PEER-REVIEWED PAPER

Bridging barriers for multi-party investments in energy efficiency – a real options based approach for common utility systems design and evaluation

Johanna Mossberg
SP Technical Research Institute of Sweden, Energy Technology, Section for Systems Analysis
Eklandagatan 86
SE-412 61 Göteborg
Sweden
johanna.mossberg@sp.se

Roman Hackl & Simon Harvey
Chalmers University of Technology, Energy and Environment, Heat and Power Technology
Kemivägen 4
SE-412 96 Göteborg
Sweden
roman.hackl@chalmers.se
simon.harvey@chalmers.se

Christian Jensen
University of Gothenburg, School of Business, Economics and Law, Business Administration, Management and Organization
Box 600
SE-405 30 Göteborg
Sweden
christian.jensen@handels.gu.se

Anders Sandoff, Gabriela Schaad, Andreas Furberg & Mattias Haggärde
University of Gothenburg, School of Business, Economics and Law, Business Administration, Industrial and Financial Management
Box 600
SE-405 30 Göteborg
Sweden
anders.sandoff@handels.gu.se
gabriela.schaad@handels.gu.se
a.furberg@hotmail.com
m.haggarde@gmail.com

Keywords
industrial energy saving, corporate investment decisions, cooperation, total site analysis, real options analysis

Abstract
Total Site Analysis (TSA) is a tool for quantifying energy savings targets in large industrial process clusters. Thereafter retrofit design tools can be used to identify efficient solutions in which the different process sites exchange excess energy with each other through the site utility system, thus reducing the overall need for external fuels/energy. Compared to energy efficiency investments identified for single companies, similar investments identified for clusters hold an inherent complexity; they assume joint investments and multi-party collaboration, which often constitute a barrier for implementation. Real Options Analysis (ROA) is a tool that can be used for helping managers to evaluate different investment options. However, previous research almost exclusively concerns single companies/actors and not the increased complexity of joint investments.

This paper presents a novel approach, showing how ROA can be applied not only to handle uncertainties regarding market development but also reduce complexity associated with multi-party cooperation in a joint energy efficiency investments based on TSA.

The approach is applied on a case study of a joint energy efficiency retrofit investment in a Swedish chemical cluster. Using ROA, the case study shows how the identified solution can divided into "investment packages" distributed over time, allowing for an initial investment by only two actors and permitting for an evaluation of both the cooperation and the market development before expanding the investment and the number of actors involved. Further, an economic assessment of the project is presented together with an analysis of the cost/benefit of gradually expanding the investment.

Introduction
In Europe, the industrial sector is responsible for about 30 % of the total energy use and about 20 %[1] of the emissions of fossil CO_2, out of which the energy-intensive process industry (e.g. pulp and paper industry, chemical process industry and iron and steel industry) stand for a significant part (Eurostat, 2009). Consequently, energy efficiency in industry is broadly acknowledged for its importance in e.g. strategy documents, political targets and policy schemes (IEA, 2012, 2013). For the energy-intensive industry as well as the power and heat sector, the energy use, and thus on-site emissions of CO_2, is associated with a limited number of geographical sites. Due to this fact, making changes in the energy system at only a limited amount of industrial sites can have significant impact on the European energy use as a whole and consequently also on the emissions of CO_2. Further, it should be noted that within the energy-intensive industry, the energy use is mainly related to the production processes rather than the support processes and thus reducing the energy use is often a complex task, requiring strategic investment decisions rather than operative decisions.

Research has shown that large volumes of standardized products can be produced efficiently in large vertically or hori-

1. This figure refers only to the actual on-site emissions and not the emissions related to e.g. electricity imported from the grid or transport of raw materials and finished products, which are allocated to the power and the transport sector respectively.

zontally integrated organizations as long as the business does not change over time, i.e., if stable, long-term conditions apply. However, technological development, R&D, rapid market changes and increasing complexity of the products and services demands a different way of defining efficiency. The companies that will succeed under these conditions are those that can make rapid adjustments, be flexible and deliver high quality adaptive efficiency – something that is often achieved through collaboration with other companies and organizations (see e.g. Alter and Hage (1993)). Complex products and processes are often more capital intensive, which further reinforces the need for cooperation to secure the necessary capital and to distribute risks. For the energy-intensive process industry, sustainable development through energy efficiency is an example of a complex challenge which often demands a larger systems approach and collaboration between different actors and/or companies to be tackled efficiently.

The potential for energy efficiency and the implementation of new technologies at a specific industrial site is among other factors influenced by whether the site consists of one isolated plant or several co-located plants, so-called industrial clusters. If situated in an industrial cluster, the industrial plants can make efficient use of common energy and transport infrastructure and/or reduce their total demand for external heating and cooling by exchanging excess heat via a common utility system. Total Site Analysis (TSA) is a tool for quantifying energy savings targets in large industrial process clusters (described by e.g. Raissi (1994); Klemeš, Dhole et al. (1997); Perry, Klemeš et al. (2008)). Thereafter retrofit design tools can be used to identify efficient solutions in which the different process sites exchange excess energy with each other through the site utility system, thus reducing the overall need for external fuels/energy. The potential for utility savings through implementation of a common utility system has been investigated for chemical clusters by e.g. Matsuda, Hirochi et al. (2009); Hackl, Andersson et al. (2011); Stijepovic and Linke (2011). TSA and retrofit design typically treats the actors in a cluster as one business entity and does not consider the complexity of joint investments or multi-party collaboration[2].

Compared to energy efficiency investments identified for single companies, similar investments identified for clusters hold an inherent complexity; they assume joint investments and/or multi-party collaboration. Joint investments and/or multiparty collaboration require that several companies should not only agree about a common investment path but also about its intertemporal distribution. Complicating factors related to joint investments are e.g. conflicting interests among the actors, lack of mandate, different risk appetite, access to funding and competing investments/other priorities[3]. Thus, it is clear that the complexity due to many participating companies and the demand for simultaneous action can be a significant barrier for implementation of joint investments in energy efficiency. One way to overcome these barriers could be to structure the investment so it reduces the exposure to these kinds of complicating factors. This can be done by a reduction of the number of participating companies and/or splitting the investment in several sequential "investment packages" that can be implemented stepwise according to their attractiveness at the time. Both options reduce the exposure to the factors mentioned above, albeit in different ways. The initial transaction cost is reduced in both cases but the second option also reduces the risk for stranded or sunk assets since it allows for an evaluation of both the collaboration and the market development before the next investment is made. A stepwise structure forces the involved stakeholders to openly discuss their assumptions and projections related to the investment and thus contribute to a common formulation and understanding of the project. Such aspects can be at least as important as the technical aspects. Thus, through the use of suitable methods the actors' exposure to the complexities of joint investments can be reduced and the use of these methods can in fact be viewed as a "tool" for facilitating cooperation.

