# Including stakeholder development plans in optimization of an integrated utility system

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A B S T R A C T

Over the last few decades, a wealth of articles on design and optimization of utility systems in industrial clusters has been published. Most of these articles seem to disregard non-technical factors, whereas these appear to play a significant role when optimizing an integrated utility system. In particular, long-term development plans that companies within a cluster make for future development of their own plants limit efficiency gains that could potentially be achieved with integration. This paper presents a model-based approach to support a utility provider in its investment decision-making to enter such an integrated cluster. This approach starts with a stakeholder analysis that includes an analysis of options. Future plans of relevant stakeholders are investigated, and subsequently included in a simulation model that mimics plant operations aiming for maximum efficiency at cluster level. This model is run according to an experimental design that explores a set of possible combinations of assets and uncertain market conditions. Model behaviour and results are interpreted to determine the negotiation position of the entrant, which then serves as a starting point for the design of a negotiation strategy. The approach is demonstrated using a realistic case study. Lastly its general applicability is discussed.

*Key words*: Optimization, Utility system, Industrial cluster, Non-technical factors, Experimental design

## 1. Introduction

An industrial cluster is a geographically bounded collection of similar and/or related firms that together create competitive advantages for member firms and the host economy (Barkley & Henry, 1997). The theory of economic development based on industrial clusters hypothesizes that the colocation of firms or industries that complement each other, compete against each other, or share utilities leads to increasing returns to scale. The increasing returns can take the form of lower unit operating costs due to the concentration of specialized suppliers or the existence of pipeline economies (Hill & Brennan, 2000). Integration in an industrial cluster, in which the consumption of energy and materials is optimized and the effluents of one process serve as the raw material(s) or energy for another process is called industrial ecology (Frosch & Gallopoulos, 1989). Similarly Chertow (2000) defined industrial symbiosis as engaging "traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity".

### *1.1 Motivation*

In recent decades, rising fuel prices, increasing costs associated with emissions of greenhouse gases and the threat of global warming made efficient use of energy more important. These developments have put more emphasis on increase in energy efficiency by energy collaboration in industrial clusters (Hackl, Andersson, & Harvey, 2011). Most industrial companies consume a lot of steam, water and electrical resources in their production process.

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Since the costs of resources have been increasing rapidly, utility networks must be optimized to reduce the overall cost of production of those essential utilities. Recently, many companies have been integrating their processes to achieve better economic performance (Kim, Yoon, Chae, & Park, 2010). The optimization of energy systems that include one or more technologies to meet the requirements of utility systems is extensively studied by many authors.

Even though industrial ecology is a concept that is known worldwide and its importance in widely recognized, its dissemination and implementation is not an easy process. Industrial routines are embedded in unsustainable practices that are difficult to change. The complexity and uncertainties of new concepts are often approached with ignorance and misperceptions. Nevertheless, the integration of economic, environmental and social dimensions in industrial activities is increasingly perceived as a necessary condition for sustainable growth (Baas, 2008). For the purpose of synthesis of utility systems, collaboration is needed. However due to the competitive character of most stakeholders in a cluster, collaboration is difficult to achieve.

### *1.2 Problem description*

Clusters often consist of several plants with different plant owners. Plant operators usually have no detailed knowledge about the energy and material flows in their neighbouring plants. During the research of Hackl and Harvey (2013) factors which are important for collaboration across company borders besides the technical feasibility were identified. One of the challenges is to investigate long term development plans for such clusters. Each company within a cluster has more or less far-reaching plans for future development of its own plant and such plans should be included in an effort towards cluster collaboration. However, data collection is a complicated process, especially if data is uncertain and about potential future plant developments. In order to cope with non-technical factors, Hackl and Harvey (2013) proposed that further research work should include non-technical factors and develop strategies to overcome obstacles in industrial cluster collaborations. Baas (2008) also noticed that it is increasingly being found that there has been too much emphasis upon the technological and mechanical dimensions of change and far too little emphasis upon understanding and working with the non-technical dimensions. Therefore, better success is being achieved by integration of the economic, environmental and social dimensions into industrial collaboration activities.

