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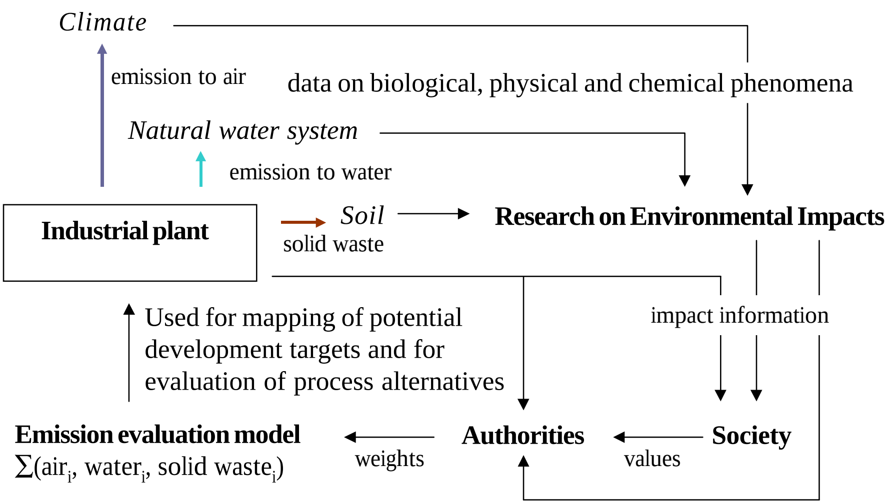

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ABSTRACT

This study is an attempt to answer the question “What kind of aspects could appear when implementing IPPC and how to deal with them?” During the study this question was attacked with methodology development and test usage. These actions were expected to result in a practical and ease way to apply IPPC principles. This development work has resulted in 1) few prototype methods and tools for practical calculations for comparing process alternatives and 2) for making evaluations of process alternatives with environmental, economical and technical aspect.

The methodology is expected to help industry by them selves and together with authorities to create and evaluate cost- and eco-effective alternatives. This study arises crucial questions: “how IPPC Articles are to be interpreted by authorities and how industry can utilise the new permit procedures”? While IPPC does not give any practical methods for how to study streams on air, water and soil as being inherently connected to each other via process (Article 6 and Article 9 item 3), now prototyped tools – CALORIE (top-down approach) and SMARTMASS (bottom-up approach) – has been proposed and demonstrated with investment and emission parameters and with elementary mass balance data. These prototyped methods enhance to set-up mass balance measurements and calculations revealing the circulation of components and mass balance connections between various waste streams. This data – flows and concentrations – can even be lifted up as additional investment criteria. These kinds of approaches should be available for industry and authorities when implementing IPPC directive.

PREFACE

This is the final report on results of KOPTI-project, being started on 3rd of February 1998 and finished on 31st January 2000. This project "*Implementation of IPPC-directive – development of new generation methodology and a case study from pulp industry*" belongs to Environmental Cluster research program. This project is carried out by VTT Chemical Technology and Jaakko Pöyry Consulting, being financed by Finnish Ministry of Environment (Suomen ympäristöministeriö), Finnish Forest Industries Federation (Metsäteollisuus ry), VTT Chemical Technology and Jaakko Pöyry Consulting.

CONTENTS

1. INTRODUCTION

An industry on a sustainable basis is founded on processes and methods of constantly increasing efficiency and productivity. These processes, under continuous refinement, aim to minimise the use of raw material, energy and capital input and to protect the environment proactively, and targeting to maximise the profit at the same time. We can crystallise two "triangle inequalities" for industry:

- a simultaneous and integrated examination of discharges to air and water and solid waste, taking into account energy, raw material and capital consumption

- combining environmental, economical and technical aspects.

The EU IPPC Directive (Integrated Pollution Prevention and Control, Council Council directive 96/61/EC) and the closely related BAT concept (Best Available Techniques, e.g. http://eippcb.jrc.es/exe/FActivities.htm) are practical examples of points where these theoretical musings move to the practical level. A great deal of limitations dictate what can in practice be done for the environment. Resources are finite, data and understanding incomplete and processes complex. *Methodology* and *tools* are needed to proceed towards optimal solutions in the IPPC/BAT-framework.

In environmental control, the IPPC Directive is a herald of a "next generation" integrated view of control and legislation. All polluting factors are seen as one whole, not as separate streams. Comparing different factors and seeking the optimal trade-off between environment, economy and technology to reduce environmental loads does prioritisation of actions. This next generation viewpoint is not restricted to process discharges (*add on*), but instead has the control of the material, energy and information flows of the whole production process as the starting point (*process changes + add on*).

2. PURPOSE OF THE STUDY

2.1 Goals

The explicit goals of this study, being the new knowledge to be created, are methods and procedural models towards on *technically and economically close to optimal plant operation,* which is expected to produce *improvement on productivity and profitability (efficiency)* and *improvement on minimising the environmental impacts of the production process related to value added in an integrated way (eco-efficiency).*

Thus, the study started from a “prioritise and control” viewpoint disaggregating the goals further to sub-goals:

New knowledge to prioritise:

- How to prioritise technological development needs in a cost-efficient fashion?
- The concept “cost-efficiency” is fraught with many dimensions
- Real costs and environmental costs
- Efficiency and eco-efficiency

New knowledge to control:

- How to control emissions and environmental impacts in an integrated fashion?
- How to control practical solutions by combining technical, economical and environmental aspects with the proposed methodology?

The ultimate goal is a "*minimum impact production facility*" for different branches. This study, naturally, is only a small step and modest start.

2.2 Utilisation of the knowledge created

The central goal of the study is to control the material, energy and information flows of a production process in an integrated and systematic fashion so that techno-economically near-optimal solutions to implement the IPPC Directive are found, reducing environmental impacts and simultaneously improving productivity, efficiency and profitability. The results of this study – being the proposed methodology and experiences on its test usage – are expected to be applicable in the future projects, in various industrial sectors. The research group behind this work has already launched new projects where to develop and to apply the methodology further.

What is the scientific value?

The new methodology and the framework, provides enhancement for creation of new knowledge on process behaviour in respect of environmental impact and enhancement for creation of new views and abstractions on a process.

What is the value for authorities?

In Figure 1 it is depicted how the developed tool is expected to provide a platform for example for the following chain of events (the place where the tool is used is circled).

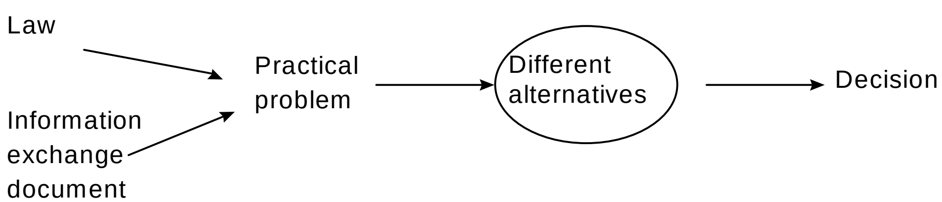

Figure 1. Tool for authorities.

What is the value for industry?

In Figure 2 it is shown how the developed tool is expected to provide a platform for industry.

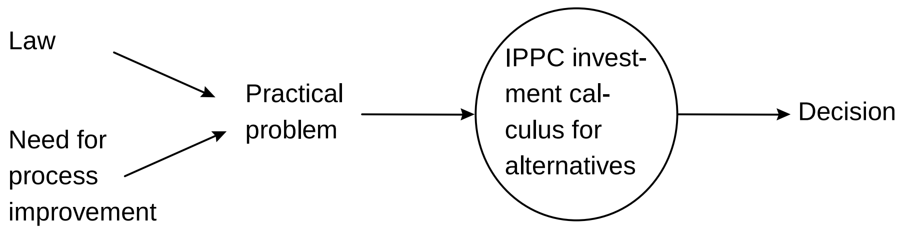

Figure 2. Tool for industry.

What is the value for all?

The underlying, common value is increased knowledge and a negotiation tool as shown in Figure 3.

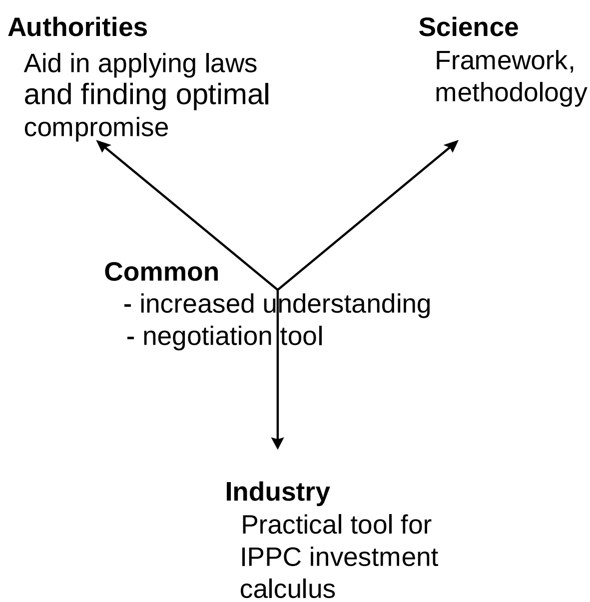

Figure 3. Tool for industry and authorities.

3. STRUCTURE OF THE STUDY

The study has been divided into two separate parts:

- the *top-down*, where the effort is to make the problem and the methodology understandable and close-to-generic,

- the *bottom-up*, where the methodology is modified and tested (with case specific needs) for enhancing the utilisation of detailed process data and knowledge.

Linkage between the top-down and the bottom-up studies

The top-down and the bottom-up projects have to fit in together (laying one puzzle) while solving the combination of the interests of science, authorities and industry (laying another puzzle). In Figure 4 it is drawn the three views (left) and the two approaches (right).

The linkage will be explained later in detail in the top-down approach (Chapter 4) and Chapter 6 where the methodologies are combined. The Table 1 gives some general indications.

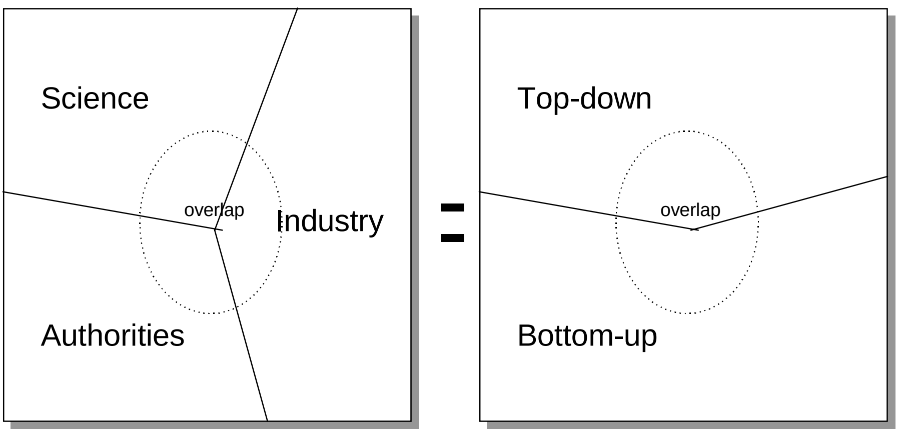

Figure 4. Linkage of top-down and bottom-up approaches.

Table 1. The main goals of top-down and bottom-up approaches.

Project component	**Goal prioritise**	**Control**
Top-down	Identify critical changes (the Snake) in investment alternatives	Visualise and understand the integrated effects (the Snake, the Triad)
	Identify best paths for investments (the Triad)	
	Identify best alternatives (the IPPC Calculus)	Make an integrated decision (the IPPC Calculus)
Bottom-up	To identify the dominant features involved an IPPC-based process improvement project	Formalise and visualise the documentation of project activities and the involved process models
	Develop a procedure to combine the performance of processes with economical and environmental aspects – SMARTMASS	Formalise and visualise the documentation of processes, aiding to focus on critical details
Together	Identifying the best actions	Having an integrated viewpoint

The tools Snake, Triad, IPPC Calculus and SMARTMASS are introduced in later chapters.

4. TOP-DOWN APPROACH

4.1 General principles and underlying philosophy

In the top-down part of the study new methods and knowledge are generated to be able to simultaneously control both emissions, costs (real and environmental costs) and efficiency in decision-making. The goal, as for the whole study, is to identify the most cost effective and environmentally beneficial actions: “What they are (which precise action)?” and “Where there are (at which point of the process)?”

4.1.1 The baseline

The European Union’s IPPC-directive (Integrated Pollution Prevention and Control) and its BAT concept are real examples of areas in which the following questions arise:

- how to control emissions to air, water and solid waste simultaneously
- how to combine environment, economics and technology in decision-making.

What is needed to solve these problems? Tools and methodology:

- to aid in understanding the concepts
- for implementing the consequences of IPPC legislation
- for mastering additional dimensions to conventional investment calculus
- for managing the production process according to the IPPC principles.

“Work in progress” best describes the current situation.

A few claims about the BAT (Best Available Techniques) concept can be crystallised in the Figure 5, using the mnemonic “TRIP”.[1]

T = Type of process
The BAT concept is related to the type of process and is not universal

R = Range of values
Excellence in environmental performance using BAT is situated in a range of values, not a single point value

I = IPPC
Excellence in environmental performance using BAT should be seen in the IPPC (Integrated Pollution Prevention and Control) Directive spirit as the combined output of all emissions, instead of as a series of one-eyed views

P = Performance
The BAT concept is linked to the environmental performance of a mill, not to a strictly defined list of equipment

Figure 5. TRIP - a few items to remember about BAT/IPPC.

Complex shifts from one media to another and different trade-offs are characteristics for these problems (for example closed water cycles decrease water consumption and emissions to water, but increase the amount of solid waste). Thereby neither traditional life cycle assessment nor traditional real/environmental economics as such are alone or combined suitable in puzzling out the answers to the questions.

[1] The TRIP acronym, the Decathlon principle (to be introduced later) and the flex hierarchy (likewise, introduced later) were developed by us in an earlier project. (Jaakko Pöyry Consulting: Consortium – BAT Emissions of the pulp and Paper Industry in the European Union. Strategic Background Paper. Helsinki 1998) They are presented here to give the necessary background for the reader, not as results from this particular project. They play a role in the philosophy underlying the new concepts developed such as the Snake, the Triad, the Lens and the IPPC Calculus.

4.1.2 Understand, prioritise and control

Our question is: Where to invest in order to receive the best results both from the environmental and economic point of view? We need to develop methodology with the aid of which we can identify a set of eco-effective, environmentally and economically sound operative actions. As criteria in the top-down approach we use the quality, cost, value-added and environmental impacts of the product or process studied.

The result of the top-down study:
"EKTA"

The EKTA (Finnish acronym of sorts for "EKoTAlous") combines

- environmental impacts
- real costs (for example manufacturing costs)
- value added
- quality indicators

based on life cycle assessment inventories. EKTA consists of three concepts we call the SNAKE, the TRIAD and the IPPC CALCULUS, and their implementation. The "Decathlon principle" can be found behind EKTA.

The Decathlon principle: You don't have to number one at everything to win the championship.[2]

Similarly, a mill does not have to achieve records in all IPPC criteria to demonstrate environmental excellence. However, the options for a mill are delimited by the way it prioritises the criteria. Concentrating on for example emissions to the air and water limits the options for solid waste management. We arrive at a "flex

[2] See footnote 1

hierarchy”[3], where the prioritised criteria appear at the apex of a pyramid. The lower on the priority ranking a criterion is, the greater the flex in performance. Figure 6 is an example of one possible flex hierarchy. The flex hierarchy is a very useful concept in developing a framework where trade-offs have to be found and cost-efficient actions identified. Neither the reader nor the concept’s creators have to see it as a universal truth.

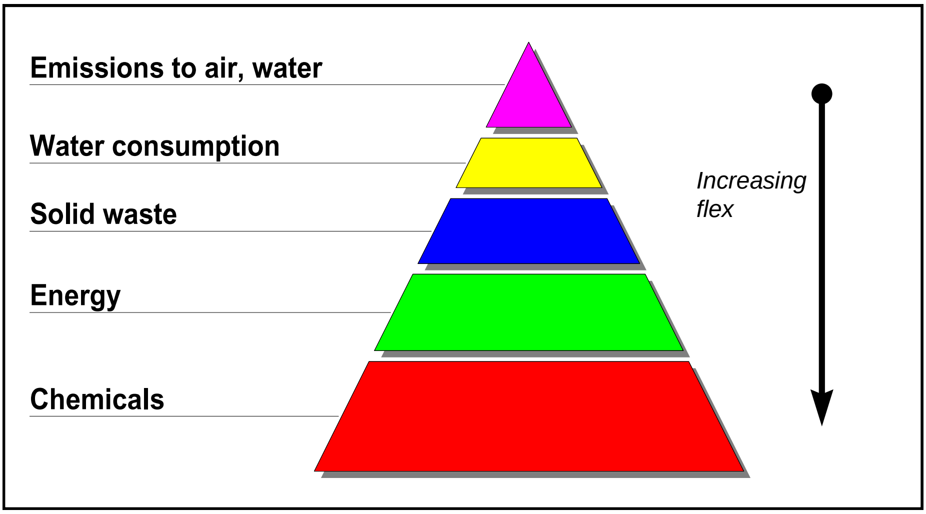

Figure 6. The flex hierarchy.