Real Options Analysis (ROA) is a flexible method that can be used for evaluating long-term, complex investments which are influenced by different types of market uncertainties (Copeland and Antikarov, 2001). In the ROA framework, structuring of the investment and identification of options is an essential part. ROA forces stakeholders to be explicit regarding assumptions and projections for the problem formulation and hence can be used in the process of investment strategy formulation. Thus, ROA is a suitable method to use reducing and/or handling the complexities of a joint energy-efficiency investment as described above.

AIM AND SCOPE

This paper presents a novel approach to assess joint investments in energy efficiency by showing how ROA can be applied not only to handle uncertainties regarding market development but also reduce complexity associated with multi-party cooperation in a joint energy efficiency investment identified by different retrofit design options based on TSA.

The approach is applied to a case study of a potential energy efficiency investment in a Swedish chemical cluster. The cluster consists of five companies producing a variety of chemical products. Today, the energy use in the cluster accounts for ~1.2 % of Sweden's emissions of fossil CO_2. Previous studies of the cluster using TSA and retrofit design has shown that up to 50 % of the fuel used in boilers could be saved if the companies invest in a common heat and utility system. However, the stakeholders involved consider the suggested investment to be too complex and are reluctant towards participating in a multi-party set-up.

The paper explores a combined, multi-disciplinary approach and provides some first experience on applying ROA for analysis of how to bridge barriers for a multi-party investment in an industrial cluster.

Methodology

This section briefly presents the theoretical methods which the paper builds upon. Existing methods for heat integration, TSA and retrofit design of process energy systems are presented first and thereafter a short introduction to ROA is given. At the end

2. Many (newer) industrial clusters are interconnected with common utility systems operated by an external part and in that case this is not a significant weakness, yet for (older) clusters without common utility systems it poses a challenge when the suggested systems are to be realized, as discussed in subsequent text.

3. In addition, barriers of technical nature can be e.g. different products, production capacities and operating times.

of the section the suggested combined approach is presented and described.

PROCESS HEAT INTEGRATION, TOTAL SITE ANALYSIS AND RETROFIT DESIGN

Process integration is a holistic method used for process design, where one considers the interaction between the process units and aims at optimizing the whole studied system rather than optimizing each process unit separately. Process heat integration refers to the concept of thermally integrating the heat sources and heat sinks of a process or a system in order to improve the internal heat exchange and thereby reduce the need for external hot and cold utilities. In an industrial cluster, industrial plants have the opportunity to reduce their total demand for external heating and cooling by exchanging excess heat via a common utility system. To be able to apply process heat integration methodology to analyse industrial clusters the Total Site Analysis (TSA) method was developed by Klemeš (1997) and Raissi (1994).

Using TSA, the theoretical energy savings target for a studied energy system (industrial cluster) can be determined. To identify feasible energy savings options for an existing energy system the TSA targeting effort must be followed by application of detailed retrofit design tools (Kemp, 2007). In the retrofit design different retrofit options for realising (parts of) the energy savings target are identified. The retrofit options usually involve modifying existing heat exchangers or investing in new units to achieve increased heat recovery. TSA and retrofit design tools focus on the technical heat transfer aspects of a studied system. Although an economic analysis of investment costs is sometimes included in such studies, issues related to the fact that creating a common utility system may need a common investment raising questions regarding cost and risk sharing between the investors are usually not addressed.

As mentioned in the introduction, the potential for utility savings through implementation of a common utility system has been investigated for both the cluster analysed in this paper and other chemical clusters (Hackl et al., 2011; Matsuda, 2009; Stijepovic, 2011). Most published case studies on TSA and retrofit analysis focus solely on the technical aspects of the results, although some also include rough economic assessments. No discussion of how TSA and retrofit analysis are (or can be) used by companies or clusters as parts of a decision making process have been reported in the related technical literature.

REAL OPTIONS ANALYSIS

Real Options Analysis (ROA) is a tool for economic analysis and evaluation of long-term, complex investments which are influenced by different types of market uncertainties. The ROA approach is sprung from a combination financial options theory and discounted cash flow theory and a key feature of ROA is the ability to incorporate flexibility in the analysis. The purpose of the flexibility is to handle different types of uncertainties, e.g. uncertainties regarding scope and timing can be handled by incorporating options to expand/contract and sequence the investment (Copeland and Antikarov, 2001). One drawback of the method is that it is requires relatively advanced mathematics compared to other more commonly used evaluation techniques cf. discounted cash flow. Another complicating factor is that ROA is a problem specific tool and thus the application has to be tailored for each analysis. This may well explain why the application of ROA to investments by single companies has been limited although suggested by several scholars as a complementary tool to the commonly used evaluation methods today (discounted cash flow analysis, NPV, internal rate of return and payback time) (Sandahl and Sjögren, 2003).

Although identified as a valuable tool, ROA is not extensively used by the process industry sector or by the energy sector although some studies have been made for e.g. valuating oil and mining projects (Armstrong et al., 2004; Colwell et al., 2003). Kihm and Cowan (2009) discuss the benefits of using real options theory for valuation of energy efficiency investments in general, however, to our knowledge ROA has previously not been applied to analyze a joint investment in an industrial process cluster.

COMBINED APPROACH

Through multi-disciplinary collaboration, facilitated by the combination of different academic backgrounds held by the authors of this paper, a novel approach for analysis of joint energy efficiency investments in an industrial cluster has been developed[4]. The approach is a result of the development which unfolded in the case study presented in the latter part of the paper (ex post).

The combined approach utilizes the methods of TSA, retrofit design and ROA and shows how ROA can be applied not only to handle uncertainties regarding market development but also reduce complexity associated with multi-party cooperation in a joint energy efficiency investment. The approach suggests a sequential process which is propelled by dialogue with the industrial stakeholders in which further analysis needs are identified, as illustrated in Figure 1.

The sequential process in which the different methods are applied is equally interesting compared to the specific results generated by the methods. We as researchers have followed this process where the industrial representatives have worked with the joint vision and the energy efficiency project, acting as advisors and experts, focusing on the industrial representatives and their considerations. We observe what happens to the stakeholders' views on barriers and challenges when they use methods such as TSA and ROA (representing technology and finance) and together investigate, discover, clarify and consider different courses of action. We also observe whether the use of the different methods contributes to changed opinions, new considerations or changed positions.

Through the different phases, the theoretical energy savings target first identified by TSA is gradually reduced to a feasible energy savings target (from a joint investment perspective and by using ROA investment strategies are suggested that reduce complexity and risk. In the following, the process and the main parts of the different phases are presented.