Economics defines investment as the act of incurring an immediate cost in the expectation of future rewards. Most investment decisions are partially or completely *irreversible*, there is *uncertainty* over the future rewards from the investment and there is some leeway about the *timing* of the investment. The three characteristics interact to determine the optimal decisions of investors (Dixit, 1994). Most decisions, almost by definition, involve some consideration of unknown factors. Often, the decision making process takes the form of "what if' reasoning, in which the outcomes of different decisions are evaluated in the light of various possible end values of the unknown factors (Greengard & Ruszczynski, 2002). Evaluation of an investment decision in an utility production unit considers economic uncertainties that include utility supply and demand as well as prices of resources.

The fact that each company within a cluster has its own plans for future developments of its plant causes uncertainty for investment decisions. Reason for this is that if a company decides to invest in a new utility production plant now, the profitability of that plant will be influenced by demand for that utility and supply of other producers. Arrow and Lind (2014) state that it is widely accepted that individuals are not indifferent to uncertainty and will not, in general, value assets with uncertain returns at their expected values. This means that decisions to invest in utility production plants in industrial clusters are slowed down or aborted because of uncertainty in the system. According to Baas (2008) the widespread adoption and implementation of concepts and practices related to industrial symbiosis has been a difficult and slow process. The uncertainty within the system due to individual plans of companies can – in the long term – deteriorate the economic performance and competitive position of an industrial cluster. It is for this reason that development plans of other companies should be taken into account in order to evaluate the robustness of a certain investment decision under system uncertainty.

### *1.3 Problem approach*

In order to establish the lowest production costs of companies' products in an industrial cluster, it is expected that all utility consumers will want to buy an utility from the producer that provides the utility for the lowest price. This behaviour is based on a *sourcing* decision. However it could also decide to produce the utility itself. If so, this decision is called a *make-or-buy* decision. If a firm decides to make an input itself, it will transact internally with a division or another part of the firm. If it decides to buy, it will contract with another organization. The rationale for this sourcing decision is simple. If contracting out parts of the operation is cheaper than doing it yourself, it is a clear case for outsourcing (Fill & Visser, 2000). Furthermore if outsourcing is decided upon, utilities will be bought from the producer that provides a utility for the lowest price.

Which producer can produce at the lowest cost at a certain moment does not only depend on its plant characteristics, such as efficiency and capacity. It also largely depends on the price of inputs used to produce a certain utility. For example if we look at the utility electricity. Electricity can be produced from coal, natural gas, biomass, etcetera. Those resources have to be bought on a market. Due to fluctuations in prices caused by market mechanisms, one source becomes more expensive than the other. For example natural gas becomes more expensive than biomass. At that point an electricity production plant that has biomass as input will produce at a lower cost than a production plant on natural gas. Therefore at that point the biomass plant will be operated to meet the demand in that cluster. However it should be noticed that this switching behaviour is bounded by plant characteristics, such as ramping up and ramping down times and minimum production loads.

If a decision has to be made about investing in a certain utility production plant (either adjusting an existing facility or building a new one), it is important to investigate how it would perform given the system it is, or will be established in. The economic performance of the utility production plant – and whether the investment will be earned back – is determined by whether the utility produced will be sold. This depends on other utility production units in the same cluster and demand for that utility in the cluster. Based on technical production characteristics of all production units in the system and the market prices for resources, it can be established what production plant will be producing at a certain moment. Based on demand and supply in the system, it can be established how often and under what conditions a certain utility production unit will be operated.

In order to analyse a utility system, it is necessary to develop a simulation model (Varbanov, Doyle, & Smith, 2004). A simulation model is a representation of the system, that shows the (expected) working of the system. In order to show the sourcing decision in the system, optimization is done.

In conclusion can be said that optimization of integration in utility systems is extensively studied by many authors. However, a systematic procedure including stakeholder plant development plans under uncertain market conditions, is still missing. Therefore this article will discuss a research approach that includes stakeholder plant development plans and uncertain market conditions in a modelling effort to support an utility provider in its investment decision-making to enter an industrial cluster. The main aim of this article is clarifying the proposed approach. To this end firstly the approach will be explained. Secondly it will be illustrated on the basis of a real world problem. This will be done on the basis of a case study, that was performed for MSc. thesis research by Bijloo (2014). Due to confidentiality of this research project, stakeholders involved will not be named with their real names. In conclusion the applicability of the proposed approach will be discussed and further research will be proposed.