The results of EKTA are analysed with the aid of sensitivity analysis (in this study interval calculus has been used as the method of analysis) and computer aided visualisation.

4.1.3 Conclusions

The problem is:

- how to control emissions to air, water and solid waste simultaneously

[3] See footnote 1

- how to combine environment, economics and technology in decision-making.

EKTA tries to answer these questions by increasing understanding, prioritising and controlling:

- environmental impacts
- real costs
- value added
- quality indicators.

4.2 Top-down methodology

4.2.1 From theory to practice

The top-down methodology consists of three items: the SNAKE, the TRIAD and the IPPC CALCULUS. Together, they form the EKTA framework (see Figure 7). All components have a role to play.

- A framework must have a scientific foundation and credibility. The Snake and the Triad are concepts building on and expanding Life Cycle Assessments. They have both already been presented either in conference proceedings or in articles in trade journals (Vasara & Lobbas 1998, Vasara & Lobbas 1999). The Snake and the Triad are the *scientific toolkit* from this top-down study.

- IPPC is also a very practical matter, and the framework must provide a *practical toolkit*. The IPPC Calculus is an investment calculus method incorporating ideas from the Snake and the Triad, but looking as much as possible like an ordinary investment calculus - to be as easy to use as possible, in making IPPC-linked investment decisions, and to be as easy to accept as possible, psychologically.

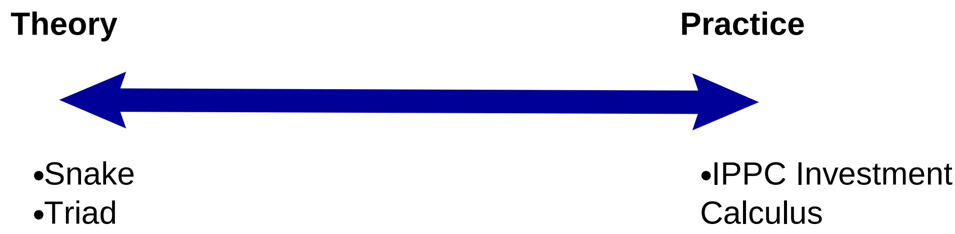

Figure 7. The EKTA framework.

The Snake contains nine dimensions, including various aspects of economics, environment, quality and value added. On the economic side, it concentrates on concepts familiar to everyday corporate decision-making. *The Triad* is an environmental zoom from the Snake and it consists of two alternative visualisations: triangles and cubes. IPPC investment calculations take the form a report template and a spreadsheet.

In the following, the components of the EKTA framework are presented one-by-one.

4.2.2 The Snake

The ultimate goal of the theoretic Snake concept can be describes as SLCA (Strategic Life Cycle Assessment), a version of LCA that it is possible to integrate as much as possible into corporate strategic decision-making, the way there being long and narrow. We drew up the following requirement list:

- make the concept general, but demonstrate it using a forest industry example
- combine, in this first version, a manageable amount of dimensions, concentrating on the economic side on concepts familiar to everyday corporate decision-making (answer: the *S-9* set of dimensions)
- try to find an image that would make it easier to remember and show the connections between the dimensions (answer: the *Snake*)

- try also to find a way to quickly view the environmental and economic impacts of different investment alternatives (answer: the *Path*)

- try, furthermore, to come up with a tool to navigate the masses of data that the concept, if implemented, will create (answer: the *Hyperbolic Life Cycle Lens*)

- make a systematic effort to investigate the connections between the dimensions (answer: the *Ratio Matrix*).

4.2.2.1 The concept

Strategic Life Cycle Assessment

Integrating life cycle assessment into strategic decision-making is about not losing one's way, about ending up in friendly corporate territory. In the example presented here, it encompasses the nine dimensions: environmental impacts, environmental stability on the markets, manufacturing costs, price volatility, fibre provenance, fibre quality, eco-efficiency, value added and investment size. This set of dimensions S-9 is used to calculate different ratios for investment alternatives. Ratios, matrices and visualisations are then applied to prepare the ground for practical decision-making. The curse of dimensionality present with nine dimensions is also left outside the scope of this study.

The Snake

The Snake in Figure 8 below is a way to present the dimensions. The dimensions have been arranged clockwise around the Snake, so that each vertebra of the snake represents the (unique) ratio between the dimensions adjacent to each other. The ratios have been arranged so that each vertebra brings some additional information (see also *The Ratio Matrix*). The Snake is a generic tool, which can be modified to contain branch-specific components. This particular Snake is customised for the forest industry. In the case of another branch, e.g. steel, telecommunications or chemicals, the vertebrae which are now forest industry-specific can be replaced.

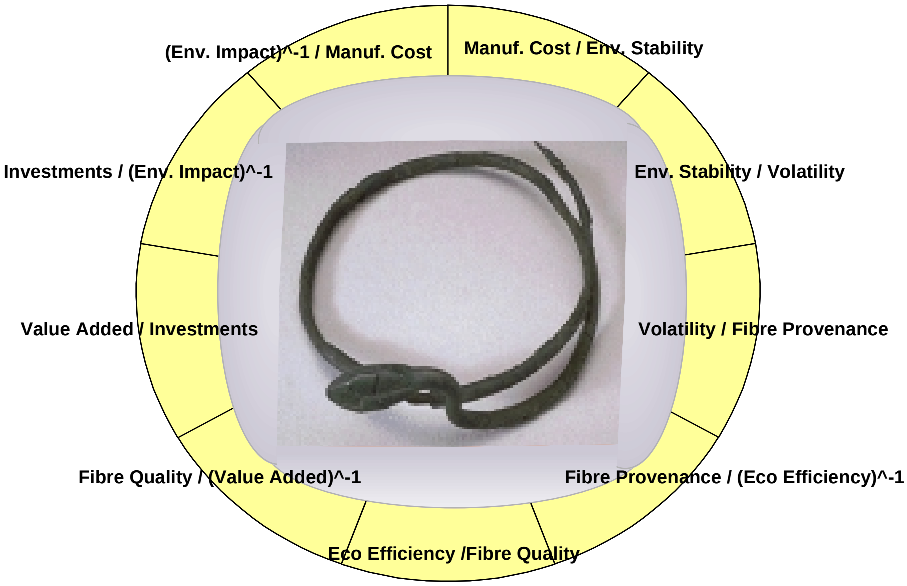

Figure 8. The Snake.

Explaining the dimensions one-by-one, we have:

Manufacturing costs in our example case include wood, chemical, energy, labour, personnel, packaging and other material costs. The lower the costs, the better.

Environmental stability is a factor which combines the environmental performance and the environmental image of the product. It takes into account e.g. emissions, energy use, quality and the image of the product. The environmental stability should be high, where as the ratio *Manufacturing costs / Environmental stability* should be as low as possible.

Price volatility describes how easily the price of the product varies and should be as low as possible, strong cyclicality being an undesired characteristic. The *Environmental stability / Price volatility* ratio can be seen as a double stability factor which takes both the environmental issues and price into consideration. This ratio should be maximised.

Fibre provenance is an index for the environmental certifiability[4] of the fibre raw material. The *Price volatility / Fibre provenance* ratio gives us a double volatility ratio which should be as low as possible.

Eco-efficiency is defined as value added per environmental impacts. *Fibre provenance / (Eco-efficency)^-1* (note the inverse) shows how effectively the main raw material is used. This ratio should be high.

Fibre quality is a factor that takes into account both the quality of the pulp and the printing characteristics of the paper. The *Eco-efficiency / Fibre quality* ratio can be used to estimate how the efficiency and quality of the product are linked together. This ratio should be low.

Value added tells how much the value of the product has grown during its processing/manufacturing compared to the value of its raw materials. Because it is desirable that both the quality and the value added are high the ratio *Fibre quality /(Value added)^-1* (note the inverse) should be maximised.

Investments are needed in the real world when decisions are put into practice. The ratio *Value added / Investments* tells how well the investments can be made to correlate with the value added of the product. This ratio should also be high.

Environmental impacts from cradle to gate are one part of the snake. Life cycle methodology is used to produce an inventory list. To evaluate the inputs and outputs in the inventory, a basket of three valuation methods is used. (Ecoscarcity/Sweden, Ecoscarcity/Switzerland, EPS system 2.0, (Lindfors et al. 1995. Nordic Guidelines on Life-Cycle Assessment. Nord 1995:20. AKA_PRINT A/S, Århus 1995) The *Investment / (Environmental impacts)^-1* (note the inverse) ratio shows how well the investments can be made to relate to the environmental impacts - the lower the ratio the better. Environmental impacts are handled in greater detail in the environmental zoom of the Snake, the Triad.

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[4] Note that we are talking about a "generic" certifiability, not about any specific forest certification program. This concept is perhaps closest to the scheme being currently worked out by European nations together (PEFC), but not opposed to the FSC scheme *per se*.

Now, we come back to the *Manufacturing costs* thus closing the circle. The last ratio is *(Environmental impacts)^-1 / Manufacturing cost* (note the inverse): the higher the ratio the better.

The Path

Our example of the Snake is as follows:

We are dealing with an integrated coated fine paper mill. In the base scenario, the wood fibre used in the mill comes from its own forests which are not certified. In addition, the electricity which the mill has to purchase is produced with a mix of nuclear power, hydroelectric power, oil, natural gas, peat and wood. (Note: because the mill is integrated it is almost self-sufficient with regard to energy). Now the mill wants to raise its environmental acceptability on the markets. It investigates two investment alternatives:

A) using 'greener electricity' [5]

B) certifying its forests

The Snake now becomes something akin to a coral snake: coloured and potentially dangerous. That is, we show the changes in the different ratios by colouring the "scales" of the snake according to the changes: green for improvement, yellow for no or negligible change, red for deterioration.

In Figure 9 below, the investment paths and their impacts are shown in what we call an *investment path diagram*. Thus, the environmental and economic impacts of an alternative, compared to the current situation, are immediately visually evident. Thereafter, a descent into details at any level can be made. A predominance of green is the sought effect.

[5] Again, a concept for which there exists no consensus definition. The exact specification is left outside the scope of this study.

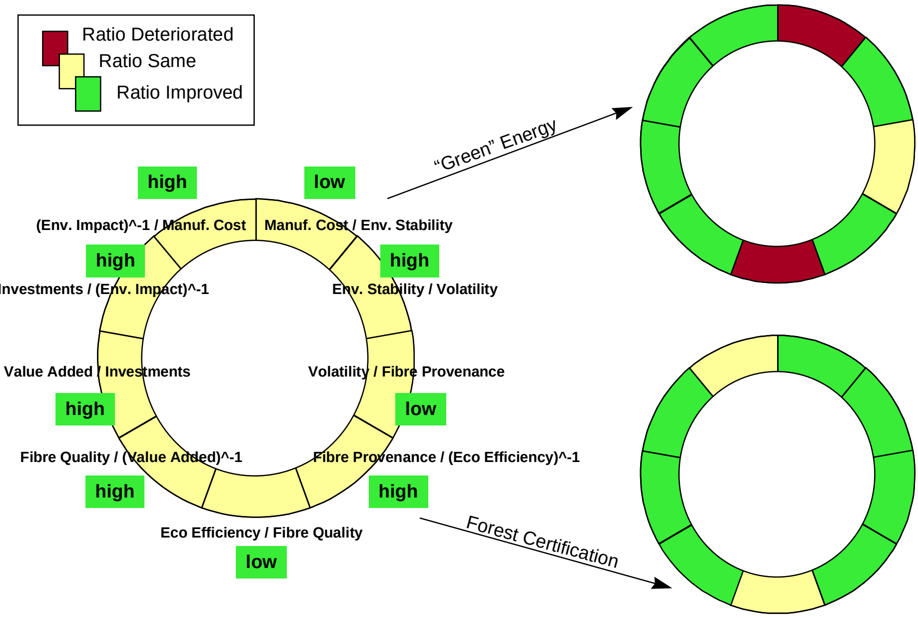

Figure 9. Path of Snakes: Environmental and economic assessment of investment alternatives.

It is to be noted that the valuation methods used in this study do not take into account the possible environmentally beneficial effects of forest certification.

The Lens

To view both the inventory data and the investment alternatives, what we call the *Hyperbolic Life Cycle Lens* can be used. We have adapted the Hyperbolic Tree developed by Xerox as a means of visualisation for hierarchical structures to be used as a Life Cycle tool, showing, highlighting, scrolling through copious amounts of data to focus on details on various levels (e.g. impact categories, individual criteria, weightings). Figure 10 below shows one view from the basic life cycle inventory for this example.

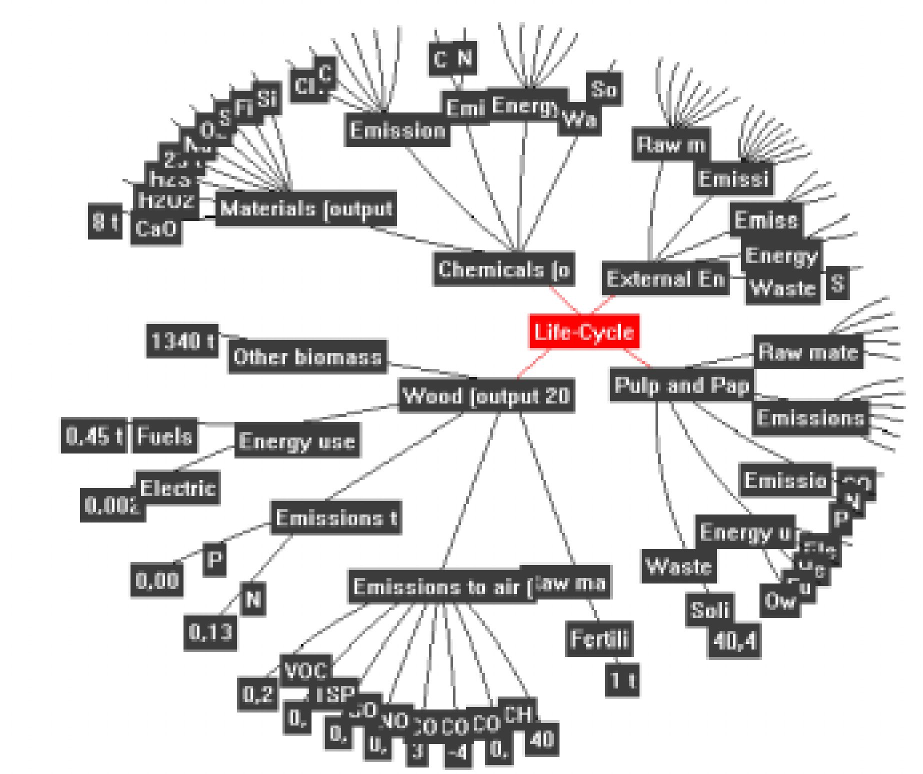

Figure 10. Using the Hyperbolic Life Cycle Lens: One view of an inventory.

The Hyperbolic Tree is a dynamic tool: only be seeing it in action it is possible to gauge its full usefulness.

The Ratio Matrix

The Snake only shows certain, selected ratios. All ratios between the nine dimensions are of course not meaningful. By calculating the reasonable ratios and placing them into a ratio matrix, we can start examining the interrelationships between the dimensions, identifying areas in the matrix (e.g. the raw-material-related area, the volatility area, the stability area).

4.2.2.2 Conclusion

- We contend that the concept shown is generic and applicable to a wide area of activities, though demonstrated only using a forest industry example.

- We contend that the dimensions used are closer to everyday corporate decision-making than is usually the case in environmental assessments.

- We believe that the Snake, the Path and the Lens find useful employment in the visualisation and clarification of results.

- We are absolutely sure that there is a great deal left to explore in what we have shown in this short overview.

In our own work, we are plowing ahead both in exploring tools, dimensions and the meaning of the ratios. Criteria such as employment effect and socio-economic factors are needed to make the model of decision-making used smoother and more complete. Our emphasis here was on the concept, which by its complex nature forced us to leave out explanations of details. However, the facts and figures are also there, to be picked out and presented with the Lens.

4.2.3 Triad: Zoom to environment

A zoom to the environmental impact vertebra of the Snake shows us the Triad with its specific environmental dimensions: emissions to water and air, solid waste, and the use of water, energy and chemicals (Figure 11).

The environmental dimensions are based on the flex hierarchy. We have a *secondary triangle/cube*, for 3 dimensions at the bottom of the flex hierarchy. That is the triangle/cube at the bottom. We then have a *primary triangle/cube* with the three most highly prioritised dimensions. Finally, if we combine these dimensions into one environmental impacts/compliance indicator and combine it with cost and quality, we get a 'golden IPPC triangle' or a 'golden IPPC cube' consisting of environmental impacts, quality and costs (Figure 12). In this way, the Triad, like the Snake, also consists of nine dimensions.

