultants to prepare individual studies for the same compressor station (GS 5). This provides an excellent comparison of the input data and the LCC analysis and NPV calculation results.
- Experts execute the studies for experts. This represents expert opinion for compressor stations.
- Study seven is related to a compressor station in Austria and applies energy costs for Austria and not Germany.

All these studies are available for analysis in full text.
The LCC analyses of the feasibility studies are examined, although the examination is omitted for study three, as no LCC analysis was applied in this study.
Details about the evaluation of energy costs and maintenance are discussed separate papers

3.3. Method

The case studies examined include a detailed and comprehensible calculation of the NPV within an LCC analysis. The input data for the feasibility studies are defined. It has in particular:

- Period under consideration (time period)
- Interest rate
- Escalation factor or inflation rate (both terms are used in the studies)
- CAPEX
- OPEX, consisting of
  - energy costs, calculated
  - from energy prices and
  - operating hours
  - maintenance costs
  - costs for CO_2 certificates

The time period, interest rate, and escalation factor are assumptions the consulting firm and the customer agree upon, and they frequently reflect the gas suppliers' estimates and expectations. Because suppliers are hesitant to disclose the internal interest rate, the computations are often done for various discount rates.
The table below shows the time period in each study and the start of the LCC calculation as applied in the studies and in the re-calculations. The start of operation and thus the start point of energy consumption is provided in right hand column.

Table 2: Time period for LCC and years of starting operations

Study	Year of publication	Time period in study	Start of LCC calculation and commissioning
1	2008	23 years	time period: 2011 – 2020 Ready for operation: mid 2011 Start operation: mid 2011
2	2011	18 years	time period: 2012 -2020 Ready for operation: 2014 Start operation: 2015
3	2014	No NPV calculation	Ready for operation: 2017 Start operation: mid 2017
4	2015	33 years	time period: 2015 -2020 Ready for operation: 2018 Start operation: 4th quarter 2018
5	2015	25 years	time period: 2015 -2020 Ready for operation: 2018 Start operation: 4th quarter 2018
6	2015	25 years	time period: 2018 - 2020 Ready for operation: 2018 Start operation: 2019
7	2005	20 years	time period: 2007 -2020 Ready for operation: 2007 Start operation: 2008
8	2001	10 years	time period: 2004 -2014 Ready for operation:2004 Start of operation 2005

CAPEX, or capital expenditures, is usually established by making budget pricing enquiries with manufacturers. The technical requirements are stated in the budget price inquiries, and the manufacturers submit a project-specific quote for the technical plant that is tailor made for the demands. This method achieves a high level of accuracy for estimated investment expenses of around +25%.

Another approach to determine OPEX is based on parameters and factors (Feasibility study 4, 5, and 7 of consultant 3). This approach of assessing investment expenditures has a lower accuracy than budget price inquiries.

The calibration of the parameters and variables is dependent on the authors' expertise and knowledge of the costs of executed projects. It is known that for study 5, the actual costs after end of the project match the projected expenses well.

The main cost drivers in terms of operational costs are energy prices. However, in addition to energy prices, the forecasting of cost development is fraught with uncertainty. This issue has been addressed in another paper.

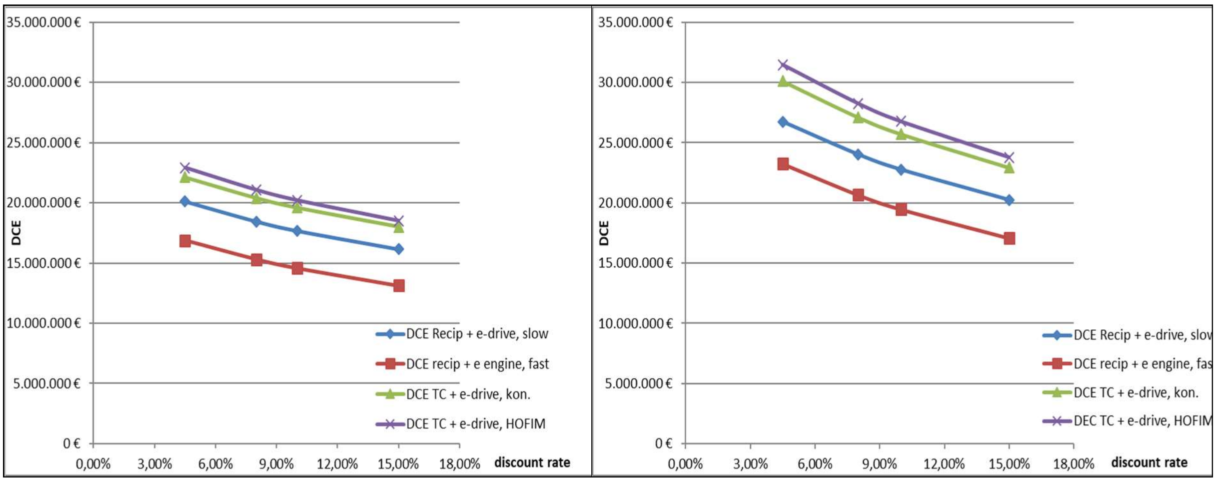
The maintenance cost is frequently described in terms of characteristics related to an operating hour (€/hr). The calculation and evaluation of maintenance expenses is subject to another paper.