## 2. Research approach

In figure 1, the research approach is shown. The problem environment is an industrial cluster in which stakeholders are unwilling to invest due to uncertainty about plant development plans of other stakeholders and market developments for resources. Furthermore utility consumers are expected to make a sourcing decision based on unit cost (Welch & Nayak, 1992). Therefore the production unit that produces the utility at the lowest cost will get to produce to meet the utility demand. From this sourcing decision, a merit-order follows.

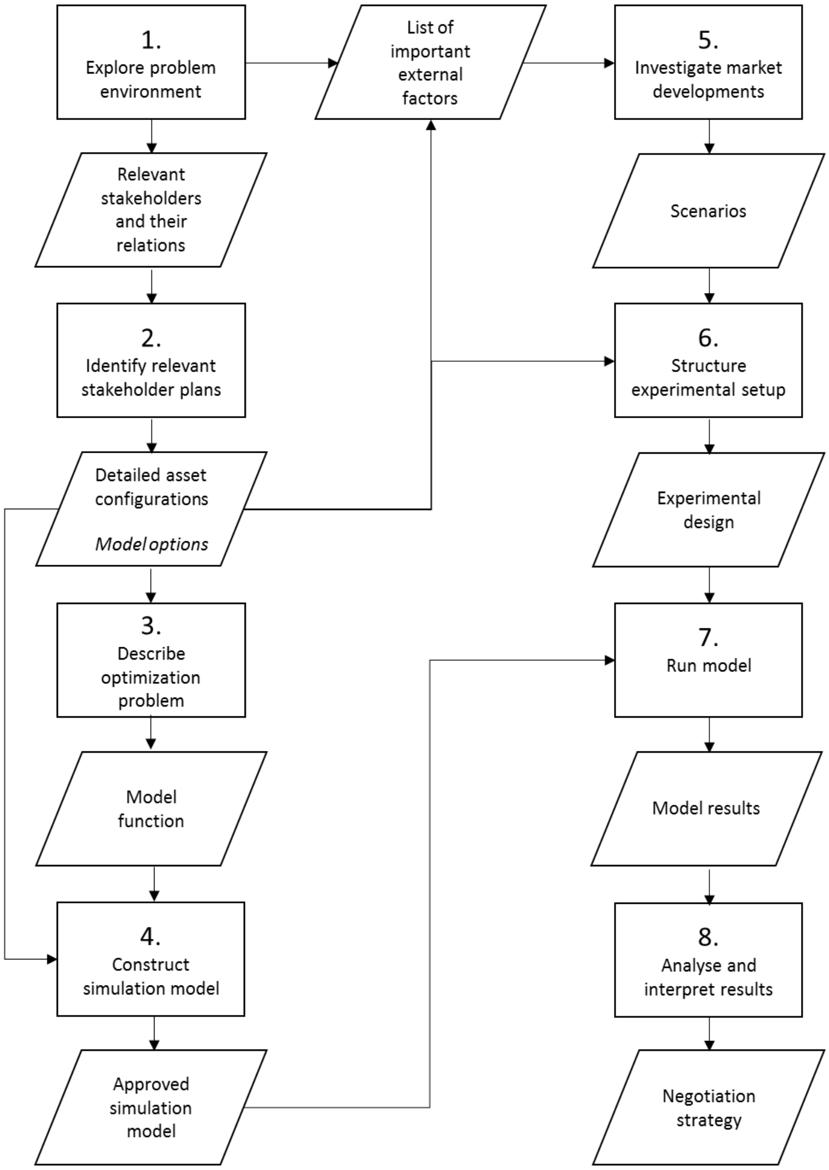


*Figure 1: Research approach to support a utility provider in its investment decision-making to enter an industrial cluster*

## 3. Case study

The research approach that is shown in figure 1 will be explained on the basis of a case study. Firstly in section 3.1 an introduction will be given to the case study. Next in section 3.2 relevant plant development plans of stakeholders will identified. The identified plans of various stakeholders will be used to construct a set of possible combinations of assets. On the basis of differences between utility production plants, a sourcing decision can be made in a particular combination of assets. Which then leads to section 3.3. In this section the optimization problem will be described, which forms the basis for the simulation model that will be constructed in section 3.4. Once the model has been approved, the simulation setup can be designed. Therefore in section 3.5 a scenario analysis will be done in order to examine possible developments in resource prices. Based on the scenario analysis, a number of scenarios will be constructed. This brings us to section 3.6 in which the experimental design will be described. Based on the set of possible combinations of assets introduced in section 3.2 and scenarios constructed in section 3.6, the number and content of model runs will be structured. When the experimental design is clear, model runs can be carried out. Finally, in section 3.7 model results can be interpreted.

