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The influence of operational flexibility on the reduction of CO_2 emissions in industrial energy production

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Realizing the emission reduction potential of an energy conservation investment depends on many factors, such as energy prices. The study shows that the link between energy conservation and emission reduction is not straightforward. Although operational flexibility has economic value, the different operational options in industrial energy production complicate the estimation of CO_2 reduction potential in the investment phase. In addition, the EU emissions trading scheme has made the investment analysis more complicated and increased the value of operational flexibility under fluctuating carbon prices. However, it seems that high carbon prices weaken the value of flexibility.

Keywords: Energy efficiency, CO_2 emissions, economic analysis, flexibility

1. Introduction

Energy efficiency has been seen as the fastest and cheapest way of reducing CO_2 emissions (IEA, 2007). At the national or international level the CO_2 reduction potential of different emission reduction policies, including energy efficiency improvement, is typically evaluated on the basis of scenario studies, where numerous assumptions have to be made about economic development, technology penetration, fuel prices, etc. In addition, typically only a few policy scenarios are compared to one baseline or reference scenario, and therefore the uncertainties of different variables are difficult to take into account.

At the installation level the CO_2 reduction potential of an energy efficiency investment is often estimated before making an investment decision. In the beginning of 2005 the European Emissions Trading Scheme, EU ETS (The European Parliament, 2003), gave a monetary value for CO_2 emissions, which added another variable to the investment analysis and estimation of CO_2 reduction potential. Laurikka (2004) stated that climate policy, including emissions trading, increases uncertainty in the business environment and consequently the value of flexibility in energy investments.

In the investment analysis the effects of uncertainties are typically studied by using sensitivity analyses. However, this approach only gives the range of solutions with the

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selected sets of input parameters, but does not help to make optimal decisions. Svensson et al. (2009) developed more advanced methodology for evaluating energy efficiency investments considering the uncertainties of future energy prices and policies. In that methodology the probability distributions of the expected values of uncertain parameters, such as future energy prices, can be taken into account by using a stochastic programming model. However, no results on the application of the methodology have been published yet.

The purpose of this paper is to discuss the effects of operational flexibility on the realization of the CO_2 reduction potential of an energy efficiency investment. In this study an individual energy efficiency investment made in a Nordic pulp and paper mill is used as a case study. The effects of flexibility are analyzed by monitoring the cost savings, energy conservation and CO_2 reduction of an investment after the realized energy prices are known. This study is based on an economic analysis and process model made by Solvo® software.

2. Materials and methods

In the case study, the hypothetical energy conservation investment in the pulp and paper mill is supposed to be made in early 2000. The investment reduces process steam consumption in the paper mill (2 MW or 1 300 MWh/month). Since CHP production is widely used in energy-intensive industry in the Nordic countries, electricity and steam used by the mill are assumed to be produced by the mill's own CHP power plant using peat and biomass (bark from the mill) as fuels.

In early 2000, the feasibility of the investment and the CO_2 reduction potential were evaluated, assuming that heat conservation reduces the consumption of marginal fuel, i.e. peat, at the mill site. Therefore, the reduction of peat consumption is named as a 'Base case' in this analysis. In addition, the effects of operational flexibility on the cost savings and the reduction of CO_2 emissions were analyzed. In the case of 'Flexibility 1°' it is possible to sell biomass to the markets as an alternative to peat conservation. In 'Flexibility 2°' there is also an option to produce additional electricity using the condensing tail of steam turbine.

Since business is based on profit maximization, management is assumed to select the most profitable operational option at each moment. We assume efficiently operating markets, which means that management has perfect information on energy markets and prices, there are no barriers to enter or exit the markets, and all the transactions are costless. In addition, we assume there is no switching cost between different fuels and operation of the condensing tail.

Figure 1 shows that the electricity price in the Nordic area has changed considerably in recent years. During the winter 2002-2003 the electricity price increased due to the low level of hydropower reservoirs and cold weather. From 2005, the EUA price has affected the electricity price because of carbon pass-through effect: according to Honkatukia et al. (2006) on average about 75-95 % of a change in the EUA price has been passed on to the price of electricity in Finland. The price of biomass has risen due to higher demand and improved competitiveness under emissions trading.

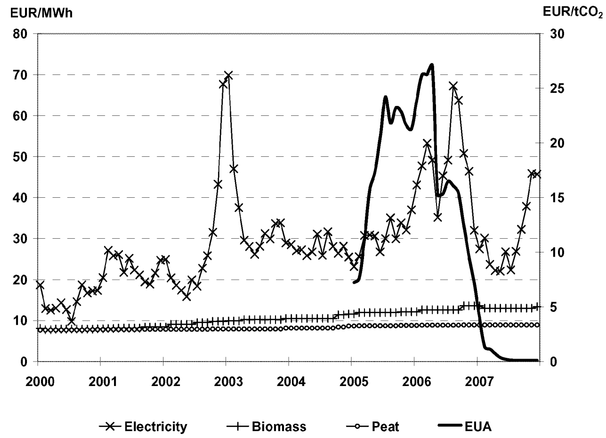


Figure 1. Average monthly prices of energy and emission allowances (EUA) in Finland in 2000-2007 (Kosunen, 2008, Nordpool, 2008)

