Planning of energy efficiency investments in a pulp mill A stochastic programming model with multiple objectives

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Outline of the lecture

- Background
- Optimization model
- Assignment



Background Energy use in Swedish industry

Total energy use in Sweden 2006* (~450 TWh)

Energy use in Swedish industry 2006 (~160 TWh)



Industry

- Transports (internal)
- Residential. service etc.
- International marine bunkers and use for nonenergy purposes



Pulp and paper

- Iron- and steelworks
- Chemical industry
- engineering industry

Based on data from the Swedish Energy Agency

*Excluding nuclear power losses, transmission and distribution losses

Background - The pulp mill





Background A pulp and paper mill



Axelsson (2008) Energy Export Opportunities from Kraft Pulp and Paper Mills and Resulting Reductions in Global CO₂ Emissions





- Not all energy saving measures can be combined --> We have to choose!
- Uncertain future energy market
 - Electricity and fuel prices
 - Emissions charges and taxes
- Several objectives
 - Economy
 - $-CO_2$ emissions
 - Etc



Important features



Optimization model Stochastic programming

Two-stage decision model



- Favours flexible and robust solutions, and solutions hedging against uncertainty
- Multistage models are also possible



 Maximization of the expected value – probability distributions are required

Modelling the future energy market

- Long-term uncertainties are there because we expect changes in policy instruments and regulations, but we do not know when or with what magnitude.
- We cannot look at history and extrapolate, since these changes has never happened before (Emmision rights, oil depletion, etc.)
- Uncertainties are not easily described by a stochastic function. They are not what we normally call "random" fluctuations, but rather big step changes.

Optimization model Scenario model





BAU Business As UsualS1 Sustainability, distant futureS2 Sustainability, near futureS3 Sustainability, very soon



Evaluating investments

Net present value

NPV =
$$-C_0 + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t}$$

Rule for 1 investment option: Invest if NPV > 0 For several options: Invest in the options which gives the highest NPV

Optimal investment plan = The investment plan with maximum *expected* NPV

maximize E[NPV(x)] :=
$$-C_0(x_0) + \sum_{s \in S} p_s \sum_{t=1}^T \frac{C_t(x_0, x_s, \omega_s)}{(1+r)^t}$$

Multiobjective programming

Pareto-optimal solutions One objective cannot be improved without worsening at least one other objective. Also known as non-dominated solutions.



Objective functions

The economic objective:

The expected net present value of the investments

$$f_{\text{NPV}} := \sum_{n \in N} \operatorname{pr}^n \left(\phi(\ell(n)) f_R(\alpha^n, \xi^n) - \psi(\ell(n)) f_C(\hat{x}^n, \hat{y}^n, \delta^n) \right)$$

The CO₂ objective: The expected "net present value" of the emissions reductions

$$f_{\rm CO2} := \sum_{n \in N} {\rm pr}^n \phi(\ell(n)) f_{\rm Em}(\alpha^n, \xi^n)$$



Finding Pareto optimal solutions

- MILP problem = > discontinuous Pareto front
- Here we choose ε-constraint method instead of the simpler (?) weighted sum approach.
 - MILP problem => non-convex set => might not be possible to find all Pareto optimal solutions using, e.g. weighted sum approach.
 - Incommensurable objectives with different magnitudes => difficult to choose weights in weighted sum approach.



Assignment - The pulp mill



Assignment

A production increase at the pulp mill

Decision taken to increase the pulp production by 25%. The recovery boiler is a bottleneck.



Optimal solution – The optimal investment plan

- Which investments are made and when AMPL: activate $\hat{x}_m^{p(n)}$
- What capacities of turbines, lignin extraction, etc have been invested in AMPL: size β_u^n

Optimization model Examples of constraints





Examples of constraints



Assignment Last year's most common questions

- Q. There are so many parameters and variables in the model and investigating all of them requires too much time. How deep should we go into details?
- A. Yes, there are a lot of variables and parameters in the model. You do not have to investigate all of them in detail. Also for me, the model is extensive, and I had a difficult task choosing which variables to describe and discuss in the lecture and in the project description. So, try to explain your results as good as possible according to your understanding of the problem.

Assignment

Last year's most common questions

- **Q.** What is the variable output (α) really representing?
 - Why is it sometimes negative?
 - Why is it sometimes substantially smaller than the capacity?
- A. The variable represents the change in energy export compared to the situation today.
 - Since there is an existing turbine at the mill today, the output of this turbine can be negative if the electricity production is decreased.
 - If investment is made in a new larger turbine (which means that the old one has to be scrapped), the maximum possible increase in electricity production (i.e. the maximum output, α) is only the increase in capacity for the new turbine compared to the old one. The capacity variable, however, always represent the total, existing capacity (in this case of the new turbine).

Assignment Last year's most common questions

Q. What does it mean when an investment is activated at more than one occasion?

- A. Investment activations which occur when the investment is already active can be explained by one of the three different situations:
 - The capacity of the equipment needs to be further increased, in which case a "reactivation" is needed.
 - The investment cost might be zero, in which case activation or no activation will give the same solution value. In these cases, the investment activation does not have to be considered.
 - There might be constraints requiring activation in order for other variables to take certain values. These are special cases that need not be considered in this project.

Assignment Last year's most common questions

- We get really low values for some variables (~10⁻¹²). Why is that?
- This is because the solver reached its optimality criteria at this point, i.e. the difference between the upper limit of the solution value and the lower limit is sufficiently small. To guarantee optimality, this difference should of course be exactly zero, but in practise, it is set to a very small positive value. If the solution had converged to exact optimality the true optimal solution would most probably have a value of the variable equal to zero. Values this small can therefore be neglected.



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Good luck!