4. The work was further facilitated by the fact that the authors have had the opportunity to follow the cluster's collaborative work close to hand over a period of two years. During this time the authors have participated in the cluster's regular meetings (where collaborative strategies and actions are discussed), performed a number of interviews with different stakeholders in the cluster and identified and carried out two student projects in collaboration with the cluster (related to barriers for realizing the joint energy efficiency investment in focus in the case study presented here).

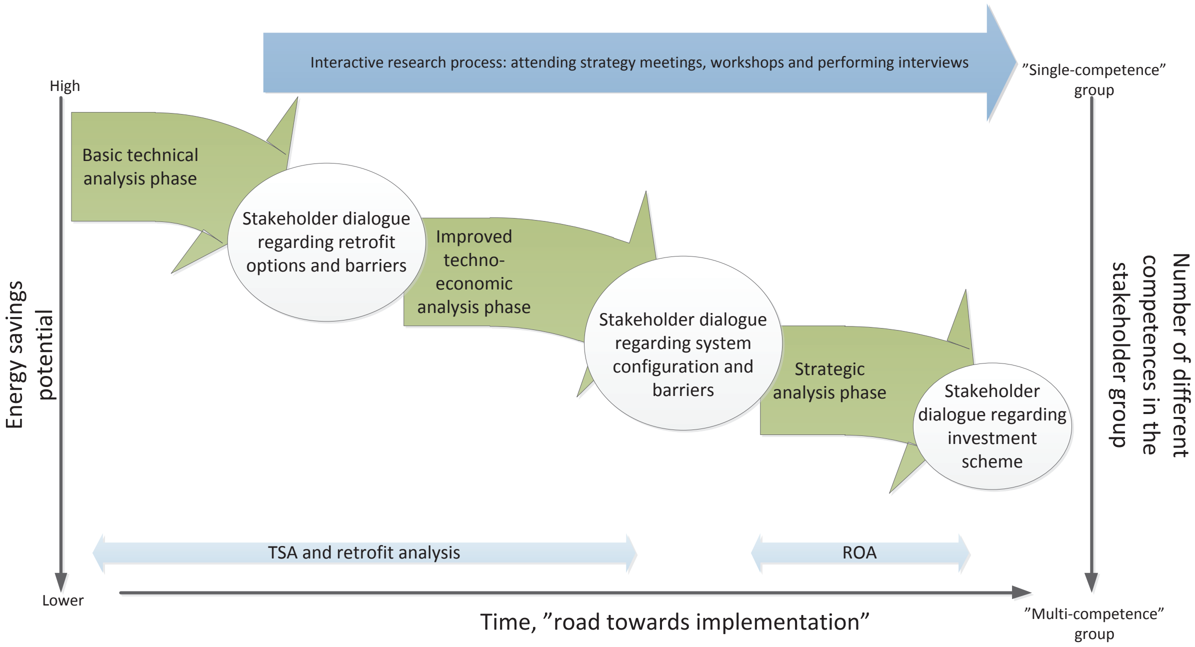


Figure 1. Overview of the sequential process of analysis phases and stakeholder dialogue by which the suggested approach is applied.

Basic technical analysis phase

The process is initiated by the basic technical analysis phase which comprises two steps, TSA and retrofit analysis. As a first step the theoretical energy savings target is determined using TSA (as described in previous section). The theoretical energy savings target cannot usually be achieved in practice since it would demand complete reconstruction of the site's energy system. Retrofit design tools can thereafter be used to identify feasible system configurations. The retrofit options involve new and/or modified heat exchangers for increased internal heat recovery, required to achieve hot utility (steam) savings and consequently fuel. New utility piping and/or fuel piping may also be required.

After this phase the identified retrofit options are analysed and discussed with the industrial stakeholders. At this stage the stakeholder group typically consists of technical personnel from the involved plants. The purpose of the discussion is to conduct techno-economic screening in order to identify feasible retrofit design options. Retrofit options which are deemed too expensive, too space-demanding or not practical for other reasons are screened out. The retrofit options which pass the screening are the ones which are judged to be feasible from a techno-economic perspective.

The basic technical analysis phase usually identifies large energy savings targets. In order to evaluate and compare the different retrofit options and proceed with the investment process the industrial stakeholders usually require a more thorough economic analysis at this stage, as described below.

Improved techno-economic analysis phase:

The retrofit options identified in the previous phase can be combined in different ways, creating different system configurations which fully or partly realise the techno-economic energy savings target. In this phase different system configurations are identified and evaluated. The evaluation is based on cost estimates and economic performance for the different systems, e.g. investment cost and discounted cash-flow rate of return. The aim is to identify cost-efficient system configurations and to compare different configurations based on economic performance and associated energy savings potential.

When one or more promising system configurations have been identified the configuration(s) are discussed with the industrial stakeholders in order to identify potential barriers for implementation. Examples of potential barriers are uncertainties regarding market development, uncertainties regarding other actors' intentions, a large number of actors involved and competing investments. To propel the process the involved actors need to clarify their views and positions regarding the investment. To reduce the complexities and uncertainties related to the investment and to initiate a strategic discussion within the stakeholder group ROA is introduced as a tool in the strategic analysis phase.

Strategic analysis phase

The investments needed to achieve the promising system configuration(s) identified in the previous phase are analysed and restructured into a number of "investment packages". The investment packages are then organized in an investment plan where they are linked and associated with different options (e.g. expansion, retraction and deferring). In the process the potential barriers identified through dialogue with the stakeholders are considered and the investment is structured accordingly. For example, if one potential barrier is the large number of actors (who need to simultaneously agree on joint action to invest) the investment can be structured into a number of packages of smaller investments with a limited (possibly only one or two) actors involved in each investment package, allowing for some actors to initiate the investment and the option for others to join at a later stage. In a similar way, if a potential barrier is uncertainties regarding the future market development of some sort the investment can be structured so that some investment packages are possible to realise at a later stage, allowing for an evaluation of the new conditions and the option not to realise the full investment if the conditions become too unfavourable. Furthermore, some parts of the investment might be excluded to reduce the complexity, e.g. if one actor is associated with only a smaller part of the energy savings potential this actor and the associated investments can be excluded in order to reduce the number of decision makers involved and thus the complexity. This way a system with an equal or smaller energy savings potential is identified but with a much reduced complexity. This structuring exercise is a prerequisite for further analysis and evaluation of the investment with ROA (and also the first step of a ROA). However, it can by itself, without further analysis, contribute to increased understanding and a common view of the investment for the decision makers involved.