### *3.1 Problem environment*

Since 2013, Energy Company A (ECA) owns an electricity production plant that runs on biomass. The name of this plant is ‘biomass plant of company A’ (BPA). This plant is located in an industrial cluster, which is called site Y. In the 1960s the first plant in this area was established by production company X (PCX). Afterwards PCX built many more plants in the same area, some of which it later sold to other companies. It is due to this history that the cluster that emerged became closely integrated in terms of product and utility flows. Therefore stakeholder dependencies are large.

Steam is a very important utility in site Y. Current steam production in site Y exists from one combined heat and power (CHP) plant that runs on natural gas and a waste incinerator. The CHP is owned by PCX and will therefore be called combined heat and power plant of company PCX (CHPX). Furthermore there is one utility company in site Y, which is also owned by PCX. Therefore this utility company will be called PCX Utility Company (PCX UC). PCX UC is responsible for the supply of steam to all steam consuming companies in site Y. Because steam supply in this cluster is controlled by one company, it is expected that this company aims to purchase steam at the lowest cost, to get the highest margin over the steam sold to its customers. Reason for this is that no internal steam market exists, which means that steam selling prices are fixed in contracts between PCX UC and its customers.

Recently steam production with a CHP became more expensive due to a rise in the natural gas price and a drop in the electricity price. Therefore PCX UC is looking for cheaper sources of steam. Besides, since the area in which site Y is established showed economic contraction and a high unemployment rate, there is large political emphasis on improving the utility system in site Y. Due to the coincidence of both trends an opportunity arose for ECA to increase profits of BPA. Since BPA is a plant with a boiler, which produces process steam that is directed to a steam turbine, it could quite easily be adjusted for steam production. Large scale steam production with BPA and providing this utility in site Y might be a solution to the problem of PCX UC. Furthermore if this solution benefits site Y, ECA can also count on political support. This is expressed by the adjustment of a subsidy scheme to provide subsidy for the co-production of steam with a biomass plant.

However ECA will only invest if large scale steam supply with BPA is an improvement to its current business case in which it solely produces electricity. Besides the expectation is that steam customers in site Y will only buy steam from ECA if it is advantageous to them compared to other options they have. Therefore the main research question is:
*Under what circumstances does steam supply of biomass plant A benefit stakeholders in site Y based on unit cost?*

For the purpose of answering the research question, the proposed research approach was be used.

### *3.2 Stakeholder analysis*

A stakeholder analysis can be used to generate knowledge about the relevant actors so as to understand their behaviour, intentions, interrelations, agendas and interests (Brugha & Varvasovszky, 2000). Firstly all stakeholders have been introduced. After describing the current system, individual companies’ plant development plans have been investigated. For this purpose metagame analysis can be used. The practical application of metagame theory is based on the analysis of options method (Bots & Hermans, 2003). The procedure of the analysis of options is extensively described in the book ‘Games, Theory and Applications’ by Thomas (2003).

It was derived that it is not likely that other companies than PCX will invest in steam production plants to fulfil their own steam demand. Reason for this is that PCX still owns most of the land in site Y and it is the main supplier of utilities other products to stakeholders. Therefore it is also not likely that ECA can establish contracts with those stakeholders directly, without involving PCX. For this reasons, PCX is viewed as the only important stakeholder for ECA.

On the basis of the analysis of options, the only realistic development plans identified for PCX are maintaining CHPX, and/or the construction of a new bio or gas boiler. ECA has two alternatives. The first one is to produce electricity, which is the current business case. It could also be adjusted for the co-production of steam and a small amount of electricity.

Every identified steam production plant in the system has been described in terms of technical production characteristics. Amongst these technical production characteristics are efficiency, capacity, types of turbines etc. Production differences between assets form the basis for the sourcing decision.

Lastly a set of possible combinations of assets has been identified. Reason for this is that it is not yet clear what the eventual combination of steam production units will be in site Y.

