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

Elin Svensson[1,*], Thore Berntsson[1]

[1] Heat and Power Technology, Chalmers University of Technology, 412 96 Göteborg, Sweden
** Corresponding author. Tel: +46 31 772 3016, Fax: +46 31 821 928, E-mail: elin.svensson@chalmers.se*

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.

Keywords: *Investment planning, Optimization under uncertainty, Process integration, Lignin separation, Pulp and paper industry*

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 a methodology for process integration investment planning under uncertainty 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.

2. 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 sensitivity analysis. 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 today.

We model the investment optimization problem using AMPL [11] and solve it using CPLEX [12]. 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.

2.1. 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.

		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.

3. Input data and assumptions

3.1. 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 a computer model representing an average Swedish market pulp mill, producing 1000 tonnes per day of bleached Kraft pulp (see also [1, 13]).

Through process integration and more efficient technology, there is a potential to achieve a steam surplus at the mill of about 25%. The steam could, for example, be used to produce more electricity in a low-pressure turbine, or to produce district heating for a nearby community, or for cogeneration of both heat and electricity. District heating could also be produced from lower-quality excess heat at the mill. Except for these traditional ways of making use of the steam surplus, there are new, emerging technologies that might become promising alternatives. We will here look at the example of lignin extraction.

For energy conversion data and investment costs, the reader is referred to [10]. The cost development scenarios for the lignin separation process are presented in Section 3.3.

3.2. Energy market uncertainty model

The energy market model used in this study is the same as the one used in the previous study on the effect of uncertain investment cost developments for emerging technologies [10]. This uncertainty model was developed using the ENPAC tool [14]. The model consists of 28 scenarios for market electricity and fuel prices, see Fig. 2. The same probability has been assumed for each scenario.

3.3. The investment cost scenarios

For the cost development of the emerging lignin separation technology, six scenarios have been used. For this technology, we have assumed that market introduction might happen in 2015 or 2020. It is assumed that market introduction might happen at the base level (L), corresponding to the estimated cost of the Nth plant assumed in previous studies (see [10]), or at a higher cost level (H), here assumed to be 50% higher than the base cost level.