All studies, except Study 1, 3, and 8, include expenses for CO_2 certificates. Emission costs are irrelevant in Study 1 since it only looks at electric drives and not gas turbines. The LCC analysis is not used in Study 3, and prices for emissions were not yet considered when Study 8 was completed in 2001.

The computation of energy costs for each option based on working hours, energy prices, and the relevant technical specification of each option is one aspect of a feasibility study. Because this work focuses on LCC /NPV the technical element will not be discussed further.
The authors utilized the a.m. input variables to conduct an LCC analysis in conjunction with the NPV calculations in order to find the best option for the investment.
In typical LCC analysis in the gas sector, just the expenditures are considered. The revenues are the same for all options since the operational regime, namely a transportation task, is defined i.e., by the requested gas demand.
For this reason, the option with the lowest NPV is the most advantageous. In fact, not the NPV is calculated but the discounted cumulated expenditure (DCE).
In the analysis of the feasibility studies, the first step is to replicate the calculation models of the authors' LCC analyses, i.e., the algorithm is replicated. Only when the replication results match those of the authors' calculation models can it be assumed that the repeated algorithm is understood and prepared for the second step.
In the second step, not the authors' input values are used, but the real, historical (from today`s point of view) costs of electrical energy and costs for natural gas.
The same applies to the costs of CO_2 certificates.
Maintenance costs which were provided by manufacturers are used instead of authors` data.
The result of the second step is the present values based on real input values. These present values differ from those of the authors. The present values are calculated for a range of the internal rate of return.
The assessment of results of the LCC analysis which were calculated with different sets of input data indicates the validity of the LCC analysis and the validity of the ranking of the options in the feasibility studies.
The outcomes of the two computations are visually contrasted, using the authors' calculation models but with assumed and with actual historical data from today's perspective.

4. Results and Discussion

The findings of the seven study' computations are contrasted. The results of the computation models are compared with the authors' input values and the actual outcomes for each research (historical values).
In certain studies, calculations are performed for a variety of operating points and a variety of working hours. The impacts can also be seen in the following diagrams.
Essential parameters are provided for each computation situation in the study.
The computed DCE (discounted cumulative expenditures) vs discount rates are shown in each graph.
Figure 1 shows the DCE for different discounting factors in study 1. Over ten years, four compressor driver types are evaluated. The analysis is based on 4,000 operational hours per year and a 3% inflation rate, which is used to discount operating expenses (energy and maintenance). The study does not consider the cost of CO_2 certificates.
Using actual historical input data does not modify the order of economic feasibility of the variations. It is hardly surprising, given that electric motors are the sole ones employed as prime movers and the drivers solely consume electrical energy. Due to the fact that only electric power is consumed, there is no competition between different energies in this study.
The most advantageous of the variants is a recip with electric drive. For an account factor of 6 %, the DCE increases from 15 million € to slightly more than 20 million € for the calculation with real (historical) input data. This is an increase of about 33 % and may affect the decision for an investment.



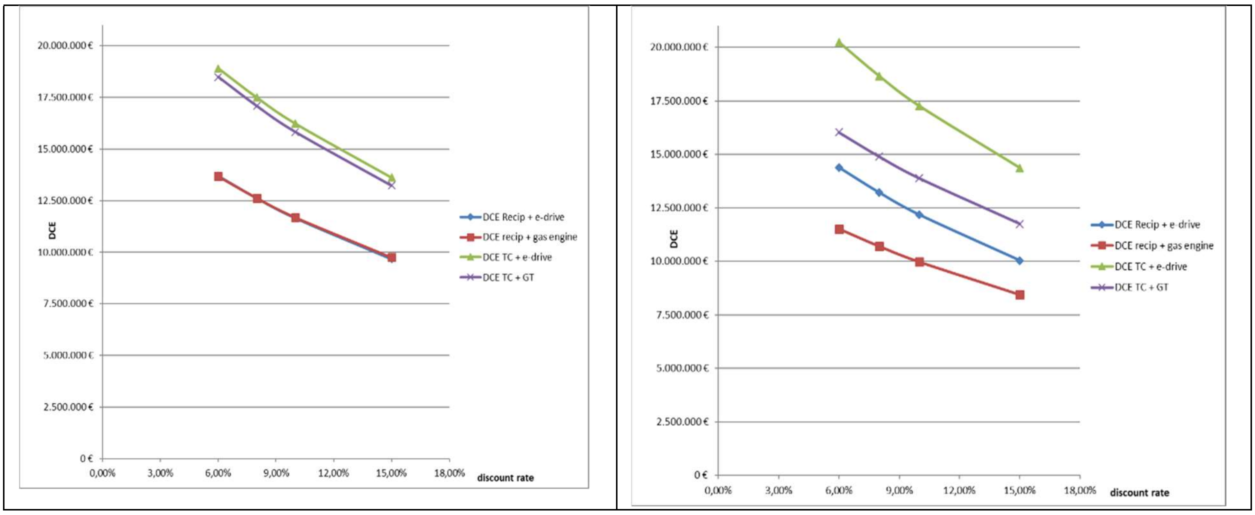
Calculation with author`s data
Calculation with real (historical) data

Recip: reciprocating compressor
TC: turbo compressor
period of time: 10 years (2011 – 2020)

Figure 1: Study 1: DCE vs. discount rate authors input data and real (historical) input data

Figure 2 shows the DCE for different discounting factors in study 2. The DCE for four options, turbo compressor and recip, each coupled with electric and gas drive, has been calculated. The time is nine years. Operating hours are 2,360 per year, with a six-year operating duration and a three-year erection time (combined with CAPEX).

