# POSSIBILITIES FOR COMBINED EVALUATION OF SOCIAL, ECONOMIC ENERGY/ENVIRONMENTAL VALUES.

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## ABSTRACT

Northern Scandinavia is an area, which is rich in natural resources and energy-intensive base industries covering several branches, e.g., Mining, Iron and Steel, Metal production, Pulp and Paper. They are often part of a community network where a change in one node affects the behavior and efficiency of its neighbors. Improvements in environmental load, energy efficiency etc. cannot simply be achieved by improving the individual units. A system approach is needed. Such methods (Process Integration) have been developed within the Nordic Countries for more than twenty years, e.g. within the Swedish national program that was launched 1989. They are been practically applied e.g. at SSAB in Luleå An excellence center for Process Integration in Steelmaking (PRISMA), with industrial partners from Sweden and Finland, has recently been founded at MEFOS in Luleå. The process integration methods have been developed to handle multi-objective problems. This is because the industry has to answer to a combined demand on energy consumption, emission limits for several substances, climate effects as well as costs.

For regional evaluation an economic model has been developed which explicitly returns changing input and output prices due to changes in e.g., production technology, derived input demand or the introduction of market instruments. Especially on smaller regional markets, changes in input demand of fibrous raw material might significantly affect its price. This price effect must be considered whenever extensive changes in the production process are considered so that the project is not, ex post, rendered unprofitable.

Another factor of great influence is local and national attitudes. These can influence both market value and political decisions. These effects can be evaluated in stakeholder studies. Co-evaluation with the technical parameters mentioned above is interesting, but an obstacle is the difference in result format. A method (CONJOINT) has been developed, by which these results can be converted into numerical parameters. For the Swedish Steel industry it has been tested within the ECO-Cycle program. An attempt to merge these methods into a combined study is presently carried an ongoing PROCESS INTEGRATION study for a Pulp and paper mill in northern Sweden. The possibility to merge into a combined tool or methodology is discussed.

## PROCESS INTEGRATION METHODS

### 1. What is PROCESS INTEGRATION

A typical process industry does not consist of independent process units. Instead, it is a network of units exchanging energy and energy media with each other. Very often the local community is also involved in the network, e.g. through power generation and/or district heating. A global approach is necessary to avoid sub-optimization, if energy is to be saved and/or environmental impacts are to be considered in such a system. The science on global tools and techniques for that purpose is named PROCESS INTEGRATION. The following definition of that science has been used by the IEA since 1993: "Systematic and General Methods for Designing Integrated Production Systems, ranging from Individual Processes to Total Sites, with special emphasis on the Efficient Use of Energy and reducing Environmental Effects". The application of Process Integration in the Swedish Process Industry has been developed in a national program since 1997[1,2]. A tool suitable for Steel Industrial sites reMIND has been developed during that time. It was successfully implemented at SSAB in Luleå, where it has been used for decision material and strategic studies [1-8]. Based on that success an excellence center PRISMA (Process integration in Steelmaking) was founded in Luleå with MEFOS, LTU (Luleå University of Technology), SSAB, LKAB and Ruukki as partners and with shared industrial /Governmental financing.

## 2. Short description of the reMIND tool and its use

The method is based on MILP (Multiple Integer Linear programming). Like in classical LP linear equations are used, but the integer programming also gives room for yes/no decisions, e.g. start or stop of units under certain conditions. (This also makes it technically possible to simulate some non-linearities by broken lines. We have, however, not used that so far).

A java based interface is used to describe the Plant system. See Figure 1.

