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A technical report documenting the results of the MCA and CBA procedures for a regional-defined single chain in Baden-Württemberg

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WP 1.5 Sustainability Impact Evaluation

A technical report documenting the results of the MCA and CBA procedures for a regional-defined single chain in Baden-Württemberg

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Executive Summary

For the evaluation of sustainability impacts in Eforwood, a two-fold set of approaches is proposed and put to test:
(1) Multi-criteria analysis (MCA) is designed to integrate data from the Eforwood database with qualitative stakeholder information and preferences.
(2) Cost-benefit analysis (CBA) and cost-efficiency analysis (CEA) perform evaluation on monetary terms.

After clarifying methodological issues in the deliverables PD1.5.2 and PD1.5.3, the evaluation tools were tested on a "real-life" example, the Baden-Württemberg single chain. The major preparatory tasks were to select available indicators, to adapt the existing chain and to search for and define feasible alternatives for the single chain evaluation. The work of the evaluation group has been strongly conditioned by the limited number of available indicators and the lack of reliable data available at the time the deliverable was to be carried out (06/07 – 12/07). In this respect, additional effort by MCA and CBA teams was required in order to be able to perform a meaningful evaluation exercise. While poor data quality is a threat to the validity of results from either of the methods, it is especially critical for the cost-benefit analysis, the sound implementation of which requires a consistent, reasonably complete and accurate dataset. Moreover, the lack of actual choice or policy alternatives to be analysed eventually precluded the CBA team from implementing cost-efficiency analysis due to conceptual infeasibility.

As a consequence of the abovementioned problems, the MCA and CBA teams focused their attention on different methodological tasks.

The MCA team put weight on software-development and initial stakeholder involvement. A software-prototype was developed based on the PROMETHEE outranking method and implemented in C++ offering a windows-based client-server technology. A stakeholder workshop was organized in Freiburg to (i) test this prototype for its applicability, and to (ii) gain experience in the procedure of stakeholder involvement in Eforwood. The feedback gathered after the workshop concerned both software-usability and general aspects of Eforwood. The MCA-prototype was well-accepted with the attempt to gather preference information, to facilitate group decision making and to support an informed decision-making process. There were also warnings that there are still many sources for black-box effects and over-simplification. Regarding the Eforwood context, the flexibility of the system to mirror

specific circumstances by chains and indicators as well as a consistent definition of system boundaries was mentioned as crucial.

The CBA team focused on the implementation of monetary evaluation of the single chain. The main issues were to test and evaluate the conversion from data as reported to the Database client into the monetary flows and values needed for undertaking a CBA and to identify gaps and needs for improvements in data reporting. We illustrate the potentials of including the value of externalities in FWC evaluations, focusing on GHG-emissions as well as non-GHG-emissions. Considerable effort in supplementary data collection was made to that end, and the experience gathered will be made available for the Modules of EFORWOOD to ease their future collection for the EU-level chains.

Summarizing, we conclude that (a) it could be demonstrated by a real life example how MCA and CBA could be applied to the analysis of FWCs, (b) data and information collected for the single chain phase of EFORWOOD still includes substantial gaps and uncertainties with regard to the exact content and context of reported indicator values. A standardized use of chain topology as well as indicator data for evaluation modules is not possible, yet; (c) MCA and CBA may interact much closer to make the best use of available information. In the current exercise the closer interaction was hampered by insufficient data.

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1 Introduction

1.1 General

Within the core product of EFORWOOD, a quantitative decision support tool for sustainability impact assessment (ToSIA), three generic and complementary evaluation approaches were proposed: Multi-criteria analysis (MCA), Cost Benefit Analysis (CBA) and Cost Efficiency Analysis (CEA). The tool will permit the analysis of the sustainability impact of a wide variety of global, national and local changes on the FWC from economic, social and environmental perspectives.

(1) Multi-criteria analysis (MCA) is designed to gather stakeholder and expert preferences for indicator weightings and performances and to synthesize transformed indicator values on a uni-dimensional scale for the comparison of decision alternatives.

(2) Cost-benefit analysis (CBA) and **cost-efficiency analysis (CEA)** perform evaluation based on monetary measures. CBA compares the costs and benefits measured in monetary terms, whereas in CEA the benefits are measured in physical terms. CBA is a more general evaluation method used primarily to identify the alternatives which increase social welfare, whereas CEA focuses on the comparison of the relative effectiveness of alternative projects in achieving a given objective.

The evaluation package is designed to evaluate alternative forestry-wood chains (FWCs) with regard to their sustainability impacts. This procedure is utilizing EFORWOOD indicators and indicator values gained from scenario calculations to assess aggregated (utility or monetary) values for alternatives and report them to the user while granting a selection of analysis features to get insight in the procedure and the results (Figure 1). Learning and exploration requires re-iterating the analysis steps in a flexible manner.

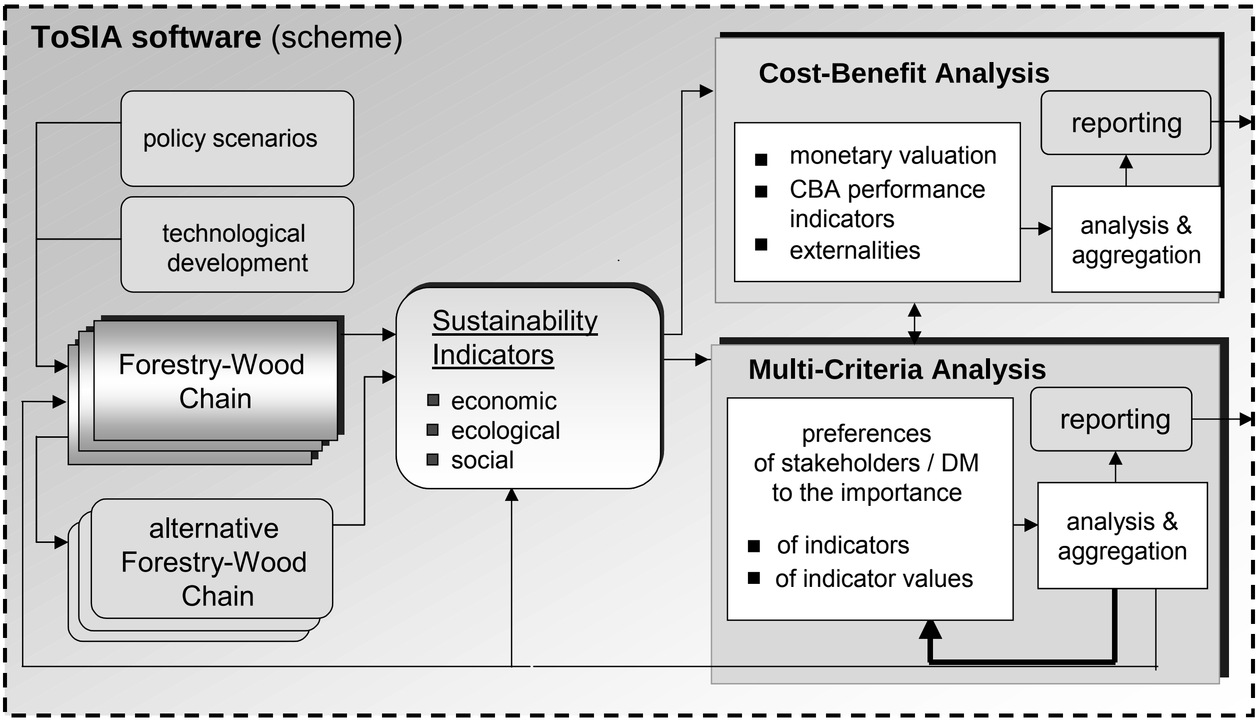

Figure 1 CBA and MCA in the EFORWOOD context.

Both methodologies and their implications for Sustainability Impact Analysis (SIA) have been thoroughly analysed in deliverables PD 1.5.2 and PD 1.5.3. It has been highlighted that tailoring evaluation methods for EFORWOOD needs will be a challenging task due to the complexity of the system to be evaluated, the potentially large and varying number of heterogeneous indicators, and the potentially large numbers of stakeholder interests as well as their spatial heterogeneity. Having prepared the methodological ground, MCA and CBA concepts were put to a first test in the context of the Baden-Württemberg single chain setting. Cost-efficiency analysis has been given up due to conceptual infeasibility of its implementation in the setting characterised by a lack of actual choice or policy alternatives to be evaluated.

1.2 Purpose of the report

The main purpose of this report is to demonstrate first test applications of MCA and CBA in the context of a regional-defined single chain in Baden-Württemberg. This is to move beyond the theoretical concepts and to test and prove applicability within the EFORWOOD concept of sustainability impact assessment.

For MCA, the main issues were the choice and adaptation of a method with regard to the needs of EFORWOOD evaluation, the development of a software prototype to support computational handling of the decision problem and to test this prototype with a stakeholder panel urging for both feedback on the approach, methodology and technical implementation as well as for experience in the work with stakeholders in a group decision environment.

For CBA, the main issues were to test and evaluate the conversion from data as reported to the Database client of EFORWOOD into the monetary flows and values needed for undertaking a CBA and to identify gaps and needs for improvements in data reporting. Finally, the purpose was to test and demonstrate the CBA method and measures along the FWCs examined as well as across modules of the different FWCs.

1.3 Structure of the report

The report is structured in two main parts according to the two main methods applied: MCA and CBA. In the MCA chapter, we begin by an introduction to the approach and a brief presentation of the method chosen, PROMETHEE. Next, we describe in some detail materials of the analysis, including the design of the stylised FWC's applied and the indicators evaluated. The core of the chapter is the presentation of the prototype MCA tool developed for EFORWOOD and the results of a test of this tool with a stakeholder panel, including the stakeholder responses and evaluation of this panel.

The CBA chapter also begins with a brief introduction to the approach. Then follows the presentation of the materials used. The design of the FWC in this case is somewhat more involved, and the chains have been extended slightly beyond that present in the Eforwood database, to allow a better illustration of the method. The data used and the set of indicators is also improved in quality and quantity compared to that present in the Eforwood database for the single chains. The new data and its origin are explained, including data on externalities (GHG and non-GHG-emissions, carbon sequestration) and their value. Next we describe the methodology in some more detail including the models and performance measures usually applied in CBA, and discuss their relevance here. The main section is the presentation of the main results of the CBA followed by a sensitivity analysis focusing on some of the main parameters of importance. Finally, we briefly discuss the results, and what brought them about and also their possible sensitivity to assumptions and possible flaws in the data. We conclude this chapter by pointing out some main limitations of the first test example of the CBA approach in EFORWOOD, and also stress some issues that EFORWOOD needs to deal with in the coming final work.

In the final chapter, we briefly compare the two methods.

2 Multi-criteria analysis

2.1 General approach

In EFORWOOD one of the proposed approaches to comprehensively analyse the sustainability impacts of forestry wood chains is multi-criteria analysis (MCA). MCA is a set of methods designed inter alia (i) to take account of multiple, conflicting indicators, criteria or objectives, (ii) to involve stakeholders, their values and preferences, (iii) to prioritise and rank management alternatives and (iv) to support a comprehensible and transparent decision process.

In PD1.5.2 the major phases of MCA procedures for the evaluation of alternative forestry-wood chains (FWC) are reviewed and recommendations for the use of MCA within EFORWOOD are given. Based on the analysis of main requirements as well as identified limitations for EFORWOOD MCA key criteria were defined which allow to screen available MCA methods for their applicability within ToSIA.

Based on the state of the art of scientific knowledge on MCA and expert opinions within the EFORWOOD panel a set of key demands for an EFORWOOD MCA tool were identified (Table 1).

Firstly, there is a high degree of flexibility required within the EFORWOOD evaluation process. There should be allowance for different aggregation levels (e.g., total chain, module-specific), for different indicator structures (e.g., flat, hierarchy, network) and absolute vs. relative evaluation of alternative FWCs.

Secondly, there is a high demand for **consistency** regarding the use and interpretation of data and indicator values (e.g., data quality for input and output within MCA), the handling of trade-offs and compensation among indicators, the definition of thresholds for indicators and the way uncertainty is dealt with.

Thirdly, addressing decision-makers and stakeholders calls for distinct **transparency** regarding the evaluation process and the generation and interpretation of results. This shall be supported by the use of comprehensible procedures, clear communication of preference elicitation and aggregation principles, emphasis of interactive components and the facilitation of group decision analysis.

Finally, the acceptance for MCA tools will strongly depend on the **user-friendliness** of the tool in terms of intuitive and accommodate ways of using it as well as manageable efforts both from the intellectual and time-consuming point of view.

2.2 PROMETHEE

Out of the methods portfolio, outranking methods were identified as potential approaches to deal with the evaluation of FWCs in a SIA context since they are efficient in the application through the general definition of preference functions and thresholds respectively. According to the analysis in PD 1.5.2, the method of PROMETHEE (II) would meet many of the criteria relevant for the application in an EFORWOOD MCA (Table 1); that is why it was chosen for the first MCA prototype application.

Table 1 Important issues and corresponding criteria for selecting EFORWOOD MCA methods.

Issue	Criterion	PROMETHEE II
Possible input (indicator values / preferences)	Cardinal/ordinal/mixed data	mixed
Form of output	Cardinal/ordinal results	cardinal
Absolute external benchmarks possible?	Relative/absolute evaluation	relative; no absolute evaluation
Aggregation principle	Outranking [OR]/single criterion[SC]/interactive[IA]	outranking
Easy to understand	Transparency	high
Possibility to model the decision problem	flat/hierarchy/network structure	flat
EFORWOOD MCA should provide results at different aggregation levels (e.g., Modules, whole FWC).	Suitable at different aggregation levels	with little modifications possible
Trade-off among indicators	Compensation/non-compensatory features/no compensation	non-compensatory
Thresholds in valuing indicator values	Thresholds	yes
Can uncertainty in data/preferences be addressed?	Uncertainty	yes
Suitability for interactive use	Interactive use	yes
Intellectual demands on the decision maker	Required knowledge of DM	intermediate
Resource demands on the decision maker	Required interaction time for analysis	low
Option to accommodate a group decision making situation	Group decision making	yes
How difficult to implement as software tool?	Ease of implementation	intermediate

PROMETHEE (Brans et al., 1986) is a representative example from the European MCA school basically describing the degree of dominance of one alternative over the other. PROMETHEE is conceived for strategic management purposes and regional planning policy processes (Brans et al., 1998). There are also examples for habitat management (Drechsler, 2004) and water planning issues (Simon et al., 2004) and some forestry related reports (Kangas et al. 2001, Kangas and Kangas 2002, Gilliams et al. 2005).

2.2.1 The PROMETHEE method

In PROMETHEE, preference functions are to be defined explicitly by indifference and preference thresholds. Basically, PROMETHEE uses the degree of dominance of one alternative over another as recommendation of a choice among different alternatives. A

typical evaluation is built of a set of alternatives, i.e. in this context, a selection of different FWCs, to be evaluated on a finite set of decision criteria. This results in an input matrix of criteria values from each alternative.
Additionally, information is needed (i) on the relative importance of the criteria (wj) which, for instance, can be elicited by direct rating, and (ii) on the preferences of a decision-making/ user concerning the criteria values of the alternatives. In PROMETHEE, the user has to choose among preference functions which differ with regard to indifference and preference thresholds. This construct, known as the pseudo-criterion approach, describes the degree of preference of one alternative over another with regard to a specific criterion (Figure 2). A pseudo-criterion is defined by the setting of two thresholds for pair-wise comparison, the indifference threshold q and the preference threshold q to evaluate each Δ_j, i.e.the deviation of indicator values of two alternatives (a_k, a_l). Analogously, this is done for each of the selected criteria.

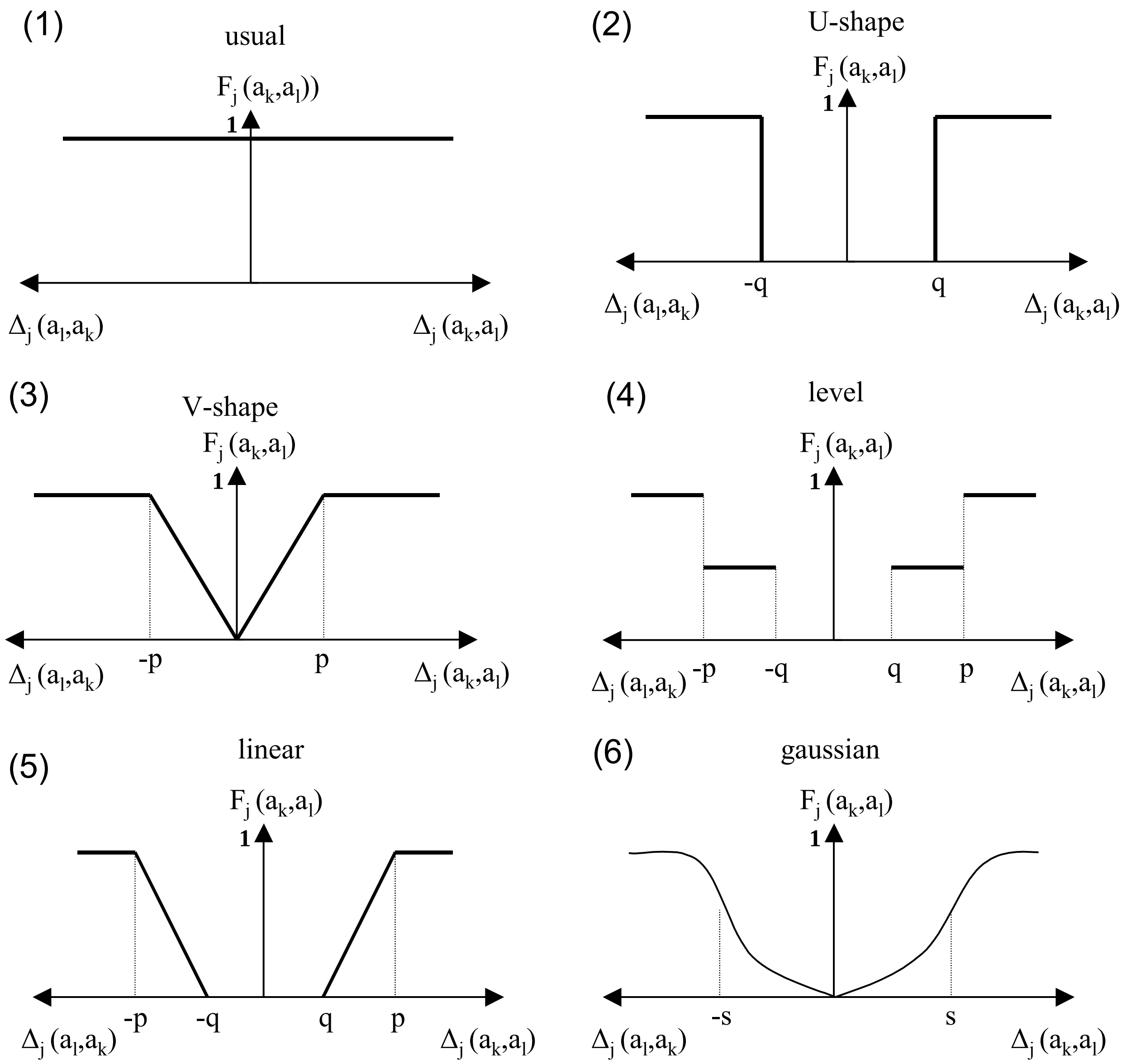

Figure 2 The six explicit preference functions used in PROMETHEE (Brans et al., 1996)

The setting of a preference and/or a indifference thresholds serves as statement of individual preferences for a pairwise comparison of alternatives within an indicator. Depending on the thresholds a deviation in the indicator performance for two alternatives will be estimated with indifference, an intermediate degree of preference or strict preference. In Figure 3, the purple deviation between A(1) and A(2) exceeds the indifference threshold and leads to strict preference for A(1) (P=1 in a U-shape), whereas the orange deviation between A(2) and A(3) is lower stating indifference (P=0) on the preference scale.