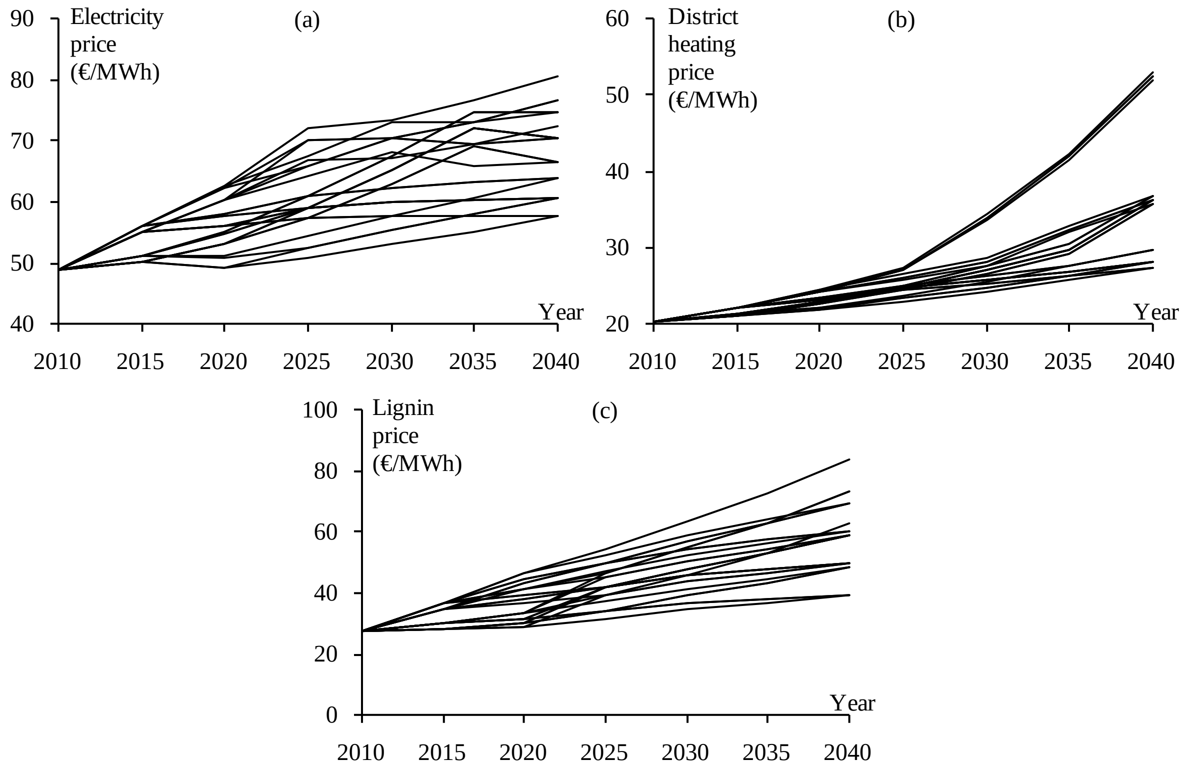

Fig. 2. a) Electricity price scenarios. b) District heating price scenarios. c) Lignin price scenarios.

Table 1 presents the different scenarios for the investment cost of the lignin separation plant. If the market introduction happens at the base cost level, the cost stays permanently at that level (Scenarios A and B). If, instead, market introduction happens at the higher cost level, the cost might stay at the higher level (Scenarios C and D), or it might drop later as a consequence of technological learning (Scenario E) if, for example, not very many plants are sold. There is also a possibility that the technology is never introduced to the market (Scenario F).

Table 1. Investment cost scenarios for the lignin separation plant.

Scenario & Market introduction (year)		2010	2015	2020	2025	2030	2035
A	2015 at base cost level	–	L	L	L	L	L
B	2020 at base cost level	–	–	L	L	L	L
C	2015 at higher cost level where cost is stabilized	–	H	H	H	H	H
D	2020 at higher cost level where cost is stabilized	–	–	H	H	H	H
E	2015 at higher cost level with drop to base cost level 2020	–	H	L	L	L	L
F	Never	–	–	–	–	–	–

–: Unavailability
L: Low cost / base cost level = Estimated cost of Nth plant
H: High cost / Higher cost level = 1.5L

4. Results

As described previously, the effect of long lead times is studied by assuming that no investments can be made already today, and that the first investments in five years must be planned for. Furthermore, we assume that the costs and personnel resources associated with planning of investment and implementation make it impossible to plan for every interesting investment opportunity. To find a number of reasonable investment packages to plan for, the model was solved for one cost development scenario at a time with the constraint that the first investments could be made in five years. The solutions obtained are presented in Table 2.

Table 2. Optimal investments 2015 in different cost development scenarios.

Scenario	Optimal investment	
A, C, E	Lignin:	64 MW lignin
	Heat pump:	32 MW delivered heat
B, D	Cogeneration:	5MW elec. and 26 MW delivered heat
F	Cogeneration:	5MW elec. and 26 MW delivered heat
	Heat pump:	19 MW delivered heat

These three packages obviously differ regarding the lignin extraction investment, but also regarding the amount and means of district heating deliveries. The reason for this difference in district heating production is that the preferred way of generating district heating is by cogeneration from low-pressure steam, but when lignin is extracted as for Scenarios A, C and E, no low-pressure steam is available. In these scenarios, district heating is therefore generated by a heat pump instead. Also in the case of cogeneration, a heat pump might be interesting to further increase district heating deliveries as in Scenario F. By this solution, the mill is, however, locked into a district heating contract of substantial deliveries for which the production based on low-pressure steam is needed to fulfill the delivery requirement. In Scenarios B and D, later opportunities for lignin extraction might make it interesting to use the low-pressure steam for lignin extraction at a later point in time. Therefore, district heating deliveries are more limited, making it possible to replace the production from cogeneration with production from the heat pump.

In some mills, the power boiler and back-pressure turbine might be oversized. Under such conditions, it would probably be more beneficial to increase district heating deliveries by increasing the fuel input to the power boiler than to invest in a new heat pump. Here, however, the boiler is already assumed to be run at maximum capacity.

Fig. 3 is a matrix showing which investments can be made in 2015 depending on what investment package has been planned for. In addition to the alternatives from Table 3, we also added the alternative to plan for a condensing turbine and a heat pump. The alternative not to plan for any investment should obviously never be better than to plan for something, since there is always an option to avoid making an investment that has been planned for. However, the ‘no investment’ planning alternative was included for comparison. It might be interesting if costs and resources for planning are considered explicitly, which they are not here.