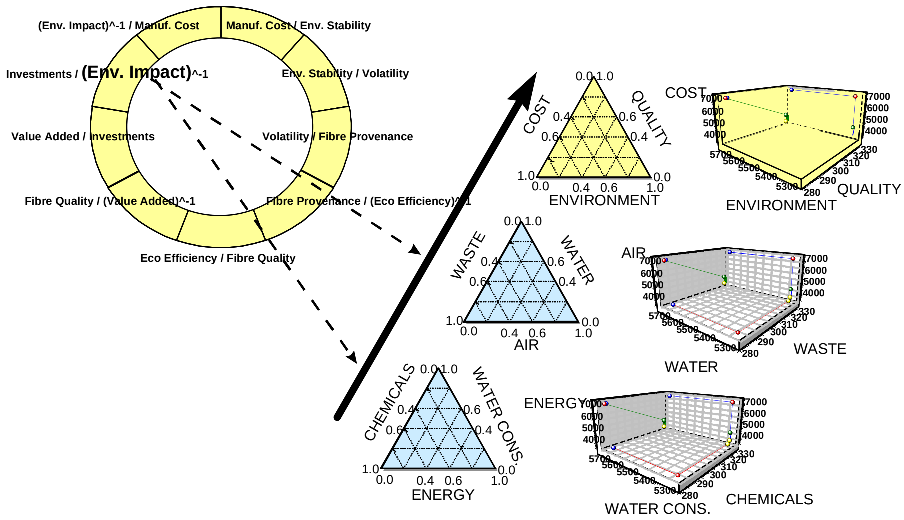

Figure 11. Zoom to environment.

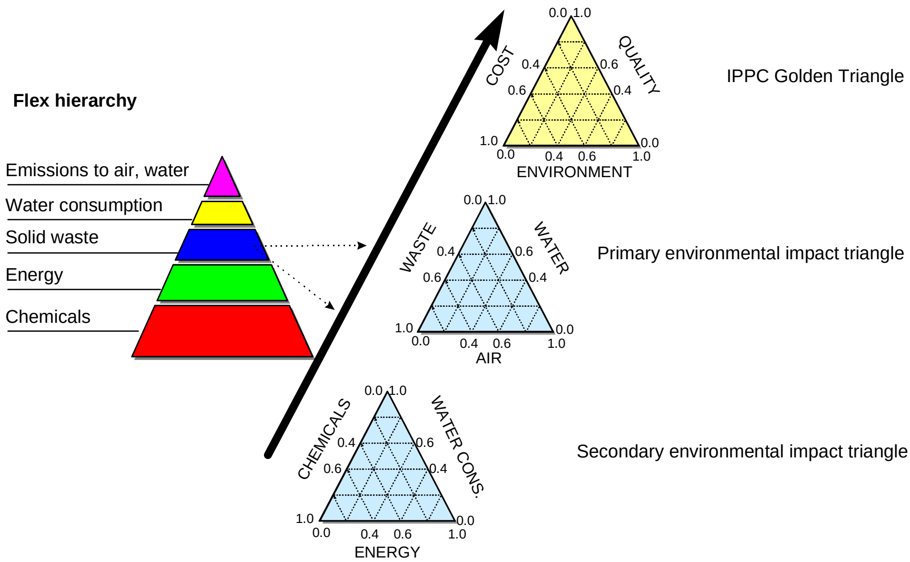

Figure 12. The IPPC golden triangle.

Let us take an example of one of the purely environmental sections of Triad: we have a hypothetical integrated LWC mill using TMP and ECF kraft pulp (*Case Base ECF*). The mill considers three investment alternatives:

- To convert to TCF (*Case TCF*). This investment alternative mainly necessitates actions on the bleaching side of the mill.

- To replace the fossil fuels used with biofuels (*Case ECF wood*) The only fossil fuels used would be the booster fuel needed. The integrate already has a fluidized bed boiler suitable for solid fuels.

- To invest in effluent treatment (*Case ECF water*) by making water use more effective. In addition, chemical treatment would be utilised.

The environmental impacts were, in our example case, calculated using the Jaakko Pöyry IMPACT mill simulation model. Using a basket of evaluators, we get the following Table 2 of evaluated impacts for the alternatives, starting with an ECF mill and going to the TCF case, increased wood use or implementing changes aiming at reductions in emissions to water. In order to get the basket of evaluators, weighting factors based mainly on ecoscarcity and effect-category methods were used.

Table 2. Environmental impacts basket.

	Base-ECF	TCF	ECFwood	ECFwater
AIR	7167	7155	4463	7167
WATER	5670	5283	5670	3644
WASTE	285	284	330	285

We can also draw paths of investments following upon each other. We can first convert from ECF to TCF (*Case TCF*). Then, wood use is increased in the energy mix (*Case TCF-wood*). Finally, measures to reduce atmospheric emissions with the aid of end of pipe cleaning are introduced (*Case TCF-wood-air*). Table 3 shows the evaluated impact values of the path.

Table 3. Environmental impacts basket for the path alternative.

	Base-ECF	TCF	TCFwood	TCF wood air
AIR	7167	7155	4475	3760
WATER	5670	5283	5283	5283
WASTE	285	284	328	328

The results of this example are presented in the following two chapters visualised with the help of triangles and cubes. It should be noted that in these chapters the values presented in the tables above are scaled between 0 (low impact) and 1 (high impact). Zero does not imply 'zero environmental impact'.

4.2.4 Triangles

We choose the three media presented in the previous chapter as the dimensions in the primary triangle and convert the numbers so that the starting point sits at the heart of the triangle. The Figure 13 shows the changes for the options. Moving from ECF to TCF only results in a small reduction in aquatic impacts. Implementing measures to reduce emissions to water in the ECF mill, predictably, results in a stronger aquatic discharge reduction. The wood use alternative for ECF results in increased landfill but reduced emissions to the air.

The Figure 14 shows what happens if the investments are done one after another. First we convert from ECF to TCF, resulting only in a small reduction in aquatic impacts. Then, we increase wood use in the energy mix. This investment results in increased landfill but reduced emissions to the air. Finally, we invest even more to measures to reduce atmospheric emissions.

In this study, we will not go into the details of interpreting triangular coordinates; we only state that some tricks are occasionally needed to have the points move in reasonable directions.

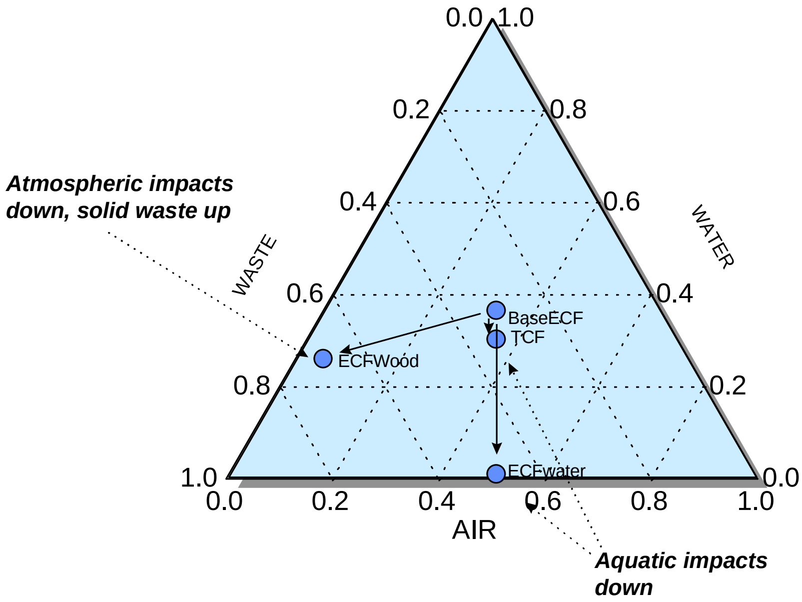

Figure 13. Environmental impact triangle: investigating three options.

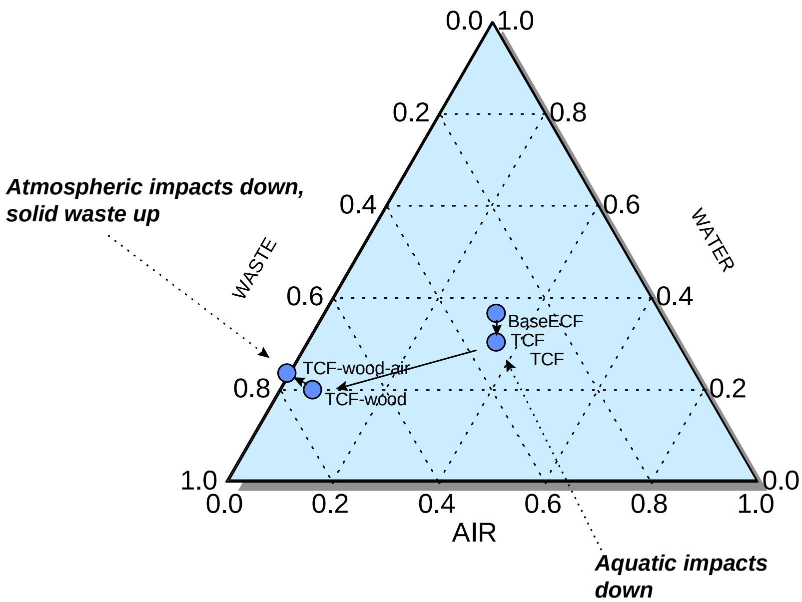

Figure 14. Environmental impact triangle: the path formed by three investments in a series.

4.2.5 Cube

A cube is maybe an easier visualisation option of the dimensions of the environment zoom than triangles due to the possible problems in interpreting triangular coordinates.

The Figures 15 and 16 below depict the same example as in the previous chapter. The Figure 15 shows the changes for the three options: moving from ECF to TCF, implementing measures to reduce emissions to water in the ECF mill and the third alternative, increased wood use in energy production. The Figure 16 illustrates the path formed by three investments in a series.

4.2.6 Conclusions on tools

The problems to solve before it can be said that pollution is prevented and controlled in an integrated fashion are, to be frank, sometimes staggeringly complex. Pollution, unfortunately, will not obey an order to reduce itself on all fronts at the same time. Instead, it shifts shape, from one medium to another. Best Available Techniques for mills are not enough, we also have to use Best Available Techniques in mathematics, environmental sciences, visualisation and other disciplines to make IPPC work.

We must balance environment, cost and quality to have the investments make sense. In what we call the Triad and the IPPC Golden Triangle / Cube, these three dimensions are combined in the same fashion as in the environmental impact triangle / cube.

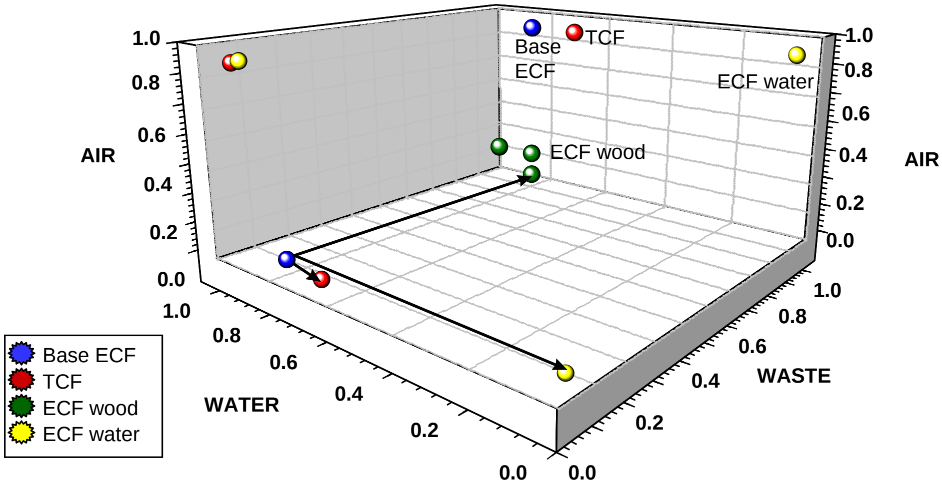

Figure 15. Environmental impact cube: investigating three options.

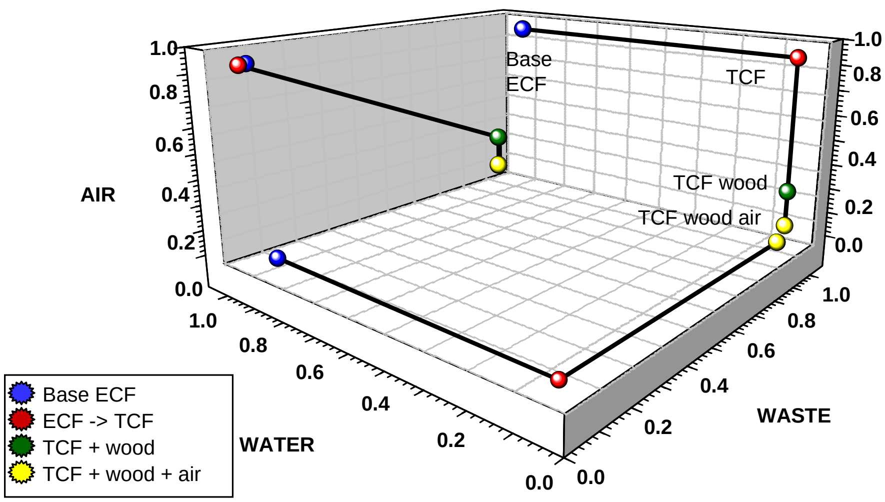

Figure 16. Environmental impact cube: the path formed by three investments in a series.

4.2.7 The IPPC Calculus: A tool for investment calculations

CALORIE has been developed as the final phase of the top-down study. It is the practical part of the results, based on the theoretical concepts also developed within the work.

CALORIE (**CAL**culating envir**O**nmental **R**eturns on **I**nv**E**stments) is an environmental-economic calculus methodology, based on normal microeconomics. It thus differs notably from methods based on macroeconomics or "willingness to pay"-type constructs.

CALORIE expands the normal investment calculus to the environmental sphere and introduces terms such as "environmental profit" (in Finnish *ympäristötuotto*), "environmental interest" (*ympäristökorko*) and "requirement of investor" (*sijoittajan vaatimus*) to environmental economics.

In CALORIE, all the values needed are physically measurable, in other words no weighting factors or conversion are needed. However, weighting factors can be used, if there is a need to present the results in aggregated / classified form.

A typical decision-making situation is the following: before an investment is made, the investment options are described with the aid of a few key figures. The investment decision is based on intelligent comparison of these parameters. In CALORIE, the environmental key figures are put in the same format as the economic key figures - alongside them as equals. The IPPC Cost-Quality-Environment triangle can similarly be put into numbers. The methodology is applicable for any activity where key parameters can be measured over time - the biggest practical problem is most likely putting quality in numeric format. However, in most of the cases that is probably feasible. The presentation that follows concentrates on the enviro-economic viewpoint, leaving quality as something domain-specific.

4.2.7.1 Terminology used in CALORIE

In the following, the financial investment terms used in this study are explained. Furthermore, there are environmental examples for each term. The following terms are defined:

- Net Present Value (NPV, *nykyarvo*)
- Environmental Net Present Value (ENPV, *ympäristöparametrin nykyarvo*)
- Internal Rate of Return (IRR, *sisäinen korkokanta*)

- External Environmental Rate of Return (EIRRExt, *ympäristöparametrin korkokanta*)

- Internal Environmental Rate of Return (EIRRInt, *ympäristöparametrin sisäinen korkokanta*)

- Return on Investment (ROI, *investoinnin tuottoprosentti, sijoitetun pääoman tuotto*)

- Environmental Return on Investment (EROI, *investoinnin ympäristötuottoprosentti, sijoitetun pääoman ympäristötuotto*).

By using the calculation methodology CALORIE developed by Jaakko Pöyry Consulting, all different environmental parameters (emissions, discharges, waste etc.) can be analysed in exactly the same way. Should there be a need for weighting, e.g. in conjunction with calculation of the Global Warming Potential, weighting can of course be used. It is not necessary, however.

It should be noted that the presented terms are highly suitable to be put into the shape of e.g. an easy-to-use spreadsheet for investment calculus.

Net Present Value (NPV, *nykyarvo*)

Net present value is a fundamental financial investment term.

- By using discounted cash flow techniques and calculating present values, we can compare the returns on investment in capital projects with alternative equal risk investments.

- If the rate of return from the project is greater than the required return from an investment, the NPV will be positive. Alternatively, if the rate of return is lower than the requirement, the NPV will be negative. A positive NPV therefore indicates that an investment should be accepted, while a negative value indicates that it should be rejected. A zero NPV calculation indicates that the firm should be indifferent to whether the project is accepted or rejected.

The NPV is calculated according to following formula:

NPV *= value + future value1/(1+rate)^1+future value2/(1+rate)^2+…+future value N/(1+rate)^N*

Environmental Net Present Value (ENPV, *ympäristöparametrin nykyarvo*)

The environmental companion term to NPV, ENPV (Environmental Net Present Value) is used to compare the environmental return on e.g. alternative actions.