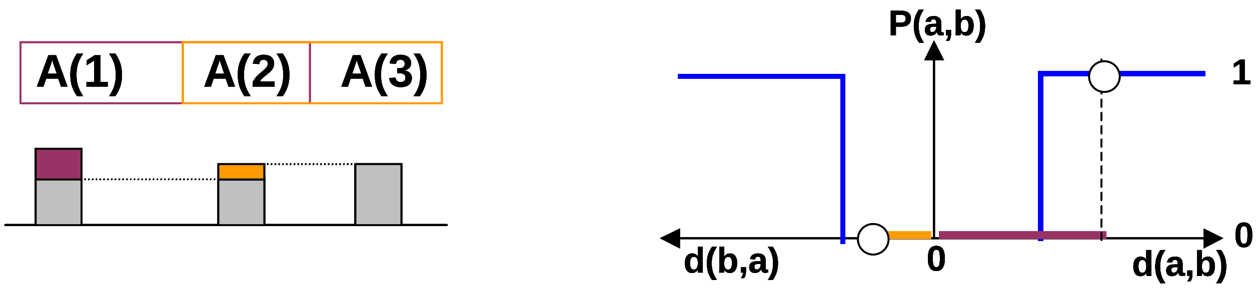

Figure 3 Example for pairwise comparison in PROMETHEE gaining in strict preference (purple) for alternative for A(1) over A(2), and indifference between A(2) and A(3)

The pair-wise comparisons of alternatives with regard to the evaluation criteria result in a summed-up and weighed degree of dominance Π of one alternative (a_k) over another (a_l) in terms of,

$$\prod(a_k, a_l) = \sum w_j F_j(a_k, a_l),$$

when $F_j(a_k, a_l)$ is the preference function and w_j the relative weight of a criterion (or indicator).

The degree of the outranking relation (dominance) is determined by the function $F_j(a_k, a_l)$, in terms of

$$F_j(a_k, a_l) = \begin{cases} 1, \text{ } when \ \Delta_j(a_k, a_l) \geq p_j \\ 0, \text{ } when \ \Delta_j(a_k, a_l) \leq q_j \\ (\Delta_j(a_k, a_l) - q_j)/(p_j - q_j), \ otherwise \end{cases}$$

From the summary of dominance relations regarding individual decision criteria two overall terms are calculated:

$$\Phi^+(a_k) = \sum \prod(a_k, a_l)/(n-1)$$
$$\Phi^-(a_k) = \sum \prod(a_l, a_k)/(n-1)$$

The positive net flow Φ^+ indicates the degree of dominance of an alternative over the others, whereas the negative net flow Φ^- covers the degree of being dominated by other alternatives

The total net flow Φ of an alternative (a_k) is then calculated by,

$$\Phi(a_k) = \Phi^+(a_k) - \Phi^-(a_k),$$

where a higher value of net flow Φ indicates a higher dominance of this alternative in terms of being favourable over the others.

PROMETHEE offers different ways to synthesize a final ranking of alternatives.

In PROMETHEE I two ordinal rankings for both Φ^{+} and Φ^{-} is calculated and compared. This parallel ranking may cause incomparabilities among alternatives (e.g., when $\Phi^{+}(a_k) > \Phi^{+}(a_l)$ and $\Phi^{-}(a_k) > \Phi^{-}(a_l)$), but retains plenty of comparative information.
In PROMETHEE I incomparabilities are erased (at the price of information loss) by calculating the difference Φ^{+} und Φ^{-} ($\Phi(a_k) = \Phi^{+}(a_k) - \Phi^{-}(a_k)$) and generating a cardinal ranking based on the total net flow.

2.3 Materials

2.3.1 Test chains

During the ToSIA development the introduction of single chains represents the first phase of a forestry-wood chain (FWC) specification. It was decided to select the single chain in Baden-Württemberg (BW) as basis for a first testing of evaluation methods. The BW chain is defined as a regional chain, i.e. all FWC processes occur within a regional context.
The original BW single chain comprises of two generalized branches of growing (M2), harvesting & transporting (M3), processing (M4), and marketing & recycling (M5) of Norway spruce timber (Figure 4):

a) a natural-regeneration system with non-mechanized harvesting and long-log transport

b) a planting system with mechanized harvesting and short-log transport

In this construction, the two branches conglomerate back again at the mill-gate with the further processes unspecified with regard to the material sources.
For designing cases for the evaluation methods, we had to modify this construction for two main reasons:

- for testing the behaviour of methods comparing alternatives at least 3 alternatives are recommended (in a relative comparison mode); the original single chains provided “one and a half”
- a veritable lack of conception and data afflicting the modules M4 and M5.

In response to this evidence, it was decided to drive the chains from forestry production to the mill-gate and cut it there. Also, the modes of harvesting were expanded by a hybrid semi-mechanized one and the product line-up and mode processing were diversified (Figure 4). For the set-up of alternatives, the processes were arranged in a combinatorial way.

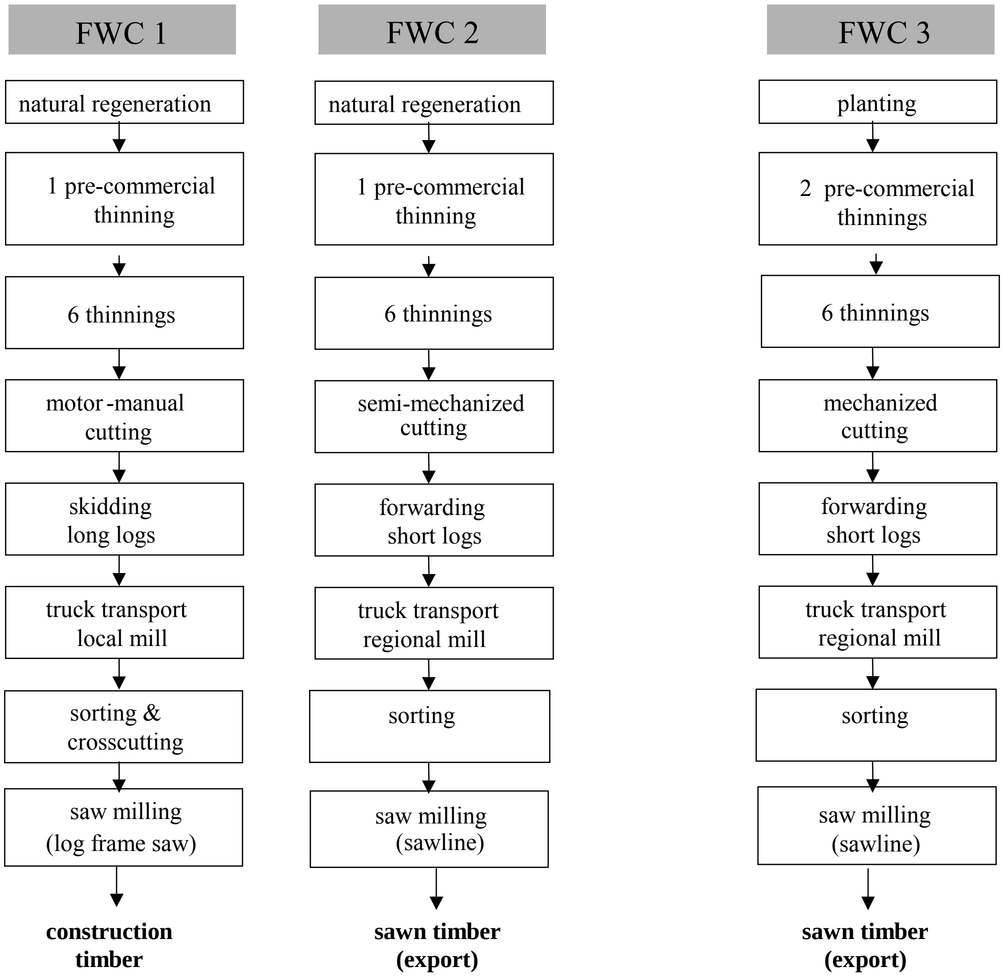

Figure 4 Alternative FWCs for the BW single chain.

The three test chains of Figure 4 were applied in the MCA study and also form the illustrative back-bone of the CBA in this report. Note, however, that the final harvest, which is included in the CBA is missing from this chain and therefore is also not included in the MCA example.

2.3.2 Indicators and indicator values

The selection of indicators for the test application was mainly driven by data availability throughout the whole selected process-line. We experienced a vast amount of non-available or non-applicable indicators and indicator values in many of the processes, thus we ended up with a selection of 7 indicators for the preparation of the MCA workshop:
Raw data were provided by the BW single-chain team, which were then prepared for the application by:

- defining common units for indicators and streamlining them through the chains (raw data were heterogeneous in this point) (Table 2)
- defining an idealistic forest model to identify a common denominator through the chains and ensure vertical summing up of indicator values

Table 2 Common indicator units (m³, i.e. m³ roundwood under bark)

Indicator	common unit
production cost	€/m³
Employment	working-hours h/m³
salaries (male)	€/m³
energy-use (of non-renewable resources)	kWh/m³
greenhouse gas (GHG) emissions	kg CO_2 equivlaents/m³
occupational accidents	qualitative score
total transport distance	km/m^3

For the derivation of a common denominator (transforming per-ha values to per-m³ values) a normal forest model was assumed:

- a forest management unit of 1000ha
- rotation period: 100 years
- annual cut: 1000ha/100y=10 ha/y
- denominator: m³

Based on these assumptions, indicator values for three FWCs were derived (Tables 3, 4, 5). Note that we assumed a qualitative score for the indicator "occupational accidents" (1- low to 4- high) because data collection activities on these issues are still ongoing.

Table 3 Indicator values of FWC 1 as applied in the MCA-part

	production cost	employment	salaries (male)	energy-use[a]	GHG	occup. accidents	transport distance
	€/m³	h/m³	€/m³	kWh/m³	kg CO2 equ./m³	score	km/m³
natural regeneration	1,2	0,0208	0,3543	0,4294	0,116	1	0
precommercial thinning	0,28	0,00496	0,08267	0,1	0,027	2	0
thinning motor-manual	17,32	0,3632	16,32	5,99	1,63	4	0
skidding	7,33	0,0928	2,28	7,47	2,01	1	0
truck transport (long logs)	7	0,0912	0,55	11,78	3,175	1	42
crosscutting and sorting	3,17	0,032	0,58	6,45	4,6	1	0
saw milling (small)	104,63	0,86848	13,34	26,92	12,8	1	0
whole chain	**140,93**	**1,473**	**33,507**	**59,139**	**24,358**	**11**	**42**

a) Only non renewable energy.

Table 4 Indicator values of FWC 2 as applied in the MCA-part.

	production cost	employment	salaries (male)	Energy-use[a]	GHG	occup. accidents	transport distance
	€/m³	h/m³	€/m³	kWh/m³	kg CO2 equ./m³	score	km/m³
natural regeneration	1,2	0,0208	0,3543	0,4294	0,116	1	0
precommercial thinning	0,28	0,00496	0,08267	0,1	0,027	2	0
thinning semi-mechanized	15	0,0688	2,67	15,53	4,18	3	0
skidding	6,13	0,064	2,15	8,61	3,2	1	0
truck transport (short logs)	10	0,11632	0,5	20,1	5,4	1	75
crosscutting and sorting	3,59	0,016	0,49	2,32	1,6	1	0
saw milling (big)	80,4	0,32	4,91	23,84	10,3	1	0
whole chain	**116,6**	**0,611**	**11,157**	**70,929**	**24,823**	**10**	**75**

a) Only non renewable energy.

Table 5 Indicator values of FWC 3 as applied in the MCA-part

	production cost	employment	salaries (male)	energy-use[a]	GHG	occup. accidents	transport distance
	€/m³	h/m³	€/m³	kWh/m³	kg CO2 equ./m³	score	km/m³
planting	3,916	0,0704	1,181	0,3577	0,0977	1	0
precommercial thinning	0,56	0,00992	0,16534	0,2002	0,054	2	0
thinning mechanized	12,1	0,0688	2,15	17,36	3,37	2	0
skidding	7,05	0,064	2,47	9,89	2,67	1	0
truck transport (short logs)	10	0,11632	0,5	20,1	5,4	1	75
crosscutting and sorting	3,59	0,016	0,49	2,32	1,6	1	0
saw milling (big)	80,4	0,32	4,91	23,84	10,3	1	0
whole chain	**117,616**	**0,665**	**11,866**	**74,068**	**23,4917**	**9**	**75**

a) Only non renewable energy.

2.4 Stakeholder workshop in Baden-Württemberg

2.4.1 Purpose and procedure

For testing MCA (and CBA) approaches in real-life examples applications in test chains (case studies) were scheduled in the DoW. Against the background of the status quo of single chain development, the following objectives for the workshop had been defined:

- to demonstrate the EFORWOOD concepts of FWCs, SIA, sustainability impact indicators and MCA evaluation to an external audience
- to test an MCA approach and a software prototype in a real-life application interactively
- to learn about stakeholder perceptions by means of feedback and discussions
- to gain impetus on the further development of both approaches and tools.

For this purpose, a stakeholder workshop was arranged in the context of the BW single chain. The organisation was a joint effort of ALUFR, BOKU, and FVA:

- the ALUFR team organized the workshop in terms of recruiting a representative stakeholder panel for the BW single chain.
- BOKU prepared contents and methodology, developed a software prototype and took over moderation and technical support of the workshop
- FVA provided the single-chain structure and underlying data

Finally, 13 participants representing different stakeholder groups (Table 6) confirmed the one-day workshop (2007-09-14) for which they were funded out of a M0 budget pool.

Table 6 BW workshop: stakeholders and their affiliations

background	no of participants
private forest	3
state forest	2
sawmills	2
policy- makers	2
Forest administration	1
environmental group	1
forest certification	1
science	1

People were to get an introduction and then expected to test a software prototype individually in a PC user-room. For the workshop, the following program was set up:

- introducing EFORWOOD, its main principles and concepts: the concept of SIA, the development of indicators and the functionality of ToSIA
- proposing the idea and purpose of MCA, some methodological background and the main features of MCA.
- demonstrating the functionalities of a new software prototype supporting MCA in EFORWOOD and employing a training example on selecting a Sports Utility Vehicle
- presenting three pre-defined FWCs as developed by ALUFR and FVA and a core set of seven available indicators for the practical exercises
- applying fully aggregated (total chain) indicators for indicator weighting, choosing among three modes of indicator weighting
- stakeholders comparing their individual preference profiles with regard to indicator importance with the aggregated results of the whole group, and iteratively responding to the group feedback
- presenting rankings of alternative FWCs to the stakeholders individually as well as referenced against the group results
- repeating the FWC exercise with a module-specific evaluation of FWCs by performing weightings within each of the modules to account for possible differences in perceived indicator importance along the FWC

- open discussion and formal feedback by means of a questionnaire focusing on the use of the proposed indicators, the applicability of MCA in the sustainability context and the features of the software prototype

2.4.2 Testing an MCA-software prototype

For computational support of MCA applications in EFORWOOD a first prototype was developed during the summer of 2007. The MCA prototype was programmed in C++ and offers a Windows-based client-server technology using XML files as data format.
From the methodological point of view, it is based on PROMETHEE II domination and synthesis algorithms which have been extended by flexible weighting schemes and different modes of demonstrating individual and group results.
The following steps of EFORWOOD MCA have been implemented in the software prototype:

- selection of indicator for the evaluation of FWCs
- demonstration of alternative FWCs and affiliated indicator values
- three modes of indicator weighting; individual and group analysis of indicator weights; whole-chain and module-specific analysis of indicator weights
- evaluation of alternatives by defining PROMETHEE-based preference functions for indicator
- two modes of ranking of alternatives (ordinal, cardinal ranking); individual and group analysis of rankings; whole-chain and module-specific analysis of rankings

Selection of indicators

First step of a MCA evaluation in EFORWOOD will be the selection of indicators that are to be employed in the evaluation. The basic set of indicators will be interfaced with the pre-selection done during the ToSIA procedure. In the MCA software, indicators may be selected on a separate screen by enabling or disabling them. This functionality comes along with information on indicators such as the detailed description or the measurement unit. Whether there is free choice to select or if indicators are locked from disabling them should be implemented in an earlier step within ToSIA. For the workshop, all indicators were fixed and pre-defined (Figure 5).