A 2% inflation rate is used as a discount in the study. A price of 15 € per tonne for CO_2 emissions from gas drivers is considered.
With the input data from the study, the DCE of the two recip variants is almost identical. Although the energy price for electric power is 2.8 times higher than the price for natural gas and the CAPEX of the two variants hardly differ, the DCE of the two variants are about the same. This is due to the different efficiencies of the drives, which also differ by a factor of 2.5-3 to the advantage of the electric drive. So, the higher price for electric power is compensated by the better efficiency of the gas drive.
The calculation with actual operating costs does not change the order, but there is a significant advantage for the gas-driven recip. The clear result of the calculation with real prices is due to the significant price difference for electricity and natural gas. With real prices, the factor is between 4 and 7.7 in 2020. The calculation with real values leads to a clearer result in the ranking.

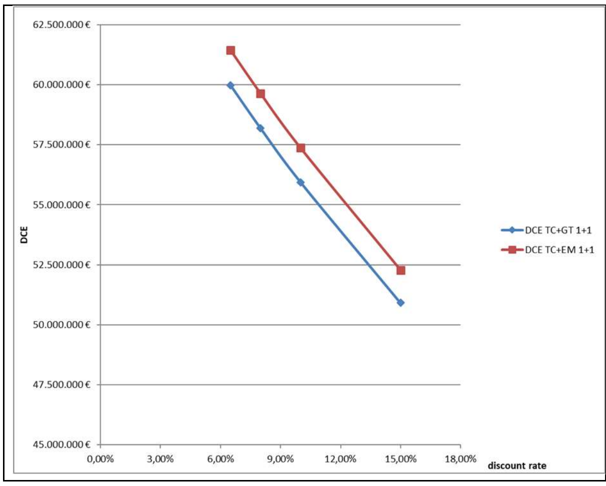


Calculation with author`s data Calculation with real (historical) data

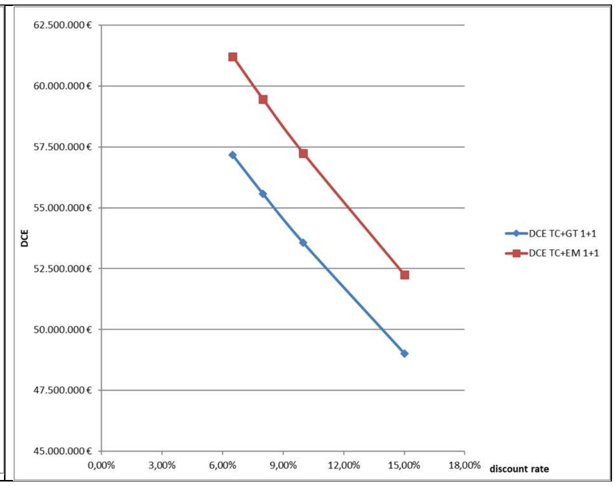
Recip: reciprocating compressor
TC: turbo compressor
GT: gas turbine
period of time: 9 years (2012 – 2020)
operating hours: 2,360 per year

Figure 2: Study 2: DCE vs. discount rate authors input data and real (historical) input data

Figure 3 compares the results of the calculations of study 4. The time period in study 4 is six years (2015 - 2020). It results in only 2.75 years in which operating costs are calculated. Three years represent erection and related CAPEX. The calculations are carried out with 1,250 and 5,000 operating hours per year. Since the operating period is short, the OPEX are low compared to CAPEX. Therefore, the different energy prices and the costs for maintenance do not have a substantial impact.
Nonetheless, even in this short time, the utilisation of actual costs results in apparent changes in discounted expenses. This effect is, as predicted, stronger at 5,000 operating hours per year than at 1,250 hours per year. The turbo compressor with gas turbine drive is the chosen option in the analysis and computation using actual values, and the benefit becomes evident at 5,000 working hours for computation with actual values.