The X’s in the matrix represent that an investment is possible, though not required. That means, for example, that if a heat pump has been planned for, this possibility exists in 2015 but there is also always an option to withdraw from the investment. This option to abandon a planned investment is especially important for lignin extraction since this technology might not even be available on the market in 2015. Based on the matrix, the optimization model was solved for different planning alternatives. The expected net present value for the alternatives in the different cost development scenarios is shown in Fig. 4.

		Possible to implement 2015				
		Lignin	Heat pump	District heating from 145 and 100°C heat	Turbine (145-100°C)	Turbine (100-35°C)
Plan 2010	Lignin and heat pump	X	X			
	Cogeneration only			X	X	
	Cogeneration and heat pump		X	X	X	
	Condensing turbine and heat pump		X		X	X
	No investment					

Fig. 3. Matrix of possible technology implementations depending on what has been planned for.

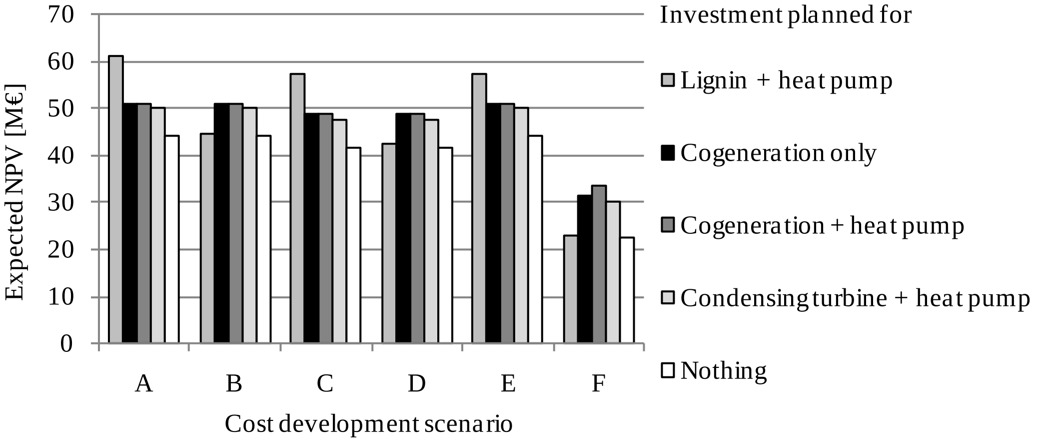

Fig. 4. Expected net present value for different planned investments in 2015.

As can be seen, depending on the cost development scenario, lignin extraction could either be by far the best or by far the worst alternative (at least except planning for nothing). This is explained by the large potential associated with this technology if it becomes a reality, which disappears if the technology has not yet become available for the pulp mill.

The good runner-up is instead cogeneration, which is either the best or the next best alternative in all scenarios. The difference is very small if you include the heat pump or not. Obviously, it is better to include the heat pump in the plan since there is no requirement of going through with the investment. In Scenario F where lignin extraction never becomes available on the market, the heat pump is slightly advantageous. As anticipated, the 'nothing' alternative is the worst one in all scenarios.

5. Discussion

In theory, the optimal planning alternative would include all different technology options, but this would obviously be difficult in practice. Principally, planning for everything means the same as staying flexible and that should be striven for. However, the underlying assumption in this study was that this is too costly to achieve in reality. Nevertheless, the lack of flexibility obviously has a cost. The results show that if lignin extraction is not planned for, but cogeneration instead, the loss is 19% in expected NPV in Scenario A (17% and 12% in Scenarios C and E respectively). On the other hand, if the plan is for lignin extraction and a heat pump but the lignin separation technology does not become a possibility, the loss is 15%, 15% and even 46% in Scenarios B, D and F respectively. Considering that the use of expected NPV as investment evaluation measure partly hides differences in cash flows because of discounting and weighting of scenarios, these losses in expected NPV are quite important (see for example [10, 15] where differences in expected NPV are related to corresponding differences in annual net profits). These high values of staying flexible by planning for many different investment opportunities imply that, strategically, it should be worth committing more organizational resources to planning of these kinds of investments.

Nevertheless, if we assume that it is not possible to invest in anything else than what has been planned for, and if we further assume that it is not possible to plan for more than a few different new technologies, results like the ones presented in Fig. 4 can be used to evaluate different investment plans. In the example presented here, investment in lignin extraction involves both the highest potential and the highest risk, while cogeneration seems to be a more robust option. The best decision depends on the decision-maker's beliefs about the probabilities of the different cost development scenarios.