### *3.3 Optimization problem*

The goal of the simulation model is to simulate the sourcing decision that is made by PCX UC. This means that the steam production units that produce steam at the lowest cost at a certain moment, will be operated to produce steam at that moment. The model will be used to optimize total system profits for the production of steam to meet the total steam demand in site Y. The cost of steam production depends on the resource from which it is made. The revenues come from possible electricity production of a facility. Therefore in this model hourly resource- and electricity price series were taken into account, based on which a dispatch decision was made.

The goal of the objective function in this research is to *maximize total system profits* over 24 hours. However the time range of a year has been chosen for optimization runs, because this is the shortest time period in which all temperature- and weather characteristics are reported. Therefore a rolling horizon was used. In this way the optimization function will be calculated for every 24 hour period in the overall time period of a year. This means that the end conditions of t=24 will be used as starting conditions for time t=25. Then the objective function starts again over the period from t=25 until t=48.

### *3.4 Simulation model*

In the simulation model all steam production plants were modelled on the basis of their technical specifications. Therefore it is a static model. In order to cope with stakeholder behaviour, a set of possible combinations of assets has been specified. These combinations of assets are simulated. To simulate how the system would behave given certain (fluctuating) price and demand series, optimization runs are done. Optimization runs will behave according to meet the objective function, explained in section 3.3.

An optimization problem should be calculated with a solver. For the purpose of this research the decision has been made to use Linny-R. This is a dedicated tool for optimization of industrial processes. Linny-R uses linear programming to calculate at what level processes should be scheduled (*decision variables*) to produce the desired quantities of end products (*constraints*) while maximizing profit (*objective function*) (Steep Orbit, 2013). It uses a branch-and-bound algorithm to calculate optimal solutions. The branch-and-bound algorithm can be used for integer as well as (non)linear programming. Furthermore Linny-R has a visual interface, which clarifies the relations between production and consumption in the system. A visual representation of the system makes model explication to stakeholders easier. Also model results can easily be transported to Excel, which makes it easy to interpret the model results due to the extensive analysis possibilities of Excel.

Before running the simulation model, it should be tested on verification and validation. Verification of a model is the step to evaluate consistency and correctness of the model. The validation of a model is considered as a check to see if the model is reliable and gives plausible results. Also it is a check to see whether this model can be used to generate the desired outcomes. To assess the validity of a model, it should be checked on conceptual model, data and operational validity (Sargent, 2005).

On the basis of the outcomes from the verification and validation tests it was proven that the simulation model constructed was sufficiently representative for the situation of future steam production in site Y. If the simulation model is approved on the basis of verification and validation, the model can be run to gain desired results.

### *3.5 Scenario construction*

The optimization runs will cover a year. The years that have been simulated for the case study are years 2017 and 2025. Expected price scenarios for these years were given as input variables in the optimization runs. These years have been chosen, because 2017 would be the first year that an alternative of steam production with BPA would be operational. Therefore this year is a good representation of the basic situation in which the BPA will produce its steam. Secondly 2025 is in the longer term, which means that prices and demand will probably have changed. Besides, since the further future is more uncertain, it will be interesting to see what effect different scenarios have on the outcomes of the optimization runs. Therefore scenarios will be constructed in order to evaluate model outcomes under different scenarios.

A scenario can be defined as a description of a possible set of events that might reasonably take place. The main purpose of developing scenarios is to stimulate thinking about possible occurrences, assumptions relating these occurrences, possible opportunities and risks, and courses of action (Jarke, Bui, & Carroll, 1998). On the basis of scenarios it can be evaluated under what circumstances a certain decision would perform well. Knowing what the circumstances are under which a decision would not turn out well, makes a decision more robust. The goal of this scenario analysis is to see how the model outputs differ under different circumstances.

The most important input variables based on which production decisions are made in this optimization problem, are *natural gas*, *biomass* and *electricity prices* and *steam demand*. For these four input variables, possible developments have been investigated. On the basis of possible developments of prices and demand, four scenarios were constructed. In each of those scenarios a different set of input variables is put together.

### 3.6 Experimental design

Experiments can be defined as a test or a series of tests in which purposeful changes are made to the input variables of a process or system so that we may observe and identify the reasons for changes that may be observed in the output response (Montgomery, 2008). It is obvious that if experiments are performed randomly the result obtained will also be random. Therefore, it is a necessity to plan the experiments in such a way that the interesting information will be obtained (Lundstedt et al., 1998).