After the restructuring the suggested investment scheme is evaluated using ROA. The evaluation is based on economic data output such as real options value (ROV) and NPV. Decision trees are generated which show optimal decisions[5] depending on time and parameter development. In addition, sensitivity analysis can be performed showing the impact of uncertainties in different parameter values, the impact of delayed decisions etc. Analysis can also be made to answer specific questions such as "what is the value of waiting (postponing parts of the investment in order to achieve additional information of e.g. market development)?" or "is it worth to invest in flexibility (to have the option for different decisions in the future)?".

After this phase the results are again discussed with the stakeholder group. The stakeholder group should in this stage preferably include a number of different competences. After the discussions the stakeholders should be able to decide whether to proceed and prepare for a joint investment or whether to refrain.

Case study – analysis of a joint energy efficiency investment in a chemical cluster

This section presents a case study where a joint energy efficiency investment in a chemical industry cluster is analyzed and evaluated using the approach presented above. For the chemical industry cluster, the results from the first two phases have been presented in previous studies by some of the authors and are thus only presented briefly, the interested reader is referred to the previous publications (Andersson et al., 2011; Hackl et al., 2011; Hackl and Harvey, 2013; Hackl and Harvey, 2014; Jönsson et al., 2012). The third phase, constituted by the ROA, has previously not been published and is presented in more detail[6].

DESCRIPTION OF THE CHEMICAL INDUSTRY CLUSTER

The analysed chemical industry cluster consists of five companies, AGA Gas AB, Akzo Nobel Sverige AB, Borealis AB, INEOS Sverige AB and Perstorp Oxo AB. The companies produce a variety of chemical products such as polyvinyl chloride (PVC), polyethylene (PE), ethylene, amines, surfactants, oxygen/nitrogen and plasticisers. Figure 2 presents an overview of the five companies in the cluster, together with their main feedstocks and products. The cluster is a major fossil feedstock consumer as well as a major emitter of CO_2 – the cluster's cracker plant alone accounts for 1.2 % of Sweden's emissions of fossil CO_2. The heart of the cluster is the Borealis steam cracker plant which supplies the other plants with ethylene, fuel gas, propylene and hydrogen.

In addition to excess process heat, e.g. from the cracker process used to supply heat to the processes, the cluster uses about 167 MW of fuel in boilers and virtually no heat exchange occurs between the different plants[7]. In 2011 the companies within the cluster adopted a joint vision: "Sustainable Chemistry 2030". Important building blocks in the work towards reaching the vision are energy and resource efficiency. During the last couple of years the companies have jointly participated in a research project performed by Chalmers University of Technology where the potential for increased energy efficiency through investment in a heat recovery and common utility systems has been analysed. In this project substantial (technical) energy savings potentials have been identified. The main findings of this project constitute the two first phases presented in the subsequent text.

TECHNICAL BASE ANALYSIS PHASE: IDENTIFICATION OF THEORETICAL ENERGY SAVINGS POTENTIAL AND SELECTION OF TECHNO-ECONOMIC RETROFIT OPTIONS

Using TSA, Hackl et al. (2011) identified that up to 125 MW of external hot utility savings can theoretically be achieved through internal heat exchange between the different cluster plants. In addition to this a surplus of 16 MW of high pressure steam can theoretically be generated from excess process heat. The practical measures required to achieve this savings potential are a circulating hot water system across the industry cluster (116 MW) and increased steam generation from excess process heat (25 MW). Thus the theoretical energy savings potential is 125 MW (external hot utility savings). However, 17 MW out of these 125 MW are not technically possible to implement due to steam pressure restrictions in some heat exchangers, giving a technical energy savings potential of 108 MW.

To fully realise the technical potential would require rather extensive and complex retrofits of the plants' energy systems such as investments in new equipment, changes in steam pressure levels, establishment of common utility systems, redistribution of steam between the individual plants, increased steam generation from excess process heat, etc. In a further study by the same authors, Andersson et al. (2011), retrofit options are identified and ranked based on their feasibility of implementation. The ranking was partly based on judgements by technical plant staff. Rough cost estimations of the retrofit options were also made. Based on the findings from the TSA-analysis made by Hackl et al. (2011) and the extended study by Andersson et al. (2011), Jönsson et al. (2011) put forward a "moderate heat integration scenario" with an energy savings potential of

5. In this case the optimal decision is the decision which for the given time (and associated conditions) gives the highest profitability.

6. An early version of the results and a more thorough background on ROA can be found in a thesis report by Furberg and Haggärde (2013). It should be noted, however, that the prerequisites, data and thus also the results presented in this paper differ somewhat from the earlier version due to further work and improvements.

7. Akzo Nobel supplies AGA with about 1 MW of steam and Borealis are transferring some steam from their polyethylene plant to their cracker plant (Jönsson et al., 2011).