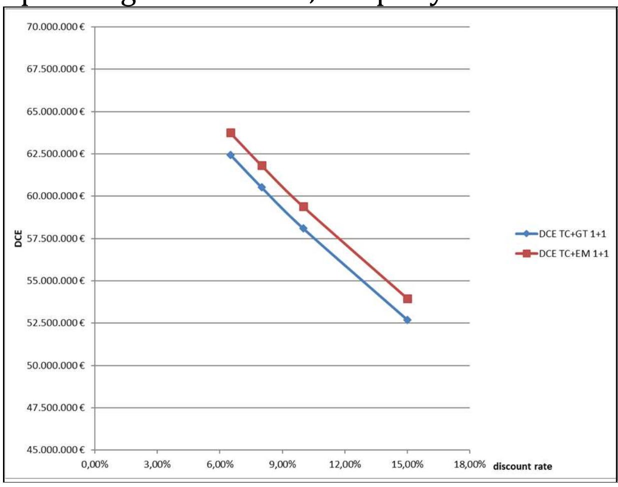


Calculation with author`s data



Calculation with real (historical) data

TC: turbo compressor
EM: electric drive
GT: gas turbine
period of time: 6 years (2015 – 2020)
operating hours: 1,250 per year



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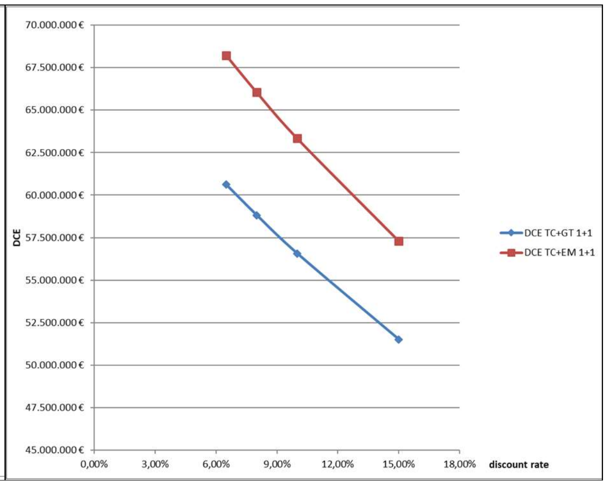


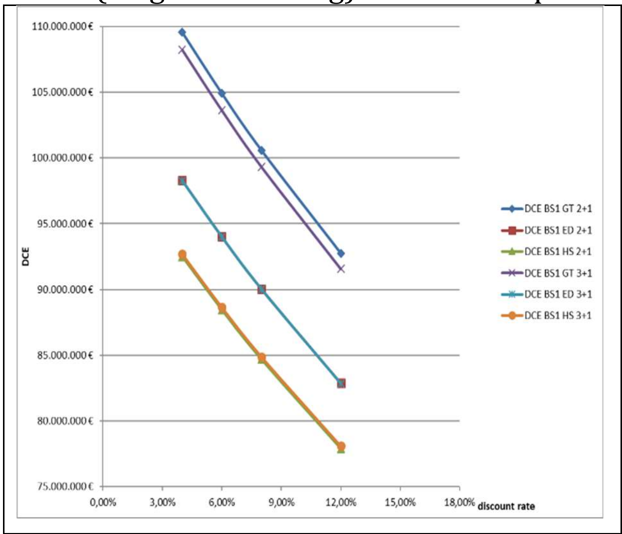
Calculation with real (historical) data

TC: turbo compressor
EM: electric drive
GT: gas turbine
period of time: 6 years (2015 – 2020)
operating hours: 5,000 per year

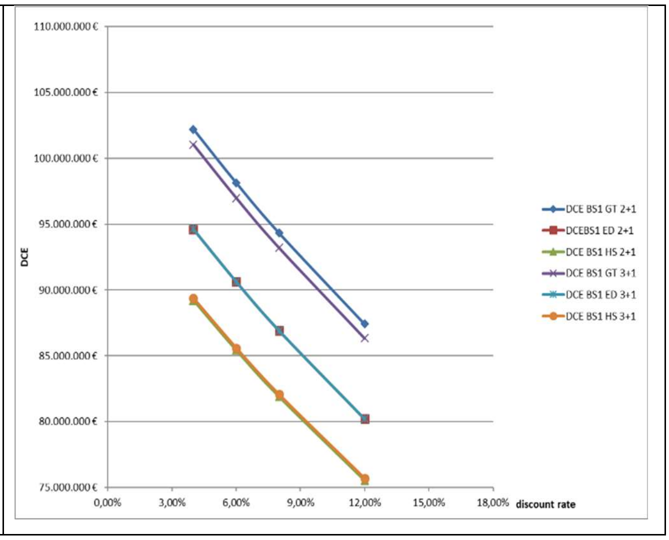
Figure 3: Study 4: DCE vs. discount rate authors input data and real (historical) input data, 1,250 and 5,000 operating hours

Figure 4 presents the calculations of study 5. Here, too, the period under consideration is six years (2015 - 2020), whereby the operating time also contains only 2.75 years. This

study also assumes different operating hours per year, namely 2,000 and 4,000 working hours each year.
With 2,000 working hours each year, there are hardly any differences between the calculations. The short operating phase of 2.75 years with low operating hours gives the CAPEX the dominant share of DCE. However, the same with 8,000 operating hours already shows apparent effects, and the DCE of the options are close together.
For both 2,000 operating hours and 8,000 operating hours, the options with electric drive are the preferred variants. However, the advantage melts away at high operating hours in both calculations. Nevertheless, the calculations in the study and the calculation with actual values show hardly any differences since the energy costs on which the study is based do not deviate significantly from the actual values. The variant with the high-speed motor (magnetic bearing) remains the preferred variant.