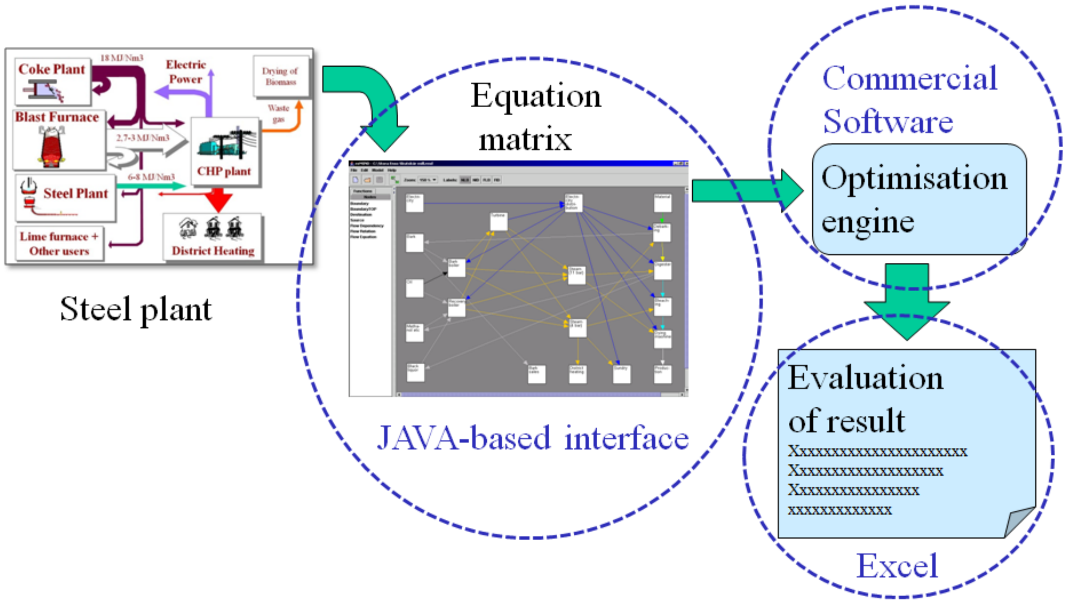


*Figure 1 principal flow of a reMind calculation*

The interface is graphical, and the network is created by drawing nodes and connections on the screen. The built-in interfaces for each node and connection can be reached by mouse-clicking to include descriptions parameters and process equations. The java program then converts this information into an equation matrix.

The matrix is treated by the optimization engine. Commercial software is used for this purpose. We use CPLEX. The result file is read and evaluated using an excel program.

## 3. Linearisation

The MILP method needs linear equations. These have been done using a mix of theoretical and empirical calculation. In some cases the process is complex, e.g. in the blast furnace. In this case we have used an existing off-line simulation model to create data which are used to create the matrix.

## MULTIOBJECTIVE EVALUATION

The reMIND model can optimize for several parameters e.g. cost, emissions, energy efficiency etc. by choosing the proper object function. However, what the companies usually need is not just optimization of a single parameter. Instead they need to find a suitable compromise between several parameters

An example is shown in Figure 2. The diagram shows a case, where optimization has been carried out for two conflicting objectives - Material Efficiency (principally, an expression for metal yield in the system) and CO2 emission. The diagram shows material efficiency on the horizontal axis and CO2 emission on the vertical axis. If the model is allowed to optimize for $CO_2$ it will suggest a solution which gives a low emission, but also a low material efficiency. On the other hand an optimization for material efficiency gives a point with high efficiency, but un-acceptable $CO_2$ emission. Between these extremes, there is an area, where an improvement on one parameter has a bad influence on the other. The best possible compromises in that area can be calculated by successive optimizations and is illustrated by the dotted line in the diagram. That line is named a Pareto front. It can be seen that there is a point on that Pareto line (marked as “Best solution??”) which gives a high decrease in $CO_2$ emission with a limited decrease in efficiency.

