EFORWOOD
Sustainability Impact Assessment of the Forestry - Wood Chain

Project no. 518128

EFORWOOD

Tools for Sustainability Impact Assessment

Instrument: IP

Thematic Priority: 6.3 Global Change and Ecosystems

Deliverable PD2.4.5
Report on feasibility of using Multi Criteria Analysis to evaluate effects of forest management alternatives on risks

Due date of deliverable: Month 38
Actual submission date: Month 41

Start date of project: 01/11/05
Duration: 4 years

Organisation name of lead contractor for this deliverable: INRA

Final version

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	X
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

PD2.4.5: Report on feasibility of using Multi Criteria Analysis to evaluate effects of forest management alternatives on risks

Hervé JACTEL
INRA – UMR BIOGECO – Laboratory of Forest Entomology & Biodiversity
69 Route d'Arcachon, 33612 Cestas, France

Manuela BRANCO, Jean-Michel CARNUS, José Ramón GONZALEZ, Wojciech GRODZKI, Bo LANGSTROM, Francisco MOREIRA, Sigrid NETHERER, Bruce NICOLL, Christophe ORAZIO, Dominique PIOU, Helena SANTOS, Mart-Jan SCHELHAAS, Karl TOJIC.

Abstract

Multi Criteria Decision Analysis (MCDA) has been developed to help decision makers choose between actions making a best compromise between different criteria of different weights. We suggest transposing this mathematical tool to develop Multi Criteria Risk Analysis (MCRA). By analogy we make a correspondence between "actions" and the EFORWOOD "Forest Management Alternatives" which we want to rank according to associated "vulnerability" to biotic or abiotic hazard as criteria, taking the likelihood of hazards as weights. Principles of MCDA are presented and the MCRA approach is explained step by step. This deliverable comes with an Excel template to help collect the required information.

Key words: risk analysis, multi criteria, hazards, biotic, abiotic, forest management alternatives.

Content

1. Rationale

1.1 Definition of risk analysis

Risks can theoretically be described as the interaction between hazard likelihood, susceptibility and exposure. Any change in one of these factors will lead to a corresponding change in risk level. Hazard likelihood is the probability of occurrence, which in forestry is usually related to the climate or to pest dynamics. Exposure can be interpreted as the values that are at stake, i.e. how much forest functions will be impacted. Susceptibility relates to how easily the system, e.g. the forest, is damaged by the disturbance agent under consideration. Forest management can have a large influence on susceptibility to biotic and abiotic hazards (see Eforwood PD2.4.3) and can thus play an important role in aggravating or reducing risks (Fig.1).

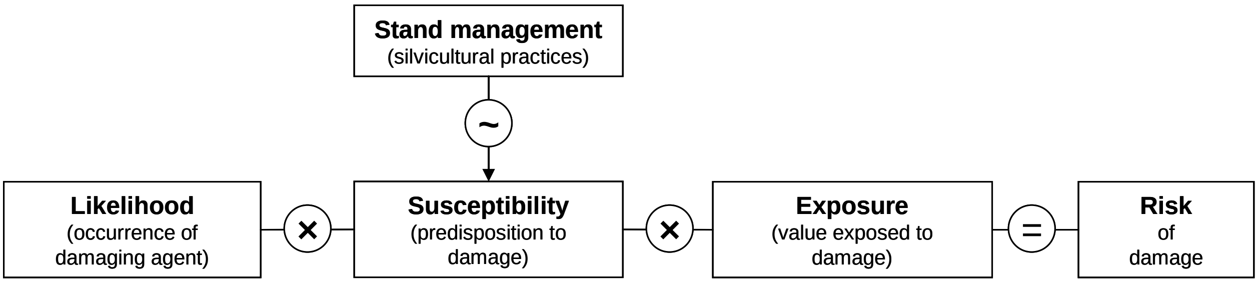


Fig.1 Conceptual diagram of risk analysis in the context of forests

Equations or quantitative models can be developed to evaluate risk for a particular hazard in a particular area if likelihood, susceptibility and exposure have been quantified, for example as probability of occurrence, probability of damage and loss values. However it is rarely the case in forestry. It is even more complicated to evaluate risk of damage in forest when several hazards, i.e. causes of damage, have to be taken into account. It is therefore almost impossible to quantitatively predict the effect of new management practices (alternatives) on overall risk in European forests. Nevertheless one may be able to provide semi-quantitative estimates of hazard likelihood, susceptibility and exposure, for example using scores. The question remains about how to combine the effects of several damaging agents but the Multi Criteria Decision Analysis (MCDA) method may offer a neat way to solve this problem.