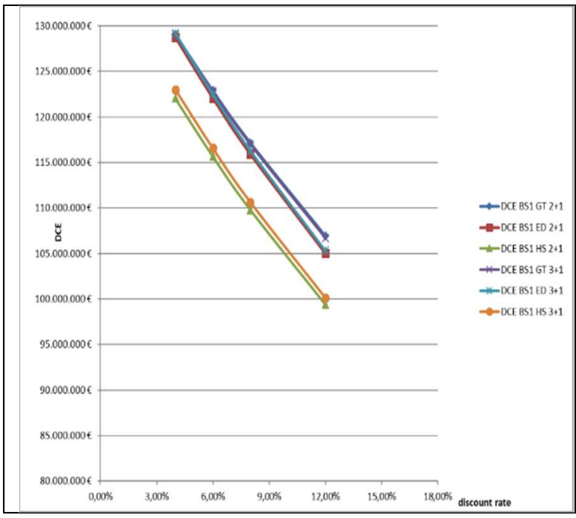


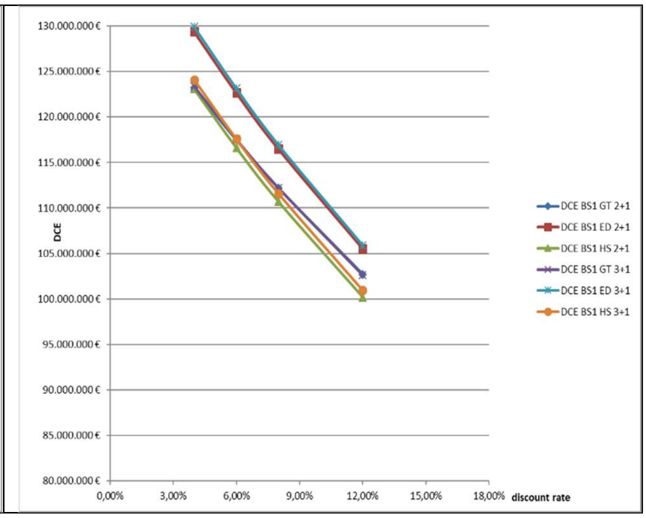
Calculation with author`s data



Calculation with real (historical) data

TC:	turbo compressor
HS	high speed turbo compressor (with e-drive)
ED:	electric drive
GT:	gas turbine
2+1, 3+1:	arrangement, units in operation and stand-by
period of time:	6 years (2015 – 2020)
operating hours:	2,000 per year



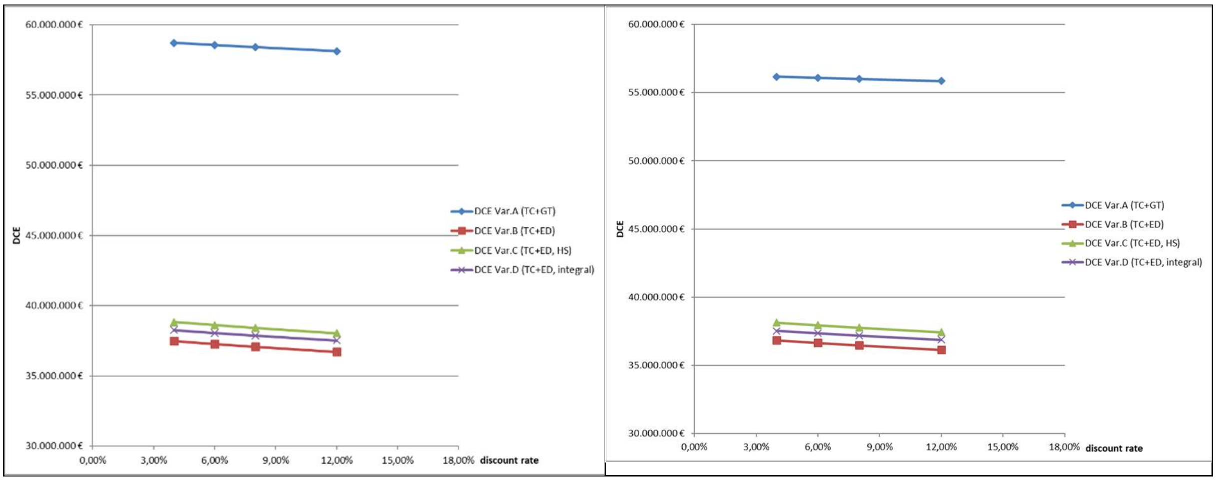


Calculation with author`s data Calculation with real (historical) data

TC: turbo compressor
HS high speed turbo compressor (with e-drive)
ED: electric drive
GT: gas turbine
2+1, 3+1: arrangement, units in operation and stand-by
period of time: 6 years (2015 – 2020)
operating hours: 8,000 per year

Figure 4: Study 5: DCE vs. discount rate authors input data and real (historical) input data, 2.000 and 8,000 operating hours