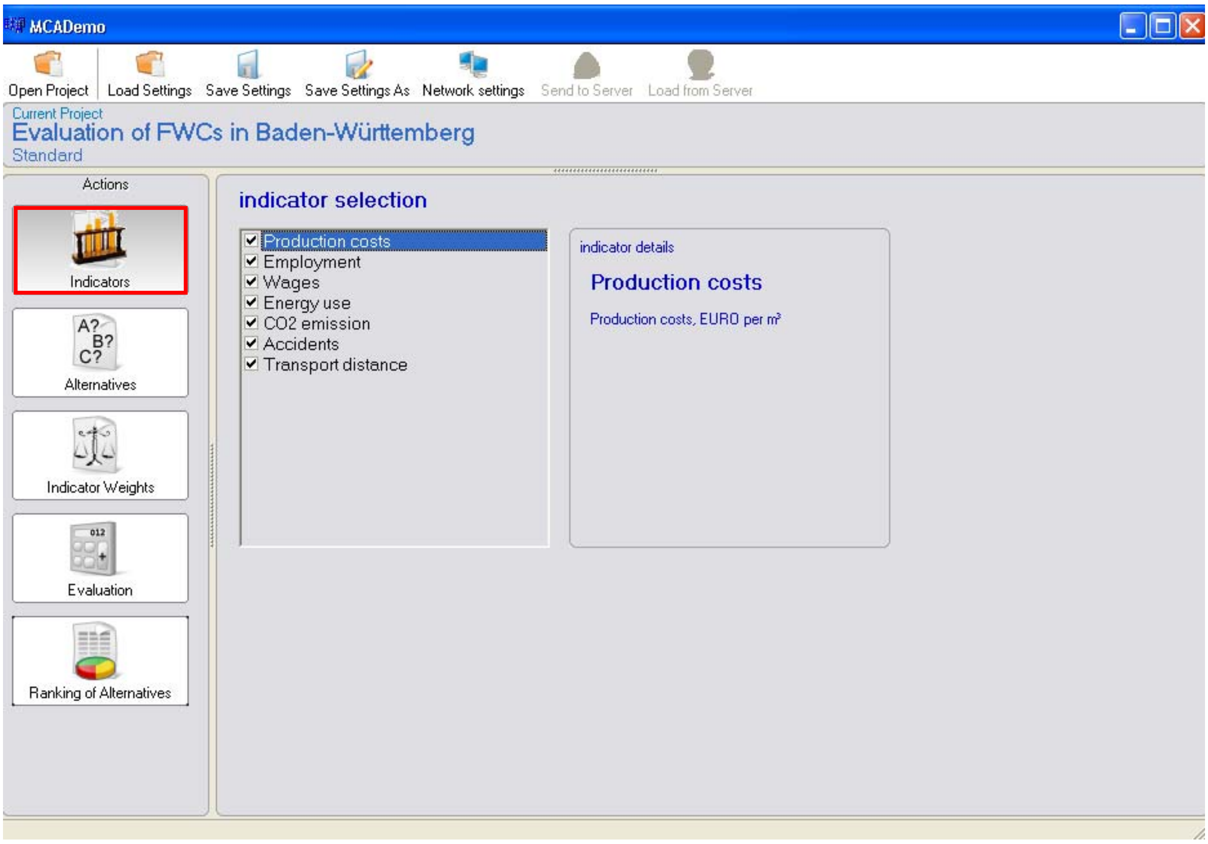

Figure 5 A screen shot from the MCA software showing selection of indicators.

Description of alternatives

All alternatives and their respective performances in terms of indicator values will be generated by the affiliated ToSIA run. The MCA software is to pick this information, condense it and give an overview if required during the evaluation procedure. In lack of an upstream ToSIA run we generated the alternatives used in a workshop directly using an XML-editor (Figure 6).

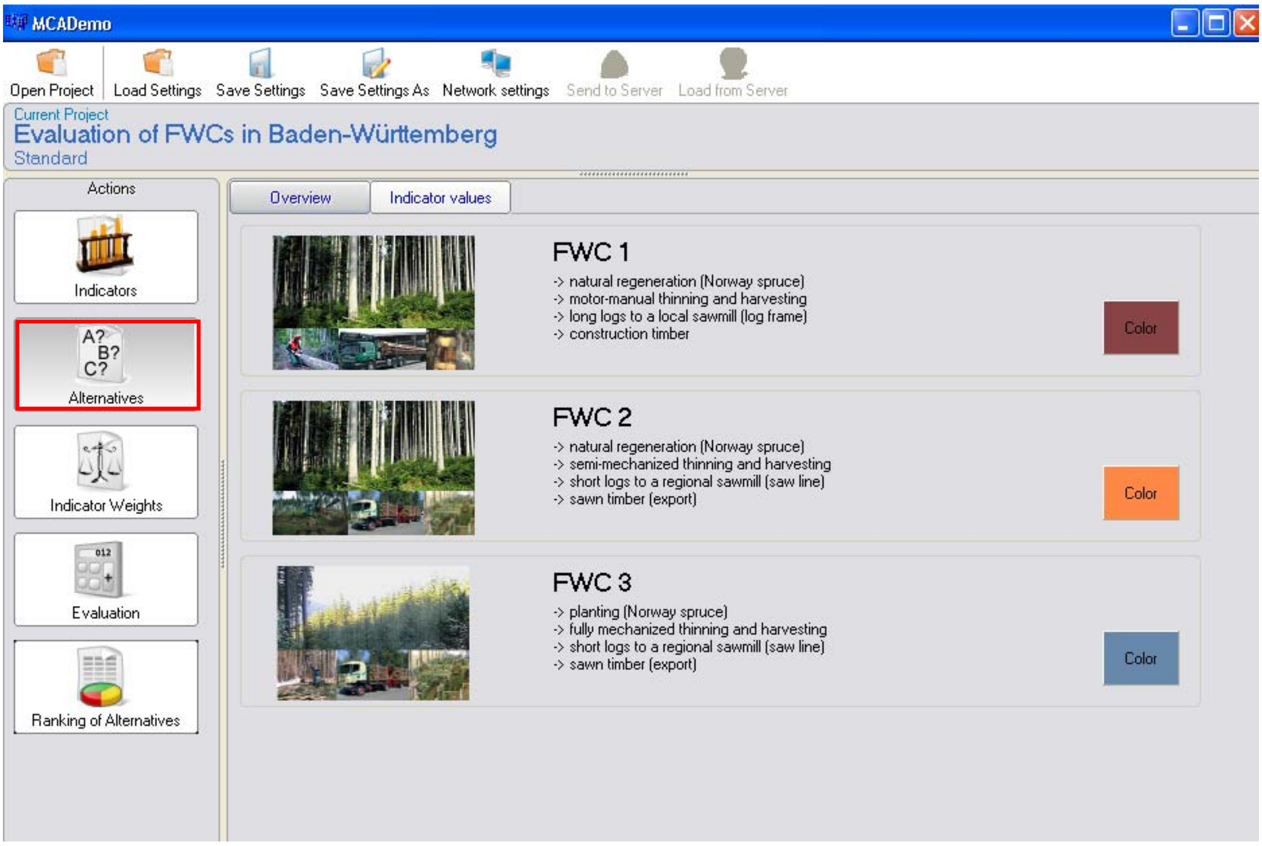

Figure 6 Description of alternatives.

Indicator weighting & indicator weights- group results

Indicator weighting is performed to assess the relative importance of indicators with regard to the sustainability impact of the total FWC or the branches represented in a module-specific approach. The software prototype provides three modes of indicator weighting (numerical, verbal, graphical) that can be chosen according to each individual's liking (Figure 7). The resulting weights can then be shown as absolute measures (as from the direct input) and as relative weights (as percentages of the total sum of weights).

Within this evaluation step, the prototype allows for an iterative procedure to gain group results of indicator weights. Participants would send their voting to the server and get updated information on the status of group results. After a finished round, users have the possibility to reconsider their voting or confirm them.

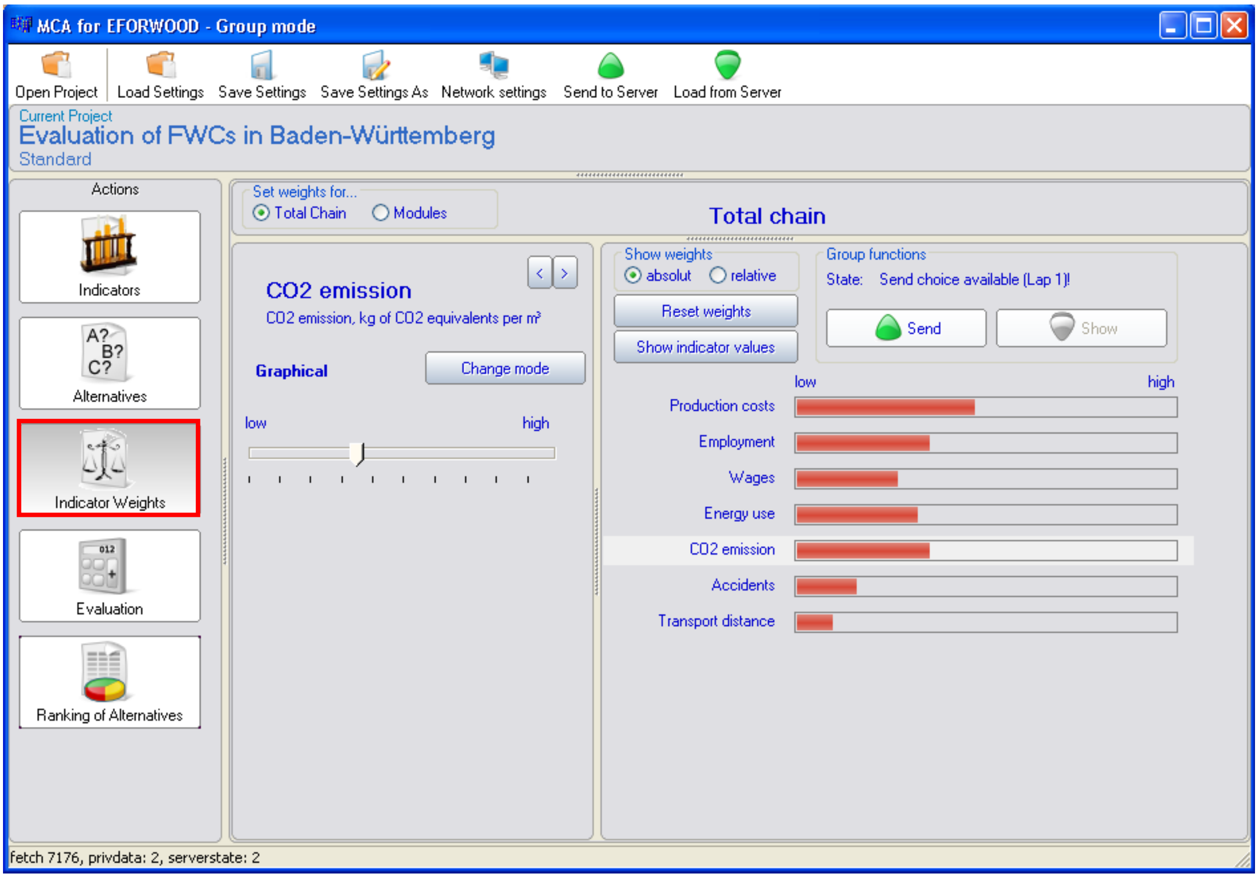

Figure 7 Elicitation of individual indicator weights.

The results of indicator weightings will then be shown in a pop-up window (Figure 8). Each participant will be shown his/her individual result (*) compared to the result of the group represented by box plots for each indicator.

In a module-specific mode indicator weighting and the representation of group results could also be done module by module.

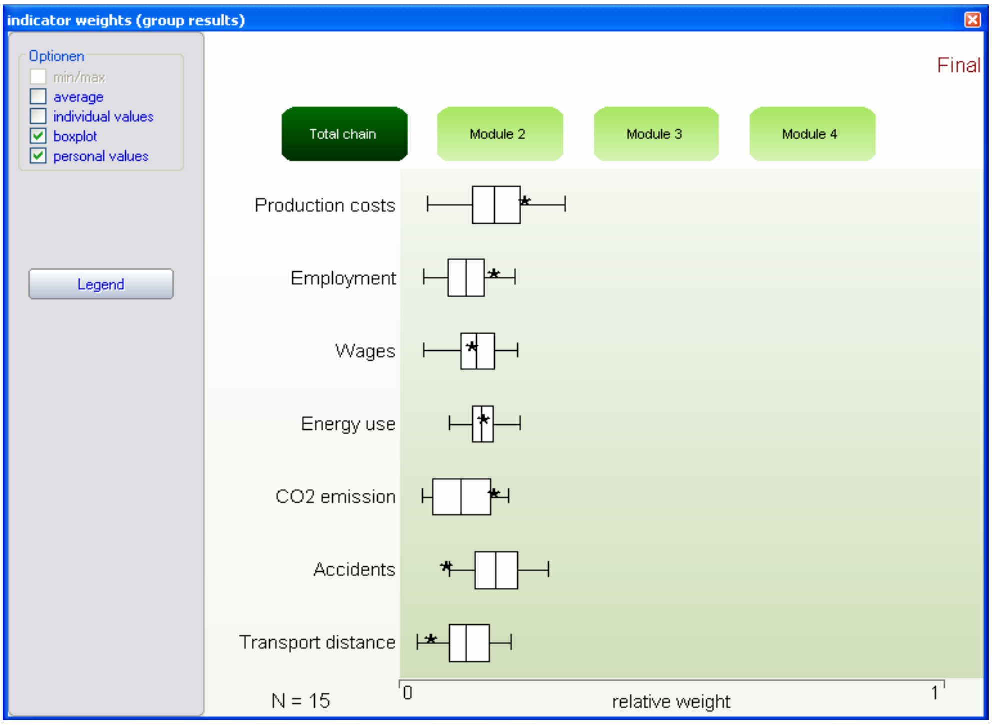

Figure 8 Indicator weights – group results for total FWC.

Evaluation of alternatives

The evaluation section contains the definition of PROMETHEE preference functions including preference and indifference thresholds as well as the direction of preference for each indicator (Figure 9). Preference functions are utilized to evaluate the performances of alternatives and the preferability of their affiliated indicator values in terms of a domination degree. In PROMETHEE there are six general preference functions to select among and to be adapted by setting individual thresholds (see Section 2.2).

For the workshop all preference functions were fixed by expert estimation and not treated by the workshop participants due to an expected work overload during the workshop.

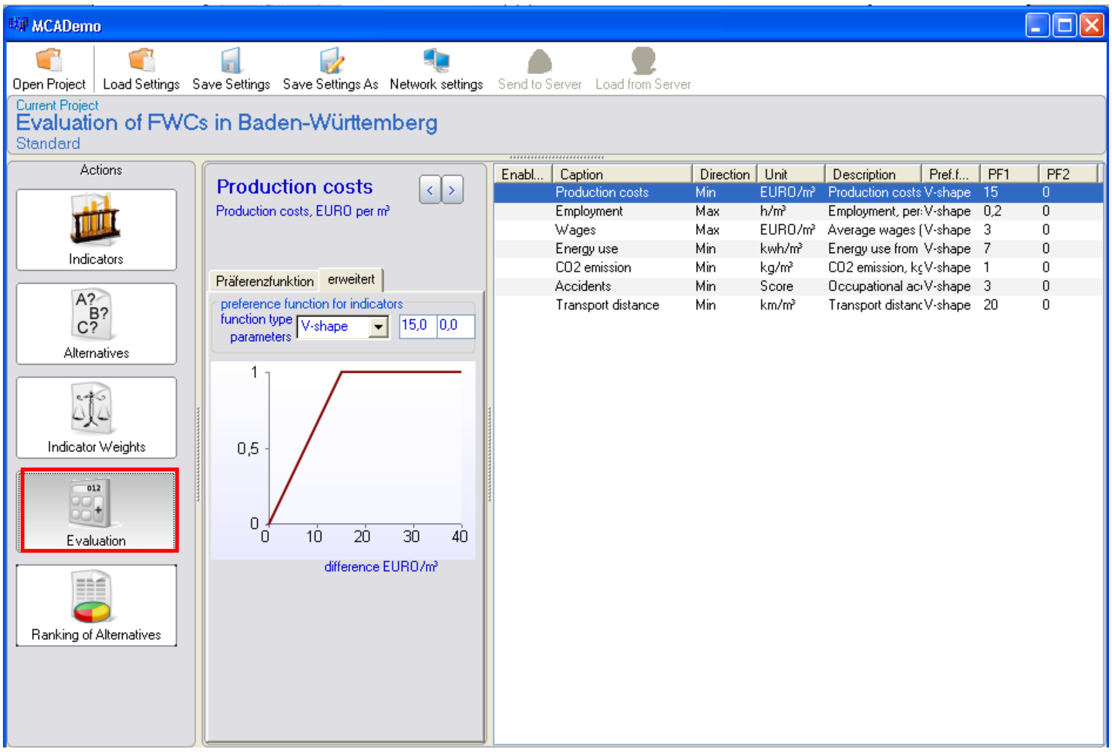

Figure 9 Production costs.

Total chain ranking results – individual and group analysis

Based on indicator weighting and the evaluation of indicator values of alternatives the dominance measures for each alternative are multiplied with the indicator weights and aggregated additively. The original PROMETHEE method provides a dominance measure ranging from –1 to +1 which we transformed due to representational reasons to a 0 to 1 scale. So, for each alternative a value of relative importance is given in a bar chart. Also, an ordinal ranking may be provided.

In the case below FWC 1 would be ranked first, FWC 2 last (Figure 10).

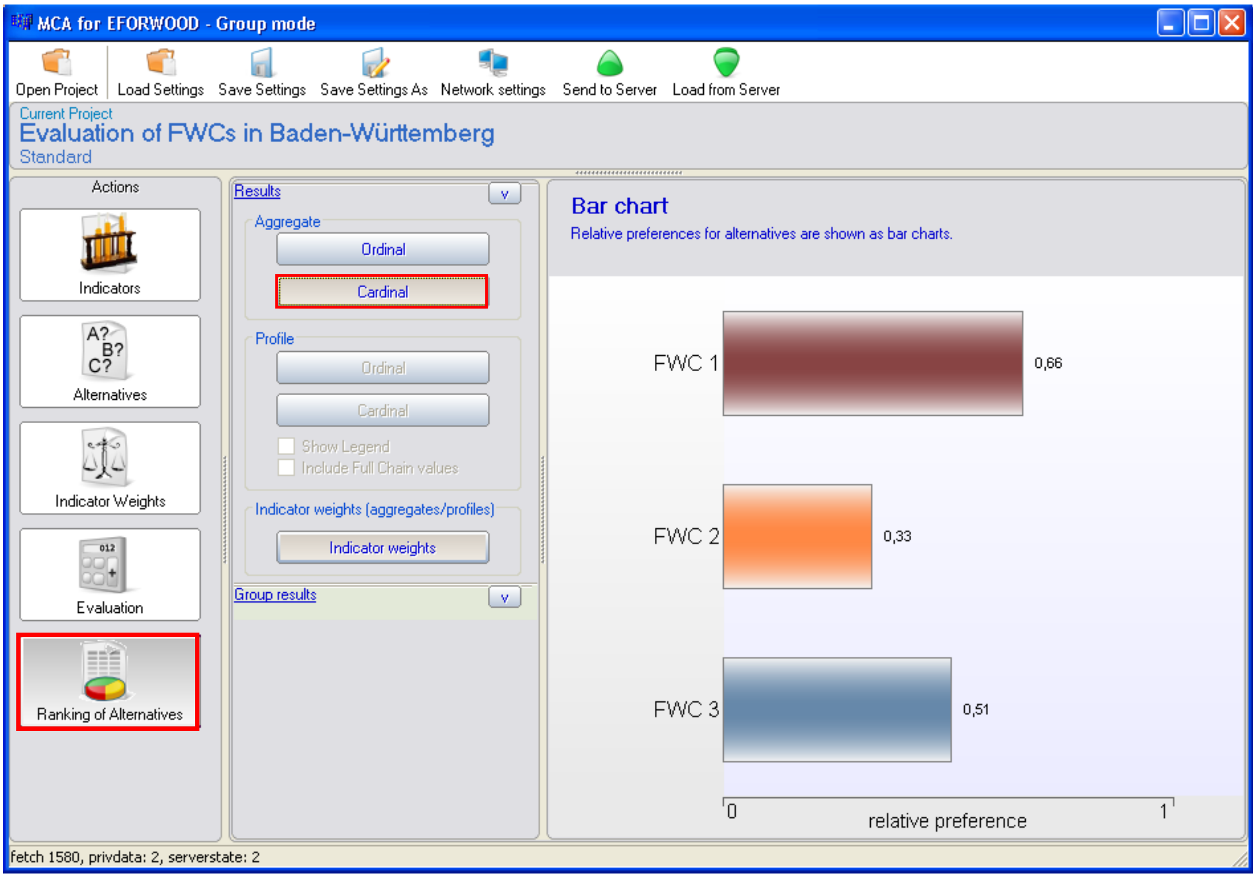

Figure 10 Evaluation of alternative FWCs – bar chart (individual ranking).