In section 3.2 it was explained that a set of possible combinations of assets would be tested. Secondly in section 2.5 it was explained that the optimization runs for every combination of assets would be done with four sets of input variables. The combinations of assets and the sets of input variables together make up the experimental design. This means that every combination of assets is run under every set of input variables. Due to this experimental design, model options can easily be compared to each other in terms of economic performance.

A representation of the experimental design will be shown below:

| | Input variable set | | | | | |
|---|---|---|---|---|---|---|
| Option | 2017 | 2025 | S.1 | S.2 | S.3 | S.4 |
| 0 | x | x | x | x | x | x |
| 1 | x | x | x | x | x | x |
| … | x | x | x | x | x | x |
| *n* | x | x | x | x | x | x |

*Table 1: Experimental design*

Every ‘x’ in table 1 represents an optimization run of the simulation model. The experimental design will exist from *n* combinations of assets times six model parameter sets. This means that *6*n* optimization runs will be conducted.

### 3.7 Model results and conclusion

After all model runs have been performed, model results can be interpreted. From data received it can be derived how often certain steam production units would be operational under certain circumstances. In other words, the production allocation in the system is simulated. Conclusions can be drawn about the viability of (investment) decisions or the likelihood of investments of other stakeholders. It can also show the robustness of every investment decision. By robustness is meant that a measure shows good results under various circumstances. If an alternative scores very well under a set of model parameters, but it scores very poorly under another set of model parameters, it would still be a risky investment.

The main research question in this article was: *Under what circumstances does steam supply of biomass plant A benefit stakeholders in site Y based on unit cost?*

From the results of all runs, it was derived that large scale steam production with biomass plant A shows the best results on a system level compared to the solo electricity alternative. Furthermore it was derived that whether PCX decides to invest in a boiler or not, it is always better off if it gets part of its steam from ECA. The same conclusions can be drawn from scenario runs. Therefore steam provision of biomass plant A of ECA in site Y seems like a robust solution to keep the steam price low in site Y. These results point out that negotiation should be possible, because entrance of ECA would improve the economic situation of PCX.

However it should be noticed that optimization runs of a simulation model based on production profits do not capture the full situation. To complete an analysis of investment decisions in utility provision in an integrated cluster, one should examine what additional costs or incomes could influence results. Besides an investment decision or willingness to negotiate with stakeholders also depends on other benefits that utility provision by a certain producer can have. To this end, in the MSc. thesis research by Bijloo (2014) these additional analyses have been done. Therefore subsidies and operational expenditures – largely based on investments costs – have been included in the analysis. Also side-benefits besides economic aspects have been taken into account. For the additional analyses, the MSc. thesis research by Bijloo (2014) can be consulted. On the basis of the model results and additional analyses, a negotiation strategy can be determined.

## 4. Evaluation

For the purpose of this thesis research, an approach has been proposed in order to include individual development plans of stakeholders into an effort to improve an utility system. It has been developed for- and tested on the case of the investment decision of an utility provider wishing to enter an industrial cluster by adjusting its biomass plant for the production of steam.

### *4.1 Strengths*

The approach has been developed to create a structured sequence of steps that can be used to include stakeholder behaviour into an optimization approach in industrial clusters. In recent years many authors have shown that large cost and energy reductions can be established by jointly optimizing utility production in an industrial cluster. Therefore it is evident that better performance is possible. However production units do not operate or build themselves. This is done by people. And this is exactly where the gap in research lies. If one were to improve an utility system in an industrial cluster, technical as well as social aspects should be included in an analysis. To touch upon this gap in scientific literature, an approach has been proposed in this research project.

The strength of this approach is trifold. Firstly, this approach was developed for a case study in which an entrant had to make an investment decision about becoming a utility provider within a cluster. Due to a structured sequence of steps that include widely known methods, this approach can easily be adjusted to other problem situations. Besides all methods use in this approach are widely known, which makes this approach an easy to use.

Secondly, using this approach does not only provide results, but most importantly it provides the user of this approach with a profound insight into the system to be modelled. The process of mapping all stakeholders, their interests and relationships, examining the technical specifications of utility production units, describing the optimization problem, exploring developments in driving forces that influence the system, modelling the full system and analysing its results, provides the researcher with a thorough insight in many aspects of the system.