- It is usually an easy task to physically measure an improvement which will follow after an (environmental) investment (e.g. decreased consumption of raw material x or decreased emissions). Exceptions are concepts such as biodiversity and sustainability, for which universally accepted definitions do not exist.

The ENPV is calculated according to following formula:

ENPV *= value + future value1/(1+rate)^1+future value2/(1+rate)^2+…+future value N/(1+rate)^N*

Example

A company is considering an investment in effluent treatment, aiming to reduce BOD. The investment should prove its worth within a period of four years. At present, the emissions of BOD are 1000 tons per year and estimated reductions resulting from the investment are 300 tons, 350 tons, 400 tons and 400 tons in the four years that follow[6]. The minimum rate of return is put at 10% (which is usual for companies' financial investments). It should be noted that we do not claim that the environmental requirements should be identical to the financial requirements. A benchmarking study should be conducted to establish different levels of requirements based on actual environmental investments. However, for this example, the minimum rate of environmental return is set at 10%. That would not seem to be an unrealistic number in this case.

[6] The baseline is year zero. Thus, the emission time series is: 1000, 1000-300=700, 1000-350=650, 1000-400=600, 1000-400=600.

Assuming an annual environmental discount rate of 10 percent, the environmental net present value of this investment is:

ENPV= -1000+300/(1+0,10)+350/(1+0,10)^2+400/(1+0,10)^3+ 400/(1+0,10)^4

ENPV equals + 136 tons

The positive net present value from the environmental investment indicates that the project satisfies the company's environmental requirements. In other words, the decrease in emissions resulting from the investment is greater than the minimum emission reduction required by the company. Therefore, the project can be accepted.

Internal Rate of Return (IRR, *sisäinen korkokanta*)

Internal rate of return is another basic financial investment term.

- It is an alternative technique to use in making capital investment decisions that also take into account the time value of money. The internal rate of return represents the true interest rate earned on an investment over the course of its economic life.

- The IRR can be described as the maximum cost of capital that can be applied to finance the project.

- The IRR is the discount rate that will cause the net present value of an investment to be zero.

The IRR is calculated according to following formula:

Investment = future value1/(1+rate)+future value2/(1+ rate)^2+… +future value N/(1+ rate)^N

Environmental Internal Rate of Return (EIRR, *ympäristöparametrin sisäinen korkokanta*)

The environmental companion term to IRR, ENPV (Environmental Internal Rate of Return) is used analogously to compare the environmental return on e.g. alternative actions.

- Again, the environmental rate of return demanded by society and/or by a company is usually based on physically measurable criteria (see 2.2. ENPV). It represents the environmental interest rate earned by an environmental investment over the course of its economic life. It indicates the environmental yield requirements set for an environmental investment and makes different investments comparable.

Investment = future value1/(1+ rate)+future value2/(1+ rate)^2+… +future value N/(1+ rate)^N

It should be noted that we have divided the term environmental internal rate of return (EIRR) into external and internal modes and they both have their own explanations and applications as follows:

- *Environmental rate of return* $_{External}$ *(*$EIRR_{Ext}$*)* is used to measure an environmental improvement against demands by some of the company's external interest groups (i.e. stakeholders, authorities, non-governmental organisations etc.). From the environmental-economic point of view, this implies that there is a certain external yield requirement set for the company in terms of environmental improvements. In this report, this external interest group is the authorities.

- *Environmental Internal rate of return* $_{Internal}$ *(*$EIRR_{Int}$*)* is used to measure an environmental improvement against demands set by the company itself or e.g. its shareholders. The company can have a direct impact on its environmental performance by e.g investing in technology. From the environmental-economic point of view, the $EIRR_{Int}$ determines a certain internal yield requirement set by the company itself in terms of environmental improvements.

Example

A company has the opportunity of investing in an effluent treatment plant which is given four years to prove its impact. The estimated annual decreases in BOD emissions are 300 tons, 350 tons, 400 tons and 400 tons (see footnote in 2.2 ENPV). At present, the emissions of BOD are 1000 tons per year.

The standard method for finding the (E)IRR_{Int} is trial and error: using a number of rates until the ENPV equals zero. For example, if we use a 10 % rate, we get a positive ENPV of 136 tons. We must therefore try a higher figure. Applying 20% gives a negative ENPV of -83 tons. We know then that the ENPV will be zero somewhere between 10% and 20%.

The discount factor is a present environmental value factor, which can be found from e.g. a standard financial table. This table gives the present value of a single payment received *n* years in the future discounted at *x%* per year.

In fact, the $EIRR_{Int}$ is approximately 16 %, as indicated by the following calculation in Table 4:

Table 4. Parameters to calculate $EIRR_{Int}$.

Year	Future value (reduction)	Discount factor (16%)	Present value (of reduction)
1	300 tons	×0,862	=259 tons
2	350 tons	×0,743	=260 tons
3	400 tons	×0,641	=256 tons
4	400 tons	×0,552	=221 tons
	Env. net present value		Σ 996 tons
	Investment (start value)		1000 tons
	(Difference		*4 tons)*

The decision rule is that if the $EIRR_{Int}$ is greater than the environmental rate of return required by the company or shareholders or stakeholders, the environmental investment is acceptable and will yield a positive ENPV.

When cash is invested in the environmental project, it cannot be invested elsewhere to earn alternative environmental returns. Thus, the environmental project go-ahead should be given only to projects exceeding the set environmental and economical requirement.

Return on Investment (ROI, investoinnin tuottoprosentti, sijoitetun pääoman tuotto)

For the financial term Return on Investment, we are dealing with

- profit as a percentage of the assets employed
- a simultaneous profitability review from the equity and liabilities points of views
- providing an useful overall approximation of the success of a firm's past investment policy
- one of the key figures in financial statement analysis.

The ROI is calculated according to the following formula:

ROI *= Profit/Investment x 100 = Returns on equity and current liabilities / Capital employed x 100*

Environmental Return on Investment (EROI, investoinnin ympäristötuottoprosentti, sijoitetun pääoman ympäristötuotto)

The environmental companion term to ROI, EROI (Environmental Return On Investment) can be used e.g. to calculate whether a company is performing in an environmentally satisfactory manner, i.e. returning a sufficiently high environmental return on starting value in environmental improvements. Depending on the situation the profit can be given either as an annual reduction or, if time dimension is added to the study, as an environmental net present value for the reduction.

EROI *= Profit/Investment x 100 = Returns on equity and current liabilities/Capital employed x 100*

Example

Consider a situation where company A decreases its BOD emissions 100 tons with new technology and company B decreases its emissions 200 tons with a similar investment. According to the laws of investment calculus, we cannot directly conclude that company B is more environmentally profitable than company A, because the target is to consider whether the companies are returning a sufficiently high return on emissions. Assume that the yearly BOD emissions were 400 tons in company A's production and 2000 tons of BOD in Company B's production. Company A's EROI is 25% (100 tons/400 tons) whereas the return for company B is 10% (200 tons/2000 tons). In contrast, the EROI measure suggests that company A environmentally outperforms company B. This example, of course, is highly simplified.

4.2.7.2 Example case

In our example case we have an integrated paper mill considering different environmental investments to improve its environmental performance. It should be noted that all the other emission parameters and even weighted parameters such as greenhouse gases can be calculated in exactly the same way. In this example we use BOD as the demonstration parameter.

To begin with, a time series of emissions for a paper mill is illustrated in Figure 17. The reasons for the yearly variations in the Figure 18 can be explained e.g. by yearly differences in quality, demand and cyclical production tons.

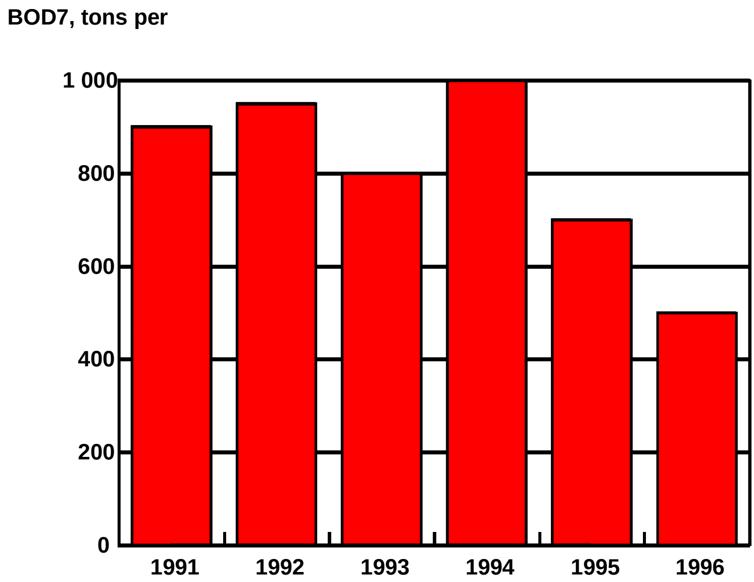

Figure 17. The emissions of a paper mill.

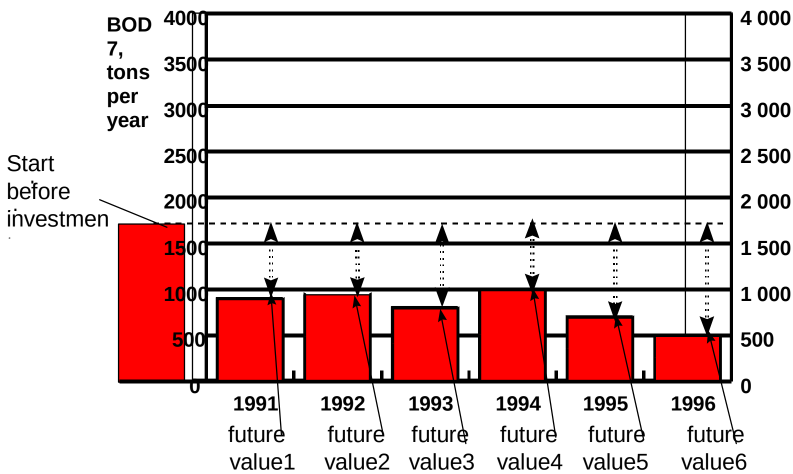

Figure 18. The environmental net present value of a paper mill.

ENPV

In year 1990 the BOD7 emissions of a paper mill were 1700 tons per year. We will use this 1700 tons as the start value. The annual emission reductions 1991–1996, resulting from an environmental investment in 1990, were 800 tons (=1700-900), 750 tons (=1700-950), 900 tons (=1700-800), 700 tons (=1700-1000), 1000 tons (=1700-700) and 1200 tons (=1700-500) as Figure 18 shows. Assuming an annual environmental discount rate of 10 percent, the net present value of this paper mill's BOD7 emissions is:

ENPV= -1700 + 800/(1+0,10) + 750/(1+0,10)^2 + 900/(1+0,10)^3 + 700/(1+0,10)^4 + 1000/(1+0,10)^5 + 1200/(1+0,10)^6

Thus, the ENPV of BOD7 equals + 2100 tons. In other words, if we had considered the investment in 1990, with the estimated reductions as in the time series, the value of the emission reductions during the time period projected to 1990 would have been 2100 tons of BOD7 for this particular environmental investment.

EIRR

By comparing the values of $EIRR_{Ext}$ and $EIRR_{Int}$ we can conclude whether the company's activities in terms of cutting emissions fulfill the requirements set by the stakeholder we are examining. In this case, the stakeholder "authoritities" expresses its requirements through ELV's (Emission Limit Values).

Figure 19 shows the emissions of the integrated paper mill in the same frame as the limit values set by the authorities. Before year 1991, the limit value was set at 4500 tons of BOD7 per year. As can be noted, in the early 90's, the limit values were set quite high above the actual emissions and were thereby easy to attain (either because of advanced environmental performance at the mill or through less strict limits for BOD7). In 1994, the authorities lowered the BOD7 limit to 1500 tons per year. Then, the gap between the BOD7 limit and the emissions of a paper mill became substantially smaller.

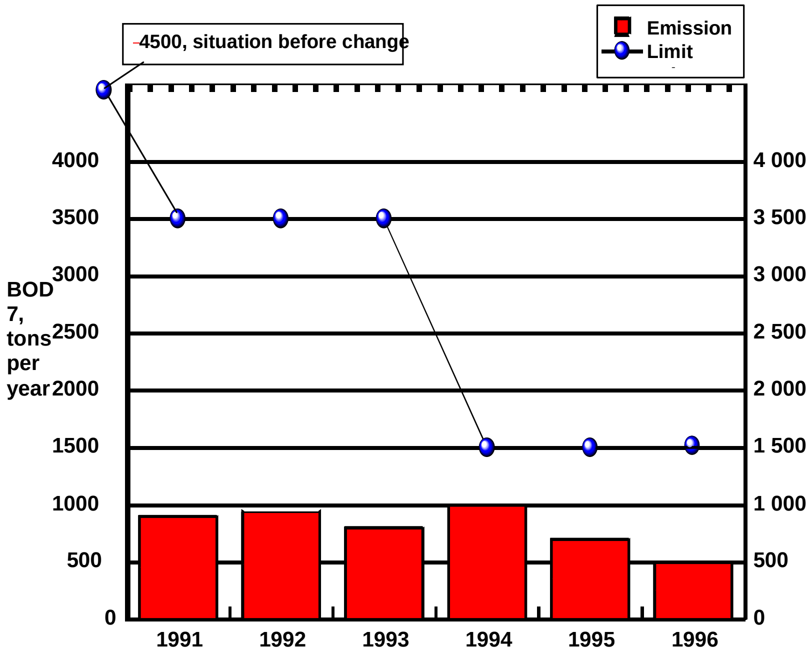

Figure 19. The emissions of an integrated paper mill in the same frame with the limit values set by the authority.

The Figure 20 illustrates the external environmental rate of return ($EIRR_{Ext}$) demanded by the authorities. Here, the BOD7 limit value set by authority can be described as the environmental rate of return on investment by society in the mill (infrastructure etc.). Each year between years 1991 and 1996, the future value is the difference between the limit value set by the authorities in that particular year compared to the value in 1990 – the situation before the change.

The mill has the BOD7 emissions of 4500 tons in year 1990. The materialised annual reductions of BOD7 emissions (i.e. future values) are in the Figure 20 1000 tons, 1000 tons, 1000 tons, 3000 tons, 3000 tons and 3000 tons. *The minimum rate of return is usually at the level of about 10% in companies' financial investments. However, this can not really be taken as a guideline for the environmental rate of return. We need to do a benchmarking study in order to establish what poor/ average/ good environmental rates of return are. At this stage, however, and as an example, 10 % is as good as any number.*

The $EIRR_{Ext}$ can be found by iteration, using a number of discount factors until the ENPV equals zero. The discount factor is a present value factor, which can be found from standard financial tables.

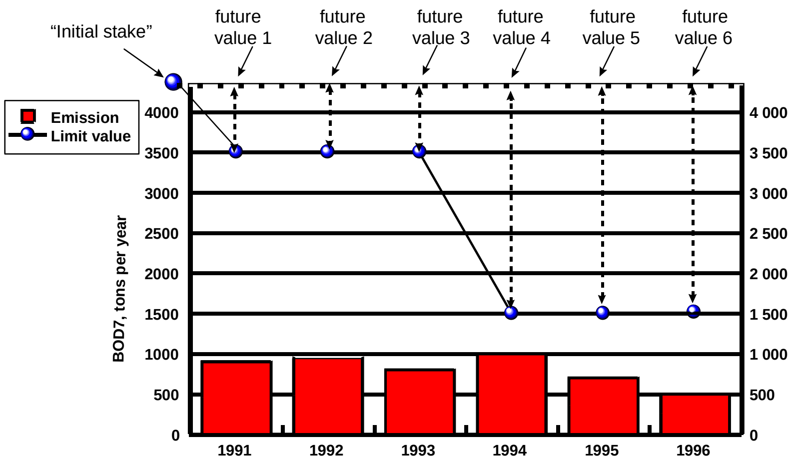

Figure 20. The External Environmental Rate of Return ($EIRR_{Ext}$).

In fact, the $EIRR_{Ext}$ is approximately 28%, as indicated by the following iteration in Table 5:

Table 5. Parameters to calculate $EIRR_{Ext}$.

Year	Net reduction	Discount factor (28%)	Present value of reduction
1	1000 tons	×0,781	= 781 tons
2	1000 tons	×0,610	= 610 tons
3	1000 tons	×0,477	= 477 tons
4	3000 tons	×0,373	= 1119 tons
5	3000 tons	×0,291	= 873 tons
6	3000 tons	×0,227	= 681 tons
	Env. net present value		Σ 4541 tons
	Initial stake (start value)		4500 tons
	(Difference		41 tons)

Next, the internal environmental rate of return will be calculated (Figure 21).