As it was the case with the indicator weighting, there is also a functionality featuring group analysis of ranking results. In a cardinal mode, again box-plots are used to reference individual preference values (*) against group results (Figure 11). Ordinal group results would be ranked according to the number of first ranks for each of the alternatives.

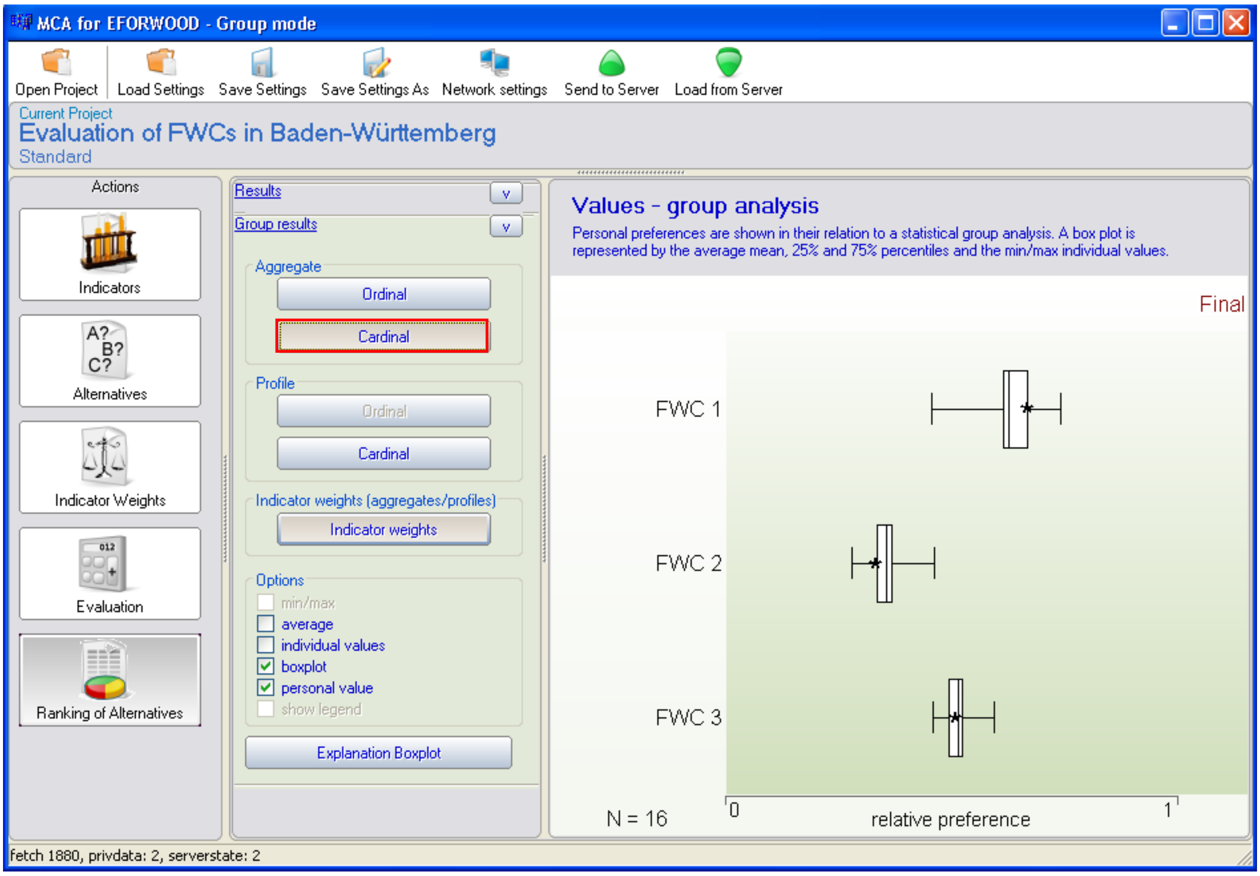

Figure 11 Evaluation of alternative FWCs – Group analysis.

Module-specific ranking results – sustainability profile

For the workshop, modules 2 (forest management), 3 (harvest & transport) and partly 4 (sawmilling) were taken into consideration. The module-specific mode is characterized by a module-by-module query of indicator weights during the process (module-specific evaluation of indicator values is not yet implemented). This should meet concerns that indicator weights may not be stable for a whole trans-business chain. Consequently, results are demonstrated as ranking profiles giving a ranking of alternatives for each module.

In the screen shown below (Figure 12) it is, for instance, indicated that FWC 1 gains highest preference in module 3 while lowest in module 4. In this mode, no full aggregation is implemented.

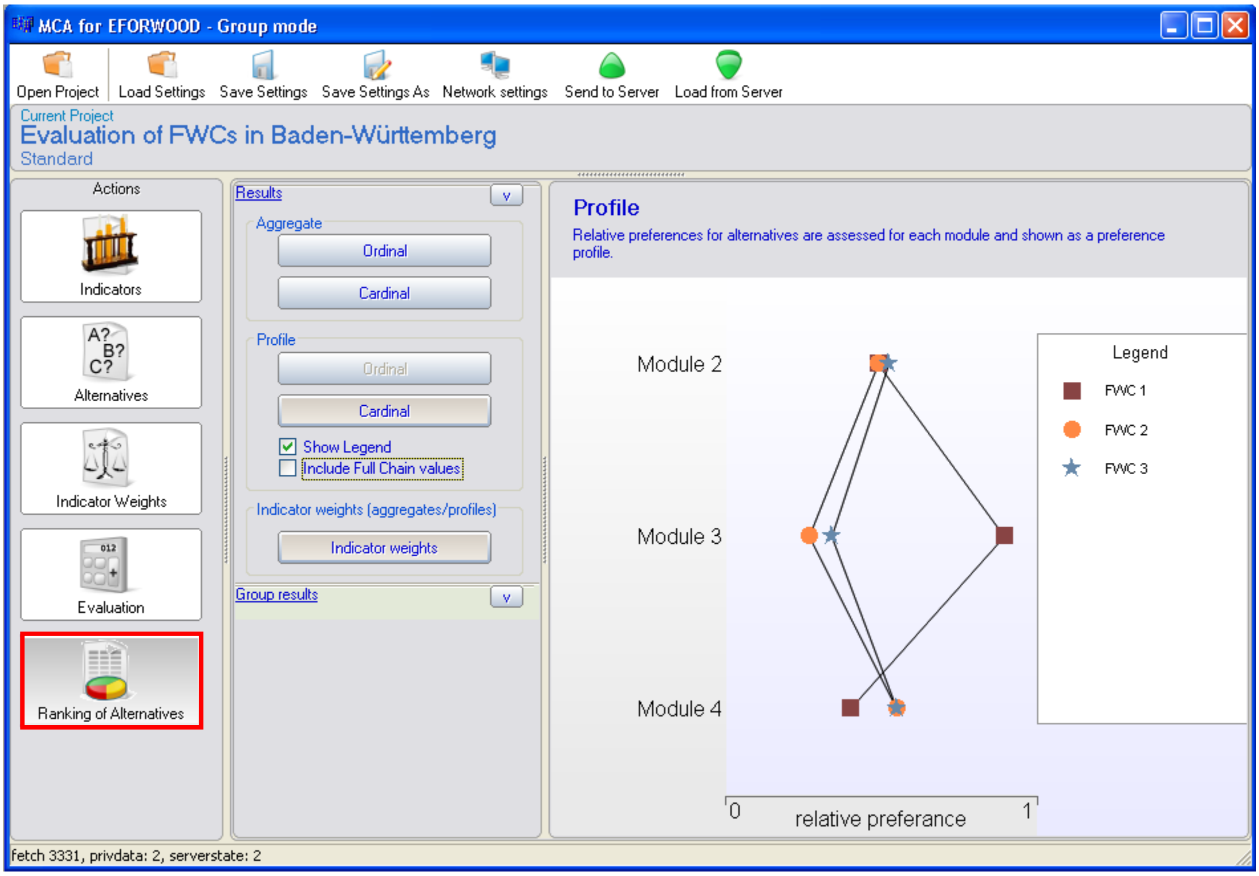

Figure 12 Evaluation of alternative FWCs – sustainability impact profile (individual profile)..

2.4.3 Discussion of MCA results

The creation of MCA results as such was not in the centre of objectives regarding the stakeholder workshop and the testing of the software prototype. It should be underlined that one can expect different kinds of results from an MCA evaluation to be chosen from:

- individual indicator weightings
- individual ranking of alternatives (ordinal and cardinal)
- group indicator weightings
- group ranking of alternatives (ordinal and cardinal)
- individual and group preferences (weights, ranking) for fully aggregated FWC
- module-specific individual and group preferences (weights, ranking profile)

Yet, if looking at the results of the workshop, participant stated a quite robust preference for FWC1, FWC 3 following and FWC 2 ranked last (Figure 11). By matter of fact, MCA results could never be expected to be very sensitive within a very limited setting such as in this case. The number of indicators is limited and even then there are strong redundancies among indicators (employment & wages, energy-use & GHG emissions).
Since the determination of preference functions was frozen and individual indicator weightings were not exceedingly diverse (Figure 8) the ranking results were strongly driven by single indicator performances. This shows that FWC 1 is best in three indicators and FWC 3 best in two indicators (Figure 13) which is align with the synthesized ranking results. Furthermore, significant differences in preferences occur mostly in Module 3 – harvest & transport, i.e. when evaluated module by module (Figure 12). Actually, alternatives appear to have been outlined most specifically within Module 3 (high amount of processes and feasible alternatives).

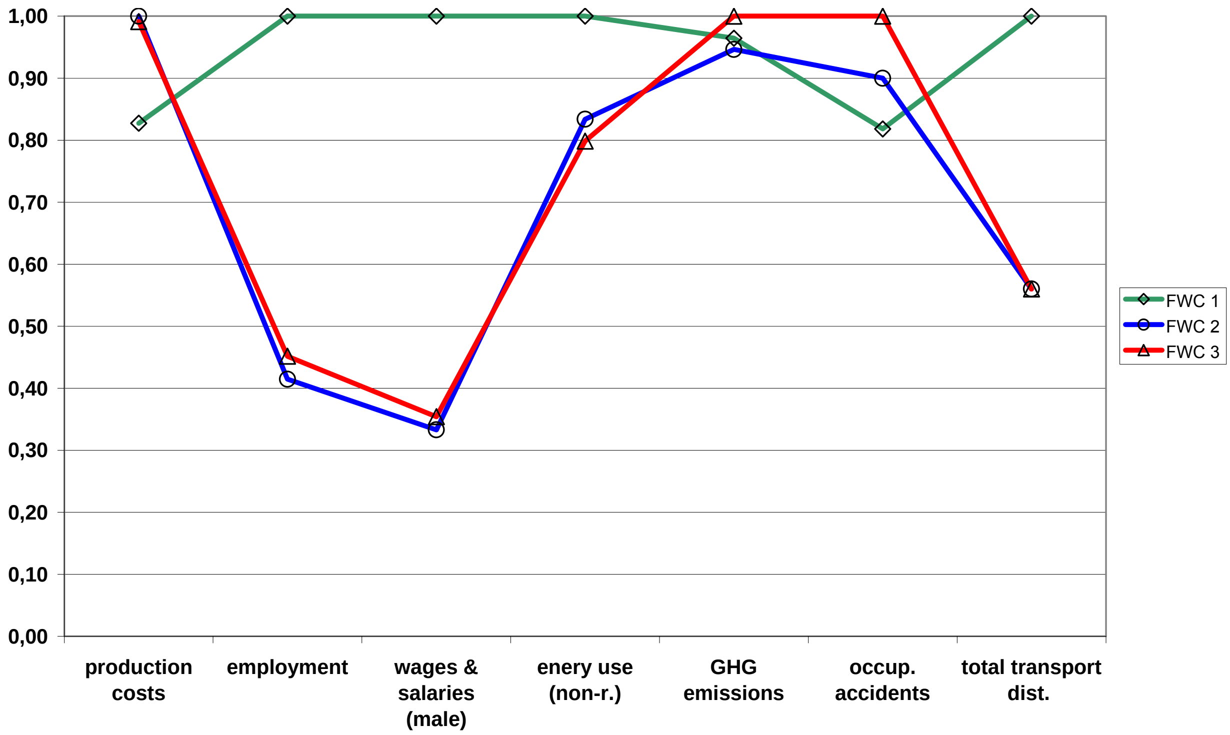

Figure 13 Normalized performances of three FWCs for seven indicators (1 = the best performance, the others relative to it)

2.4.4 Experiences and feedback

It follows from the setting of the workshop that a combined agenda of information and application parts would require a high level of efforts from the participants. Nonetheless, we experienced an exceedingly ambitious and motivated audience during the whole day both in thematic discussion and dealing with the software tool. Most of the participants were unaware of EFORWOOD, so it was the first aim to make the audience an informed one concerning EFORWOOD concepts, the use of indicators and the implications of using MCA.
Interactive discussion was facilitated both intermediately during the workshop and in a fixed block for open discussion following the software application.
Referring to the main demands on a MCA solution for the evaluation of FWCs the following messages can be subsumed from the informal feedback and discussion.

Flexibility

- Generally, the attempt to foster flexible approaches within the MCA application (modes of weighting, total chain and module-specific evaluation) was acknowledged.
- For some people, the formulation of questions with regard to the comparison of attributes (indicators) would make the weighting procedure more comprehensive.
- There was criticism on working with pre-defined FWCs and the fixed indicator sets as it would make the decision environment inflexible. So, the possibility of modifying alternatives would appear as beneficial to the participants.

Consistency

- There were plural statements that pre-defined FWCs would hardly meet the backgrounds of forest sector stakeholders because FWCs would appear too abstract or generalized.
- For the same reasons, there was a common call for more matured and balanced indicator sets.
- There need was articulated for much stronger delineation and communication of system boundaries when charged with evaluation of alternative FWCs. Without that, the process of preference elicitation could appear as arbitrary.
- The point was raised that the expression of indicator weights could vary depending whether it is asked for as value-based or pragmatic statement (without or with knowing the alternatives in advance).
- There was also discussion on the relation to CBA and the messages drawn from both methods.

Transparency

- Generally, the MCA approach was highlighted as a transparent initiative for evaluation.
- Yet, the workshop setting with fixed preference functions was identified as a high potential source for lack of transparency within the evaluation.
- The facilities to recall indicator values for FWCs at any time during the evaluation procedure were acknowledged.
- Still, information on the derivation and context of indicator values would be a valuable basis for the participants to perform the evaluation.

User-friendliness

- Generally, there was a high degree of user-friendliness attested to the software prototype although the audience did not have much experience in using software tools for decision support.
- The features of group decision analysis were acknowledged in particular.
- There is still need for a stronger semantic guidance through the singular steps of evaluation.
- It was acknowledged that there was strong support and guidance by the moderator team, which led to the conclusion that strong guidance and presence of a facilitator could be one of the prerequisites of a successful MCA application in the context of EFORWOOD.

As formal end of the workshop a questionnaire was distributed to collect formalized feedback and complement the informal information gained from open discussion during the whole day. Feedback was collected on:

- individual background
- EFORWOOD indicators
- the design of BW-FWCs
- the MCA approach
- the software prototype
- weighting of indicators
- demonstration of results
- organisational matters

Figure 14 shows the cumulative results of the questionnaire. Generally, we experienced a complaisant feedback, an impression which was also supported by the active will to be working and discussing during the whole day. There was no doubt on the usefulness of MCA in general and on the proposed software prototype despite we had fundamental discussions on black-box effects due to fixing the preference function, for instance.
Evidently, people had some problems with the extent of the indicator set (2b) and the way how to find their own reality in the pre-defined alternatives (3b) which we explained with the premature state of test chains at this point in time. Yet, there are strong indications that an indicator set is demanded that is balanced and covering all relevant sustainability aspects. System boundaries must be clarified and communicated in any evaluation procedure.