Lastly, the results that are gained from model runs and from the analysis of the system, can be used for multiple purposes by various stakeholders. The approach does not always have to be used by the stakeholder that need to make an investment decision. It could also be used by a (governmental) authority of that system to make plans for supporting the cluster. Besides the model and its results do not only have to be used one-sided, it could also be shared in a negotiation process.

### *4.2 Weaknesses*

The approach as executed, although it is well useable and it provides insight in system performance, has some minor weaknesses. Two points of criticism on the approach are listed below.

Firstly, a weakness of this approach is that it has difficulty to cope with a multitude of alternatives. If a large number of alternatives is to be considered in a project, for example many technologies for a certain utility production unit or many currently installed utility production units should be considered, then this might result in a very extensive experimental design. This could lead to a countless number of model runs. However for a case like that, a fractional factorial experimental design could be used. On the basis of results, many combinations of assets could probably be excluded from further analysis.

Secondly, stakeholder alternatives that can be identified are always biased. It is based on the knowledge that the researcher has at that moment. However due to the need for a quite detailed analysis, in which important technical specifications of all utility production units in the system are represented, the model and its results provide the researcher with a feeling of correctness. But still it should be taken into account that it is a simulation model, based on what the researcher thinks is reality. Therefore model results should always be considered with caution.

A point of consideration is that the approach has been tested on just one case. Since the approach has been conceived to answer the research question of the MSc. thesis research by Bijloo (2014) it is very much focused on that case study. The applicability for other utility systems should be tested to be able to state that it can be used for the purpose mentioned before. Furthermore no other approach has been applied to the case study of ECA, which means that the applicability of this approach cannot be compared to other approaches. This means that there is no frame of reference.

Overall, the approach has been found well suited for the type of problem concerned in the case study. It took into account other stakeholder plans and market uncertainties, which provided a robust analysis of the system. Furthermore it is a structured approach, which makes it easily repeatable and provides an ease in interpreting data. The steps that had to be taken to meaningfully answer the main research question were logical and resulted in data that could reliably be interpreted.

## 5. Conclusion and recommendations

Cooperation between companies within industrial clusters can strengthen the competitive position of individual companies in those clusters. Localization of production within industrial districts provides opportunities for the industrial district as a whole to secure internal economies of scale and external benefits denied to isolated firms, which causes an improvement in the competitive position of individual firms (Newlands, 2003). Although much work has been published on the design and optimization of utility systems in industrial clusters, none of them include non-technical factors. Long term plant development plans of stakeholders should be included in an effort to improve an utility system. This article introduced a model-based approach to support an utility provider in its investment decision-making to enter an industrial cluster.

### *5.1 Conclusion*

By means of this article an approach that can be used for including development plans of individual stakeholders in an optimization effort of a utility system has been shown. Furthermore on the basis of the case study, that was briefly introduced in this article, it was shown that this approach can be used to support an utility provider in its investment decision-making to enter an industrial cluster. This research approach can be used when all information about the technical specifications of the utility plants is available, as well as a case in which information is not fully available. However in that case, as in the case study, data collection and estimations should be done very thoroughly as well as data validation of the model. Furthermore the shortages of the model should be taken into account when analysing the results.

### *5.2 Recommendations*

To improve the research approach proposed in this article, these are suggestions for further research:

- The same steps as in the approach could be applied, but the sequence of steps could be changed. Starting by modelling the current situation could identify realistic adjustments to the system on the basis of model results. Afterwards every alternative could be included in the model to test whether its influence on the model results is as expected. The new results could be the basis to investigate stakeholder plans in the system.

- Secondly, the research approach could be improved by application of game theory for the design of a negotiation process. The design of a negotiation strategy will then be considered on the basis of two 'rivaling' theories, namely cooperative and non-cooperative game theory. By considering both 'games', the optimal outcome can be assessed, which can be used to design a suitable negotiation strategy.
- Lastly, agent base modelling is a class of computational models for simulating actions and interactions of autonomous agents (both individual or collective entities) with a view to assessing their effects on the system as a whole. Recently agent based modelling has been applied to solve optimization problems whose domains present several inter-related components in a distributed and heterogeneous environment (Barbati, Bruno, & Genovese, 2012). Since agent based modelling could be used to represent actual interactive social behaviour of stakeholders during model runs, this method could well be used for the inclusion of stakeholders plans into an optimization effort.