If one of the options to reduce peat consumption or sell biomass to the market is selected, the CHP electricity production decline and the reduced electricity production has to be made up with electricity purchase from the market. From the beginning of 2005, in the case of reduced peat consumption at the mill site, there has been a possibility to sell emission allowances (EUAs) equal to the reduced CO_2 emissions. Sold biomass is assumed to replace heavy oil in district heating production. In the case of additional electricity production using the condensing tail of the steam turbine, the electricity purchased from the market can be reduced. The profit maximization target can be simplified to the maximization of cost savings (*CS*) due to the energy conservation investment according to the following function:

$$MaxCS = -(\Delta Q_{peat} * p_{peat} + \Delta EUA * p_{EUA} + \Delta Q_{bionass} * p_{biomass} + \Delta E_{purchased} * p_{electricity}) \qquad (1)$$

where ΔQ_{peat} is the change in peat purchased, p_{peat} is the price of peat, ΔEUA is the change in emission allowances needed due to reduced peat consumption, p_{EUA} is the price of emission allowances, $\Delta Q_{bionass}$ is the change of biomass consumption, $p_{biomass}$ is the price of biomass, $\Delta E_{purchased}$ is the change of the purchased electricity and $p_{electrcity}$ is the price of electricity.

For each operational option the CO_2 reduction potential at the national level is calculated according to the principle presented in our previous article (Siitonen et al., 2009) using the following equation presented first by Möllersten et al. (2003):

$$CO_{2\,National} = CO_{2\,Mill} + CO_{2\,Grid} + CO_{2\,Heat} \qquad (2)$$

where $CO_{2\,Mill}$ is the change in CO_2 emissions from the mill site, $CO_{2\,Grid}$ is the change in CO_2 emissions from grid-based electricity production and $CO_{2\,Heat}$ is the change in CO_2 emissions due to fuel (i.e. biomass) export from the mill.

3. Results and discussions

Based on process modeling made by Solvo®, the variables in the equation (1) can get the sets of values presented in Table 1. In the same table, the CO_2 reduction potential of the different operational options is presented.

Table 1. Reduction (-) and increase (+) of fuel consumption, electricity purchase and CO_2 emissions, in different operation options

Operation option	ΔQ_{peat} MWh/month	$\Delta Q_{biomass}$ MWh/month	$\Delta E_{purchased}$ MWh/month	$CO_{2\,Mill}$ t CO_2/month	$CO_{2\,Grid}$ t CO_2/month	$CO_{2\,Heat}$ t CO_2/month	$CO_{2\,National}$ t CO_2/month
Reduction of peat consumption	-1986	0	423	-757	360		-397
Selling of biomass	0	-1986	423	0	360	-534	-174
Production of additional electricity	0	0	-272	0	-231		-231

Figure 2 shows the cost savings of the different operational options. Producing additional electricity has been the most feasible option during periods of high electricity prices (see Fig. 1). In 2007, the sale of biomass was feasible because of collapsed EUA and electricity prices. Overall, after introducing the EU ETS at the beginning of 2005, the variation of cost saving in the different operational options has been larger than in the previous years.

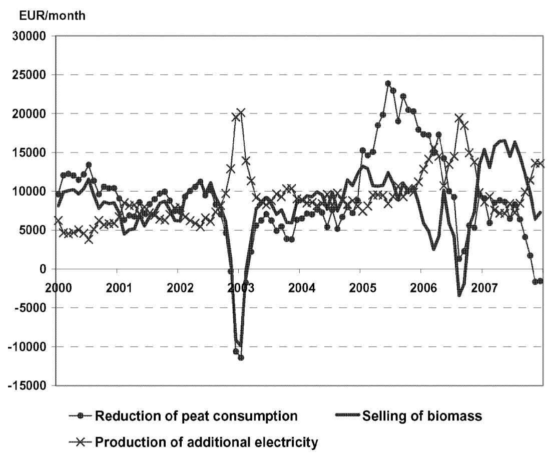
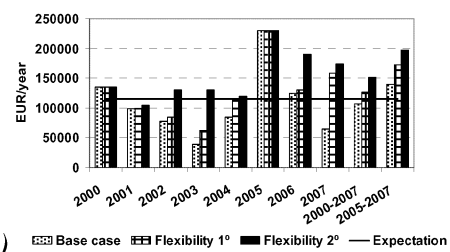


Fig. 2. Cost savings of different operational options

Figure 3.a shows that the flexibility of the energy production process increases the cost savings of energy conservation investment, as the theory expects. However, Figures 3.b and 3.c indicate that operational flexibility weakens the realization of the potential for conserving energy and reducing CO_2 emissions compared to the marginal fuel saving

expected in the investment phase. If the potential for reducing CO_2 emissions had been evaluated based on the options other than the reduction of peat consumption, the realization of potential would have corresponded better to the expected potential at the investment moment. Therefore, in the case of operational flexibility, more attention has to be paid to estimating the energy conservation and CO_2 reduction potential in the investment phase. Especially, if there are big differences in the CO_2 reduction potential of different operational options, the risk of a shortfall in expected emission reduction might be high – around 30 % in this case study.