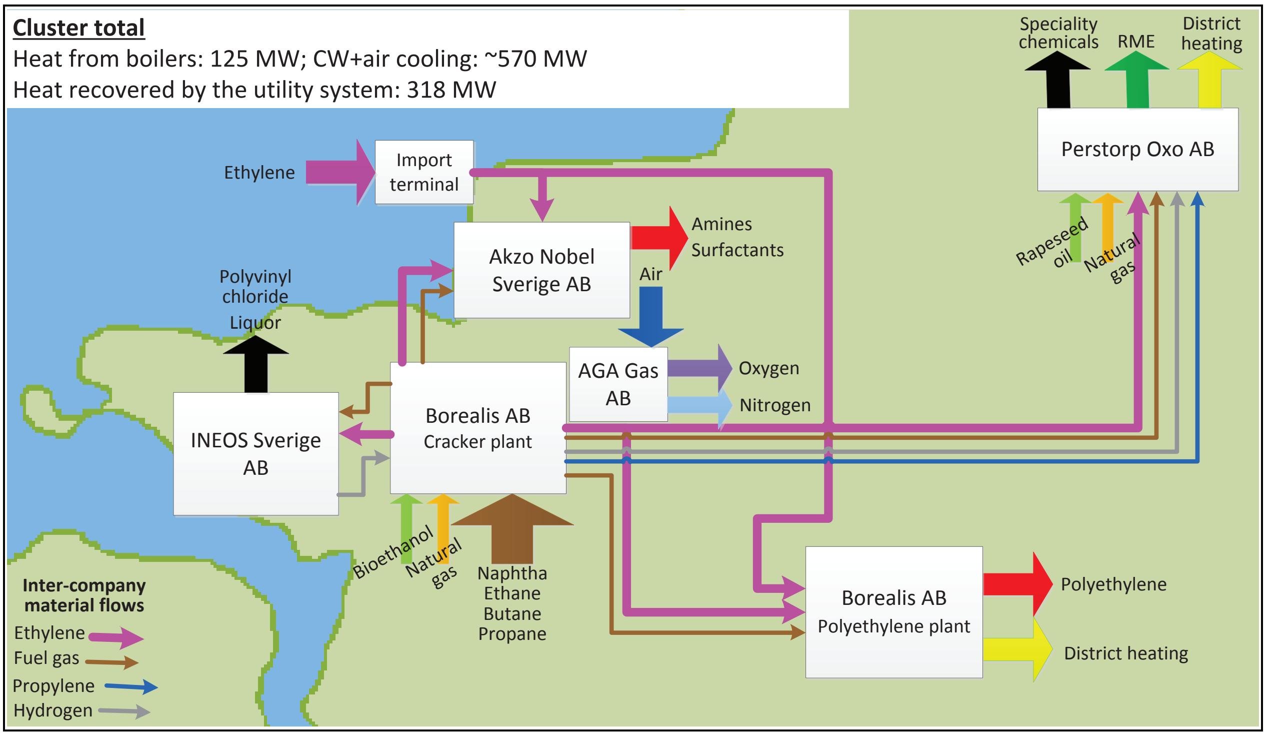


Figure 2. An overview of the chemical cluster in Stenungsund. For each company major inputs and outputs are presented (arrows), as are the material exchanges within the cluster. The nitrogen and oxygen produced by AGA Gas AB are used by the other plants in the cluster as well as exported. This figure was first presented in Jönsson et al. (2012).

67 MW. To realise this "moderate heat integration scenario", retrofits need to be made to the energy systems of all six process plants. The retrofit options required are the ones which are judged to be relatively easy to implement from a technical perspective through modifications of heat exchanger area and piping. Furthermore, for these retrofit options sufficient space is available to conduct the modifications and no additional pipe racks are needed.

Although the energy efficiency potential identified was substantial (one actor described it as "one of the largest single energy efficiency potentials in Sweden") the project did not progress. In discussions with the stakeholders uncertainties regarding the profitability of the project and the quality of the economic calculations were identified as significant barriers for propelling the project. The stakeholders also expressed the wish of identifying the most promising retrofit options from an economic rather than an energy efficiency point of view. The demand for a more thorough economic evaluation and comparison of different system solutions initiated the next analysis phase.

IMPROVED TECHNO-ECONOMIC ANALYSIS PHASE: EVALUATION OF TECHNO-ECONOMIC SYSTEMS AND IDENTIFICATION OF BARRIERS FOR IMPLEMENTATION

As previously stated, a number of different systems solutions are available to reach different parts of the energy savings potential. Building on their above presented work Hackl and Harvey (2013; 2014) developed a methodology for comparing cost-efficient and site-wide common heat recovery system configurations. The purpose of the methodology is to identify different system configurations and compare them regarding energy savings potential and economic performance (e.g. NPV, capital intensity).

Using the methodology, five promising system configurations with energy savings potentials between 20.6 MW and 53.6 MW of hot utility were identified. When compared, two systems showed superior economic performance (based on NPV and payback time), one system with a heat savings potential of 20.6 MW and one system with a heat savings potential of 50.8 M.

The system with the lower energy savings potential of 20.6 MW showed the highest discounted cash flow rate of return, 34 %, and only involves two of the five companies. Since only a minor share of total energy savings potential is reached it is suggested that this system configuration could be considered a first step towards (later) implementing a larger system giving further energy savings.

The larger system configuration with an energy savings potential of 50.8 MW of heat showed the highest net present value. The system reaches a major part of the identified energy savings potential and involves three of the five companies. In their work, Hackl and Harvey (2013) identify preparatory investments which enable an extension of the smaller system towards the larger system at a later stage.

In parallel with the work presented above a dialogue was held with the industrial stakeholders regarding their view on the suggested systems and potential barriers for implementation. Through this dialogue, two main barriers were identified: 1) multiple actors involved in the investment and 2) future uncertainties regarding the value of the energy saved (related to the price of natural gas) (Komi and Mofakheri, 2013). As an example, some of the company representatives drew on previ-

Table 1. Data for base and expansion investments – cost and associated energy savings.

	Investment	Cost		Savings Natural gas		Savings Steam		Premium (option expand)	
Base	B1: Steam pipe (Borealis, Perstorp)	39.0	MSEK	0	MW	0	MW	0	MSEK
Base	B2: HW1 79 °C (Borealis, Perstorp)	160.2	MSEK	25.8	MW	20.7	MW	31.1	MSEK
Base	B3: Fuel pipe (Borealis, Perstorp)	129.6	MSEK	6.8	MW	5.5	MW	0	MSEK
Base	B4: HW2 95 °C (Borealis, Perstorp)	142.1	MSEK	17.7	MW	14.2	MW	31.7	MSEK
	Sum. Base investment (B1-4)	***470.9***	***MSEK***	***50.4***	***MW***	***40.3***	***MW***	***62.8***	**MSEK**
Expansion	E1: Steam expansion one company (INEOS)	95.5	MSEK	13.1	MW	10.5	MW	–	MSEK
Expansion	E2: Steam expansion two companies (INEOS, Akzo Nobel)	164.2	MSEK	16.6	MW	13.3	MW	–	MSEK

ous experience of prospective investments where the aim was to make a joint investment with a majority of the companies. However, when implemented these investments all ended up being bilateral with only two investing companies. A majority of the company representatives saw bilateral agreements/investments as a preferable over multi-party investment.

Together with the identified barriers the two system configurations and the identified path from the smaller (simpler) system towards the larger system were used as a starting point for the next analysis phase, described below.

STRATEGIC ANALYSIS PHASE: RESTRUCTURING OF INVESTMENT TO REDUCE COMPLEXITY

As mentioned above, multi-party collaboration was identified as a main barrier for implementation of a joint utility system investment. Consequently the aim when restructuring the investment was to identify and order investment packages in such a way so that only two companies initiate the investment and that the other companies have the opportunity to join at a later stage. One company, AGA Gas, was only marginally involved in the identified retrofitted solution(s) and thus it was decided to not include them at all to further reduce the complexity. This way, the promising system configurations previously identified was restructured into six investment packages out of which four constitute a base investment with only two companies, Borealis and Perstorp, involved and two are expansion investment packages allowing for one or two additional companies to join the investment later on, INEOS and Akzo Nobel. The base investment is constituted by two hot water circuits (B2 and B4), a steam pipe (B1) and a fuel pipe (B3).

Table 1 presents key data for the base investment and expansion investment. For the base investment, "Cost" refers to the cost for the actual investment package without having the option to later expand the investment through one of the expansion investment packages. To have the option to expand the investment at a later stage a "premium" has to be paid. For the two expansion investment packages the investment costs assume that no other expansion investments are realised (i.e. the expansion investments are not complementary).