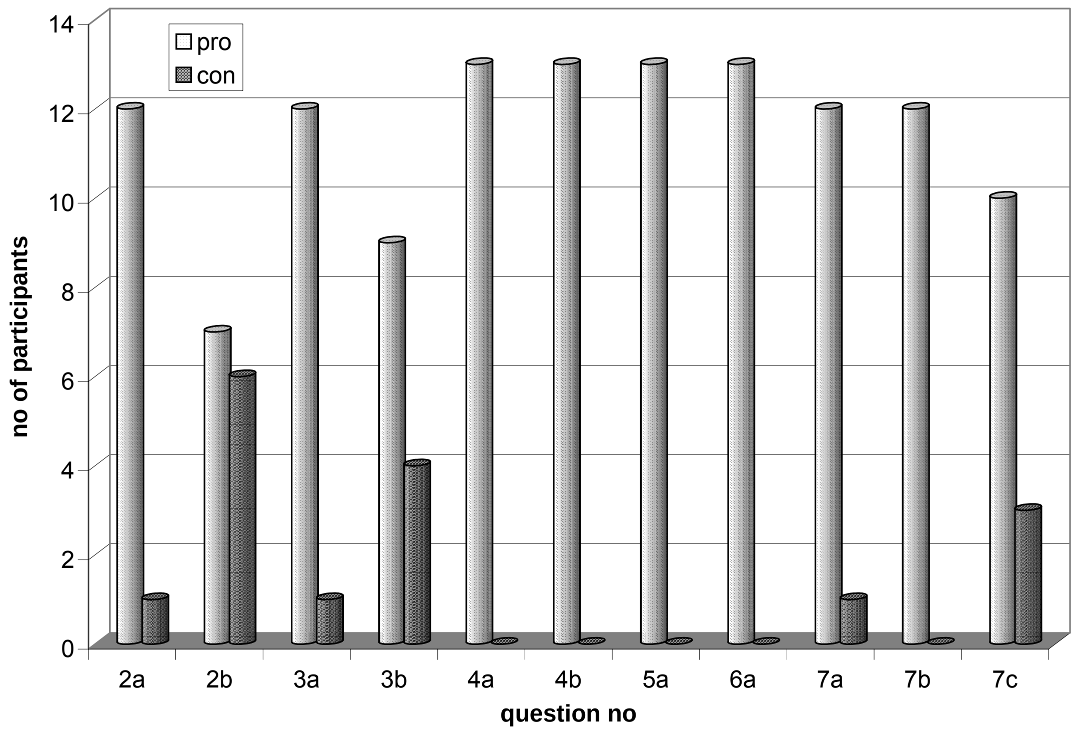

Figure 14 Stakeholder agreement (pro) and disagreement (con) on selected questions within the BW workshop: (2a) significant indicator set, (2b) sufficient number of indicators, (3a) demonstrative structure of FWCs, (3b) FWCs relevant for BW, (4a) MCA useful for sustainability evaluation, (4b) MCA comprehensive, (5a) software user-friendly, (6a) indicator weighting methods suitable, (7a) representation of results appropriate , (7b) group analyses of weights and rankings useful, (7c) extra-benefit from module-specific analyses

3 Cost-benefit analysis

3.1 General approach to cost-benefit and cost-efficiency analyses

Cost benefit analysis is a technique for the assessment of the relative desirability of competing alternatives. In the context of the EFORWOOD project, cost-benefit as well as the closely related cost-efficiency analyses are used to evaluate the overall sustainability impact of different policy measures on the forestry wood chains. The assessment involves the comparison of the status quo (baseline case) to one or more alternatives considering the incremental differences between the baseline case and the alternatives. The CBA compares the costs and benefits measured in monetary terms, whereas in the CEA the benefits are measured in physical terms. CBA is a more general evaluation method used primarily to identify the alternatives which increase social welfare, whereas CEA focuses on the comparison of the relative effectiveness of alternative projects in achieving a given objective or bringing about a desired change. Moreover, when the non-marketed benefits are considered, CEA allows for more flexibility as the benefits do not have to be valued in monetary terms, which is a controversial issue. PD1.5.3 reviews the major phases of CBA and CEA procedures for the evaluation of alternative forestry-wood chains and provides recommendations for the use of these methods within EFORWOOD.

The objective of this section is to document the results of the cost-benefit analysis applied to the Baden-Württemberg single chain. In this setup, our aim is to compare two different technological systems within a given (fixed) policy framework. For the purpose of the analysis, we consider FWC 1 (natural regeneration with non-mechanized harvesting and long-log transport) as a baseline system, and FWC 3 (planting regeneration with mechanized harvesting and short-log transport) as an alternative technological system. Thus, roughly speaking, the CBA will evaluate the social gain or loss from switching from FWC 1 to FWC 3. Due to the lack of actual choice or policy alternatives to be evaluated, we had to give up the implementation of the cost-efficiency analysis of the Baden-Württemberg single chain.

In the framework of the EFORWOOD project, the social perspective on the cost-benefit analysis is taken as the benchmark. A social CBA attempts to assess the overall impact of a project improving the welfare of the society as a whole, rather than of the (private) agents that implement the project. Social costs and benefits usually differ from private ones because of the existing market imperfections, which may take the form of (i) imperfect competition in the market, (ii) government intervention in the market (e.g. taxes, subsidies, and price regulation), (iii) externalities and public goods.

CBA results may be expressed in different ways, including internal rate of return, net present value and benefit-cost ratio.

3.2 Material

3.2.1 Test chains

The cost-benefit analysis, unlike the multi-criteria analysis, does not require a minimum number of alternatives for the comparison. Therefore, and due to data availability issues, the analysis is applied to the two original test chains, namely to FWC 1 and to FWC 3. These chains correspond to the ones used in the MCA (see Section 2.3.1), with the sole difference that the final harvest and the side processes and products have been included in the CBA for the purpose of completeness. Figure 15 illustrates the two FWCs used in the CBA. Each box indicates a process in the natural regenerated and planted spruce test chains in the Eforwood database. The length of each of the four phases, indicated by the curly brackets, is based on ToSIA outputs and corresponds to the 'time multiplier' used in ToSIA. Following a normal forest approach, one can think of a number of age classes in each phase instead of a time multiplier.

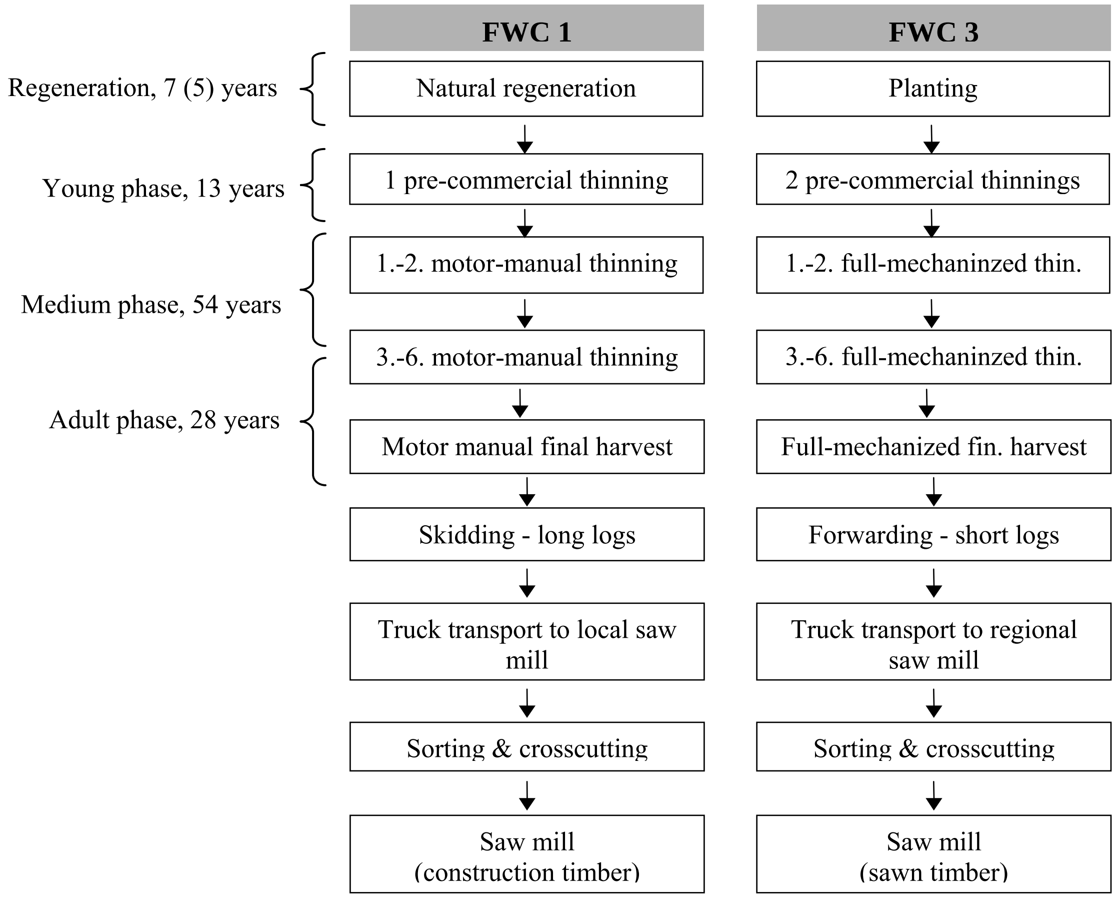

Figure 15 Alternative FWCs for the BW single chain as applied in the CBA.

The two FWCs represent two different regeneration methods – natural regeneration and planting; two different technological approaches to harvesting and skidding/forwarding and two different end products. Table 7 shows the characteristics of each of the two chains based on the figures from ToSIA.

Table 7 Forest characteristics, based on ToSIA figures.

	FWC 1	FWC 3
Forest management unit, ha	2018,58	1747
Rotation period, years	102	100
Area of each age class, ha	19,79	17,47
Yield per ha per rotation, m^3	1000	1000

3.2.2 Selection of relevant indicators

The selection of indicators for the cost-benefit analysis is based on data availability in the Eforwood database as well as on the requirement for additional indicators in order to calculate the social GVA.

Given the current set of indicators, the cost-benefit analysis can be performed in two different ways, namely:

- applying the General GVA approach; or
- applying the Component approach.

The *General GVA approach* relies on the use of the data from the indicator Gross Value Added and the data from the relevant externality-related indicators. This approach considers the reported GVA indicator data as a proxy for the economic and partially social value of the FWC to the society. This approach requires the GVA data to be collected in an accurate and consistent manner for all the comparable alternatives. As the experience in the first phase of the project has demonstrated, it has been difficult to obtain GVA data of a good quality. Namely, the value of the GVA indicator currently available from the Eforwood database is either reported as zero, non-available or abnormally high. Therefore, this approach is currently not feasible for the performance of the CBA analysis.

The *Component approach*, on the other hand, relies on the use of the data from other indicators to derive the Gross Value Added, which would be used as a proxy for the economic and social value of the FWC. This GVA is computed based on the information on the revenues (not included in the Eforwood database) and the indicator Production costs. As in the General GVA approach, the relevant externality-related indicators are also used for the evaluation of the environmental impact of the FWC.

Table 8 summarizes the information on the indicators used in the CBA and their common units.

Table 8 Indicators and indicator units as used in the CBA basis data

Indicator	common unit
Production cost (incl. land rent, excluding non-productive costs)	€/m³
Energy use (of non-renewable resources)	kWh/m³
Carbon sequestration	tons of carbon/ m³
Greenhouse gas emissions	kg CO_2 eq./m³
Non-greenhouse gas emissions into air	
- SO2	g/m³
- CO	g/m³
- NOx	g/m³
- NMVOC (or HC)	g/m³
- PM	g/m³

3.2.3 Indicator values

For the purposes of the analysis, the data on the abovementioned indicators has been double checked and modified whenever considered necessary. The modifications have been introduced whenever the indicator values were either absent from the database, or when the reported values were abnormally high or low. This section reports the measures that have been taken to remediate the incompleteness or non-reliability of the data (including additional data sources), and also provides a complete listing of the indicator values applied in the cost-benefit analysis.

Production costs

The indicator Production costs provides detailed information on the costs of different resources (labour, energy, raw materials etc.) associated to each technological system. We assume that this indicator is measured in terms of opportunity cost and that it reflects the economic cost of the best alternative use to which the resources in question could be assigned to. The indicator values for raw material use, labour, energy and other productive costs are extracted from the Eforwood database. In some cases, adjustments had to be made due to the inconsistencies found in the interpretation of the reference units by data collecting partners[1].

The production cost data on transport processes (1000079 in FWC 1 and 1000042 in FWC 3) has been modified, as the indicator values for these processes available from the Eforwood database were considered excessively high.

Transport costs

It is assumed that a truck able to carry 30 tons is used with an average load of 90 %. According to the database, timber with 18% MC has a density of 437 kg/m3, so green timber with a MC of ca. 55 % (Heding & Jakobsen, 1985) weighs approx. 700 kg. The truck then carries 39 m^3. Using transport distances from the MCA study and transport costs from a quick phone survey to Danish timber transport companies, the following costs are derived:

- FWC 1: With a distance of 42 km, total transport time incl. lift-time is 3,5 hours at an hourly cost of 125 €, equalling a total of 437,5 €, which approximates a cost of 11,2 €/m3.
- FWC 3: With a distance of 75 km, total transport time incl. lift-time is 4,5 hours at an hourly cost of 125 €, equalling a total of 562,5 €, which approximates in a cost of 14,4 €/m3.

Saw milling costs (process 1000068) are not reported in the Eforwood database, so these had to be computed based on the additionally collected information and were found in line with the values used for the multi-criteria analysis.

[1] For example, whereas the production cost data has been provided in per ha per process for most of the processes, it has been provided in per ha per year for some processes (e.g. 1000086).

Saw mill costs

The largest component of the sawmill cost structure is the cost of delivered logs, often around 60-75 % of total production costs, depending on how efficient the saw mill is. According to Price Water House Coopers' biannual report on global lumber benchmarking from 2002 European sawmills had average operational costs of 40 €/m3, which is close to 40 % of total costs assuming logs are sold at 55 €/m3 (Campell, 2004). These numbers are used for FWC 1, while for FWC 3 log prices are 47 €/m3 resulting in somewhat lower saw mill costs due to a larger sawmill; 38 €/m3.

These costs are in line with the values used in the MCA, considering that the production costs of this process used in the MCA study include the costs of the raw materials.

Energy use (from non-renewable resources)

This indicator has been used to obtain the modified information on the non-greenhouse gas emissions. The database indicator values are used for all processes, except for transportation (1000079 and 1000042), sorting and crosscutting (1000076 and 1000082), and saw milling (1000068). The data for these processes has been derived from the MCA-study.

Carbon sequestration

The two FWCs differ in the underlying normal forest model, cf. Table 7. FWC 1 uses a total of 2018.58 ha whereas FWC 3 uses 1747 ha. The rotation ages are almost the same. The effect of this is twofold. First, FWC 1 is more expensive in terms of land rent, the annual opportunity cost of the additional land exceeding 20,000 €/year. Second, in the normal forest of FWC 1, there is at all times a larger carbon stock than in the corresponding FWC 3 forest. Note that this carbon stock is constant in the normal forest: growth equals harvest by assumption in a steady state normal forest.

The higher carbon sequestration has a value of course, and by switching from one FWC to another this value will be gained (or lost). We estimate the value of this loss or gain as:

- (C-stock in FWC1 – C-stock in FWC3) × Carbon price = Value of C-stock change

In the real world a switch from one normal forest to another will take many years and this value will be realised gradually over these years, and thereby be affected (reduced) by discounting until the annual net change in stock is again zero in the new normal forest. Here, however, we do not have an explicit model for such a transition. Therefore, for use in CBA and the net present value calculations, we approximate the gradual change by converting the above value estimate to an annual value flow equal to:

- (Value of C-stock change) × discount rate = annualised value of C-stock change

This is a crude approximation, which will however serve the purpose of illustration in the test phase.

Non-greenhouse gas emissions into air

The indicator values of non-greenhouse gas emissions in the Eforwood database are mainly missing or are not reliable; therefore, an additional effort has been made to estimate emission values for the relevant processes in FWC 1 and FWC 3. The values for non-greenhouse gas emissions have been obtained from several sources related to the specific machinery of each process in the FWC. Data is mainly derived from a database provided by the German Federal Environment Agency (ProBas, 2005), but also from the trade association for Danish transport companies, International Transport Denmark (ITD, 2008), and from a study of timber machines (Athanassiadis, 2000). Each data source provides pollution measures as an amount of emitted pollutant per energy output (g/kWh) and the corresponding emission values are, therefore, based on the amount of non-renewable energy (indicator Energy use (from non-renewable resources)) used in each process. Appendix A describes the derivation of the emission values in more detail.

Land rent

Land rent is an important component of the production costs, which is not collected in EFORWOOD. For the purposes of the analysis, the annual land rent in Baden-Württemberg is assumed to be 75 €/ha in 1999 prices (see Doll, 2005). Using the GDP deflator for Germany available at EconStats (www.econstats.com/weo/C062V021.htm), this value is equivalent to 79 €/ha in 2005 prices.

Data on product prices

The data on the end- and intermediate product prices has been collected to account for the economic benefit that the analysed technological systems bring about. Timber from the thinnings and the final harvest is sold either at the roadside in the forest (e.g. saw logs and poles and pulpwood), or at the saw mill. Table 9 provides information on the relevant prices. Observe that the sale of standing timber and logs delivered to the saw mill creates costs and revenues inside the FWCs, which cancel out in the calculation of the total chain GVA, but are relevant for the computation of the module-specific GVA.

Table 9 Prices of different products used in the CBA

Products	FWC 1 €/m^3	FWC 3 €/m^3
Standing timber	10,40	9,30
Saw logs and poles, at road side	47,00	47,00
Pulpwood, at road side	38,00	38,00
Delivered logs, M3 → M4	55,00	47,00
Construction timber	205,00	--
Sawn timber	--	160,00

All the prices except for the pulpwood have been provided by the data collection experts. The pulpwood price is based on the Norwegian price for spruce based pulpwood (see Bolkesjo, 2005). Bolkesjo (2005) reports the average price of 275 NOK/m3 in 2000 prices, which is equivalent to about 38 €/m3 in 2005 prices.

Final harvest data

The data on the final harvest is not available in the Eforwood database and had to be calculated. It is assumed that each hectare produces 1000 m3 of harvestable timber during a rotation. Using ToSIA thinning volumes from each age class and assuming the final harvest follow the same processes until the saw mill as the thinning yield from 3.-6. thinnings, the following figures are derived:

- FWC 1: A final harvest of 625 m3/ha of which 506 m3 is skidded to the road and 466 m3 transported to the saw mill. Intermediate volumes sold at road side.
- FWC 3: A final harvest of 575 m3/ha of which 454 m3 is forwarded to the road and 313 m3 is transported to the saw mill. Intermediate volumes sold at road side.

This corresponds to total harvested and sold amounts stated in Table 10. Total harvested amount includes the harvest from 1.-6. thinnings and the final harvest. Total sold amount includes the skidding from 1.-6. thinnings and the final harvest.

Table 10 Final harvested and sold amounts

	FWC 1 (m^3)	FWC 3 (m^3)
Final harvest	12368,75	10045,25
Total harvested amount	19793,60	17501,69
Total sold amount	15929,06	13590,04

Basic data as applied in the CBA

Tables 11 and 12 show indicator values in units per m3 for each of the relevant indicators used in the CBA calculations. Energy usage values under ‘thinning’-heading are volume-weighted averages of the 6 thinnings. Final harvest values are based on values from 3.-6. thinning as stated in the Eforwood database.