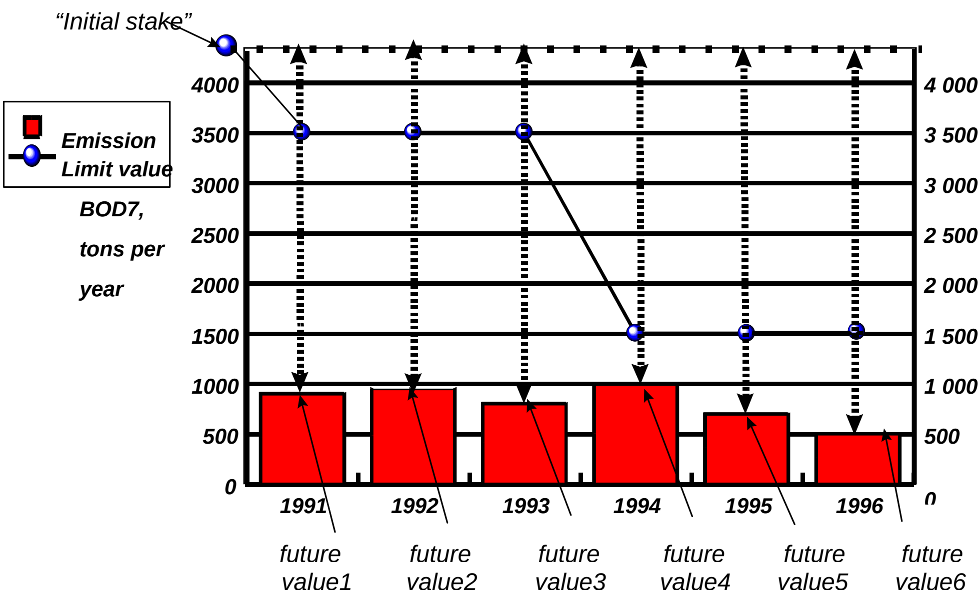

Figure 21. The Internal Environmental Rate of Return (IRR_{Int}).

The example is the same, but this time we examine the actual emission reductions instead of the limits demanded by the authorities. The annual materialised reductions in BOD7 emissions (i.e. future values) are 3600 tons, 3550 tons, 3700 tons, 3500 tons, 3800 tons and 4000 tons. The minimum rate of return is 10%.

For the $EIRR_{Int}$ after six years, we have 78%, well above the 28 % set by the authorities.

EROI

In Figure 22, the environmental return on investment (EROI) is presented. In year 1990 the BOD7 emissions of a paper mill were 1700 tons per year. We will use this 1700 tons as the start value. The implemented emission reductions of a paper mill were 800 tons, 750 tons, 900 tons, 700 tons, 1000 tons and 1200 tons during the years 1991–1996.

As we previously calculated the environmental net present value of a paper mill, we will use this outcome as the gained profit of an environmental investment. The ENPV equals 2100 tons.

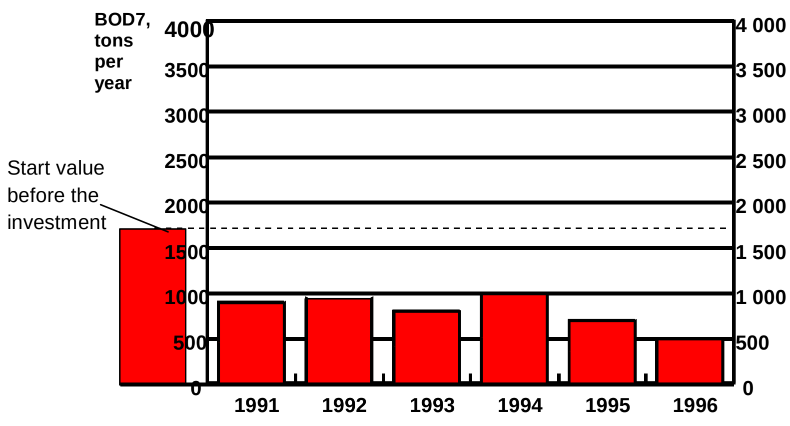

Figure 22. The Environmental Return On Investment of a paper mill.

According to this we can calculate the environmental ROI as follows:

EROI= (2100 tons/ 1700 tons) x 100= 124 %

Again: as we have not performed a benchmark study, we have no absolute yardstick to measure this against yet – we do not know whether this was an excellent environmental investment or a poor one. However, the benchmark study is just about collecting enough data on actual environmental investments and analysing them – there is no methodological problem, only the problem that we are at the first stages of examining a new system.

4.2.7.3 Key benefits and comparability table

The key benefits and comparability characteristics of CALORIE are shown in Figure 23.

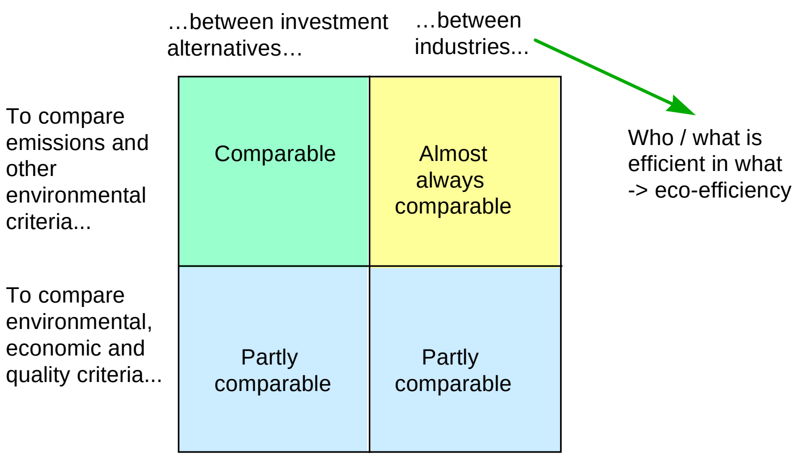

Figure 23. The key benefits and comparability characteristics of CALORIE.

The comparability of investments can be summarised as above:

- With CALORIE, investments are in practice fully comparable when it comes to comparing emissions and other environmental criteria between investment alternatives at one facility or several similar facilities.

- With CALORIE, investments are mostly comparable when it comes to comparing emissions and other environmental criteria between investment alternatives in different branches of industry.

- With CALORIE, investments are partly comparable when it comes to comparing environmental, economic and quality criteria between investment alternatives at one facility or several similar facilities.

- With CALORIE, investments are partly comparable when it comes to comparing emissions and other environmental criteria between investment alternatives in different branches of industry.

4.2.7.4 Conclusions

The calculation methods used in CALORIE are natural extensions to normal investment calculus. The methodology used in CALORIE is familiar in its fundaments to industry and investment makers.

CALORIE enables the comparison of all emissions between each other in the same way as dollars are compared in traditional investment calculus. The emissions studied are comparable even if no weighting factors are used. However, if need be, the emissions can be classified and valuated.

An investment can thus be be described with a few key figures signifying its economic and environmental effects, for example IRR (Capital), EIRR (Global Warming Potential), EIRR (Acidification).

4.2.7.5 Sensitivity analysis of Environmental Net Present Value

To study the sensitivity of ENPV, seven mill simulations were done. The calculations were made with Jaakko Pöyry Consulting's IMPACT mill simulation program. The IMPACT is a computer programme developed for calculating the most important material flows in a pulp and paper mill. It is created mainly by professor Bertel Myréen and doctor Petri Vasara at Jaakko Pöyry Consulting. The program can be used for determining values for real mills or for hypothetical ones. The coefficients have been chosen according to Finnish conditions but they are well suitable for all northern conditions. For south European mills, these values seem to be a bit exaggerated. The programme has been mainly programmed with the Turbo Pascal version 5.5 language, and the text files have been edited with Turbo Pascal's editor, but they can also be edited with other editors. It is divided into seven parts that provide data from processes.

1. Production amount
2. Wood consumption
3. Chemicals

4. Energy need and production
5. Water discharges
6. Air emissions
7. Solid wastes

The simulated mill was an integrated mill with a TMP and kraft pulp lines. The paper mill used the furnish presented in Table 6.

Table 6. Furnish of the simulated paper mill.

Fibre raw material	**Share (%)**
TMP	37
Softwood kraft bleached	16
Fillers	28
Coating pigments	10
Sizers and binders	4
Moisture	5

Two different fuel mixes were simulated (see Table 7).

Table 7. The simulated fuel mixes 1 and 2.

Fuel	**Mix 1**	**Mix 2**
Wood	0.3	0.4
Coal	0.2	0.1
Oil	0.1	0.0
Natural gas	0.3	0.5
Peat	0.1	0.0

The simulated investments were:

1. Investment in new scrubbers on power boiler, recovery boiler and lime kiln. The simulated boilers contained already electric precipitators. Fuel mix remains mix 1.

2. Investment in new scrubbers on power boiler, recovery boiler and lime kiln. The simulated boilers already contained electric precipitators. Fuel mix changes to mix 2.

3. Investment in a new fluidised bed boiler. Fuel mix remains mix 1.

4. Investment in a new tertiary effluent treatment plant.

5. Investment in fluidised bed boiler, scrubbers, evaporation plant and a tertiary effluent treatment plant. Fuel mix remains mix 1.

6. Improvement of secondary effluent treatment plant.

7. Improvement of secondary effluent treatment plant and dewatering section.

The studied cases were not alternative investments. However, they are well suited to an EROI sensitivity analysis, because a sufficiently wide variation in the value range can be obtained.

4.2.8 Sensitivity analysis

The values received from IMPACT- mill simulation program were used in EROI calculations. Emissions to water and to atmosphere, solid waste and material consumption were characterised for all of the cases. Due to the different nature of the cases, some of these parameters remained practically static whereas others changed significantly. All together the EROI varied from +450 % to -800 % at an annual discount rate of 8 percent. It must again be emphasised that the sensitivity of EROI and the other enviro-economical parameters should be studied in more detail to be able to characterise limits for good environmental investments.

The Figure 24 shows how the EROI of emissions to water varied for the seven cases. It can be seen that the investments did not notably affect AOX, COD and water consumption. In cases four, five, six and seven the environmental return on investment of BOD, TSS (total suspended solids) and nutrients seemed to jump to a much higher level.

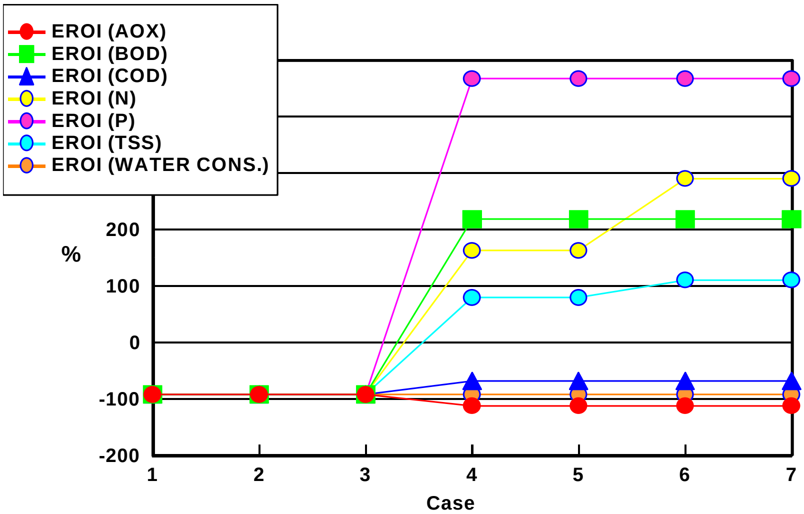

Figure 24. Variation of EROI of emissions to water.

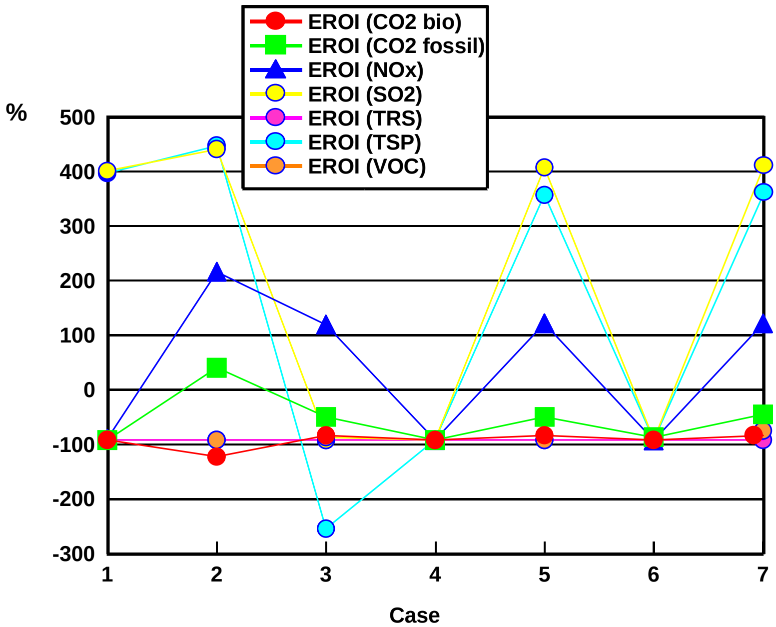

Figure 25. The variation of EROI of emissions to air.

The variation of the environmental return on investment of emissions to air is shown in the Figure 25. The value -93 % indicates that there has not been any change on this parameter[7]. This is the case for example for biogenic carbon dioxide, which stays almost the same in all of the simulations. The biggest variations can be seen in TSP (total suspended particulates). In those cases were scrubbers are used the EROI (TSP) is around 400 %. In case number six the TSP emissions stay unchanged and in case number three the amount of suspended particle emissions is higher than in the base case.

The Figure 26 shows the environmental return on investments for raw material consumption and waste generation. In the cases four, five, six and seven the amount of solid waste increases. As regards the other parameters, in the investments the EROI is -93 %[8], that is, their value stays unchanged.

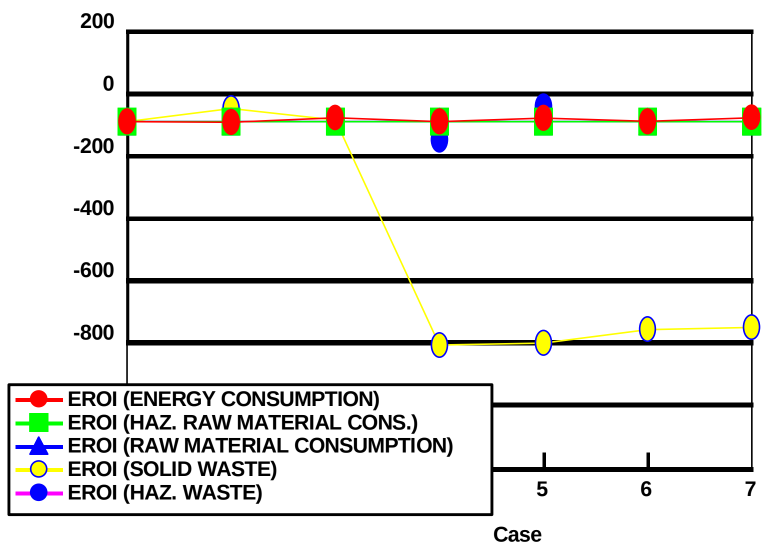

Figure 26. EROI of raw material consumption and waste generation.

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[7] It should be noted that "93 %" is not a universal, magical constant: it happens to be the result with these particular assumptions.

[8] See previous footnote

All the seven cases and the 17 parameters studied can be seen at the same time in the Figure 27. Many parameters stay unchanged in these example cases. However, for example in cases four and six, both positive and negative environmental returns on investments are received. This is why it is important to study the overall effect of investments, not just look at one emission parameter. In a decision making situation, after the changes in emission parameters have been characterised, the local conditions must also be taken into account. Here, environmental impact classification comes into the picture. Only in this way is possible to find truly integrated solutions.

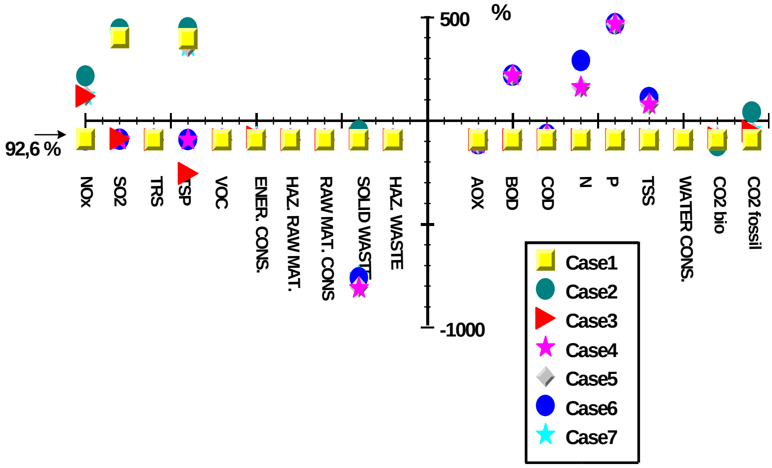


Figure 27. All the seven cases and the 17 parameters studied for EROI.