For the base investment packages work has to be done in Borealis cracker plant. This work can only be done whiles the cracker is shut down and thus the base investment packages need to be timed with the maintenance stops which take place every sixth year. Consequently, the option to invest in the base investment packages is available first in 2021[8]. The two expansion investments can be implemented at any time (after the base investment) and are thus assumed available options from 2021 until the following cracker stop in 2027. A flowchart illustrating the suggested investment scheme is presented in Figure 3.

As can be seen in Figure 3, the suggested setup allows for initiating the investment with a lower complexity due to only two involved companies and having the benefit of evaluating both the collaboration and market development before deciding about a possible expansion including more actors.

Evaluation

In the following text an evaluation of the suggested investment scheme (Figure 3) is presented. Table 2 presents the key data used for calculation of NPV and ROA. The natural gas price given in Table 2 is the initial price set at project start (thereafter is can increase or decrease depending on market development[9]).

Figure 4 shows the generated decision tree. The decision tree shows the optimal (i.e. most profitable in terms of highest discounted project value) option/decision to choose at any given time and market situation. Since the NPV for the base investment is positive the base investment will be chosen when it is first available at the start of the project (invest year 2020, implemented and in operation by year 2021). Choosing to expand the investment when possible is the optimal choice from an economic point of view, indicated by the "green wall" in 2021. The expansion option that is the most beneficial depends on the market development (of e.g. the natural gas price) and it is only for very beneficial market developments (such as high natural gas price) that the larger expansion, including both INEOS and Akzo Nobel, is the best choice (represented by the light green area in Figure 4).

Figure 4 also shows that if the decision to expand the investment is delayed. If the market development is unfavourable

8. The next cracker stop in 2015 does not provide enough time to plan the investment.

9. The natural gas consumed by the Cluster is provided through a pipeline originating in Germany. Thus historical data for German natural gas prices were used as input data for calculating the combined volatility. For a description regarding calculation of the combined volatility and modelling of trees the reader is referred to Furberg and Haggärde (2013).

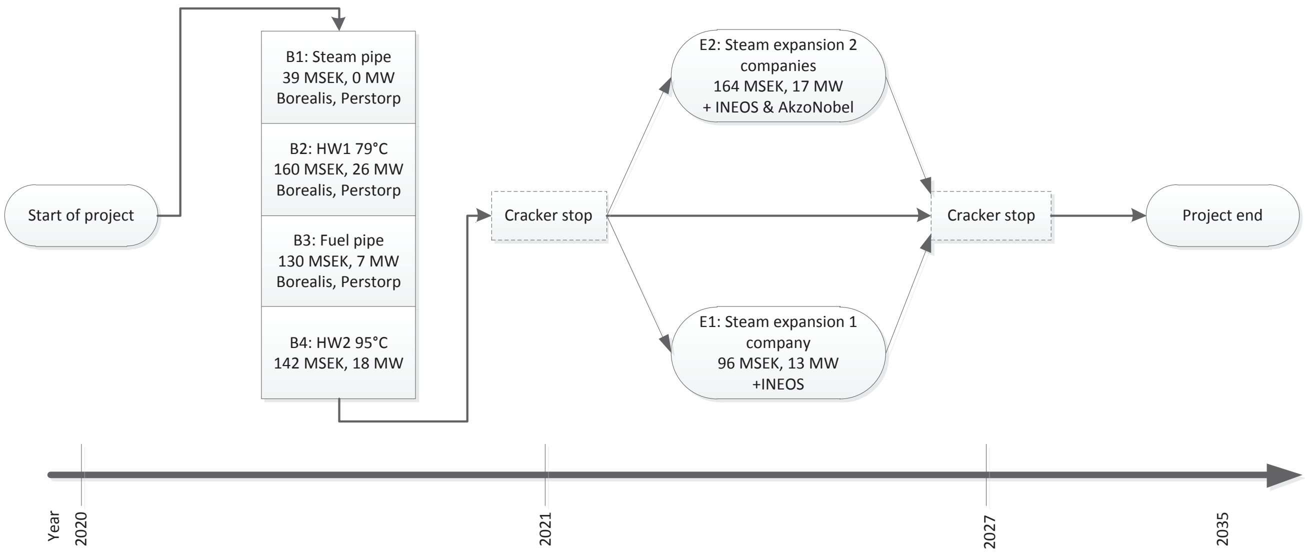


Figure 3. Flowchart of the suggested investment scheme. The numbers in the boxes show the investment cost (in MSEK) and natural gas savings (in MW) for each "investment package". The figure builds on a figure presented by Furberg and Haggärde (2013).

Table 2. Data for calculation of NPV and ROA.

Risk Neutral Rate	2.0	%	Natural Gas Price (initial value at project start)	320	SEK/MWh
Combined Volatility	13.4	%	O&M (cost)	3.0	% of investment cost
Hurdle rate	12.0	%	Project life time	15	Years
Investment period	10	Years	Profit generation time	14	Years
Corporate Tax	22.0	%	Time resolution	1	Month
Yearly Running Hours	8,000	Hours			

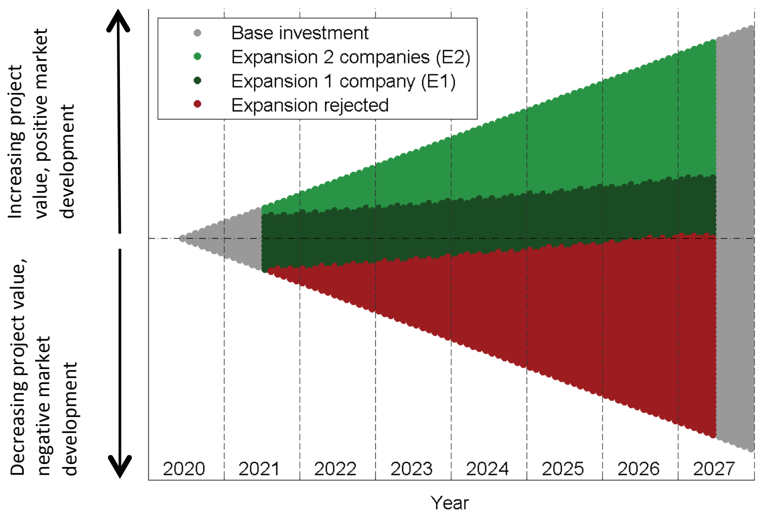


Figure 4. Decision tree showing the expansion options. The tree is plotted using a logarithmic scale (y-axis). The decision tree is associated with a value tree and an asset tree (similar figures with PV in MSEK on the y-axis) which are not shown here (due to space considerations).

Table 3. Summary of economic results.