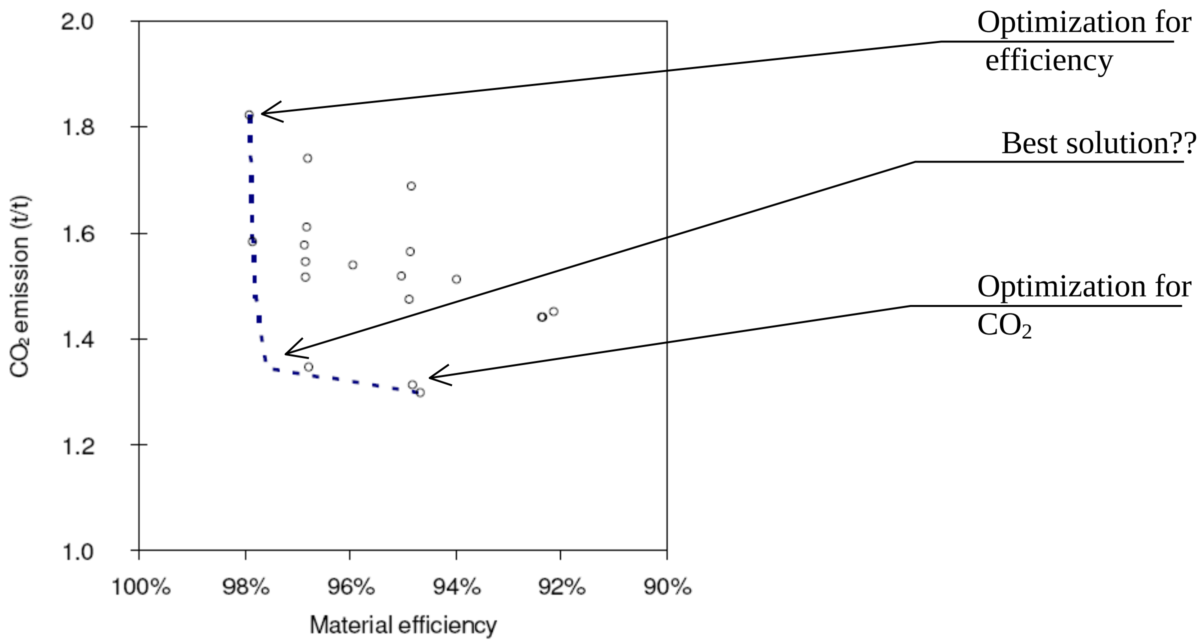


*Figure 2 Example on Pareto analysis: Emission vs. Material efficiency [4]*

## ECONOMIC MODELING: REGIONAL EVALUATION

### 1. Economic model: a computable partial equilibrium model (CPE)

All statements about the future are uncertain. However, the degree of uncertainty can be reduced if addressed properly. The fundamental philosophy of economic modeling is to combine information from the past with current understanding in order to give a likely range of outcomes. In practice, this requires the construction of simplified models of economic behavior that examines the relationships between key economic factors.

## 2. What is CPE

Compared to Computable *General* Equilibrium models (CGE), that allow endogenous interaction between all sectors in an economy, Computable *Partial* Equilibrium models (CPE) allow some sectors to be treaded as exogenous. The basic difference between partial and general equilibrium analysis is in the treatment of prices. In the former, all prices other than the price of the good being studied are assumed to remain fixed whereas in the latter, all prices are variable and all markets clear. Hence, secondary effects are ignored in partial equilibrium models. These models are generally based on a set of input demand and output supply equations. There are equations representing the behavior of economic agents such as producers, consumers, investors, government and foreign markets. Most models rely on data for a specific year (benchmark or baseline) to specify the numerical relationships in the model.

Generally, all economic agents act in an optimizing behavior, subject to the relevant constraints, allowing the relevant markets to clear. Transactions are conducted at equilibrium prices. The quantity supplied must match the quantity demanded for every factor of production and for all goods and services consumed. Hence, all interaction among the markets is taken into account and, consequently, all interrelationships between sectors are explicitly considered. More specifically, the model is designed to study short term effects of changing market conditions on various actors in the regional forest cluster.