Table 11 Indicator values of FWC 1 as applied in the CBA-part

	Production costs €/m^3	Energy use[a] kWh/m^3	Carbon seq. ton/m^3	GHG emis. CO2 equi. Kg/m^3	SO2 g/m^3	CO g/m^3	NOx g/m^3	NMVOC (HC) g/m^3	PM g/m^3
Natural regeneration	1,75	0,430	0	0,117	0,186	0,501	1,665	0,253	0,111
Young phase	1,31	0,100	0,003	0,027	0,003	3,432	0,032	1,526	0,034
Medium phase	6,43	0	0,198	0	0	0	0	0	0
Mature phase	3,33	0	0,210	0	0	0	0	0	0
Thinning:									
- Motor-manual cutting	17,88	6,069		1,970	0,186	205,5	1,917	91,41	2,019
- Forwarding	5,12	7,476		1,890	3,227	29,28	60,51	3,063	3,981
- Truck transport (long logs)	11,20	11,78		3,175	0,028	2,652	32,77	1,131	0,247
- crosscutting and sorting	1,58	6,450		4,600	3,857	1,084	3,412	0,181	4,270
Final Harvest:									
- Motor-manual cutting	11,97	4,280		1,600	0,131	145,0	1,352	64,47	1,424
- Forwarding	4,85	7,040		1,890	3,039	27,57	56,98	2,884	3,749
- Truck transport (long logs)	11,20	11,78		3,175	0,028	2,652	32,77	1,131	0,247
- Crosscutting and sorting	1,58	6,450		4,600	3,857	1,084	3,412	0,181	4,270
sawmill, operational costs	40,00	26,92		16,40	16,10	4,523	14,24	0,754	17,82
Weighted total chain	**65,15**	**40,49**	**0,411**	**19,05**	**15,77**	**199,67**	**82,81**	**80,06**	**19,33**
Total chain, end product	**82,42**	**57,00**	**0,411**	**27,81**	**23,34**	**184,73**	**110,45**	**71,19**	**27,66**

a) Only non renewable energy.

Table 12 Indicator values of FWC 3 as applied in the CBA-part

	Production costs €/m^3	Energy use[a] kWh/m^3	Carbon seq. ton/m^3	GHG emis. CO2 equi. Kg/m^3	SO2 g/m^3	CO g/m^3	NOx g/m^3	NMVOC (HC) g/m^3	PM g/m^3
Regeneration by planting	4,31	0,358	0	0,097	0,155	0,417	1,387	0,211	0,092
Young phase	1,59	0,200	0,003	0,054	0,006	6,873	0,064	3,056	0,067
Medium phase	6,43	0	0,198	0	0	0	0	0	0
Mature phase	3,33	0	0,215	0	0	0	0	0	0
Thinnings:									
- Full mechanized cutting	11,37	17,734		4,701	7,500	68,1	140,6	7,2	9,3
- Forwarding	5,39	9,869		3,050	6,656	38,769	80,109	4,055	5,271
- Truck transport (long logs)	14,40	20,10		5,400	0,048	4,524	55,92	1,930	0,422
- Crosscutting and sorting	1,20	2,335		1,666	1,387	0,390	1,227	0,065	1,536
Final Harvest:									
- Full mechanized cutting	10,26	15,860		4,277	6,707	60,9	125,75	6,42	8,275
- Forwarding	5,01	9,170		3,050	6,186	36,02	74,44	3,768	4,898
- Truck transport (long logs)	14,40	20,10		5,400	0,048	4,524	55,92	1,930	0,422
- Crosscutting and sorting	1,20	2,335		1,666	1,387	0,390	1,227	0,065	1,536
sawmill, operational costs	38,00	23,84		16,40	14,26	4,005	12,61	0,668	15,78
Weighted total chain	**55,24**	**46,00**	**0,416**	**17,85**	**19,43**	**104,20**	**225,48**	**14,25**	**20,99**
Total chain, end product	**84,53**	**71,86**	**0,416**	**30,94**	**28,75**	**113,09**	**271,40**	**16,12**	**31,07**

a) Only non renewable energy.

3.2.4 Identification and valuation of relevant externalities

In economics, an externality[2] is defined as an unintended action caused by an economic agent that influences the utility of another agent (external) without being fully or directly reflected by market prices (Merlo and Croitoru, 2005).

Whenever the implementation of a certain project has an impact on the environment representing positive or negative externalities, these external effects must be taken into consideration in the process of project evaluation. The changes in the quality or quantity of environmental goods and services produce changes in social benefits associated with their consumption, which should be accounted for in the CBA and CEA. Not including environmental impacts in the CBA and CEA leads to an over- or underestimation of social benefits of the project.

The externalities considered for the purposes of the CBA and CEA are GHG and non-GHG emissions, and carbon sequestration. Their associated indicator values in g/m3 are listed in Tables 11 and 12. The corresponding cost estimates of pollution are shown in Table 13 for each pollutant. These externalities cover the most important air pollutants and also the most studied ones (see for example, Rabl & Spadaro, 2002; Hartman et al, 1997; Forkenbrock 1999). Greenhouse gases have been the subject of intense investigation and scrutiny due to the climate change and global warming debate and fast evolving market for carbon trade. The other externalities, known as the classical air pollutants (Spadaro & Rabl, 2002) have also received wide attention due to their more direct impact on human health and wellbeing.

The emission of GHG and non-GHG pollutants is associated with a variety of social costs due to the adverse effects on climate change and global warming, increased occurrence of different illnesses, loss of scenic beauty due to smog, and damages to crops, ecosystems as well as buildings. There are a wide variety of methods to estimate these costs, some of which are described in PD1.5.1.

For the purposes of the cost-benefit analysis, the social cost estimates for these externalities are provided in a form of a low and a high estimates, representing the two extremes of pollution costs. For the non-GHG pollutants, the low estimate is based on the abatement cost method (e.g. the cost of reducing emissions at the source) as it is relatively inexpensive to install emission reducing technological devices, which consist primarily of a one-time cost followed by a permanent decrease in emissions. The high estimate is based on health costs measured by years of life lost (YOLL) and hospitalization costs. They include both market-based costs – such as the cost of illness, and wage and productivity losses, as well as non-market costs – such as the willingness to pay (WTP) to avoid pain and suffering. They often also include mortality costs, based on YOLL and the Value of Life Year Lost derived from society's WTP to avoid an anonymous premature death.

For the GHG emissions, the social cost estimates are based on the marginal damage cost approach. Pearce (2003) has reviewed a number of studies evaluating the social cost of carbon, and his conclusion is that the probable range of marginal damages is in the range of $4-9 tC. Other sources, however, advocate for a higher cost of carbon. In the ExternE project (ExternE, 2005), various studies on the social cost of carbon have been reviewed, and the upper bound of 50 €/tCO2 eq. has been suggested based on the national cost estimates performed in The Netherlands. ExternE project uses a value of 19 €/tCO2 eq. as a point estimate. In the UK, DEFRA report on the basis of Stern review (DEFRA, 2007) suggests the

[2] For more detail on externalities see PD1.5.1.

value of 32 €/tCO2 eq. (in 2005 prices) to be used in the project appraisal. Earlier studies by the UK Government Economic Service (GES, 2002) recommended the value of 34 €/tCO2 eq., with a range of 18 €/tCO2 eq. to 66 €/tCO2 eq. (all in 2005 prices). For the purposes of the current evaluation exercise, a lower bound of 2 €/tCO2 eq. (following Pearce's findings) and an upper bound of 50 €/tCO2 eq. have been adopted for the social cost of carbon. These low and high cost estimates will be used for the sensitivity analysis, whereas a point estimate of 20 €/tCO2 eq. is used for the main cost-benefit analysis.

Table 13 Social cost estimates associated with emission of pollutants. The low and high estimates reflect two fundamentally different approaches to pollution valuation, abatement cost estimation and health and damage cost estimation. All figures are in 2005-€ / kg pollutant.

Pollutant	SO2	CO	NOx	HC	NMVOC	PM	GHG, CO2 eq.	
Low, €/kg	0,274	0,023	0,224	0,045	0,410	0,055	0,002	Point est.
High, €/kg	11,262	0,045	17,681	0,045	0,788	180,186	0,050	0,02

There is a high degree of uncertainty attached to the cost figures, as the large range between the two cost estimates indicates. The emission rates and costs provided by the data sources are themselves related to some uncertainty and statistical errors, which have not been taken into account. Data from different sources are based on studies from different environments, e.g. pollution is more costly in urban than rural areas, and the fact that a large part of the emissions in the FWC take place in forested areas are not accounted for. Moreover, abatement costs are relative easy to assess, while health costs are often a minimum estimate, since not all possible health effects can be identified, let alone quantified. However, despite these uncertainties in the estimation of emission costs, they show that it is important to include externality costs in order to carry out a sound social cost-benefit analysis.

3.3 Relevant assumptions

Definition of the time horizon

In EFORWOOD, the current FWCs are defined in such a way that all processes in different stages of the chains occur simultaneously, that is, they run in parallel. TOSIA integrates in each time period the indicator values across all the FWC-processes modelled. The indicator data will be provided for the years 2005, 2015 and 2025, that is, the time horizon of 20 years is considered. Currently only the data for the year 2005 is available. Due to this fact and in order to be able to perform a sound cost-benefit analysis, it has been assumed that the indicator values remain the same throughout time (that is, the indicator values for the years 2015 and 2025 are the same as for the year 2005). This simplifying assumption is clearly not in line with reality. However, as the objective of this exercise is to demonstrate the *functionality* of the CBA, it has proved useful and also enables us to set-up calculation procedures which can be adapted to possible scenarios affecting the different FWCs in varying ways over time.

Scope of the analysis

For the reason of tractability, we will adopt a partial equilibrium model[3] in order to limit the scope of the relevant impacts of the project. Any project and any policy change produces a whole set of effects, which spread out to affect the whole economy. It is obvious that the cost-benefit analysis cannot take explicit and detailed account of all of such a chain of effects. Therefore, and in accordance with the DOW (2005)[4], the scope of the project impacts should be contained within the established system boundaries. This limitation implies that the CBA and CEA in EFORWOOD will not in general include the study of the indirect economic impacts of the analyzed project on the economy as a whole, including jobs in other sectors and other impacts of technology changes. Furthermore, it will not in general include minor environmental impacts or the impacts for which adequate measures (either physical or monetary) are not available.

Market competition

Perfect competition is assumed whenever market distortions are not significant, therefore the market prices (net of taxes) are considered to be good estimates of the marginal cost.

Inflation

Inflation is the loss of the value of money over time, or in other words, the increase in prices overtime. CBA controls for inflation using estimates of future costs and benefits that are expressed in terms of a specific year's prices. These are referred to as constant or real prices (as opposed to nominal or current prices) from which the overall effect of a general price inflation has been removed. We assume that all the prices and costs used in the analysis are measured in real terms and the year 2005 is taken as a reference year for this purpose.

Choice of the discount rate

Once all the relevant costs and benefits are expressed in monetary terms, it is necessary to convert them into a common measure, their present value. This process is called discounting and it is based on the fact that the individuals have time preferences between consumption in different periods. The rate at which an individual is willing to exchange the present consumption is called the discount rate. The higher is this discount rate, the greater preference is given to the present consumption. For the purposes of our analysis, a discount rate of 4% has been selected, which is based on the German discount rate for the year 2005 used by the EC State Aid control[5]. Sensitivity analysis is performed using alternative discount rates of 2% and 5% to determine the importance of the discount rate in the relative performance of the FWCs.

[3] A partial equilibrium framework assumes that the prices in the analysed sector (e.g. forestry) are independent of the demand and supply conditions (and of the changes in these conditions) in other sectors (e.g. energy).

[4] "In EFORWOOD, a partial equilibrium model for forestry and forest industries will be used to analyse how changes in one production process (or a specific group of processes), for example as a result of the impact of policy implementation, in the FWC can change – through changes in demand and supply – the chain before and after the process concerned, and how this will affect other chains. This model will also be used to analyse global aspects of FWCs by looking at mutual influences on levels of sustainability of inherent inter-dependencies between European and regions outside Europe." (DOW, 2005)

[5] See http://ec.europa.eu/comm/competition/state_aid/legislation/reference_rates.html.

3.4 Methods

3.4.1 Performance measures of the CBA

Net present value calculation

The main CBA performance measure used in the evaluation of the BW regional spruce chain is the Net Present Value (NPV). The net present value of the project is defined as:

- $$NPV(S) = \sum_{t=0}^{T} \frac{S_t}{(1+d)^t} = \sum_{t=0}^{T} \frac{B_t}{(1+d)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+d)^t},$$

where S_t is the net benefit of the project at time t, d is the discount rate and T is the time frame ($T=20$). The net benefit of the project is the difference between the benefits (B_t) and costs (C_t) associated with the studied alternative.

The net present value is a simple indicator which is useful both for identifying beneficial projects and for selecting the best project out of several alternatives. A project is accepted whenever $NPV > 0$, because its benefits outweigh the costs. The greater is the NPV, the more desirable is the project. Therefore, alternative projects can be ranked on the basis of their net present values.

Internal rate of return (IRR)

The internal rate of return is defined as the critical value of the interest rate at which the project has a net present value of zero, in other words, when all costs are equal to all benefits when discounted by that rate. That is,

- $$IRR : NPV(S) = \sum_{t=0}^{T} \frac{S_t}{(1+IRR)^t} = 0.$$

IRR is usually expressed as a percentage. The calculation of the IRR does not require the identification of the discount rate. However, it should be remembered that any project that has relatively large positive net flows in early stages will generate a relatively large IRR. Thus, IRR tends to favour short-term investments.

When dealing with *investment projects*, the interpretation of the IRR is straightforward. The project is acceptable if and only if the IRR is greater than the actual value of the interest rate. For the *disinvestment projects* – projects where early returns are followed by later costs – the interpretation of IRR is different. In this case IRR is interpreted as the lowest value of the interest rate that would justify undertaking the project. Thus, the project should be undertaken if IRR is lower than the true value of the interest rate.

Note that for projects where cash flows switch between positive and negative more than once over the project life time, there may be more than one solution to the IRR-equation (more than one root). Also, if the cash flow never switches sign, IRR cannot be determined. Finally, the IRR approach assumes re-investment of intermediate flows at the IRR-level of returns, whereas the NPV assumes re-investment at the chosen discount rate. For these reasons the NPV is often considered the more conservative and reliable criteria.

Benefit-cost ratio (BCR)

The benefit-cost ratio is the relation between the discounted benefits and the discounted costs:

- $$BCR = \sum_{t=0}^{T} \frac{B_t}{(1+d)^t} \Big/ \sum_{t=0}^{T} \frac{C_t}{(1+d)^t} .$$

If $BCR > 1$, then the discounted benefits outweigh the discounted costs, and hence, the project results in net gains for society. The higher is the ratio, the greater are the benefits relative to the costs. Note, however, that the benefit-cost ratio is insensitive to the magnitude of net benefits and, therefore, may favour projects with smaller costs and benefits over those with higher net benefits. In addition, BCR is sensitive to the definition of costs and benefits, and will vary if, for example, costs are defined as negative benefits.

3.4.2 Cost-efficiency analysis

Cost-efficiency analysis measures the cost of achieving a particular benefit. In this case, the costs (discounted) are measured in monetary terms whereas the benefits can be measured in physical terms. CEA is appropriate whenever it is unnecessary or impractical to consider the case whenever:

- each alternative has the same annual benefits expressed in monetary terms;
- each alternative has the same annual effects, but the monetary value cannot be assigned to the benefits.

Cost-efficiency analysis provides an answer to how to spend a given amount of money obtaining the greatest benefit from the resources available, or how to achieve a given benefit at the lowest cost. For example, cost-efficiency analysis would be of a great help to identify which of the given alternative measures brings down the CO2 emissions to a required level at the lowest cost.

3.4.3 Sensitivity analysis

The CBA is obviously dependent on the data and values entering the calculations. Several of these may be estimated with some uncertainty or in any case liable to frequent changes. In the current study, the sensitivity analysis is performed using a *variable-by-variable* approach. This approach attempts to isolate the effect of a change in one variable on the performance indicators of the cost-benefit analysis (e.g. NPV, BCR, etc.). It is performed in four steps.

1. All important factors affecting the cost-benefit flows should be listed.
2. For each factor, a range of possible values should be defined. For example, the estimates for each factor could be prepared under "best-case (optimistic)", "most likely", or "worst-case (pessimistic)" scenarios. In practice, these values are usually based on past experience with similar project evaluations or expert opinion. Moreover, the range is sometimes expressed as one or two standard deviations from a mean (or an expected value).
3. For each value of each factor the relevant performance indicators should be calculating holding the values of all the other factors unchanged.
4. The resulting performance indicators should be examined to determine the degree of overall variation and which factor or factors is/are most responsible for variation in the estimates.

For the purpose of informed decision making, it is important to undertake sensitivity analysis of the CBA results with respect to parameters considered of key importance. In the present report we undertake sensitivity analysis with respect to:

- the social cost of carbon
- the discount rate
- the land rent

For each of the variables that are analysed, the following performance indicators are to be computed:

Sensitivity indicator (SI): The SI summarizes the effect of change in a variable on the project NPV. The SI is calculated as the ratio of the percentage change in the NPV to the percentage change in a variable, that is:

- $$SI = \frac{NPV_m - NPV_s}{NPV_m} / \frac{V_m - V_s}{V_m},$$

where NPV_m is the net present value in the main case (initial NPV before the sensitivity test); V_m is the value of the analysed variable in the main case (initial value of the variable before the sensitivity test); NPV_s is the net present value with the sensitivity test; and V_s is the value of the analysed variable with the sensitivity test.

A high value of SI indicates project sensitivity to the variable. For variables where percentage changes are not meaningful, the percentage change in the NPV should be stated along with the stated change in the variable.

Switching value (SV): The SV shows the percentage increase in a cost item (decline in a benefit item) required for the NPV to become zero. The SV is itself a percentage, the percentage change in a variable for the project decision to change. The formula of the SV is the following:

- $$SV = 100\% * \frac{NPV_m}{NPV_m - NPV_s} * \frac{V_m - V_s}{V_m},$$

where the variables are defined as above.

A high SV implies a very substantial change in the variable before the project decision is affected. A low SV, in turn, indicates that there may be a significant risk for the project outcome.

3.5 Results

This section presents the results of the cost-benefit analysis, as well as of a sensitivity analysis on selected variables.

3.5.1 Results of the cost-benefit analysis

The first step in the actual cost-benefit analysis is to derive the Gross Value Added for each of the modules and for the whole chain. This calculation is presented in Tables 14 and 15 for the FWC 1 and FWC 3 respectively. Observe that in the first column, the economic and social

GVA is computed without taking into account the environmental externalities (GHG and non-GHG emissions and carbon sequestration). These externalities are accounted as a cost (GHG and non-GHG emissions) and as revenue (carbon sequestration) in the remaining columns. Recall also that in the valuation of the relevant externalities, the low and high estimates refer to the costs of the non-GHG emissions (see Table 13), whereas the GHG emissions and the carbon sequestration are valued using the point estimate of 20 €/tCO_2.

Table 14 Gross Value Added (in €) with and without externalities for FWC 1. Revenues from externalities are derived from carbon sequestration, while costs refer to GHG and non-GHG emissions.