Present value expansion (PV_expansion)	668	MSEK
Present value base investment (PV_base)	596	MSEK
Real options value (ROV)	72	MSEK
Increased profit for system with expansion options compared to only base investment (net ROV = ROV-premium)	9	MSEK
Static net present value (base investment, sNPV)	125	MSEK
Expanded net present value (including expansion options, eNPV)	197	MSEK

(e.g. a decreasing natural gas price) the most optimal choice could be not to expand the investment, illustrated by the red area in Figure 4 (this is further analysed in the sensitivity analysis below). Further, if the risk neutral rate is increased (which today is fairly low and in the analysis set to 2 %, see Table 2) the profitability of the expansion options will be reduced causing the red area of the figure to translate upwards.

The economic results for the joint investment are summarized in Table 3. The results assume that the optimal decision (from an economic point of view) is taken in every time step. Results for the base investment alone (without options to expand the investment) are also included for comparison.

As can be seen in the table, the NPV for the full investment (including options to expand) is 197 MSEK which can be compared to the net present value of 125 MSEK for the base investment alone. Further, the project value for full investment scheme (Figure 3) is 668 MSEK. Compared to the project value for the base investments alone (596 MSEK) it can be seen that including the expansion options increase the project value by 72 MSEK. However, since a premium of 63 MSEK need to be paid in addition to the expansion investment costs in order to prepare the system for expansion (see Table 3) the total profit for the investment scheme with expansion options is 9 MSEK higher compared to an investment scheme including only the base investment (net ROV). As can be seen the added value of implementing also the expansion investment is rather limited (9 MSEK). However, the expansion investment gives rather significant additional savings of natural gas; compared to the base investment the expansion investment gives roughly an additional 25 % savings (13 MW).

Sensitivity analysis

Below the sensitivity analysis presented show 1) the impact of parameter uncertainties for key parameters, 2) the impact of a delayed investment decision for the expansion investments and 3) a simulation of random walks and an associated estimated distribution of the project value.

Figure 5 shows the impact of parameter uncertainties for five key parameters on the expanded net present value for the investment (eNPV, top graph) and the real options value (ROV, bottom graph). As can be seen in the figure, variations of the hurdle rate and the natural gas price have the largest impact on both eNPV and ROV. Variations in the operation and maintenance costs and the risk free rate of return show a small impact whereas variations in the volatility only shows marginal impact.

The hurdle rate will be known once an investment decision is made whereas the future natural gas price at any given time will remain uncertain. In the analysis the initial natural gas price is set to 320 SEK/MWh (see Table 2). As can be seen in Figure 5, the natural gas price can be reduced by about 10 % while retaining a positive value of net ROV[10] and by about 25 % for the eNPV to remain positive. This indicates that for a natural gas price of 288 SEK/MWh (90 % of initial price) or higher it will be beneficial to go for a flexible investment scheme where the system is prepared for the option to expand at a later stage. However, if the hurdle rate is reduced (set to 12 % in the analysis) the natural gas price can be reduced further before the net ROV (and the eNPV) becomes negative. Interestingly enough both eNPV and ROV are rather sensitive to changes in the hurdle rate, but even a large increase (50 %) doesn't result in a negative outcome.

Forward simulation in terms of random walks can be used to estimate the probable outcome of the project. For this analysis 100,000 random walks were simulated. Here the purpose of the random walks is to estimate the distributions of chosen options (expansion investment E1, expansion investment E2 or expansion rejected) and their impact on the ROV. This way an analysis can be made regarding if it is worth paying the premiums to prepare for an expansion or not. The random walks are based on the market development (natural gas price etc.) and run from the start of the project until the expansion options are available. When a random walk comes to the time for taking a decision on an expansion option the current market is compared with the market conditions in the decision tree and the most profitable option is chosen.

Figure 6 presents the distribution of the 100,000 random walks for two different scenarios, one where the expansion options are available from year 2021 (as described in the suggested investment scheme in Figure 3) and one where an investment decision regarding the expansion investments is delayed until year 2025 (as described above).

As can be seen in Figure 6, the most probable project outcome is the base investment followed by the expansion investment including one additional company (referred to as P(E1) in the figure). For the case when the expansion options are available from year 2021 the 'one company expansion' (E1) is the outcome for almost all walks (>99 %). Also for the case of a delayed expansion decision the E1 is the most probable outcome, ~75 % of the walks. An interesting result is that a full, two company expansion (E2) is a very unlikely project outcome (0.3 % respectively 0.6 % for the two cases). Thus it can be argued that

10. Net ROV refers to the ROV reduced by the premium.

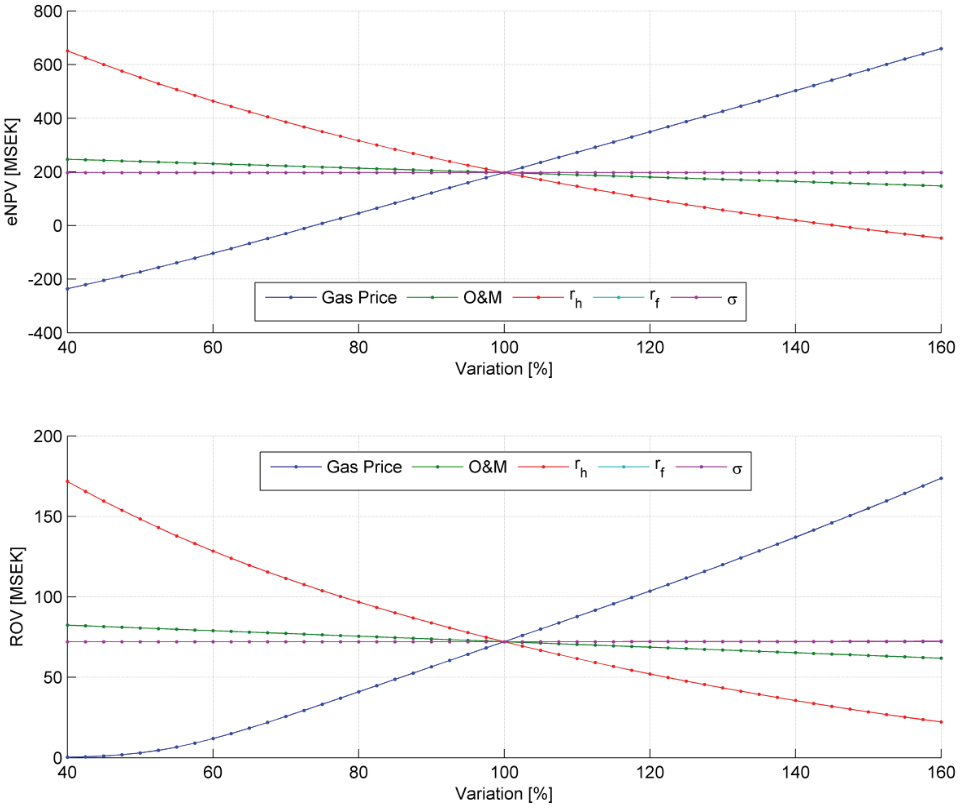
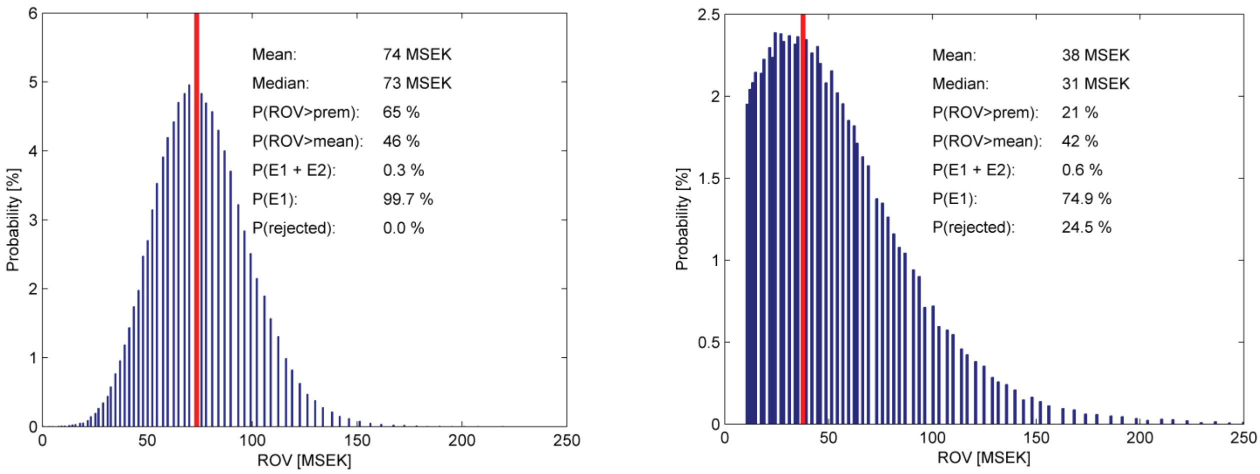