As figure 3.a shows, the introduction of EU emissions trading has increased the economic value of flexibility, just as Laurikka (2004) stated. Because the high EUA prices from 2005 to the beginning of 2006 improved the competitiveness of the base case, i.e. reduction of peat consumption (with high CO_2 emission factor), the expected CO_2 reduction potential was reached. However, after EUA prices dropped below 10 EUR/tCO_2 in the end of 2006, the effect of increased flexibility was similar to the years before the launch of EU ETS.



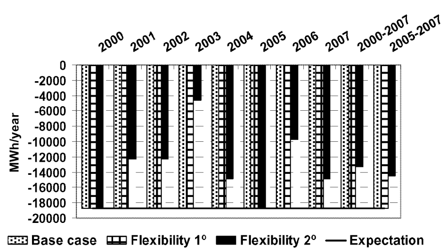
a)

Base case: Reduction of peat consumption.

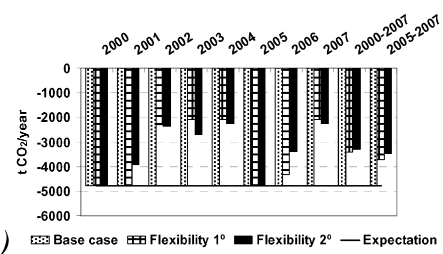
Flexibility 1°: an option to sell biomass to the market as an alternative to peat conservation.

Flexibility 2°: an option to produce additional electricity using the condensing tail of the steam turbine as an alternative to peat conservation or biomass selling.

Expectation: based on prices in January 2000.



b)



c)

Fig. 3. a) Cost savings, b) energy conservation and c) reduction of CO_2 emissions in different operational options compared to the expectations in the investment phase

Although EUA has the same price all over Europe, the energy prices and carbon pass-through effect vary between countries. Therefore, the effects of emissions trading on operational flexibility may differ between different market areas. For example, in the UK the importance of the price ratio of coal and natural gas has risen after the launch of EU ETS, but in Spain, where the electricity market is more regulated, the effects of emissions trading are smaller.

4. Conclusion

Energy conservation is considered to be a promising way of reducing CO_2 emissions. However, evaluating the CO_2 reduction potential of an energy conservation investment is not so straightforward. The launch of EU ETS complicated the analysis of an energy conservation investment because the EUA price and its effects on energy prices have to be taken into account. Our study shows that: 1) a more complicated investment environment and strong fluctuation of the EUA price increases the economic value of operational flexibility, 2) increasing the operational flexibility of industrial energy production makes it more difficult to estimate the CO_2 reduction potential of energy conservation investments, 3) in the case of high operational flexibility, more attention has to be paid to the future uncertainties when the CO_2 reduction potential of energy conservation investments is estimated, and 4) high EUA prices seems to weaken the value of operational flexibility in the case where there are big differences in the CO_2 reduction potential of different operational options.

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References

The European Parliament and the Council of the European Union, 2003. Directive 2003/87/EC of the European Parliament and of the Council of October 2003 establishing a scheme for greenhouse gas emissions allowance trading within the community and amending Council Directive 96/61/EC.

Honkatukia J., Mälkönen V. and Perrels A., 2006. "Impacts of the European Emission Trade System on Finnish Wholesale Electricity Prices," VATT Discussion Papers 405, Government Institute for Economic Research (VATT).

IEA, 2007 World Energy Outlook 2007, OECD/IEA 2007, Paris.

Kosunen, P., 2008, Fuel Prices in Finland 2000-2007, Pöyry Energy Oy.

Laurikka, H., 2004. The impact of climate policy on heat and power capacity investment decisions. In: Hansjürgens, B. (Ed.), Proceedings of the Workshop "Business and Emissions Trading" held in Wittenberg, Germany, November 11–14

Möllersten K., Yan J. and Westermark, M., 2003, Potential and cost-effectiveness of CO_2 reductions through energy measures in Swedish pulp and paper mills, Energy 28:691-710.

Nordpool, 2008, Electricity and EUA prices, www.nordpool.com/asa/

Siitonen, S., Tuomaala M. and Ahtila P., 2009, Implications of process energy efficiency improvements for primary energy consumption and CO_2 emissions at the national level, First International Conference on Applied Energy, 5 - 7 January 2009, Hong Kong.

Svensson E., Berntsson T., Strömberg A-B. and Patriksson M., 2009 An optimization methodology for identifying robust process integration investments under uncertainty, Energy Policy, Volume 37, Issue 2, February 2009, Pages 680-685.