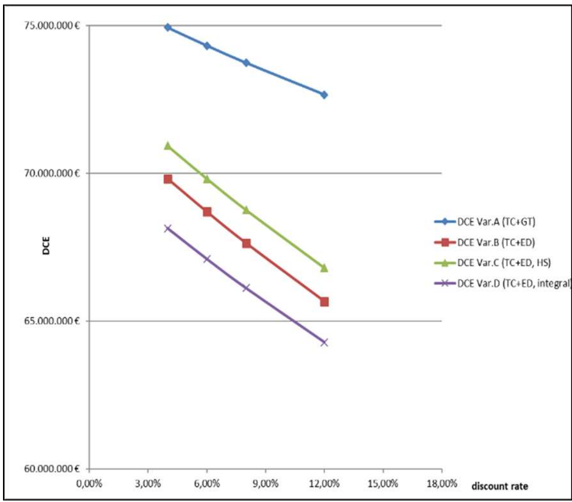
Figure 5 shows the results of study 6 for 1,260 and 8,000 operating hours. The time period is only three years. For the lower operating hours, the DCEs for turbo compressors with different e-drive types are close to each other - the variant with gas turbine drive is significantly higher. The reason for this lies in CAPEX, which are approx. fifty-three million € for the gas turbine variant and approx. thirty million € for a variant with its e-drives.
With operating hours of 8,000, the picture changes, mainly when calculating with actual values. The variant with gas turbine becomes the second cheapest variant (with a discount factor of 4 %). The ranking already changes for two years of operation when calculating with actual values.
The operating costs for the gas turbine variant are significantly lower. The efficiency of the gas turbine is only about 30 % of the efficiency of the electric drive. The price for electricity in the study is 5.75 times higher than for natural gas and overcompensates for the poorer efficiency. The actual prices even show a factor of 6.9.



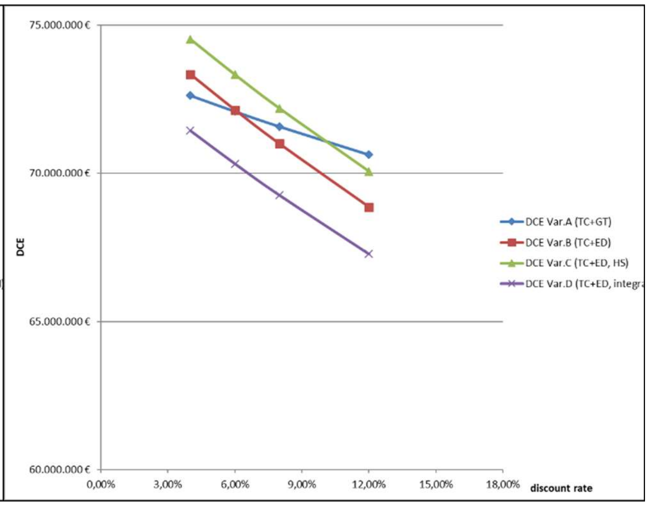
Calculation with author`s data Calculation with real (historical) data

TC: turbo compressor
HS high speed turbo compressor (with e-drive)
ED: electric drive
GT: gas turbine
integral: TC+ED, high speed, in one casing
period of time: 3 years (2018 – 2020)

operating hours: 1,260 per year



Calculation with author`s data



Calculation with real (historical) data

TC:	turbo compressor
HS	high speed turbo compressor (with e-drive)
ED:	electric drive
GT:	gas turbine
integral:	TC+ED, high speed, in one casing, comparable to MoPiCo
period of time:	3 years (2018 – 2020)
operating hours:	8,000 per year

Figure 5: Study 6: DCE vs. discount rate authors input data and real (historical) input data, 1,260 and 8,000 operating hours

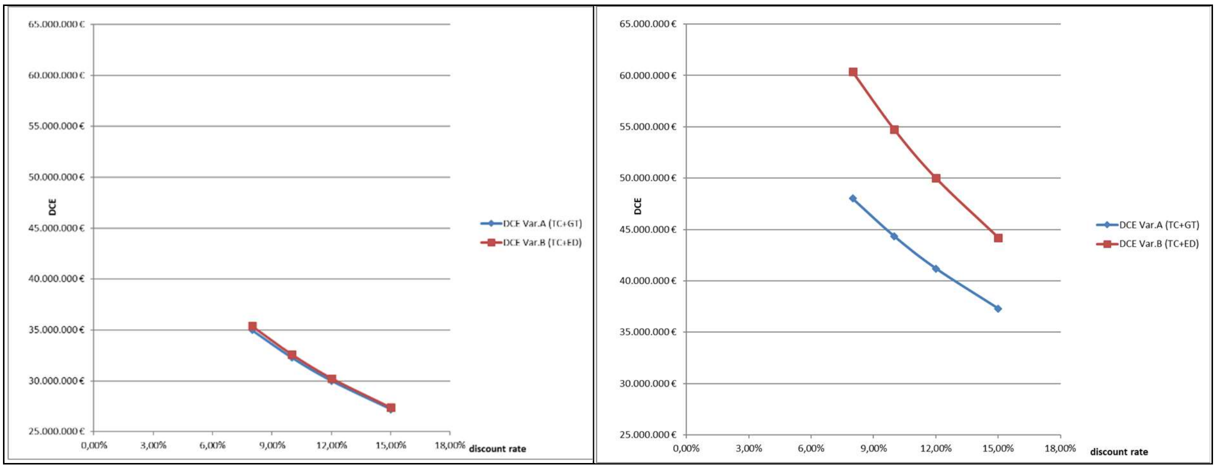
Figure 6 shows the results of study 7. Here, too, the influence of the operating hours (4,000 and 8,000) on the result is evident.