Figure 5. Sensitivity analysis of parameter uncertainties' impact on eNPV (top) and ROV (bottom).



Expansion investment options available between the years 2021–2027.

Delayed decision regarding expansion options until year 2025 (available 2025–2027). Note that ROV = 0 is excluded because it interferes with the picture.

Figure 6. Distribution of 100,000 random walks. The thicker line indicates the mean value.

it is only worth paying the premium to have the option for one company (INEOS) to join the investment.

Case study summary and concluding reflections

This paper presents a novel, multi-disciplinary approach for analysis of joint energy efficiency investments in industrial clusters. The approach is sprung from a multi-disciplinary research project where we, through a case study, have followed and supported five chemical industry companies in their joint strive towards "sustainable chemistry 2030". The approach builds on TSA, retrofit analysis and ROA and it is here suggested to serve as a "tool" for the constituent actors to understand and handle the complexities of the joint project/investments. Since the approach forces the industry stakeholders to be explicit regarding assumptions and projections it is here suggested that the approach, through the use of strategy building methods such as ROA, functions as a "tool" for common understanding and strategy formulation which in turn facilitates collaboration and propels the project/investment process forward. A summary of the case study results are presented below together with some concluding reflections regarding the suggested approach:

- For the chemical industry cluster in focus, the case study shows how the previously identified retrofit solution(s) can be modified and divided into "investment packages" distributed over time, allowing for a "simpler" initial investment by only two actors and permitting for an evaluation of both the cooperation and the market development before increasing the complexity by expanding the investment and the number of actors involved.
- For the given data, it is worthwhile to initiate the project by implementing the base investment as early as possible. Furthermore, it is beneficial to prepare the system for an expansion at a later stage. The smaller expansion investment with only one additional company joining the investment is almost always preferred over the larger expansion investment including two additional companies. The natural gas price and the hurdle rate show significant impact on the results and thus could be worth a more thorough analysis.
- When the ROA results were discussed with the companies the stakeholder group had been broadened to include competences from different parts of the organizations (technical personnel, financial expertise and higher level decision makers). This suggests that a multi-disciplinary approach, requiring inclusion of multi-competences at the different companies, broadens the stakeholder group and adds additional (strategic) aspects to the previously "one-dimensional, technical investment" and thus bringing it closer to implementation The companies expressed gratitude for having the joint energy efficiency project evaluated using both technical and economic methods.
- The two companies involved in the base investment have decided to jointly proceed with the project making their own internal analysis using the ROA as a starting point. This suggests that the results in fact contributed to solving the issue regarding who should take action; it gave the two companies the right to take lead and legitimacy to exclude some of the other companies in the further process without causing a conflict.
- The specific results generated when applying the approach on a project/investment (as exemplified in the case study) should not be seen as a complete decision support for the industrial stakeholders. However, the results facilitate a focus on the solutions/collaborations which are judged to be most beneficial from an economic and/or organizational point of view and thus the results serve as a basis for the further process. Through the sensitivity analysis key parameters with large impact on the results can be identified enabling the further analysis to focus on generating reliable values for these parameters. The results can also be used as a base when discussing how to divide the investment burden and the potential profit of the investment, something which is important to address to ensure progress in the investment process.
- A prerequisite when designing the options was that the investments are made in each company respectively since in this chemical cluster all companies today are responsible for generating their own utilities (for heating and cooling). This prerequisite is demanding and if it could be disregarded a larger share of the energy savings potential might be implemented. One possibility could be for one company to take responsibility for the common utility system. This utility provider could be either an external utility supplier (as in many newer chemical clusters) or one of the existing chemical cluster companies. The cluster companies could sell their excess heat to the utility provider and buy back the utilities necessary (steam, hot water, cooling).This would reduce the complexities associated with the energy efficiency investment and allow for a more financial perspective.
- The suggested approach is a result of the development which unfolded in the case study where the companies' joint work has been followed for more than two years. During this time, the recurrent stakeholder dialogue has been of great importance. That the stakeholders themselves asked for enhanced decision support is identified as a key for creating credibility and interest in the results from the strategic analysis phase, without this ROA might be viewed as a "too complicated" method. Further the credibility of the results was strengthened by the fact that the industrial stakeholders recognized the NPV generated in the ROA as similar to the NPV calculated earlier in the process.

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Acknowledgements

This work has been carried out within the project 4C, the Collaborative Chemistry Cluster Case study, which is primarily financed by the Swedish Energy Agency. The authors would like to thank the participating chemical industry companies in Stenungsund for their kind collaboration and support.