The model is constructed to reflect the economical and institutional relationships the currently prevails in the regional forest cluster. It can thus be used to analyze different hypotheses and predict distribution effects from changing market conditions.

## 3. Model optimisation

Due to differences in input mix and input prices, production costs vary across the sectors in the regional forest cluster. Furthermore, production costs also vary within a specific sector due to variations in productivity across individual plants. In general, the production cost for a given technology and sector can be described by an industry cost function

$$c^i\left(\mathbf{p^i};\overline{Q}^i\right)$$

where $\overline{Q}^i$ is a fixed level of output in industry *i*, $\mathbf{p^i}$ is a vector of input prices. The cost function is treated as additively separable in input prices and output, i.e., $c^i\left(\mathbf{p^i};\overline{Q}^i\right)=g^i\left(\mathbf{p^i}\right)+h^i\left(\overline{Q}^i\right)$, where $g^i(\cdot)$ is homogenous of degree one and $h^i(\cdot)$ is increasing and convex $(h'>0,h''>0)$. This formulation implies that a shift in factor prices will have an equal effect on all plants with a given technology in a given industry (Chambers, 1994).

The first order derivatives of the cost function with respect to input prices give the conditional input demand functions [10].

$$\frac{\partial c^i\left(\mathbf{p^i};\overline{Q}^i\right)}{\partial \mathbf{p^i}}=\hat{\mathbf{x}}^{\mathbf{i}}\left(\mathbf{p^i};\overline{Q}^i\right)$$

where $\hat{\mathbf{x}}^{\mathbf{i}}$ is a vector of conditional input demand. The model includes international markets for all intermediate products. The international prices are determined by global supply and demand. Regional input prices may, however, vary due to differences in input quantities.

The model allows for substitution between domestic and international intermediate products. In addition, in the products processes, substitution is possible between raw material inputs in as far the individual industries have a strictly positive demand for the raw material. Figure 3 illustrates the optimization process for a representative pulp and paper mill. The mill in the example is a single output producer.

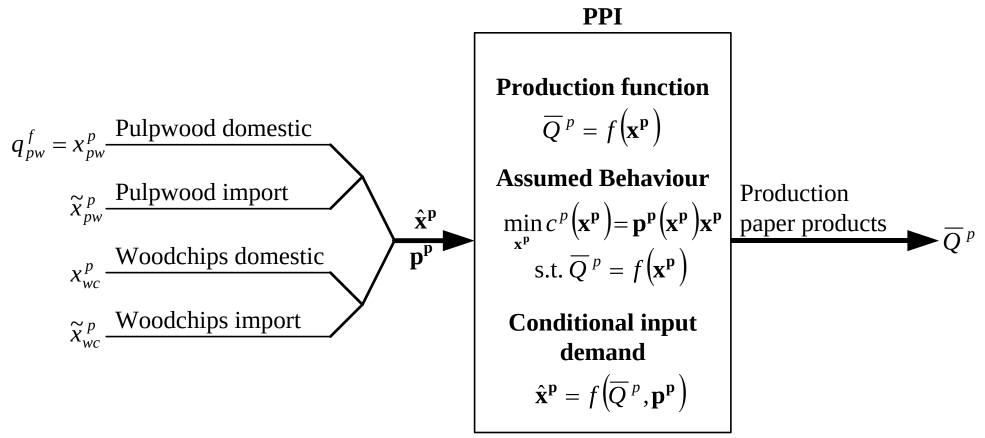


*Figure 3 Illustration of optimisation process for a representative pulp and paper mill*

## SOCIAL VALUES: EVALUATION USING CONJOINT

Conjoint analysis has been used extensively in marketing, transportation and health care since the 1960’s [11]. During the last ten years the method has also been used to assess preferences for environmental [12] and energy [13-14] issues.