FWC 1	Without externalities	With low estimate externalities		With high estimate externalities	
M2		Value	Total	Value	Total
Revenues	205.853,44	962472,02	1168325,46	962472,02	1168325,46
Costs:					
Natural regeneration	34712,06	56,94	34769,00	1069,41	35781,46
Young phase	25870,24	24,89	25895,13	169,73	26039,97
Medium phase	127170,54	0,00	127170,54	0,00	127170,54
Mature phase	65940,28	0,00	65940,28	0,00	65940,28
GVA M2	**-47.839,68 €**		**914.550,51 €**		**913.393,21 €**
M3		Value	Total	Value	Total
Revenues	826.072,73	0,00	826072,73	0,00	826072,73
Costs:					
Standing timber	205853,44	0,00	205853,44	0,00	205853,44
Motor-manual cutting, total	280844,63	1389,49	282234,12	8467,46	289312,09
Forwarding, total	78873,77	851,54	79725,30	28619,27	107493,03
Truck transport, total	143552,52	1662,97	145215,49	9572,08	153124,60
Sorting/crosscutting, total	20251,16	1202,93	21454,09	12368,99	32620,15
GVA M3	**96.697,22 €**		**91.590,30 €**		**37.669,42 €**
M4		Value	Total	Value	Total
Revenues	1.576.514,28	0,00	1576514,28	0,00	1576514,28
Costs:					
Delivered logs	704945,59	0,00	704945,59	0,00	704945,59
Saw milling	512687,70	4305,50	516993,20	50908,66	563596,36
GVA M4	**358.881,00**		**354.575,50**		**307.972,33**
Total GVA	**407.738,54 €**		**1.360.716,31 €**		**1.259.034,97 €**

Table 15 Gross Value Added (in €) with and without externalities for FWC 3. Revenues from externalities are derived from carbon sequestration, while costs refer to GHG and non-GHG emissions.

FWC 3	Without externalities	With low estimate externalities		With high estimate externalities	
M2		Value	Total	Value	Total
Revenues	162.765,72	856966,05	1019731,77	856966,05	1019731,77
Costs:					
Regeneration with planting	75340,77	41,79	75382,56	496,05	75836,82
Young phase	27733,21	213,57	27946,77	257,20	27990,41
Medium phase	112262,22	0,00	112262,22	0,00	112262,22
Mature phase	58210,04	0,00	58210,04	0,00	58210,04
GVA M2	**-110.780,52 €**		**745.930,17 €**		**745.432,28 €**
M3		Value	Total	Value	Total
Revenues	595.357,09	0,00	595357,09	0,00	595357,09
Costs:					
Standing timber	162765,72	0,00	162765,72	0,00	162765,72
Full-mechanized cutting, total	187811,47	2114,81	189926,28	41547,21	229358,68
Forwarding, total	70236,42	1102,45	71338,86	20286,23	90522,64
Truck transport, total	116769,61	933,81	117703,42	8854,95	125624,56
Sorting/crosscutting, total	9730,80	30819,79	40550,59	31117,41	40848,21
GVA M3	**48.043,08 €**		**13.072,22 €**		**-53.762,72 €**
M4		Value	Total	Value	Total
Revenues	778.464,04	0,00	778464,04	0,00	778464,04
Costs:					
Delivered logs	381123,02	0,00	381123,02	0,00	381123,02
Saw milling	308142,01	2717,21	310859,23	5775,51	313917,52
GVA M4	**89.199,00**		**86.481,79**		**83.423,49**
Total GVA	**26.461,56 €**		**845.484,18 €**		**775.093,05 €**

Once the total chain and module specific GVAs are identified, we can compute the annual GVA of the proposed change from the FWC 1 to FWC 3. The results are presented in Table 16.

Table 16 Annual GVA of the change from FWC 1 to FWC 3 (in €) with and without externalities for a discount rate of 4%.

Module	Without externalities	With low estimate externalities	With high estimate externalities
M2	-62.941	-168.620	-167.961
M3	-48.654	-78.518	-91.432
M4	-269.682	-268.094	-224.549
Total chain	**-381.277 €**	**-515.232 €**	**-483.942 €**

Based on these values, we can compute the net present value of the proposed change using the chosen discount rate of 4%. The results are presented in Table 17. As one can observe, the NPV is negative, therefore, the change from FWC 1 to FWC 3 is not beneficial to society.

Table 17 Net present value of the change from FWC 1 to FWC 3 (in €) with and without externalities.

Module	Without externalities	With low estimate externalities value	Total	With high estimate externalities value	Total
M2	-918.327	-1.541.899	-2.460.226	-1.532.277	-2.450.605
M3	-709.880	-435.725	-1.145.604	-624.145	-1.334.025
M4	-574.949	23.174	-551.775	658.507	83.559
Total chain	**-2.203.156**		**-4.157.605**		**-3.701.071**

Table 18 presents the results of the benefit-cost ratio. As one can observe, the shift from FWC 1 to FWC 3 results in lower costs, but also in reduced benefits. The reduction in the benefits, however, outweighs the savings in costs, and this is demonstrated by the positive BCR, which is larger than one. In this case, one can conclude that the change from FWC 1 to FWC 3 is not beneficial to the society.

Table 18 Benefit-cost ratio (BCR) of the change from FWC 1 to FWC 3 (in €) with and without externalities. Benefits and costs relating to CO2 sequestration and emissions are based on a value of 20 €/tCO2 for both low and high estimates of externalities.

	Without externalities	With low estimate externalities	With high estimate externalities
Discounted benefits	-5.696.285 €	-7.235.651 €	-7.235.651 €
Discounted costs	-3.493.128 €	-3.078.046 €	-3.534.580 €
BCR	**1,63**	**2,35**	**2,05**

The internal rate of return (IRR) is negative, as for any discount rate from 0% to 100% the NPV is positive. Therefore, we can conclude that the FWC 1 is always better for the society than the FWC 3.

3.5.2 Sensitivity analysis

The sensitivity analysis has been performed for the following variables and parameters:

- the social cost of carbon
- the discount rate
- the land rent

Table 19 presents the parameter values considered in the sensitivity analysis.

Table 19 Parameter values for the sensitivity analysis.

Variable	Unit	Main case	Lower bound	Higher bound
Social cost of carbon	€/tCO2	20	2	50
Discount rate	%	4	2	5
Land rent	€/ha	79	60	100

Tables 20 and 21 present the results of the sensitivity analysis for the case with low cost and high cost estimates for externalities respectively.

Table 20 Sensitivity analysis with low cost estimates for externalities.

Variable		NPV	% change in NPV	% change in variable	SI[a]	SV[b]
Discount rate						
Main case	4%	-4.157.605 €				
Lower bound	2%	-4.017.710 €	3,36%	50,00%	0,07	1485,97%
Upper bound	5%	-4.197.617 €	-0,96%	-25,00%	0,04	2597,75%
Land rent						
Main case	79 €/ha	-4.157.605 €				
Lower bound	60 €/ha	-4.232.892 €	-1,81%	24,05%	-0,08	-1328,17%
Upper bound	100 €/ha	-4.074.394 €	2,00%	-26,58%	-0,08	-1328,17%
Carbon cost						
Main case	20 €/tCO2	-4.157.605 €				
Lower bound	2 €/tCO2	-2.396.464 €	42,36%	90,00%	0,37	212,47%
Upper bound	50 €/tCO2	-7.092.841 €	-70,60%	-150,00%	0,37	212,47%

a) SI = sensitivity indicator. b) SV = switching value.

Table 21 Sensitivity analysis with high cost estimates for externalities.

Variable		NPV	% change in NPV	% change in variable	SI[a]	SV[b]
Discount rate						
Main case	4%	-3.701.071 €				
Lower bound	2%	-3.474.780 €	6,11%	50,00%	0,12	817,77%
Upper bound	5%	-3.776.382 €	-2,03%	-25,00%	0,08	1228,60%
Land rent						
Main case	79 €/ha	-3.701.071 €				
Lower bound	60 €/ha	-3.776.357 €	-2,03%	24,05%	-0,08	-1182,33%
Upper bound	100 €/ha	-3.617.860 €	2,25%	-26,58%	-0,08	-1182,33%
Carbon cost						
Main case	20 €/tCO2	-3.701.071 €				
Lower bound	2 €/tCO2	-1.939.930 €	47,58%	90,00%	0,42	189,14%
Upper bound	50 €/tCO2	-6.636.307 €	-79,31%	-150,00%	0,42	189,14%

a) SI = sensitivity indicator. b) SV = switching value.

As one can observe, the trends are perfectly intuitive. Firstly, the higher is the discount rate, the lower is the NPV, i.e. the less beneficial is the switch from FWC 1 to FWC 3. Secondly, since FWC 3 uses less land, the increase in the land price makes FWC 3 more attractive, that is, the NPV becomes less negative. Thirdly, since the (positive) carbon balance in FWC 1 is higher than in FWC 3, the increase in the social cost of carbon makes FWC 1 more attractive and therefore, the NPV decreases.

The sensitivity indicator SI demonstrates that the NPV is not very sensitive to the changes in the discount rate and the land rent. However, the social cost of carbon plays a more important role, and the NPV is quite sensitive to that variable. This is supported by the switching value SV. Figures 16, 17 and 18 illustrate the results of the sensitivity analysis.

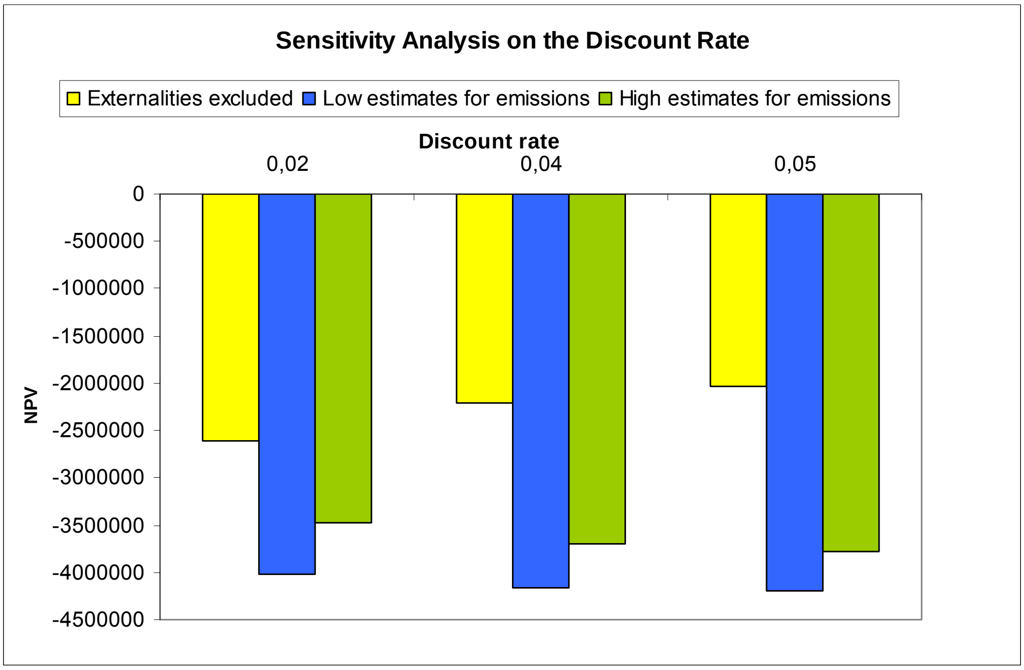

Figure 16 Results of the sensitivity analysis on the discount rate.

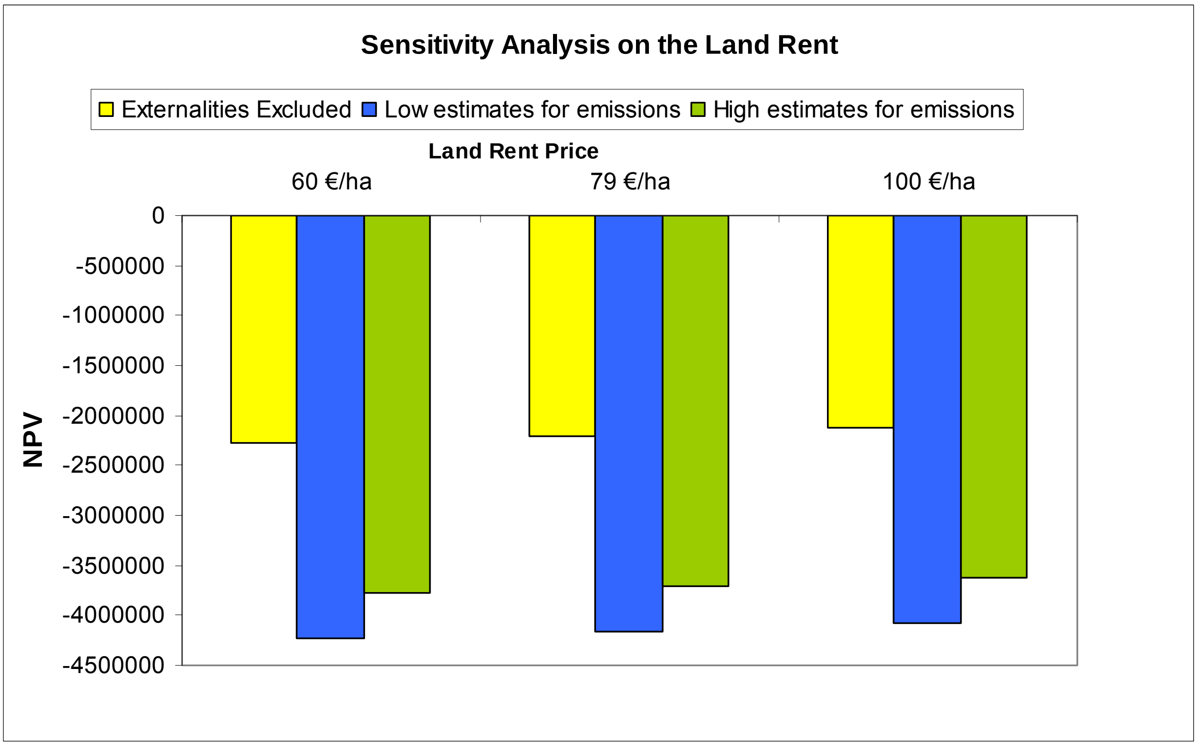

Figure 17 Results of the sensitivity analysis on land rent.

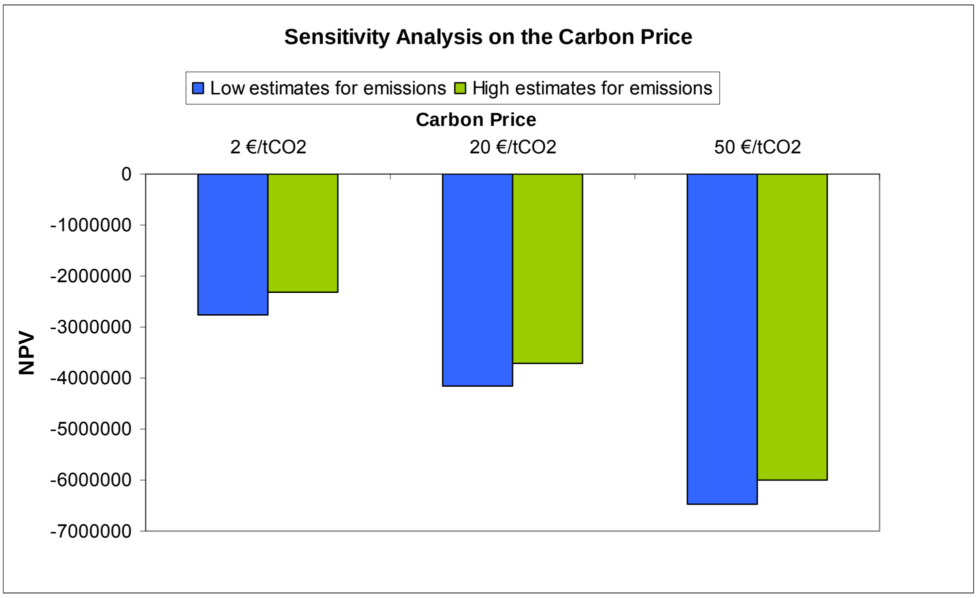

Figure 18 Results of the sensitivity analysis on the social cost of carbon.

3.6 Discussion of CBA results

Usually a CBA is applied to analyse the economic consequences of moving from a current situation, a status quo or a baseline situation, to one or more alternatives reflecting different decisions, e.g. with respect to policy design, investments etc.
At this stage, however, EFORWOOD has not yet advanced to the stage where different policies and scenarios are elaborated and data are collected or constructed that could reflect these different scenarios or decisions. Therefore, for the purpose of this study, we have chosen to consider the FWC 1 as the current status quo or baseline situation and the CBA then concerns the switch from FWC 1 to FWC 3. Such a switch would imply several changes in choice of technology, product mixes etc, along the chain, and the results of the CBA illustrate nicely how these changes are reflected in the socio-economic effects of the switch.

The GVA without externalities

In Tables 14 and 15, the second column from the left, we see the estimated GVA calculated by Modules for both FWC 1 and FWC 3. We see significant differences between the two FWCs in every module. In M2, the sources of these differences are several: First, the method of stand reestablishment is different, the planting operation in FWC being substantially more costly than the natural regeneration in FWC 1, see also Tables 11 and 12. Another major source is the differences in the chosen roundwood production options. That of FWC 1 requires a larger land area in the normal forest, than does the chosen option in FWC 3. This has direct costs in terms of the opportunity cost of land, which is around 79 €/ha per year in these calculations. While the regeneration method works in favour of FWC 1, the land rent costs work in favour of FWC 3. A decisive factor, however, is the fact that given the available data the chosen production of roundwood products in FWC 3 is sold at considerably lower price than the products of FWC 1. This works in favour of FWC 1 and in combination with the cheaper regeneration method, these factors outweigh the larger land rents to be paid in FWC 1.

We note that for both FWCs the estimated economic GVA-measure is negative. This may indicate that prices of output are set too low, but perhaps also that land rent is perhaps in the upper end of the realistic opportunity costs. In any case, given the available data in M2, the estimated economic GVA measure would favour FWC 1.

Turning to M3, we see that the choice of round wood products to produce in the two different chains have significant effects on the GVA. The higher quality products of FWC 1 are accompanied by larger costs of cutting, transport and sorting, but this is outweighed by an assumed higher output price in FWC 1. The immediate effect being that also in M3, the estimated economic GVA-measure would favour FWC 1. A similar pattern is seen in M4: FWC 3 benefits from much lower costs of input and sawmilling, but also suffers in terms of a much lower value of output produced. Again, in M4 FWC 1 is favoured as compared to FWC 3.

The overall result across Modules is accordingly that FWC 1 is to be preferred for FWC 3, at least when only the estimated economic GVA measure is considered. This can be seen from the flow values of GVA-measures as well as the NPV-evaluation of the switch as reported in Table 17. The NPV is negative by a fair margin indicating that with FWC 1 as the assumed status quo the switch to FWC 3 would be far from beneficial.