4.3 Summary of top-down part

- In the top-down part, the progress was from the abstract to the practical.

- At the topmost level of abstraction, the Snake, the Path and the Lens were developed to visualise and aid in grasping the many different impacts of e.g. environmental investment. This level was, apart from this report, presented at the ENTREE ’98 conference in (Vasara and Lobbas 1998).

- At the intermediate level, the IPPC Golden Triangle was developed to make priorisation and cost-quality-environment analyses more manageable. This level was also presented in a trade article (Vasara and Lobbas 1999).

- At the most practical level, the CALORIE framework for environmental calculus was created as an extension of standard investment calculus. CALORIE was also presented at ENTREE ’99 (Vasara et al. 1999).

- We believe that these three levels together constitute a step in the right direction in both integrated decision making tools and the practical implementation of the IPPC Directive. However, among needs for improvement, we can list:

  - increased “terminological stability”: fool-proofing the logic in extending investment calculus to the environmental arena

  - benchmarking environmental investments in different areas to establish a platform for classifying environmental investments as poor/ average/ good

  - dealing with e.g. cyclicality and the 80/20-problem.

5. BOTTOM-UP APPROACH

This part of the study originates from an earlier work founded and executed in VTT Chemical Technology. The earlier work was part of *'Metsäteollisuuden kemikaalikierrot'* –research program and now the work have been completed within this study. The former research program provides a solid background and database for the activities performed in bottom-up approach.

5.1 Introduction and motivation

During the last decade the trend is that citizens, authorities and industry is becoming more and more concerned of harmful impacts of products and production processes. At the same time it has been noticed that just to monitor and restrict flows to environment separately will not result in the optimal solution both for environment and for production. To monitor and to control emissions, production and economy separately may result to shift some harmful components from one emission stream to another, and in the worst scenario this could unintentionally result even decreased economy and increased environmental impact. Furthermore, some of the environmental impacts may remain unidentified or their real importance is not taken under consideration in time. Some kind of overall analysis in terms of process based control of water and air emissions and solid waste generation is required together with analysis of technical and economical aspects in order to avoid surprises in overall costs, in process performance or damage in public relationships.

Activities involved a production plant, such as process R&D activities and production planning are usually evaluated simultaneously with economical and technical aspects. The expected performance of any made investment is dependant on how well the performance of the system under investment can be prescribed (i.e. modelled) to function in the future. At the early stage of the bottom-up approach it was assumed that this probably requires harnessing the engineering knowledge, process data and economy to serve environmental aspects. To achieve the understanding and control of large problem space necessitates integration of various domains, such as process engineers, environmental engineers and even authority instances. The linkages among parties involved in industrial process development projects are sketched in Figure 28. This figure demonstrates how the process development is linked via information flows to a wider context on environmental issues and industrial decision making. The figure also demonstrates the role of emission evaluation model. One of the issues of this work is to study how IPPC-directive (Integrated Pollution Prevention and Control, Council directive 96/61/EC) can be applied to support the information exchange.

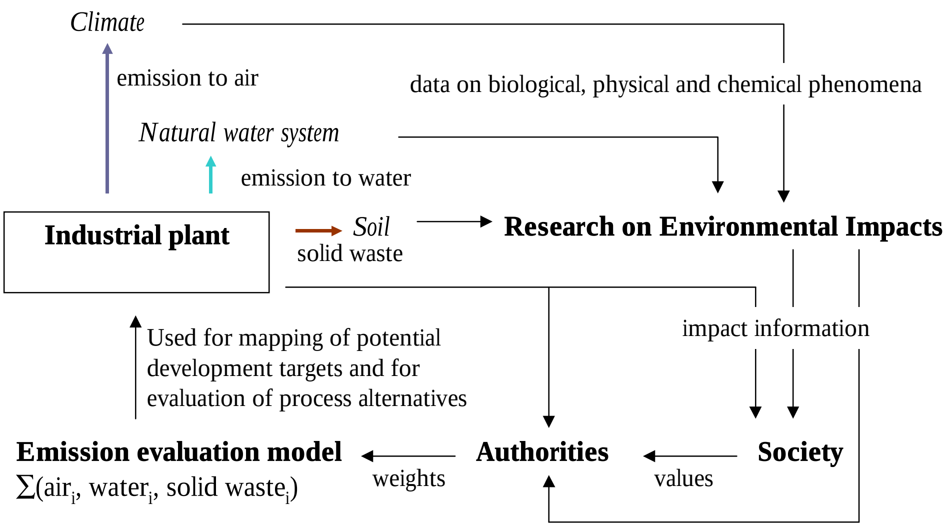


Figure 28. Environmental information exchange.

5.2 Purpose of the bottom-up approach

The bottom-up approach has somewhat the same goals as top-down approach. However, the goals are realised based on detailed process data, making thorough analysis how to utilise plant data. The purpose definition is a very important step in methodology development projects but now in this study it is extraordinarily crucial where the application area is very large-scale.

5.2.1 Goals of bottom-up approach

In the bottom-up approach it is focused on how to utilise elementary mass balance data, requirements engineering and calculations of process streams of a pulp mill. This work demonstrates the principles of bottom-up approach and few means to fulfil the set goals of the case study in practice. This part of the work is supposed to produce new knowledge how to utilise mass balance data in the following point of views:

1) technology; properties of plant, processes and streams

2) environment; concentrations of streams and possibility to normalise various emission streams

3) economy; production costs, investment costs, and profit

4) combined; mapping of potential development targets form a plant.

New knowledge is also that all the point of views are included into evaluation of any plant and process, which also accounts the consideration of the mutual relationships of the views. Moreover, this part of the study has produced a new practical mapping method for helping to follow those four point of views in practice, making the management of these kind of studies more efficient.

5.2.2 Format of the created knowledge

At the very early stage of the project it was set few specified formalisms to be utilised for the created methods. These formalisms were:

- *Extended PID-like process flow sheets* for describing the process behaviour in respect of productivity, environmentally and economically. This graphical process description format should also enable to capture interactions among these three aspects.

- *Numerical values of process variables* (technical, economical and environmental) for exact and specified description of behaviour of processes. This format is expected to be efficient for demonstrating how to bind detailed process data and process evaluation criteria.

5.2.3 Utilisation of the knowledge created

The utilisation of the data and knowledge created in this part of the work can be seen best through the case study. To sum up few beneficial characteristics from the bottom-up approach are as follows:

- to mirror how process data (what kind of data, for what purpose) can be utilised in respect of IPPC-principles in future projects (see Chapters 1, 2.1, 2.2, 5.1 and 5.2.1)

- to set a starting point for calculation techniques producing the data required to implement the IPPC-principles in the future projects

- to set up written documents and computer tools and aids for making the implementation of the methodology easier and systematic in future projects

- to serve as a reference both for industry and authorities how to benefit from IPPC-principles in future projects.

5.3 Structure of the bottom-up approach

Bottom-up approach consists of a network of performed research activities that are presented in Figure 29. First the initial form for the methodology has been set, and then the methodology has been under continuous refinement. The prototyped methodology has been tested on a case study, which has been selected from real industry. The real test case is expected to make the abstract methodology as concrete – as figures and data. The developed methodology is evaluated continuously during the study and after numerous rounds it has taken the form now being reported.

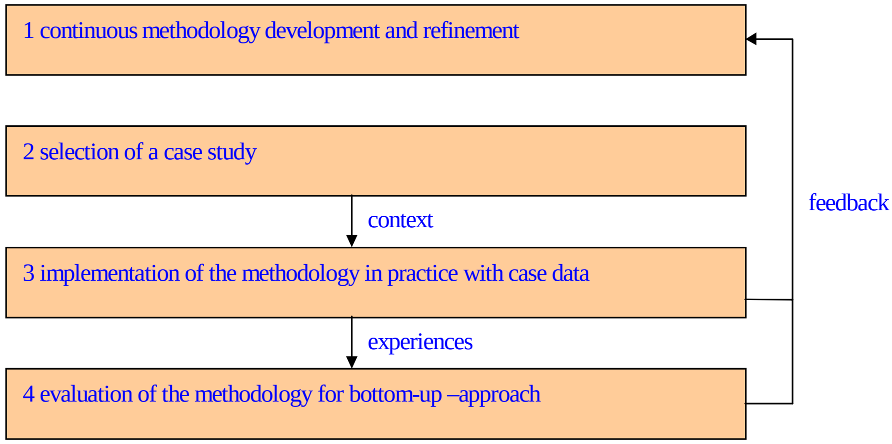


Figure 29. Network of the bottom-up approach.

5.3.1 Target of the bottom-up approach: Methodology for making real investments

The developed methodology for bottom-up approach takes advantage of IPPC-directive, trying to make it easy to apply. In the following the framework behind the methodology is introduced. The framework consists of 1) procedural model of process development project, 2) conceptual model of a process and 3) user's argumentation. The use of the procedural model and the process model, as well as decision and design argumentation is expected to reduce the gap between environmentally and productively oriented process improvement projects. In other words, this methodology aims to provide a framework for combining environmental performance, with detailed process models and economy. This methodology is also expected to help the mapping of potential development targets in the process.

Procedural model of the methodology

A generic procedure – a list of actions – has been compiled which is the basis of the bottom-up methodology. This procedural model is depicted in Figure 30. Any activity triggered during a process development project is expected to fit into this generic list. The outlook of this kind of procedural model might seem to be trivial at the first sight. Let us give a more detailed description on the steps in the list.

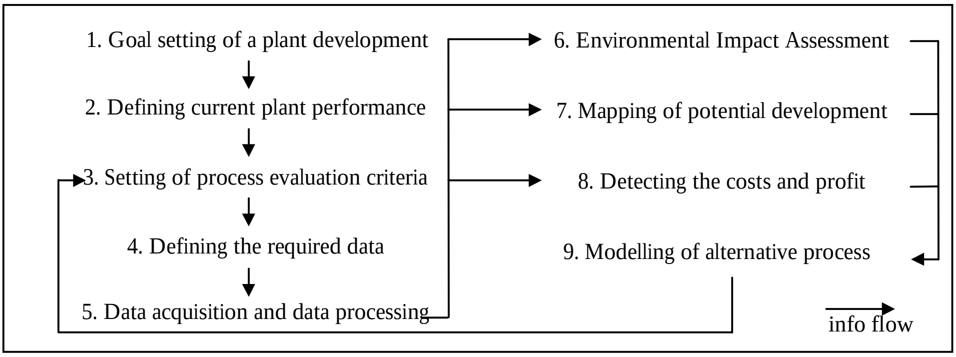


Figure 30. Procedural model of a process development project.

′Goal setting of a plant development project′ is the most crucial part in any process improvement or development project, which should be specified carefully before starting to act in a project. Too often, these specifications are not so fully documented. This step contains the description of the knowledge to be created and assignments of resources for carrying out the development actions. Usually the goal of a process development project can be described as creation of enough knowledge for decision making on real investments improving ′performance of current (or available) processes′, or constructing "totally new" process. To launch and carry out the process design work necessitates developing a conceptual process model. In this work a generic conceptual process model has been developed (see *Process model*). This generic conceptual process model contains the documentation of real process and process model evaluation criteria, which are used for capturing technical, environmental and economical expectations of, process performance. Now, after goal setting, defining current plant performance and setting of process evaluation criteria it is possible to ′define the required data′ properly.

′Data acquisition and data processing′ is followed after the goal setting (steps 1 to 4). How to realise this step, depends on the available resources and skills of the organisation. Development of generic methods for aiding to solve specific – but still multidisciplinary – development problems would be very difficult, and it is not done in this work. Methods to formulate and to solve material and energy balances is given *e.g.* by Reklaitis *et al.* (1983). However, any specific method or engineering approach can be aided and systematised with a proper goal setting and problem formulation, as supported by the developed methodology.

′Environmental impact assessment′ of a plant is truly a difficult task. It deals many coupled phenomena and involves many organisational instances, each having their own point of view and knowledge on the subject (see Figure 28). For a developed process design (=process model) the environmental impact assessment is even more difficult because no measurements can be taken and usually only few of the harmful components can be modelled or simulated. This methodology aids the environmental assessment by providing a transparent platform for emission inventory models, discussions and organisational instances involved. The emission model to be used in the evaluation should ease to normalise components, as well as waste fractions to air, water and soil. Such a model - integrated Index of Emission Impact (IEI_{int}) – is proposed for IPPC directive by Cleary (1998). The model is utilised here for making the comparison of process alternatives more systematic and transparent.

$$IEI_{int} = \Sigma[(w_1e_1)_i+(w_2e_2)_i+(w_3e_3)_i]$$

where 1, 2, 3 denotes emissions to air, water and soil, i denotes components, w denotes weight of a component in a flow and e is emission per production. Weight can be seen as being dependant on other parameters; w = f(productivity, e, harmfulness factor)

Next, ′potential development targets′ are mapped in more detailed. This requires to make a systematic study for defining what are the parts in the available process solutions that should or could be modified; reactions, transport phenomena, flows, temperature control, and so on. A technique used for this purpose, and systematically supported by this methodology, is to backtrack the flows of the components, making evaluation on emission in alternative process solution. In other words, environmental impact assessment and mapping of potential development targets forms kind of detailed Life Cycle Assessment (LCA) characterisation, but utilising further the emission inventory data (see Figure 31). This stage is completed with ′cost and profit detection′ (e.g. unit operation costs, fixed costs, variable costs, ROI, etc. …) and with comparison of alternative investment targets. Usually the cost and profit detection can be seen as a separate task followed by the process modification, but now it is taken as a concurrent part beside production and environmental aspects during the development work.

The last step in the loop is ′modelling the alternative processes′. Any available modelling technique can be used, but this methodology aids the modelling work by providing a documentation format for binding environmental and economical aspects into the process model. It should be noted that process modelling also includes process synthesis, for example to design (and model) a new flow distributor in order to achieve a proper, say, temperature profile for realising less harmful compounds. This step should reveal the effects of the new structure to other process units and to the whole process.

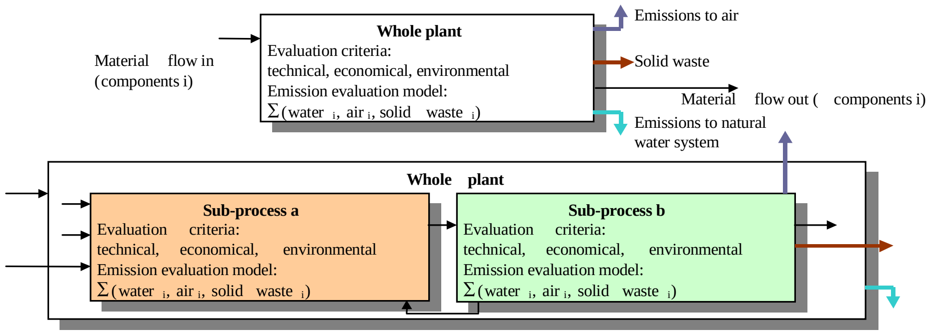


Figure 31. Process detailing to backtrack the routes of the critical components.

According to the methodology, all the activities in a process development project should be linked with a process model (or to a part of a process model) involved. In this way all the activities can be integrated and backtracked from detailed process modelling up to environmental and economical impact assessment of whole process. This feature also provides means for more efficient project management, as well as data and knowledge transformation among project staff.

Generic process model of the methodology

An important part of the methodology is a generic model for a process to be developed – process model. The process model is used for describing an existing industrial process or a new process to be developed. Still the usage of the process model can be restricted to a specified part of a process. The process model is composed of ′material′, ′physical-chemical (and biological) phenomena′, ′process boundary′ (walls or phase interface), ′flow′ (material, energy, information and cash), ′exterior part′ (being more or less under direct control of human) and 'environment' (being out of direct control of human). Let’s take an example: A plant has sub-processes, being connected by flows, and it also has an exterior dump ground and environment (climate, nearby soil and natural water system). The Exterior part - the dump ground - in turn, can be modelled as a process having its material, phenomena, exterior part and environment. Obviously the behaviour of the dump ground depends on the behaviour and material flow from the plant. The usage of the process model makes it possible to take various views on a process: productively (main streams of a process), environmentally (emission streams and flows of environmentally harmful components in the process) and economically (current and potential investment targets, unit operation costs, and so on). It makes difference how the balances and views are formed. In order to make logical decisions, external parts should be taken into the views and balances explicitly. To combine all the various views with a unified modelling technique enables a systematic mapping of new efficient solutions as environmentally, productively (technically) and economically. A view on a process model is shown in Figure 32.