Conjoint analysis uses the ability of the human mind to make decisions based on several factors simultaneously, thus forcing the participants to make a trade-off between the factors [15]. In a conjoint analysis, a number of factors are varied through a factorial design, creating different alternatives. The respondents are asked to rank the hypothetical alternatives and the responses can be used to analyze each respondent’s individual preferences as well as group-level preferences. The conjoint task can be presented through questionnaires, interviews or through a computer survey. The results from the survey can be presented as main effects and interaction effects or as regression coefficients, i.e. numerically.

In the Swedish steel industry, conjoint analysis has been used to evaluate environmental objectives of different stakeholder groups. The participants were asked to rank nine alternatives where four environmental objectives were varied. A short information sheet was attached to the survey, and apart from the conjoint task the respondents were asked to give some socio-demographic information. There was also a part of the questionnaire with general environmental questions. The socio-demographic facts along with the respondents environmental statements in the last part of the questionnaire can be used to group respondents, thus creating subgroups previous unknown. The results showed that emission of carbon dioxide was considered the most important environmental objective, followed by use of non-renewable energy, use of non-renewable resources and weight reduction of products.

Conjoint analysis is valuable tool for eliciting and comparing stakeholder preferences. Process integration deals with energy intensive industries. To implement energy conservation, production processes often needs to be altered. The internal preferences and attitudes within the industry are essential for an efficient change process, also the preferences of the surrounding society such as neighbors, local policy makers and local authorities’ needs to be taken into account when the management sets its energy conservation strategy.

Industrial decisions on new or changed technology are dependent not only on technical parameters but also on expected effects on political/social parameters, e.g., local and national attitudes and their effect on political decisions. Many study methods give results in a form that is difficult to combine with the technical parameters. Conjoint analysis combined with multivariate data analysis can be used to convert the stakeholder preferences into numerical parameters [16]. Partial least squares regression, PLSR, enables the results to be presented both on an individual level as well as group level. These different presentation forms can be of great use when the results are to be communicated and if the results should be combined with other assessments. It is of interest to find an evaluation method or combination of methods where technical and non-technical parameters can be described as a combined decision material. This will need a cross-scientific study involving both data on the technologies, system analysis, psychological and stakeholder studies etc. The long term vision is theoretical and practical knowledge to create a general tool for evaluating the combined energy, environmental, social and economic value of new processes and/or modification/improvement of existing processes.

## MERGED EVALUATION AT A PULP AND PAPER PLANT

A project for implementation of Process integration at a pulp and paper plant in Northern Sweden is presently being carried out. It is headed by LTU dept Energy Technology.

The project involves the building and use of a reMIND model of the plant. Initially the model describes the existing production system. The long term aim is to increase the modeling and optimization also to include future structural changes, e.g., including of Biorefinery units. In parallel to that a CPE economic model is built to study the regional economic interaction with the regional forest cluster market and pricing. Also a Conjoint study is being started to study the attitudes of local stakeholders to the plant and its possible future structure. At this stage these studies are made in parallel and the result is afterwards merged manually to give a combined evaluation.

## DISCUSSION

### 4. Universal model for combined Technical-economic-social Evaluation

The long term vision is that the knowledge gained by manual merger of different methods and can be used to create tools and a standard methodology for combined evaluation. It should, however, be pointed out that this does not necessarily mean that all evaluation steps are merged into one single computer super model. Such attempts often lead to rejection because people do not understand (Figure 4). Also errors and bugs become more difficult to eliminate.

Instead the aim is to find a methodology where the sub results are merged together using the human brain as glue. Such mergers are already being successfully used within two of the methods described above: Pareto analysis and conjoint analysis. Also the superior ability of the human brain itself is the result of such a merger: two brain halves with a very different way of thinking work together. The Idea of the combined evaluation must be to merge these two halves with a third one (the computer), and to do it in a way where (½+½+½) does not become less than (3 X ½).