From economic GVA-measures to a CBA with externalities valued

Turning to the other columns of Tables 14 and 15 we find CBA calculations taking into account GHG as well as non-GHG emissions and carbon sequestration. We show directly in these Tables the results of relying either on the low-end estimates of costs of non-GHG emissions (typically avoidance cost estimates) vs. the high-end estimates (typically estimated welfare economic losses from emissions). We begin by focusing on the emissions.

In M2 we see very small numbers here, and very little differences between the FWCs, as only the planting operations really contribute with emissions. In M3, we see, however, larger differences with FWC 3 showing much higher emissions, implied by the use of more machinery for cutting, sorting and cross-cutting as compared to FWC 1, which use relatively more amounts of labour and leave much of the processing to M4 and the sawmills. The consequence is that taking into account the potential costs of emissions in M3 further decreases the attractiveness of FWC 3. However, turning to M4, we see that the postponing of several operations to the sawmill in FWC 1 also implies that potentially higher costs of emissions may be experienced here. Thus, in M4, taking into account these externalities improves the performance of FWC 3 relative to FWC 1 a bit. The overall effect, however, is not enough to change the overall evaluation that FWC 1 is preferred for FWC 3.

Finally, we turn to the inclusion of carbon sequestration in the chains. In the present rather simplistic model, we only know that 1000 tC is harvested in M2 every year, but we have too little information to model the carbon sequestration downstream from the living biomass in M2, including continued sequestration and delayed emissions etc. in the modules M3-M5. Therefore, we focus on the fact that to produce these 1,000 tC every year, the forest of FWC 1 needs to be somewhat bigger than the forest in FWC 3. This implies that a switch from FWC 1 to FWC 3 would, per produced unit tC, imply a decrease in the carbon stock of the normal forest – once the change has been undertaken, the available data indicate that the carbon stock in the normal forest will be more than 36,000 tC lower – decreased from around 328,000 tC to around 292,000 tC. We have provided a rough estimate of how this value could be included in a CBA of undertaking such a switch. We assume that every year a percentage equal to the discount rate is lost (when switching from FWC 1 to FWC 3). With a 4% discount rate this implies a switch over 25 years. With the baseline price (which could be considered high) of

20 €/tCO_2 the effects of this decrease in carbon stock is quite significant in economic terms, see Tables 14, 15 and 17.

The overall result across Modules is accordingly that also in the CBA-calculations, we find that FWC 1 is to be preferred to FWC 3. This can be seen from the flow values of CBA-measures as well as the NPV-evaluation of the switch as reported in Table 17. The NPV is negative by a fair margin indicating that with FWC 1 as the assumed status quo the switch to FWC 3 would be far from beneficial.

In spite of the result not changing, i.e. FWC 1 is still the preferred FWC, we see the potential of including the cost and benefits of externalities also in the CBA of a change in policy, technology etc. Differences in the costs of emissions across FWC are significant enough to be seen in the overall figures. And one could imagine that for other combinations of key parameters the results could change.

Sensitivity analysis

The potential of sensitivity analysis is illustrated in Section 3.5.3, where sensitivity is investigated in three one-dimensional analyses. We see that the effects of changing the parameters are intuitively understandable, e.g. increasing land rent improves the performance of FWC 3 relative to FWC 1 due to lower land use. However, we also see that the overall result of finding FWC 1 better than FWC 3 is not changed for these sensitivity analyses.

We note that one could find this result to change for e.g. combined effects of higher land rents, lower social costs of carbon and, a factor not analysed here, a lower difference in the value of wood products produced along the chain.

3.7 Limitations in the analysis and major problem areas

Conceptual problems and limitations of the CBA

- **Equity consideration:** CBA places equal weights on all individuals. The alternative is to assign more weight to disadvantages or low income groups. CBA should include the analysis of distributional effects to answer the question of who gains and who loses from a given project.
- **Discounting:** CBA uses a constant discount factor in the analysis. This result in low present value of future values, and thus may give an impression that the future generations are not considered adequately. The alternative is to apply hyperbolic (time-declining) discount rates.
- **Moral objections:** CBA relies on the Kaldor-Hicks criterion, according to which a resource reallocation is desirable if the gainers could potentially compensate the losers and still be better off. No actual compensation need take place.
- **Shadow prices:** Market failures lead to an incorrect set of prices which inaccurately measure marginal social costs and benefits accruing from the project implementation. The results of the CBA largely depend on the extent to which these prices are accurately estimated.
- **Valuation of externalities:** Different valuation techniques are applied in order to derive the value of the externalities to the society. Both the techniques themselves as well as the actual values may be questioned on their applicability limits. A related problem is the

question of risk, uncertainty and ignorance, especially as related to the environmental impacts of the project.

Particular problems and limitations

- **Interpretation**: Usually a CBA is performed with cost and benefits accruing at different time periods, but here the CBA is performed in the context of a “normal forest” model, where all costs and revenues occur simultaneously each year.

  This has several implications: Firstly, in relation to timing and discounting of costs and benefits. Secondly, the switch from FWC 1 to FWC 3 and the corresponding change in carbon stock, and production patterns etc. in reality takes time and occurs non-linearly, but in the CBA an immediate change is assumed.

- **Change in carbon stock**: The switch from FWC 1 to FWC 3 and the corresponding change in carbon stock takes time in reality and will occur non-linearly, but in the CBA here it is modelled as an immediate switch in annual flow based on the discount rate and the carbon stock.
- **Reliability of data**: Quite a large number of additional data (e.g. prices, etc.) had to be collected for the current analysis in order to perform the CBA. The reason being that the data in the test chains were in several cases not complete or not reliable. While this additional effort was possible for this fairly limited chain, it is not possible for the coming EU-scale FWC models of TOSIA. It is important to take the lessons learned here forward into the coming efforts of EFORWOOD.
- **Missing products and services:** Likewise, the current FWC test chains are quite small and simplified. In the coming large-scale models, we may find a higher complexity including e.g. alternative forest products (e.g. wood fuel), non-wood forest products and forest services (e.g. hunting and recreation), which are not included in the analysis due to lack of data and valuation difficulties.
- **CEA:** For this deliverable we had to give up the cost-efficiency analysis due to conceptual infeasibility for the simple case analysed here: The ‘choice’ between on of two possible FWCs in the Baden-Wurttemberg region. There is a lack of actual choice or policy alternatives to be analysed.

4 Synthesis from MCA and CBA perspectives

Designed as a comparative study on MCA and CBA issues for the evaluation of sustainability impacts in EFORWOOD, the work progress turned out to become more and more heterogeneous.

The most hampering reason was the lack of reliable and consistent data at the point of time D1.5.5 was planned to be completed. This had different implications for the different partners:

- the MCA group put emphasis on the development of the software prototype and the preparation of a stakeholder workshop, two tasks which were rather independent from data availability
- the CBA group had to put efforts in adapting and cross-checking existing data as well as generating additional data by literature review, telephone queries, etc.

Both methods (with the CEA finally being abandoned) exercised an example at Baden-Württemberg single chain or some derivates used as alternatives respectively. At the latest when the MCA-group had to perform the workshop with very short-handed data it was evident that a common view of MCA and CBA was out of gain. The two groups had different foci, used different indicators and different data.

Yet, there is a broad impact to be expected from these efforts. MCA started with "external" aspects of sustainability impact evaluation (software application, stakeholder feedback) whereas CBA struggled with "internal" data problems (consistency checks, data needs).

Hence, this deliverable wraps up a portfolio of evaluation methods that are strongly different in their foundations (Table 22).

Table 22 MCA and CBA compared

	MCA (Promethee)	CBA
Background	decision theory	economic theory
Problem	objective-based	project-based
Scale	preference scale	monetary scale
Data	qualitative and quantitative	quantitative
Aggregation	weighted sum	additive
Valuation	relative ranking	absolute valuation
Preferences	stated weights and preferences of experts	individual preferences measured by opportunity costs and WTP/WTA
Time dimension	user directly asked about time preferences	discount rates are used
Uncertainty	indifference of judgments (preferences)	future discount rates, land rent, price development
Scenarios	sensitivity analysis	sensitivity analysis
Participation	required	non-essential
Trade-offs	compensation	substitution
Results	preferability of each alternative expressed by a score or ranking	net benefits of each alternative in monetary terms

The evaluation exercise has demonstrated that CBA has very specific demands on data quality and available parameters, so the data for the demonstration had to be collected externally from the Eforwood database. Crucial information for CBA was missing on GVA, a variety of cost factors, land rents or non-greenhouse gas emissions. On the other, MCA is able to work with many kinds of qualitative and quantitative information since all information is transformed to a common scale by means of preference elicitation. Hence, it is possible to work with incomplete data. MCA aims at completing data lacks with expert knowledge and synthesizing empirical data with (subjective) preferences and stakeholders.

This experience implies an evaluation procedure that is very much in line with Rabl and Holland (2008) who recommend to quantify as many terms and their monetary equivalents as possible and then use MCA for all issues that are not feasible for CBA monetary valuation. Hence, a step by step procedure is implied where in the best case CBA results such as a cost-benefit ratio could be input for a subsequent MCA, combining economic valuation with a more holistic approach including stakeholders and decision makers. CBA (and CEA) will help to create a picture of the socio-economic impacts of alternatives, their efficiency and their sensitivity to economic key parameters such as discount rates, rents or externalities. Based on that, MCA could foster structural understanding, learning processes, conflict resolution, and finally decision-making (Gamper and Turcanu, 2007). MCA could utilize more standardised economic criteria, whereas CBA would benefit from stakeholder involvement and consensus-based aggregation of monetary values (Sijtsma, 2006). The essential message is that these evaluation methods are not designed as substitutes for each other, but rather should be implemented together. In this understanding, potential conflicts between CBA and MCA can be overcome and a multifaceted evaluation toolbox can be developed.

5 Literature

Athanassiadis, D., 2000: Energy consumption and exhaust emissions in mechanized timber harvesting operations in Sweden. *The Science of the Total Environment,*. 255, 135-143.

Bolkesjo, T.F., 2005: Projecting pulpwood prices under different assumptions on future capacities in the pulp and paper industries. SilvaFennica 39(1), 103-116.

Brans, J.P., Macharis, C., Kunsch, P.L. (1998): Combining multicriteria decision aid and system dynamics for the control of socio-economic processes. An iterative real-time procedure. European Journal of Operational Research 109: 428–441.

Brans, J.P., Vincke, P., Mareschal, B. (1986): How to select and how to rank projects: The PROMETHEE method. European Journal of Operation Research 24: 228-238.

Campell, C., 2004: *Global Lumber Benchmarking. How Does your Mill Measure up?* Forest & Paper Industry Practice. PriceWaterHouseCoopers, Vancouver.

Drechsler, M. (2004): Model-based conservation decision aiding in the presence of goal conflicts and uncertainty. Biodiversity and Conservation 13: 141–164.

DEFRA, 2007: *The social cost of carbon and the shadow price of carbon: what they are, and how to use them in economic appraisal in the UK*. Economics group, Department for Environment, Food and Rural Affairs (DEFRA). December 2007. Authors: Richard Price, Simeon Thornton, Stephen Nelson. Available online: http://www.defra.gov.uk/environment/climatechange/research/carboncost/pdf/background.pdf

Doll, H., 2005: Impacts of the reform of the Common Agricultural Policy (CAP) on land markets in Germany. *Agricultural Economics – Chech*, 51, 194-201

ExternE, 2005: *Externalities of Energy, Methodology 2005 Update*. European Communities. Available online: http://www.externe.info/brussels/methup05a.pdf

Forkenbrock, D. J., 1999: External costs of intercity truck freight transportation. *Transportation Research Part A*, 33, 505-526.

Gamper, C.D., Turcanu, C. (2007): On the governmental use of multi-criteria analysis. Ecological Economics 62: 298-307.

GES, 2002: *Estimating the social cost of carbon emissions*. UK Government economic service, Working paper 140. January 2002. Available online: http://www.hm-treasury.gov.uk/media/5/F/SCC.pdf

Gilliams, S., Raymaekers, D., Muys, B., van Orshoven, J. (2005): Comparing multiple criteria decision methods to extend a geographical information system on afforestation. Computers and Electronics in Agriculture 49: 142–158.

Hartman, R. S., Wheeler, D., Singh, M., 1997: The cost of air pollution abatement. *Applied Economics*, 29, 759-774.

Heding, N., Jakobsen, H., H., 1985: *Drying of wood chips for fuel* [Tørring af grønflis til fyringsformål]. Skovteknisk Institut, report 2.

ITD, 2008: *Emission calculator* [online]. International Transport Denmark. Cited November 2007 [revised 2005]. Padborg, Denmark. Available online: http://www.internationaltransportdanmark.com/Miljoe/emUK.asp?MenuID=10&EmneID=16

Kangas, J., Kangas, A. (2002): Multi criteria decision support methods in forest management. In: Pukkala, T. (ed.): Multi-objective Forest Planning. Dordrecht: Kluwer Academic. Managing Forest Ecosystems Vol. 6., 37–70.

Kangas, A., Kangas, J., Pykäläinen, J. (2001): Outranking Methods as Tools in Strategic Natural Resources Planning. Silva Fennica 35(2): 215–227.

Merlo, M. and Croitoru, L. (eds.) (2005): Valuing Mediterranean Forests: Towards Total Economic Value. CABI Publishing.

Pearce, D. 2003: The social cost of carbon and its policy implications. *Oxford Review of Economic Policy*, vol. 19 (3), 362-384.

ProBas 2005*: ProBas* [online]. UmweltbundesAmt and Öko-Institut e.V. Cited November 2007 [revised 2005]. Umweltbundesamt, Berlin, Germany. Available online: http://www.probas.umweltbundesamt.de

Rabl, A., Holland, M. (2008); Environmental Assessment Framework for Policy Applications: Life Cycle Assessment, External Costs and Multi-criteria Analysis. Jounal of Environmental Planning and Management 51: 81-105.

Sijtsma, F. (2006): Project evaluation, sustainability and accountability. Combining cost-benefit analysis (CBA) and multi-criteria analysis (MCA). Dissertation, University of Groningen. REG-Publication no.27.

Simon, U., Brüggemann, R., Pudenz, S. (2004): Aspects of decision support in water management – example Berlin and Potsdam (Germany) I – spatially differentiated evaluation. Water Research 38: 1809–1816.

Spadaro, J. S., Rabl, A., 2002: Air pollution damage estimates: the cost per kilogram of pollutant. *International Journal of Risk Assessment and Management*, 3, 75 – 98.

Appendix A

Derivation of non GHG emission rates – for use in the GVA/CBA

The emission rates of non GHG are based on 1) energy consumption (kWh/m3) in the different processes as stated in the database and in the MCA data, and on 2) known emission rates (g/kWh) of each pollutant from the machinery used in the FWC processes. The Eforwood data base client has been consulted for process descriptions that could clarify the circumstances concerning energy use, e.g. a references and description of processses. The emission rates originate mainly from the German Probas database, but also from single studies/projects as noted in PD 1.5.5. In the Probas database emissions are given for NMVOC, which are combined emissions of HCs (excl. CH_4) and aldehydes. In studies apart from Probas, emissions are given for HCs alone. Pollution of HCs (incl. CH_4 - methane) contributes to tropospheric ozone and may already be included in the CO_2-equivalent group, which is not treated here. A reference list can be found at the end of this document.

Below follow detailed descriptions of emission rates calculations for pollutants in each process:

<u>Regeneration phase (FWC 1 & 3):</u>
For all pollutants (incl. NMVOC) emission figures are based on emission rates for diesel engines used in forest tractors, ref. 4. The tractors are used with aggregates for preparation of the soil before natural regeneration and for machine planting in the case of BW chain 3. The energy consumption, on which the emissions are based, is found in the database.

<u>Young phase incl. pre-commercial thinnings (FWC 1-3):</u>
Thinning is assumed to be done motor-manually and emissions figures for all pollutants (incl. NMVOC) are based on emission rates from a two-stroke engine in a forest aggregate running on petrol and oil mix, ref. 5. The energy consumption, on which the emissions are based, is found in the Eforwood database.

<u>Motor-manual cutting, (FWC 1):</u>
For all pollutants (incl. NMVOC) same procedure as for the young phase, ref 5. Energy consumption is derived from the Eforwood database.

<u>Full mechanized cutting (FWC 3):</u>
Due to lack of SO_2 data for harvesting machines, emission rates for the forest truck has been used, ref. 4. Emissions for other pollutants (incl. HCs) are based on timber machine emissions, ref. 1. Energy consumption derived from the Eforwood database.

<u>Skidding and forwarding (FWC 1-3):</u>
Due to lack of SO_2 data for harvesting machines, emission rates for the forest truck has been used, ref. 4. Emissions for other pollutants (incl. HCs) are based on timber machine emissions, ref. 1. Energy consumption is derived from the Eforwooddatabase.

<u>Truck Transport (FWC 1-3):</u>
It is assumed that similar trucks are used for transport of short and long logs. For all pollutants (incl. HCs) emission rates are based on a 40t long-haul truck with a EURO III engine, ref. 2.

This deviates from the 30t truck assumed for transport in calculations of transport costs. Energy consumption is derived from the MCA study.

Crosscutting and sorting and saw milling (FWC 1-3):
Crosscutting, sorting and further processing is assumed done at the saw mill, which uses electricity from the grid. In Germany electricity is generated from renewable resources, fossil resources and nuclear power and the Probas database provide emission rates for all pollutants related to this power mix, ref. 3. Energy consumption is derived from MCA data.

Reference list:

1. Athanassiadis D. 2000. Energy consumption and exhaust emissions in mechanized timber harvesting operations in Sweden. The Science of the Total Environment. 255, 135-143.

Info: Information regarding emissions from timber machines. Emissions from processing of oil and diesel are not included, but the data are available in the article.

2. ITD, 2008: Emission calculator [online]. International Transport Denmark. Cited November 2007 [revised 2005]. Padborg, Denmark. Available online.

Info: Emissions based on studies performed by Volvo on a variety of truck and lorry engines.

For the following 4 references:
ProBas, 2005: ProBas [online]. UmweltbundesAmt and Öko-Institut e.V. Cited November 2007 [revised 2005]. Umweltbundesamt, Berlin, Germany

3. Probas – Details: El-KW-Park-DE-2000-Grundlast. Link: Probas_elec

Emissions from electricity generation consumed by *sawmill* and for *crosscutting and sorting*.

4. Probas – Details: Forst\Dieselmotor-Antrieb-100% (end)-DE-2000. Link: Probas_forst

Emissions from a diesel engine in a 'forestry truck'used in forestry operations.

5. Probas – Details: Forst\Zweitakter-Antrieb-100% (end)-DE. Link: Probas_saw

Emissions from a two-stroke engine from a forest aggregate. Used for emissions from motor-manual thinnings