5.1. Limitations

The work presented in this paper provides a good starting point for an investment planning methodology where consideration is given to the long lead times that are often involved in these kinds of decisions. There are, however, some limitations which might make it difficult to use the methodology for some applications where these aspects are of importance. Further work with model development should focus on these issues. For example, the costs associated with evaluation, planning and detailed analyses of different investments and their implementation are not explicitly considered in this model. It should also be possible to differentiate these costs and the length of the planning lead time between different kinds of investment alternatives. Further work is needed, too, if not only the initial lead time but also the lead time for subsequent investment stages should be accounted for.

6. Conclusions

The proposed approach for modeling of long lead times for planning of industrial energy efficiency investments gives a more realistic representation of this kind of decision-making. An example illustrates how the planning of future investments can be guided by using this systematic approach considering uncertainties in future energy market conditions as well as in cost development of new technologies. The results clearly show the importance of considering the long lead times involved in the investment planning, since significant values are at stake by making the right or the wrong decision about which investments to plan for.

We have also shown how the proposed approach can be used to value flexibility in the planning of industrial energy efficiency measures. The example demonstrates that the value of this flexibility can be quite high. There is, however, a trade-off between the value of this flexibility and the associated planning costs required to obtain it. It is therefore important to continue the work regarding long lead times to incorporate these planning costs.

Acknowledgements

The project was financed by the Process Integration research programme funded by the Swedish Energy Agency and by the Södra Foundation for Research, Development and Education.

References

[1] M. Olsson, E. Axelsson, T. Berntsson, Exporting lignin or power from heat-integrated Kraft pulp mills: A techno-economic comparison using model mills, Nordic Pulp and Paper Research Journal 21, 2006, pp. 476–484.

[2] A. Van Heiningen, Converting a Kraft pulp mill into an integrated forest biorefinery, Pulp & Paper-Canada, 107, 2006, pp. 38–43.

[3] V. Chambost, J. McNutt, P.R. Stuart, Guided tour: Implementing the forest biorefinery (FBR) at existing pulp and paper mills, Pulp & Paper-Canada, 109, 2008, 19–27.

[4] S. Consonni, R.E. Katofsky, E.D. Larson, A gasification-based biorefinery for the pulp and paper industry. Chemical Engineering Research & Design, 87, 2009, 1293-1317.

[5] M. Marinova, E. Mateos-Espejel, N. Jemaa, J. Paris, Addressing the increased energy demand of a Kraft mill biorefinery: The hemicellulose extraction case. Chemical Engineering Research & Design, 87, 2009, 1269-1275.

[6] R. Fornell, Energy Efficiency Measures in a Kraft Pulp Mill Converted to a Biorefinery Producing Ethanol, Licentiate Thesis, Heat and Power Technology, Chalmers University of Technology, 2010.

[7] K. Pettersson, S. Harvey, CO2 emission balances for different black liquor gasification biorefinery concepts for production of electricity or second-generation liquid biofuels, Energy, 35, 2010, pp. 1101-1106.

[8] E. Svensson, A.-B. Strömberg, M. Patriksson, A scenario-based stochastic programming model for the optimization of process integration opportunities in a pulp mill, ISSN 1652-9715, no. 2008:29, Mathematical Sciences, Chalmers University of Technology, 2008.

[9] E. Svensson, T. Berntsson, A.-B. Strömberg, M. Patriksson, An optimization methodology for identifying robust process integration investments under uncertainty, Energy Policy, 37, 2009, pp. 680–685.

[10] E. Svensson, T. Berntsson, Planning future investments in emerging technologies for pulp mills considering different scenarios for their investment cost development, Submitted for publication, 2010.

[11] R. Fourer, D.M. Gay, B.W. Kernighan, AMPL: A Modeling Language for Mathematical Programming, Duxbury Press / Brooks/Cole Publishing Company, 2nd Edition, 2003.

[12] IBM ILOG, CPLEX: High-Performance Software for Mathematical Programming and Optimization, Version 12.1.

[13] E. Axelsson, M. Olsson, T. Berntsson, Heat integration opportunities in average Scandinavian Kraft pulp mills: Pinch analyses of model mills, Nordic Pulp and Paper Research Journal, 21, 2006, pp. 466–475.

[14] E. Axelsson, S. Harvey, Scenarios for assessing profitability and carbon balances of energy investments in industry, AGS Pathways report 2010:EU1, 2010.

[15] E. Svensson, T. Berntsson, Using optimization under uncertainty to study different aspects of process integration investment decisions – The example of lock-in effects, Proceedings of ECOS, 2010.