Two options are considered. Option 1 is a turbo compressor with an electric motor, and option 2 is a turbo compressor with a gas turbine drive. The time period is 14 years (2007 - 2020).

The calculation with values from the study does not show a clear picture for either 4,000 or 8,000 operating hours. No preferred option can be identified. Both CAPEX and OPEX (energy costs, costs for CO_2 certificates and maintenance costs) hardly differ in total between the options.

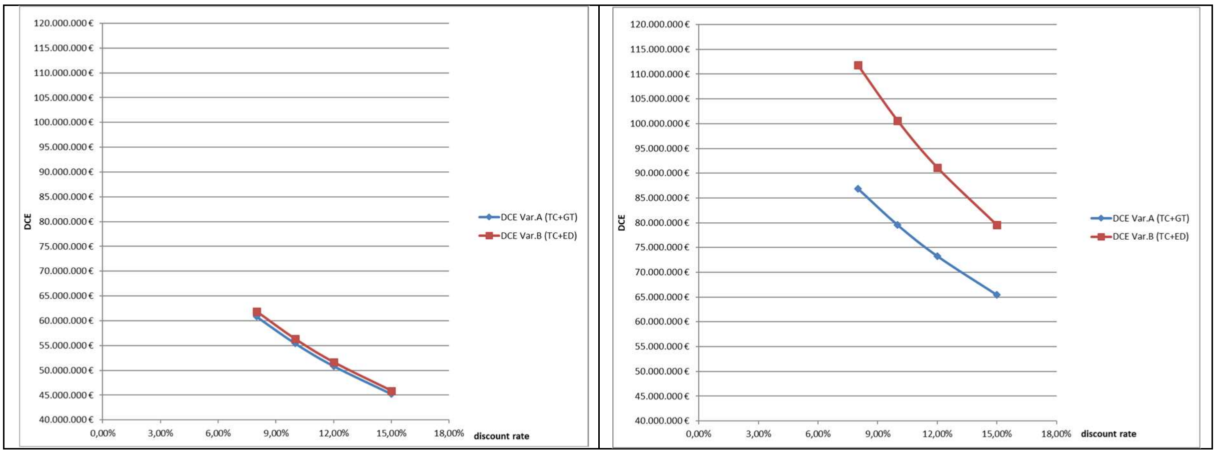
The calculation with the actual values clearly shows the increasing price difference between natural gas and electricity. In comparison, there is a factor of 3.9 between the two energy sources in the study, and in reality, the factor is up to 7.7 in 2020.

The calculation with actual values shows that gas turbine drive is the more advantageous variant, and it applies to the calculation with 4,000 and 8,000 operating hours.



Calculation with author`s data Calculation with real (historical) data

TC: turbo compressor
ED: electric drive
GT: gas turbine
period of time: 14 years (2007 – 2020)
operating hours: 4,000 per year



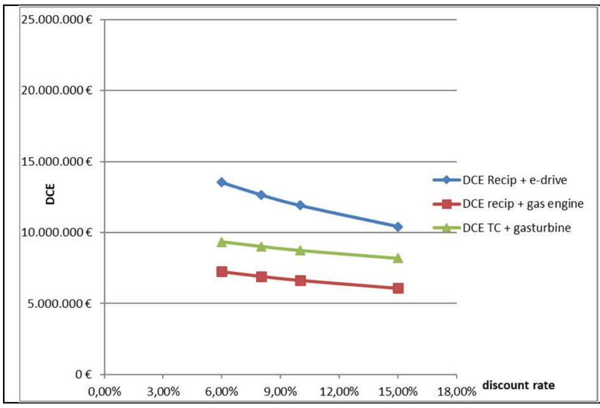
Calculation with author`s data Calculation with real (historical) data

TC: turbo compressor
ED: electric drive
GT: gas turbine
period of time: 14 years (2007 – 2020)
operating hours: 8,000 per year

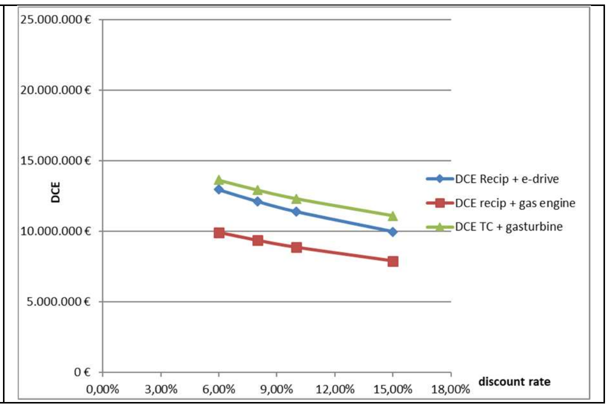
Figure 6: Study 7: DCE vs. discount rate authors input data and real (historical) input data, 4,000 and 8,000 operating hours

Figure 7 summarises the results of study 8. The time period is eleven years (2004 - 2014). The study was prepared for 4,650 operating hours per year. Three options are considered: Recip/gas engine, Recip/e-drive, and turbo/gas turbine. The order of the options changes, but the preferred option remains unchanged.