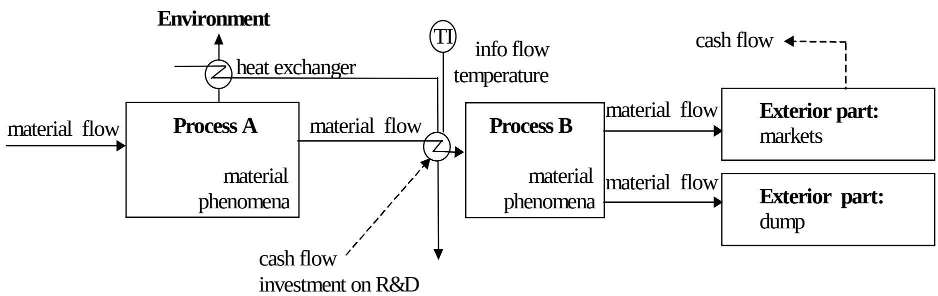


Figure 32. Process model with four types of flows; material, energy, information and cash.

User's argumentation

The argumentation is included as an essential item of the methodology. Usually the crucial part of knowledge of an R&D project is the argumentation behind the reported results and modelling decisions. This means that the argumentation behind the activities and models should be documented, such as decisions on the models or modelling technique. This methodology aims to provide a systematic way for documenting the argumentation. In Figure 33 it is shown how an argument is linked to the other elements of the methodology.

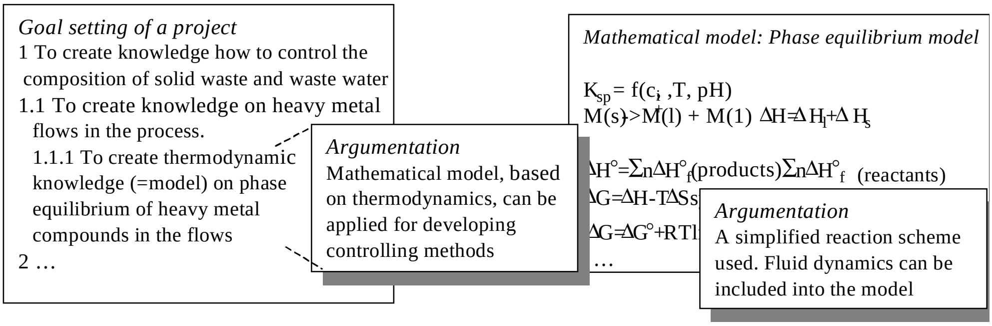


Figure 33. Argumentation of project and process modelling decisions.

Computer tool support

From the beginning of the methodology development work it was known that the usage and testing of this kind of methodology is difficult without a computer support. The usage of the methodology may involve many instances and people, and large amount of information, which necessitates constructing an information system. For this reason a computer tool has been prototyped with a methodology engineering tool, MetaEdit+® (1999). This tool enables to construct a database for the methodology with graphical user interface. It guides users to follow the methodology and enables to build linkages to external software environments; now Excel ® applications and databases. According to the methodology, the tool also assists to document the links among process models, modelling activities involved and their argumentation. In this project the developed tool has been applied for viewing the case models and to store the case data.

5.4 Pilot project: Mapping of development targets and sketching of an alternative process solution for a process unit in a pulp mill

This case is a hypothetical example taken from a real pulp mill. The project is called ”Development of potential development targets and sketching of alternative process solutions”. The pilot project was carried out by following the procedural model presented in Chapter 5.3.1.

5.4.1 Purpose for the pilot project

Goal setting of a plant development project

The main goal of the project is “to find out new possibilities for pollution reduction, simultaneously considering productivity and economy”. For this purpose “knowledge on inherent process based connections among waste emissions to water, air, and soil should be generated”. Secondarily, the case project is also expected to “result in new knowledge on the process behaviour”. These goals are specified further during the pilot project advances.

Setting of process evaluation criteria

The initial and general evaluation criteria for the development project were set in three terms

1) technical aspects; productivity and kappa

2) economical aspects; operation costs, environmental costs, payback time and return on investment

3) environmental aspects; ${}_{water}BOD$, ${}_{water}COD$, ${}_{water}P$, ${}_{water}N$, ${}_{air}NO_X$, ${}_{air}SO_2$, ${}_{air}CH$, ${}_{air}CO$, ${}_{solid}$waste generation [t/day, t/ADt], ${}_{solid}$waste properties [c(i)].

Also the evaluation criteria are specified further when specifying goals as the project advances. Few specified criteria on modelling views and balance areas resulted from ‘*mapping of potential development target*’ are shown in Chapter 5.4.3.

5.4.2 A technique used: Smart measurement of mass balances – SMARTMASS

Next it is briefly described the foundations and a formal way for compiling mass balances. During the project a new method – SMARTMASS – has been compiled. Before showing how some calculations has been performed in this study, few words about balance calculations are in order. In very general form mass and energy balance for a process – both for continuous or batch process, and both for steady state and non-steady state process – can be formalised as follows (see e.g. Reklaitis et al. 1983).

The first step is to define balance boundaries that can be a fixed or a differential volume element. The proper balance volume may be a collection of many separate balance volumes, in other words, if necessary, balance volume may be divided into sub-processes, e.g. according to rigid process boundaries. The collection of many process balance volumes is called here as balance area, as shown in Figure 34.

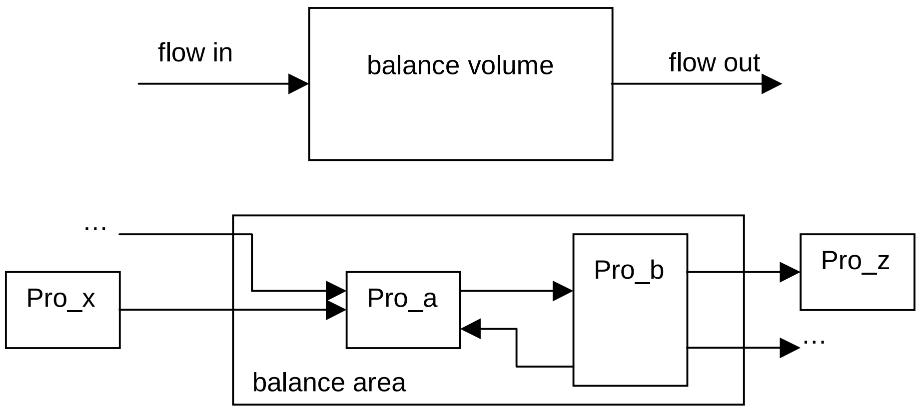


Figure 34. Balance volume and an example balance area.

The mathematical equations for mass and energy balances in general form are as follows:

material flow in – material flow out = material generation + material accumulation

energy flow in – energy flow out = energy generation + energy accumulation

These balances can be specified further for various process analysis, optimisation and design purposes. There are general formalisms both for homogenous and heterogeneous process systems; Stirred Tank Reactors (STR), Continuous Stirred Tank Reactors (CSTR), batch processes, tubular process systems and their variations, such as semi-batch reactors, fluidised bed reactors and columns of many kinds (see Froment and Bischoff 1990). To solve these phenomenon based balance models usually requires to specify many model parameters, such as reaction kinetic parameters, momentum transfer coefficients, dispersion coefficients, diffusion coefficients, bubble size distributions, heat transfer coefficients or even material time distributions and flow field parameters for a vessel.

The second step is to compile a proper balance model for specified purpose. In this project it has been decided to utilise elementary mass balances of process streams for describing the current process performance in order to map potential development targets and to sketch alternative process solutions. The decision to use only elementary mass balances is made because of limited data and resources available and it was expected that elementary mass balance data from the current plant can be sufficient for the purpose of the case study (see goals of the case study in Chapter 5.4.1). Another simplification in this project is that the processes in specified balance areas are assumed to be in steady state condition during data collection and sampling. In order to utilise elementary or component mass balances with steady state models necessitates to ensure that processes inside a balance area are in steady state or in some known exact state during sampling. This can be checked out though careful process data collection and analysis, and through careful experimental design and sampling. To know the characteristics of the process dynamics is the key question for the selection of the proper balance models and balance areas. Elementary steady state mass balance reduces to:

$$n_i^{out} - n_i^{in} = \frac{dn_i}{dt} \equiv 0$$

The third step, after thorough analysis of the concepts of the model, is to evaluate the balance model with its numerical values. The technique used in this project utilises the measured elementary balance data for describing how the elementary material (elementary components, such as heavy metals) transports and circulates in the process. In order to meet the goals of the case study, the flow data is utilised for modelling phase distribution coefficients, which can be very time consuming through phenomena based models. The flow data and the phase distribution coefficients are applied for calculation of alternative process structures together with the data from the plant and equipment producer. Modellers should be very careful and to make sure that the thermodynamic conditions of an alternative process are in the proper thermodynamic regime. Of course the measured elementary or component balances from a plant can be extended with some laboratory experiments or data from equipment producer, such as new phase distribution coefficients of a process unit in changed temperature.

Component and elementary mass balances in reactive process systems can be formalised as set of bilinear equations (see Schraa and Crowe 1998). During the pilot project a commercial tool for data analysis, processing and solving the mass balances with 'data reconciliation' technique was shortly tested. This tool (RECON®, *e.g.* http://www.pvtnet.cz/asc/www/chemplant/home.htm) minimises the deviation of measured flow data of continuous steady state processes to the mass and energy conservation lows by utilising non-linear programming (NLP) technique. The absolute or relative maximum errors of measurements are taken into account. Also reactions for process units can be accounted but now, with elementary mass balances, this utility has not been used. In this project the tool was applied within a limited mass balance area (see Chapter 5.4.2) for

- calculation of the reconciled (usually improved) mass balance from the measured data
- calculation of metal concentrations in non-measured streams
- reporting if the reconciled balance is off the error limits of streams (gross measurement error detection).

In this study there are few reasons that might end up to gross errors, caused by bad experimental design for flow data reconciliation purposes ($d_{n(i)}/dt \equiv 0$ is not true) or by true systematic or non-systematic analysis or measurement error. For taking out all the benefits from data reconciliation requires very careful experimental (or sampling) design, for example in order to eliminate, if possible, the errors caused by non-steady-state process dynamics.

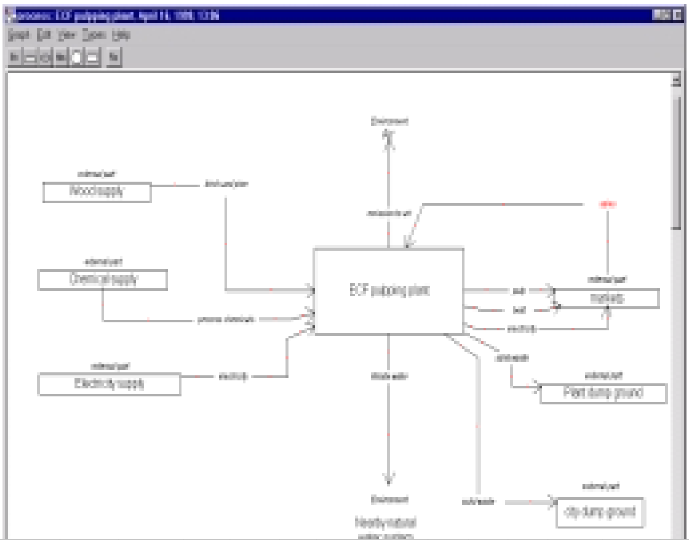
5.4.3 Process models of the pilot project

Mapping of alternative development targets

During the '*mapping of potential development targets*' various balance areas were studied. The whole plant was the balance area for the first model and the balance data was taken from environmental report of the plant. The first model with its IEI-index (see Chapter 5.3.1) and evaluation criteria are shown in Figure 35.

About the IEI-index it should be noted that the index is used for making the targeting more systematic. A single IEI value or value of one of the IEI-terms is meaningless in this work. It is “safe” to compare a term, such as air, with the same term in an alternative solution. The comparison of a term with another, such as air and water, requires a total commitment to the weightings and scaling factors, which normalise the terms.

The mapping step has been run over few balance areas of the plant, and according to possible effect to the IEI-value the mapping has ended up to solid waste from settle-filter section. The IEI calculations are implemented as MS Excel® -files which are linked to process descriptions in MetaEdit+. Now, the plant might consider (1) processing of the dregs and to relocate the dregs with lower costs, approved by authorities. On the other hand, the plant might also consider (2) a process modification to remove the lime sludge flow to filter and to replace the pre-coat filter with another type of filter, which is expected to result in lower operation costs of settler-filter section. In the second alternative the plant may also evaluate weather it is possible to relocate the dregs. Both these modifications necessitate to set few additional evaluation criteria. According to IPPC and IEI-index one of the crucial environmental criteria in this case is heavy metal content of dregs. These two process alternatives are to be compared to each other with environmental, technical and economical criteria. The balance area of alternative 1 with its IEI-index and further specified evaluation criteria are shown in Figure 36.



Scaling factor	group 1	1	
	group 2	1000	
	group 3	1000000	
Weight	Air	1	
	Water	1	
	Soil	1	

$IEI_{int} = \Sigma\alpha\,[(\beta_1\gamma_1)_i + (\beta_2\gamma_2)_i + (\beta_3\gamma_3)_i]$

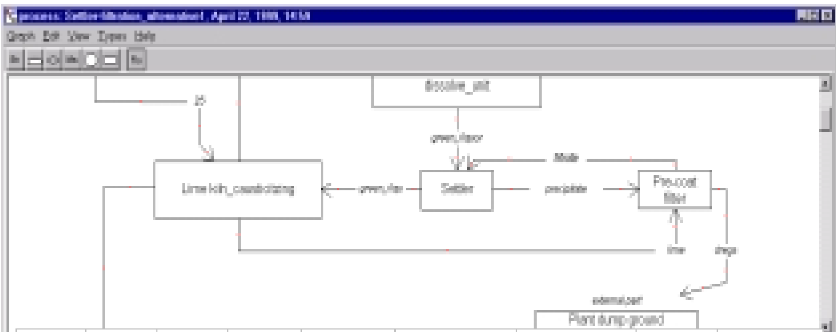
missä		
	IEI_{int}	= integrated environmental index
	α	= ratio factor
	β	= weight factor
	γ	= emission per production
	1,2,3	= emissions into air, water and soil
	i	= components

IEIint-1

	Emission g/mol	BOD	COD	P	AOX	N	S02 <	N0x <	VOC	CO	CH	Cd	Hg	Pb	Partic. <	
	Scaling Weight	1	1	1	1	1	1	1	1	1	1	1000000	1000000	1000	1	
Air	1						220000	1840000							150000	2210000
Water	1	200000	12000000	4000	140000											12344000
Soil	1															0
		200000	12000000	4000	140000	0	220000	1840000	0	0	0	0	0	0	150000	**14554000**
															[mg/ADtn]	

Technical	**Economical**	**Environmental**
production	Waste management costs	BOD, COD, P, N
product quality	Operation costs	NOx, SO2, CH, CO
technical feasibility	Payback time	solid waste generation [tn/day, tn/ADtn]
Consitency with ongoing R&D projects		waste composition [mg/ADtn, mg/day] applicability of solid waste relocation

Figure 35. The whole plant captured with MetaEdit+ (top), few IEI-values (middle) and the initial evaluation criteria (bottom).



NOx <	VOC	CO	CH	Cd	Hg	Pb	Particles <	
46,008		28,01						
1	1	1	1	1000000	1000000	1000	1	
								0
								0
				104	1	175		104998882
0	0	0	0	104176471	647059	175353	0	**104998882**
								[mg/tn pulp]

Technical	**Economic**	**Environmental**
filter quality > now	Operation costs < now	Over all amount kg/ADtn < now
Capacity > now (1l/s)	Payback time > 1½ a	Composition Cd, Pb, Hg mg/ADtn
Feasibility = adequate	Waste management costs < now	Applicability for dgers relocation=yes|n
…		Process impact [IEIint] < now

Figure 36. Alternative 1: A part of the whole process (top) with few IEI values (middle) and some further specified evaluation criteria (bottom).

Modelling of the alternative process solution

To prescribe (i.e. model) the effect on streams caused by the modification in alternative 2 can be very cumbersome. In this case it is question how to utilise the elementary mass balance data for prescribing the behaviour of a process section in the altered thermodynamic state. Fortunately, this process modification, being the removal of the lime sludge flow to filter and replacing the pre-coat filter with another type of filter, is proposed to function in the same thermodynamical state (p, T and pH) which will probably (assumption) result in the same solid-liquid phase distribution of heavy metals in the filter as in the case of alternative 1. In order to model and solve the mass balance (which is usually necessary) for thermodynamically altered (e.g. T, p or pH) process equipment by utilising measured flow data from the existing plant, obviously necessitates some laboratory or equipment producer data, say, solid-liquid phase distribution in new equipment. In Figure 37 it is shown the sketched process structure and part of the RECON calculation output of alternative 2.

After modelling of the settler-filter section, the elementary mass balance is calculated over the whole plant, which reveals the effect of the process modification in the alternative 2 to other environmental emission streams of the whole plant. For example the excess lime sludge must be taken out from some other point in the process. However, the heavy metal content in the lime sludge is 5 times lower than the heavy metal content of dregs and the pure lime sludge can be utilised for example as fertiliser, which may result in lower costs than to dump the lime sludge with dregs. Unfortunately, this was not thoroughly studied and quantitatively calculated during the project. Finally, the values for the all process evaluation criteria are solved and a comparison between the alternative 1 and 2 can be performed.