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## References

Arrow, K. J., & Lind, R. C. (2014). Uncertainty and the evaluation of public investment decisions. *Journal of Natural Resources Policy Research, 6*(1), 29-44.

Baas, L. (2008). Industrial symbiosis in the Rotterdam Harbour and Industry Complex: reflections on the interconnection of the techno-sphere with the social system. *Business Strategy and the Environment, 17*(5), 330-340.

Barbati, M., Bruno, G., & Genovese, A. (2012). Applications of agent-based models for optimization problems: A literature review. *Expert Systems with Applications, 39*(5), 6020-6028. doi: http://dx.doi.org/10.1016/j.eswa.2011.12.015

Barkley, D. L., & Henry, M. S. (1997). Rural industrial development: to cluster or not to cluster? *Review of Agricultural Economics, 19*(2), 308-325.

Bijloo, M. (2014). Entering an integrated cluster (Faculty of Technology Policy and Management, Trans.). Delft: Delft University of Technology.

Bots, P. W., & Hermans, L. M. (2003). *Developing 'playable metagames' for participatory stakeholder analysis.* Paper presented at the Proc. 34th Annual Conf. of Int. Simulation and Gaming Assoc.(ISAGA).

Brugha, R., & Varvasovszky, Z. (2000). Stakeholder analysis: a review. *Health policy and planning, 15*(3), 239-246.

Chertow, M. R. (2000). Industrial symbiosis: literature and taxonomy. *Annual review of energy and the environment, 25*(1), 313-337.

Dixit, A. K. (1994). *Investment under uncertainty*: Princeton university press.

Fill, C., & Visser, E. (2000). The outsourcing dilemma: a composite approach to the make or buy decision. *Management decision, 38*(1), 43-50.

Frosch, R. A., & Gallopoulos, N. E. (1989). Strategies for manufacturing. *Scientific American, 261*(3), 144-152.

Greengard, C., & Ruszczynski, A. (2002). *Decision making under uncertainty*: Springer.

Hackl, R., Andersson, E., & Harvey, S. (2011). Targeting for energy efficiency and improved energy collaboration between different companies using total site analysis (TSA). *Energy, 36*(8), 4609-4615.

Hackl, R., & Harvey, S. (2013). Framework methodology for increased energy efficiency and renewable feedstock integration in industrial clusters. *Applied Energy, 112*, 1500-1509.

Hill, E. W., & Brennan, J. F. (2000). A methodology for identifying the drivers of industrial clusters: the foundation of regional competitive advantage. *Economic Development Quarterly, 14*(1), 65-96.

Jarke, M., Bui, X. T., & Carroll, J. M. (1998). Scenario management: An interdisciplinary approach. *Requirements Engineering, 3*(3-4), 155-173.

Kim, S. H., Yoon, S.-G., Chae, S. H., & Park, S. (2010). Economic and environmental optimization of a multi-site utility network for an industrial complex. *Journal of Environmental Management, 91*(3), 690-705. doi: http://dx.doi.org/10.1016/j.jenvman.2009.09.033

Lundstedt, T., Seifert, E., Abramo, L., Thelin, B., Nyström, Å., Pettersen, J., & Bergman, R. (1998). Experimental design and optimization. *Chemometrics and Intelligent Laboratory Systems, 42*(1), 3-40.

Montgomery, D. C. (2008). *Design and analysis of experiments*: John Wiley & Sons.

Newlands, D. (2003). Competition and cooperation in industrial clusters: the implications for public policy. *European Planning Studies, 11*(5), 521-532.

Sargent, R. G. (2005). *Verification and validation of simulation models.* Paper presented at the Proceedings of the 37th conference on Winter simulation.

Steep Orbit. (2013, 30 January ). What is Linny-R? Retrieved 8 August, 2014, from http://actoranalysis.com/steeporbit/linnyr/what-is-linny-r/

Thomas, L. C. (2003). *Games, theory and applications*: Courier Dover Publications.

Varbanov, P. S., Doyle, S., & Smith, R. (2004). Modelling and Optimization of Utility Systems. *Chemical Engineering Research and Design, 82*(5), 561-578. doi: http://dx.doi.org/10.1205/026387604323142603

Welch, J. A., & Nayak, P. R. (1992). Strategic sourcing: a progressive approach to the make-or-buy decision. *The Executive, 6*(1), 23-31.