The prediction of the prices for electric energy is very well made in the study. Therefore, the curve for the e-drive option is almost unchanged.
The price for natural gas was assumed too low by a factor of three. Therefore, the DCE for the two natural gas options increased. Due to the gas turbine's poorer efficiency than the gas engine, the energy costs for the gas turbine are higher.
The calculation with actual input data causes a change in ranking for recip/e-drive and turbo / gas turbine.
DCEs are considerably higher (app. 30%) for the options with gas drivers. The too low DCE calculated with study data could lead to a decision what may be not supported by DCEs calculated with real data.



Calculation with author`s data



Calculation with real (historical) data

Recip:	reciprocating compressor
TC:	turbo compressor
period of time:	11 years (2004 – 2014)
operating hours:	4,650 per year

Figure 7: Study 8: DCE vs. discount rate authors input data and real (historical) input data

5. Conclusion

Seven feasibility studies performed by experts from consulting firms between 2001 and 2015 were analysed in this article. Following ISO 15663, the goal of these feasibility studies is to select a preferable option among a set of investment possibilities. CAPEX and OPEX (energy and maintenance expenditures) are calculated and discounted using the NPV method.
The first step is to replicate the calculation models of the authors' LCC analyses, i.e. the algorithm is replicated. In the second step, not the authors' input values are used, but the real (historical data from today`s point of view) for energy (electricity and natural gas) are applied. Maintenance costs are derived from data provided by manufacturers and processed with real data for inflation rate.
The challenge in estimating energy prices for electricity and natural gas is especially noticeable. This forecast is required since the evolution of energy prices is uncertain when these studies are performed. The authors primarily selected the energy costs at the time of the study's production and used an escalation factor to forecast future cost trends. This escalation factor, which is typically 2% to 3%, is employed during the time under consideration in the feasibility studies. There is no differentiation made between the various energy sources here. However, electricity and natural gas costs differ dramatically, with natural gas growing more slowly or even declining, whilst electricity prices climb significantly (among others caused by taxation for financing the energy transition in Germany)
This paper shows that a calculation with real, from today's perspective, historical values for energy costs leads to divergent results in the determination of the preferred option.
It is shown that the discounted expenditure (DCE) changes significantly, as shown in study 1. Even if the order of the variants remains unchanged in this case, the higher amount of the discounted expenditure could have a decisive influence on the investment's decision.
On the other hand, it can be shown for study 2 that the use of actual values leads to a clear ranking of the options investigated. Using the input data for the study: two variants are indistinguishable in terms of DCE; with actual data, there is a clear preference for a Recip with a gas engine.
Studies 4 and 5 hardly show any differences for the calculations with study values and actual values. The main reason here is the short operating time of 2.75 years (which results from the year of production of the feasibility study), which overweighs the CAPEX compared to the OPEX. Here, using actual values for energy does not lead to any deviating results.
A change in the ranking in study 6 is even more startling. Although the preferred variant (turbo compressor with an electric drive as an integrated machine) stays unchanged, the turbo compressor with gas turbine jumps from fourth to second place in the ranking.
In studies 7 and 2, it is evident that utilising actual values results in an unambiguous ranking. In the feasibility study, the variations investigated are a little distinct in terms of DCE. The gas turbine wins the computation using actual values.
The preferred option remained unaltered in Study 8. The two other options modify their place in the ranking.
The feasibility studies used to select a preferred option for investment in the German natural gas infrastructure do not always result in the optimal variant. The reasons were elaborated on in the previous chapters. The leading causes are not to be found in the

model itself: namely the calculation of the DCE, but in the input values and here, above all, in the expected development of these input values for the future.
Since the expert models in their structure essentially correspond to state of the art, as outlined in publications and relevant codes and standards (especially the ISO 15663), these models do not need to be adopted.
The uncertainties regarding the development of energy prices and inflation factors will remain, and their prediction is associated with uncertainties with influence on the validity of the ranking based on calculated DCE with the NPV method.
Not only uncertainties in macroeconomic data may impose uncertainties on the results. Also, the prediction of operating conditions, i.e., operating hours, will significantly impact the calculation. Operating hours associated with energy prices are a significant cost driver and impact the ranking. The forecast of the operating conditions of the compressors is a demanding task.
Risk assessment and sensitivity analyses must be added to the expert models for risk mitigation.
The following measures are appropriate and are proposed:

- Sensitivity analysis of input data
- Determine a probability range of a set of input data for which an option is best
- Cost driver identification
- Apply standard deviation on the ranking of life cycle costs (ISO 15663, 2)

These sensitivity analysis measures should be used in the investigations to reduce uncertainty.
Economic data and the calculation of NPV (or DCE) are the basis for decision-makers. A complete picture shall include not only economic data but also measures for risk mitigation and sensitivity analysis. The studies must also include technical analyses of options and the characteristics of the gas supplier's operation regime.

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