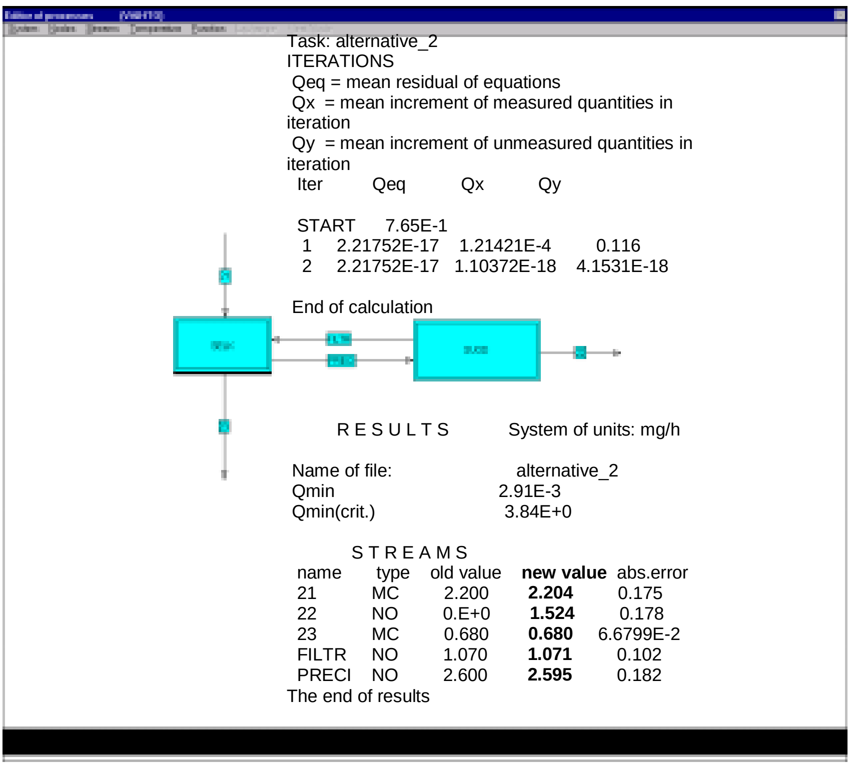


Figure 37. Process alternative 2 with reconciled mass balance for a heavy metal (Cd).

5.4.4 Process performance of pilot project: alternatives 1 and 2

The performance is evaluated with technical, economical and environmental criteria according to the principles of IPPC. Also the effect of the process modification on the performance of other environmental streams are evaluated as required in IPPC. The values of the criteria are presented in Tables 6, 7 and 8.

Table 6. The values of the technical criteria involved the settler-filter section. 'a' denotes the alternative 1 and 'b' denotes the alternative 2.

Technical criteria	a	b
Filter quality	30-60% solids	30-60% solids
Liquor production	83 t/h	83 t/h
Soluble alkali after filter	2-6%	2%
Technical feasibility and readiness to redesign the lime circulation	not necessary	fair
Technical feasibility and readiness to relocate dregs	fair	fair

Table 7. The values of the economical criteria involved the settler-filter section. 'a' denotes the alternative 1 and 'b' denotes the alternative 2.

Economical criteria	a	b
Equipment operation costs	x	x-0.9mmk/y
Fresh lime costs	x	Reduced ~10% x-500t*x mk/t/a
Payback time	-	5y 3m (target 1½a)
Design and training	-	300 kmk
Waste management costs	calc. 1 (110 kmk/a)	calc.1 (52 kmk/a)
of dregs	calc. 2 (495 kmk/a)	calc. 2 (234 kmk/a)
	calc. 3 (1 800 kmk/a)	calc. 3 (900 kmk/a)
Investment	x mk	x+6 Mmk

Table 8. The values of the environmental criteria involved the settler-filter section. 'a' denotes the alternative 1 and 'b' denotes the alternative 2.

Environmental criteria	a	b
C_{Cd} in dregs	9 mg/kg	12 mg/kg
C_{Pb} in dregs	16 mg/kg	19.2 mg/kg
Possibility to relocate dregs	possible	Possible
Possibility to relocate the lime sludge	no	Possible
Total dregs flow	5 400 t/a	2 600 t/a
	(10 000 t/a)	(5 000 t/a)
	(20 000 t/a*)	(10 000 t/a*)
IEI-index (Cd, Pb)	-	Reduced 60-80%
Effect on emissions on air	-	b=a (no change)
Effect on emissions on waste water	-	b~a (not calculated)
Effect on emissions on other solid waste streams	-	b~a (not calculated)

The assumed, and now calculated, effect in settler-filter section for alternative 2 was that the concentration of the heavy metals – Cd and Pb (Hg was below detection limit) – in dregs are going to be about 20% higher in the alternative solution. The final effect of the alternative 2 is 10–15% higher heavy metal content as now measured in the final solid waste from chemical recovery section. On the other hand, alternative 2 achieves lower fresh lime consumption which slightly reduces the operation costs. The mass flow of dregs is about third of now being measured (alternative 1), but this may not reduce the total waste management costs (contrary to settler-filter section in Table 3) because the excess lime sludge is to be taken out from some other point in the process. However, it might be possible to relocate the pure lime sludge with low costs, say as a fertiliser as in the case of alternative 1, and then the overall costs of alternative 2 may be lower than in alternative 1. This is an optimisation problem, and probably a linear one, which has not been fully solved during this project.

The selection of the evaluation criteria is very crucial. For example according the IEI-index, which is proposed to be applied in IPPC-directive, results in lower overall concentrations of heavy metals in dregs in alternative 2 than in alternative 1. This is because the harmful components are calculated in unit; mg/production. Concentration per production does not account whether a component is diluted with some inert material, say Cd-flow to dregs, or being stored as more concentrated. However, weighting factor can be used for compensating this effect. This pilot project did not use or compile any automated method to sum up the technical, economical and environmental criteria for helping or systematising the overall evaluation. The authors did not expect any advantages to occur by integrating the evaluation categories as one index.

5.5 Performance of the bottom-up approach

Performance of bottom-up approach is evaluated in respect of how the developed methodology fits to the principles of IPPC directive, and the evaluation is also made in respect of the set goals of the approach. In Chapter 7 the final evaluation is given on how bottom-up is linked with top-down approach and how they are expected to serve each other.

5.5.1 Bottom-up approach in respect of IPPC directive

The list of procedures presented in Figure 30 accounts the IPPC directive articles as shown in Table 9.

Table 9. IPPC directive and the bottom-up methodology.

IPPC Article	Article content	Congruent step in the bottom-up methodology
Article 6, Applications for permits	'measures planned to monitor emissions into the environment'	1, 2, 3, 6
	'the sources of emissions from the installation'	4, 5, 7
	'the nature and quantities of foreseeable emissions from the installation into each medium as well as identification of significant effects of'	7, 9
	'the proposed technology and other techniques for preventing or, where this not possible, reducing emissions from the installation'	7, 9
	'measures planned to monitor emissions into the environment'	2, 6
Article 9, Conditions of the permit	Item 3; '… values for pollutants listed in Annex III, and their potential to transfer pollution from one medium to another (water, air and land) …'	1, 2, 3, 6
	Item 6; '… measures relating to conditions other than normal operating conditions …'	3, 6, 7, 8, 9
Article 10, BAT and environmental quality standards	'…achievable by the use of the best available techniques …'	6, 8, 9
Article 12, Changes by operators to installations	Item 1; '…necessary measures to ensure that the operator informs the competent authorities of any changes planned…'	9 and see Figure 5
Article 16, Exchange of information	Item 3; '…Reports on the implementation of this Directive and its effectiveness compared with other Community environmental instruments shall be established in accordance with the procedure laid down in Articles 5 and 6 of Directive 91/692/EEC …'	See Figure 5.
Article 18, Community emission limit values	'… Council will set emission limit values…'	3

In respect of the usability of the bottom-up approach, it does matter how the articles are going to be realised by authorities in member states. In respect of process data and possibilities to make process improvements the cruicial steps are 1) how the emission limit values are to be interpreated, 2) how the IPPC Annex III is to be realised and 3) what – if any – emission models are to be applied, for example the one proposed by Cleary (1998) (see Chapter 5.3.1). While IPPC does not give any practical methods for how to study streams on air, water and soil as being inherently connected to each other via process (Article 6 and Article 9 item 3), now the bottom-up approach has proposed one method – SMARTMASS (see Chapter 5.4.2) – demonstrated with elementary mass balance data.

5.5.2 Overall evaluation of bottom-up approach

The evaluation criteria for bottom-up approach were listed in Chapters 5.2.1 and 5.2.2. Bottom-up approach methodology meets the set requirements for *integrating technological, environmental and economical aspects*. Also the *systematic way to model the inherent connections among water emissions, air emissions and solid waste* is achieved. The formalism requirement; *Extended PID-like process flow sheet, is fulfiled as a process model* (see Chapter 5.3.1) *and as a prototype computer tool support* (see Chapter 5.3.1). The requirement for numerical values is realised through the pilot project.

According to the methodology developers the pilot project served a fairly good platform for demonstrating the principles and practical usage of the bottom-up approach. *The data available and the data produced gave a comprehensive study on how to utilise elementary mass balance measurements for sketching alternative structures for improved process performance for a pulp mill.* Although the investment decision, weather to invest or not for either alternative 1 or 2, was not completely solved, this demonstration is fairly successful. However, other pilot projects might be required for demonstrating how to attack modelling problems with phenomena based modelling techniques within the bottom-up approach. The drawn overall conclusions are presented in Chapter 8.

6. LINKAGES OF BOTTOM-UP AND TOP-DOWN APPROACHES

In Chapter 3 it was described how top-down and bottom-up approaches are connected to each other. Now, this description can be specified with case data. In Figure 38 it is depicted what are the data flows between the approaches.

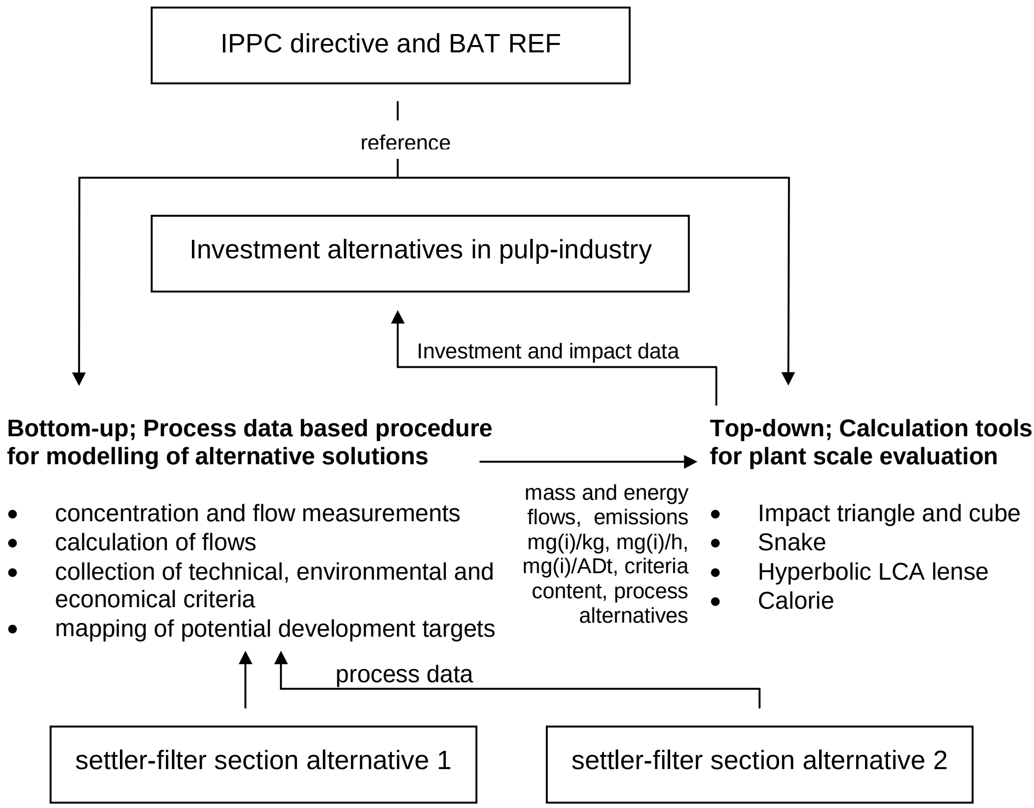


Figure 38. Data connections between top-down and bottom-up approaches.

Though, these connections can take numerical form via case data, but the data flows are not calculated during this project. However, the compiled procedure is expected to ease the implementation of true case data from industry in future projects after the methodology development phase carried out during this study.

7. PERFORMANCE OF THE STUDY AND FINAL CONCLUSIONS

The goal of the study

- The practical goal of this study was to take the first steps towards practical solutions for the following situation: a mill has to respond to a request for integrated pollution prevention and control (IPPC) by evaluating a set of investments. The mill must be able to

  - ✓ evaluate the economic, environmental and quality levels resulting from each investment,

  - ✓ present the *integrated (*environmental, economic, technological) view of these investments both internally (to all levels of management) and externally (to e.g. authorities)

- prioritise: make a balanced, integrated decision better than before

- produce the necessary information for this at levels from top management to process engineer

- master the integration of issues also at process level

Approach

- The study took the “Channel Tunnel” approach to the problem, which was simultaneously approached from the top-down and bottom-up perspective. In the the case of the Channel Tunnel, the different (French and British) sides did encounter each other in the middle. We believe the same phenomenon to have occurred here. Therefore, the final conclusions of the bottom-up and top-down components are also integrated.

Three I's of IPPC: Integration, Implementation and Information

INTEGRATION

- IPPC is about making integrated decisions; about integrating cost, quality and environment; about integrating environment, technology and economy.

- A systematic way to collect design, investment and environmental criteria from a plant has been demonstrated.

- Inherent connections among water, soil and air have now been taken under systematic evaluation within mass balance calculations.

- A set of linked methodologies and visualisation techniques for environmental investments (the Snake, the Path, the IPPC Golden Triangle) have been developed in order to fuse cost, environmental and quality criteria.

IMPLEMENTATION

- IPPC as an abstract principle leads to implementation on a very practical level: a mill has to make an investment in time, effort and money to achieve a desired change. Due to the indestructibility of matter, a reduction in emissions to air does not disappear, it changes form. The mill has to find the best practicable *integrated* solution.

- A technique - SMARTMASS - has been demonstrated to extend the usability of elementary mass balance measurements.

- An environmental investment calculus methodology - CALORIE - has been developed and demonstrated as an extension to standard investment calculus.

INFORMATION

IPPC also has the characteristic of increasing the need for information on several levels. An investment must on the top level be dealt with in an integrated manner, but the investment is mostly about changes to the process, where more information of a more precise nature must be available.

- Measured process flow data (concentrations and streams) has been utilised for mapping of development targets and sketching of alternative process solutions

- Conceptual frames and prototype computer tool support for open formatted model documentation and communication has been compiled.

- The top-down concepts have been specified so as to make the production of a computer toolkit for the visualisation and evaluation of environmental investments as logical and smooth a process as possible.

- The data flows between the bottom-up and top-down parts have been charted as a step towards seamless integration of the process and strategy levels.

ALL-IN-ALL:

Sufficient knowledge on connections between cost, quality and environment cannot be generated:

- without careful analysis of process data and measurements.

- without careful analysis of data on actual environmental investments in different branches of industry

However, we believe that for the task of priorisation of investments, combining the techniques developed during this study (e.g. SMARTMASS and CALORIE) form a coherent step in the right direction.

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Title

Implementation of IPPC-directive

Development of a new generation methodology and a case study in pulp industry

Abstract

This study is an attempt to answer the question "What kind of aspects could appear when implementing IPPC and how to deal with them?" During the study this question was attacked with methodology development and test usage. These actions were expected to result in a practical and ease way to apply IPPC principles. This development work has resulted in 1) few prototype methods and tools for practical calculations for comparing process alternatives and 2) for making evaluations of process alternatives with environmental, economical and technical aspect.

The methodology is expected to help industry by them selves and together with authorities to create and evaluate cost- and eco-effective alternatives. This study arises crucial questions: "how IPPC Articles are to be interpreted by authorities and how industry can utilise the new permit procedures"? While IPPC does not give any practical methods for how to study streams on air, water and soil as being inherently connected to each other via process (Article 6 and Article 9 item 3), now prototyped tools – CALORIE (top-down approach) and SMARTMASS (bottom-up approach) – has been proposed and demonstrated with investment and emission parameters and with elementary mass balance data. These prototyped methods enhance to set-up mass balance measurements and calculations revealing the circulation of components and mass balance connections between various waste streams. This data – flows and concentrations – can even be lifted up as additional investment criteria. These kinds of approaches should be available for industry and authorities when implementing IPPC directive.

Keywords

pulping industry, environmental impacts, IPPC, directives, EU, environmental protection, air pollution, water pollution, energy consumptiom, raw materials

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