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The effect of long lead times for planning of energy efficiency and biorefinery technologies at a pulp mill

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ABSTRACT

The pulp and paper industry has many promising opportunities in the biorefinery field. To reach this potential, investments are required in new, emerging technologies and systems solutions which cannot be quickly implemented. In this paper, an approach to model the necessarily long planning times for this kind of investments is presented. The methodology used is based on stochastic programming, and all investments are optimized under uncertain energy market conditions. The uncertain cost development of the emerging technologies is also considered. It is analyzed using scenario analysis where both the cost levels and the timing for market introduction are considered. The effect of long lead times is studied by assuming that no investments can be decided on now and implemented already today, and only investments planned for today can be implemented in, for example, five years. An example is presented to illustrate the usefulness of the proposed approach. The example includes the possibility of future investment in lignin separation, and shows how the investment planning of industrial energy efficiency investments can be guided by using the proposed systematic approach. The example also illustrates the value of keeping flexibility in the investment planning.

1. Introduction

As a result of the increased climate concern in society, energy market conditions are bound to change, and energy and products based on renewable feedstock will gradually be valued higher. The pulp and paper industry, which already today is a large user and producer of biomass-based energy and materials, therefore has a large opportunity to increase and diversify its revenues through different biorefinery concepts (see e.g. [1–7]). For mills to become successful in this biorefinery arena, process integration investments are required to ensure energy efficiency of the combined pulp and paper production and biorefinery process. This also calls for investments in new, unproven technologies, with highly uncertain investment costs – for example, carbon capture, black liquor gasification, or lignin extraction.

Investments in these emerging technologies are not quickly implemented. Time is needed for analyzing different options, planning of construction including any shutdowns of the plant, contracting, and so on. This results in long lead times from the first decision to start planning for a certain technology path until the plant is finally run continuously at full load. This is true also for traditional options being evaluated in competition with emerging technologies.

Considering that new decisions cannot be immediately implemented if they have not previously been planned for, decision-makers need guidance – not only regarding what investments to make – but also, and more importantly, to what future investments should be planned for. Better tools to aid decision-makers in this field will hopefully lead to that more of these energy efficiency and emission-reducing measures are carried out. The purpose of this work is therefore to further develop our methodology for process integration investment planning under uncertainty [8–10] to consider these aspects of long-term decision-making. Here, we will also use the proposed approach to illustrate the effect of a five-year planning lead time in an example of a pulp mill that considers a future possibility of investing in lignin separation.

The work presented in this article is a direct continuation of the work presented in our previous article in which we presented the approach for planning of process integration investments in pulp mills considering uncertainty in the investment cost development of emerging biorefinery technology [10]. Here, we only briefly present the basic methodology and instead concentrate on the extension which enables the study of long lead times (see Section 4). For related work on planning of process integration investments in pulp mills under uncertainty, the reader is referred to [8,10].

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2. Related work

During the last decade, several studies have been published on plant-level, energy-related investments under uncertainty (see e.g. [11–18]). For the energy consumer side, there are fewer publications available. One example is a study of energy-saving investments in the horticultural sector [19]. Up until recently, however, the only attempts to study the effects of uncertainty when analyzing process integration investments in energy-intensive industry have been based on sensitivity analysis (see e.g. [20,21]). To our knowledge, there are only a few published articles which have proposed some kind of more sophisticated approach for dealing with uncertainties in process design of integrated biorefineries or other complex industrial energy systems of large-scale energy consumers. For uncertainty in energy and product prices – in addition to our own work based on stochastic programming [8,9] – an approach based on Monte Carlo analysis has also been suggested [22]. For the design of a single energy conversion process – in difference to the design of the energy system of all integrated processes in an industrial plant – a stochastic optimization approach based on evolutionary algorithms has also been proposed [23]. However, there is no statement of which parameters have been considered uncertain. A single energy conversion process was also the scope of a study of an absorption cooling system presented by Gebreslassie et al. [24]. None of the studies mentioned above consider the uncertainties related to the development of the investment cost of new technologies. Furthermore, none of them considers the lead times required in the decision and planning process.

3. Methodology

The methodology used in this paper is based on a methodology for optimization of process integration investments under energy market uncertainty [8,9]. In this work, we have used an approach which in addition allows the influence of the investment cost development for new, emerging technologies to be studied [10]. While investments are optimized under uncertainty in energy market parameters with a stochastic programming approach, the effect of different cost developments on the optimal solution is studied through a scenario analysis. For each cost development scenario, the solution to the optimization model will be an optimal investment plan with respect to the expected net present value (NPV) based on the information we have about the future energy market today.

We model the investment optimization problem using AMPL [25] and solve it using CPLEX [26]. A strategic view of the analyzed investments is assumed, and the discount rate is therefore set to 9.3% over a 30-year-long planning horizon.

The interested reader is referred to our previous work for more detailed descriptions of the methodology for optimization of process integration investments under energy market uncertainty based on multistage stochastic programming [8,9] and our approach to consider also uncertainty in investment cost developments [10].

4. Long lead times for investment planning

Here, we use the expression 'lead time' to denote the time between the decision to invest and the actual implementation or installation of the technology invested in. This is simply modeled based on the assumption that it takes a few years to analyze, plan and prepare for these extensive process changes. When studying the effect of long lead times it is therefore assumed that it is too late now to decide about investments that should be implemented today, and the first investments will instead be implemented in five years.

Since there are costs associated with evaluation and planning of investments – mainly related to the time committed by engineers, consultants, etc. – a basic assumption is that it is not possible to plan for all investments that might be of interest. In this way, although the planning costs are not explicitly accounted for, they are implicitly considered in the proposed modeling approach. The idea of the proposed approach is then that investments planned for today will constrain what will be possible to implement in five years.

To find different planning alternatives, the approach is to start by optimizing the investment in each cost development scenario assuming that the first investment will be in five years. This will, however, lead to solutions where different investments should be made in five years depending on the cost and price development. Based on the solutions obtained, a matrix can be constructed that shows which investments will be possible to implement depending on what has been planned for. A general illustration of such a matrix is shown in Fig. 1.

The matrix could also contain other investment solutions based on experience from working with the model and the mill. The model will then be run for each of the planning alternatives, with possibilities for implementation as constraints. Thereby the results of different investment plans considering an initial lead time of five years can be analyzed, and the best one possibly identified.

Long lead times should also be modeled for later points in time, but this makes the model and especially the solution of the optimization problem hard. As a first step towards an improved understanding of the effects of lead times we therefore settle for the initial lead time. Experience shows, however, that for a majority of investment plans, very few investments are made at later points in time. Therefore, the modeling of later lead times should not be as important. Furthermore, the optimal solution will obviously result in a plan also for later investments, even though it is not considered that decisions have to be made years before the actual implementation and hence possibly before future energy prices and cost reductions have been revealed.

5. Input data and assumptions

5.1. The pulp mill

We have applied the proposed approach to a pulp mill example that has previously been presented by the authors [10]. This mill is

		Possible to implement 2015				
		Technology 1	Technology 2	Technology 3	Technology 4	Technology 5
Plan 2010	Investment package 1	X	X			
	Investment package 2		X	X		
	Investment package 3		X		X	
	Investment package 4					X

Fig. 1. Generic matrix for investment planning.