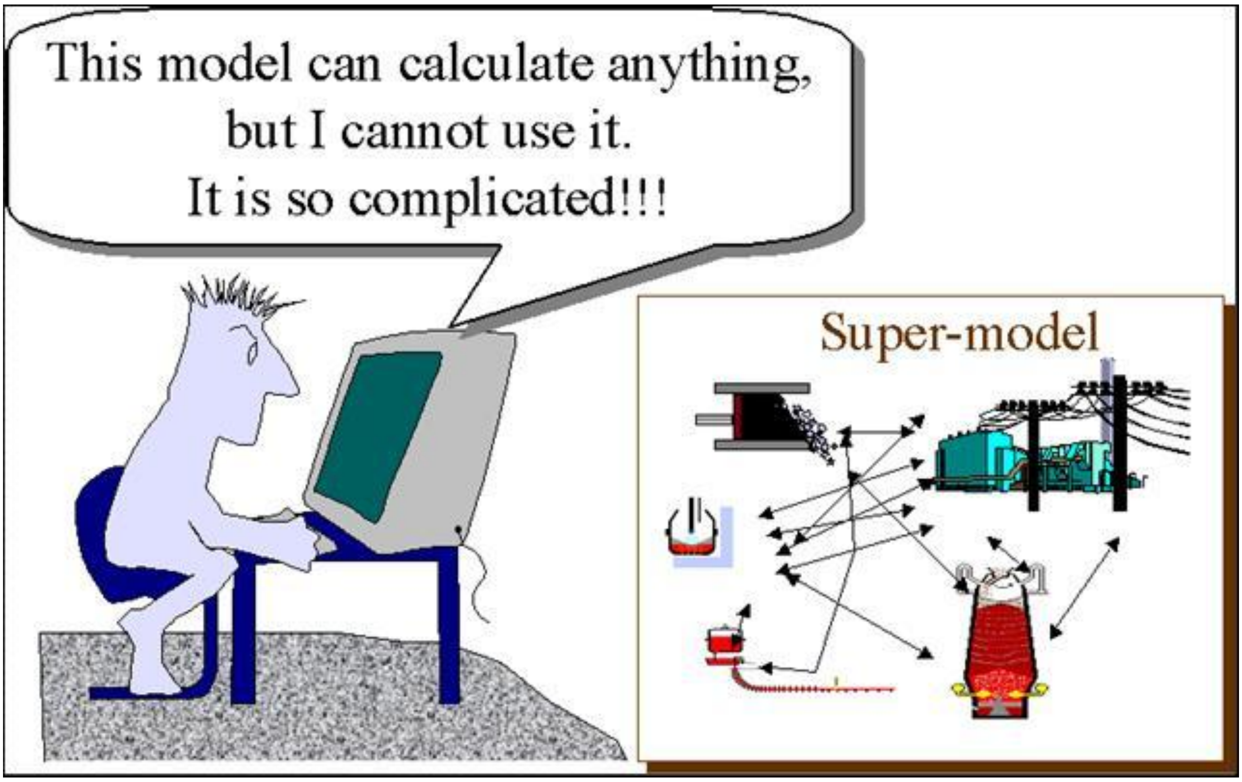


*Figure 4 Danger with computer Supermodels [1]*

### 5. Model size vs. problem profile and size

The size and ambition level of a model must be in proportion to the purpose. The models described in this paper occupy a space of midsize models that can be used for single or multi-objective optimization of operation and design at plant sites, considering the interactions within the sites, with surrounding society and in some cases with regional units. These models have reached a very successful industrial implementation. Using frequency for a single site can be characterized as intermittent very intense project periods of some months with long intervals between. In Sweden this has resulted in an organization where the models and knowledge is concentrated as centers at institutes and/or Universities.

## CONCLUSIONS

Methods for technical, economical social evaluation of production sites and their applications in Swedish industry are described.

Ongoing work on merged evaluation is described shortly.

The possibility to create methodology and/or tools for combined evaluation is discussed.

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