1.2 Principles of Multi Criteria Decision Analysis (MCDA)

To illustrate the principles of MCDA we will use the following decision problem: a forest company wants to plant a new stand in a given forest area. Four potential tree species compositions have been identified and forest managers are discussing the advantages and weakness of each one. In this situation several criteria have to be taken into account: various costs (seedlings price, site preparation costs), potential wood production, environmental impacts (water use), and biodiversity and amenity values. When managers will have to make a decision, i.e. a choice between the different stand compositions, multiple objectives will come into play: reduce costs, improve wood yield, reduce environmental impacts, and improve biodiversity conservation. Usually, no single forest composition can be the best on all criteria at the same time and managers have to select a best compromise. This is a difficult problem because different criteria are evaluated according to different units (Euros, tons, number of endangered species) and ranges. MCDA have been developed to assist decision makers with this challenge.

1.2.1. PROMETHEE method

MCDA are based on outranking methods such as PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) developed at the Brussels Free University by Brans, Mareschal and Vincke (1986). They use pairwise comparison because decision-makers naturally tend to compare each action one-to-one with all other actions.

The first step in MCDA is to draw the evaluation table in which all the relevant information for the decision problem has to be entered. Each row corresponds to one possible action (one possible stand composition). Each criterion corresponds to one column, and is evaluated according to one unit and scale and one objective (to minimize or maximize).

Tab.1 Example of Evaluation table

Actions (forest composition)	**Criteria**			
	Plantation costs	Biomass yield	Water use	Biodiversity value
	€	Tons/ha/year	mm/m²/year	very bad to very good
	minimize	maximize	minimize	maximize
Pure pine				
Pure eucalypt				
75% pine – 25% eucalypt				
25% pine – 75% eucalypt				

1.2.2. Preference functions

To be able to compare the different criteria despite their different measurement unit, preference functions are used. The second step is then to design a preference function for each criterion, which allows deciding whether one action has to be preferred to another action according their respective criterion's value. The preference function translates the difference between the values of two actions on a single criterion in term of a preference degree. The preference degree increases with the difference between values and is expressed on a percentage scale (varying from 0 to 1).

Different preference functions are available and represented on fig.2.

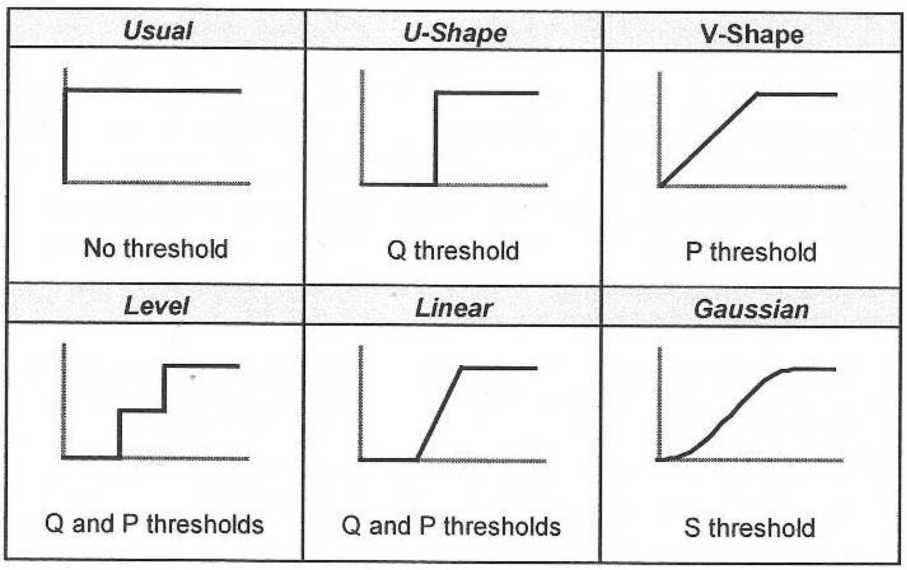
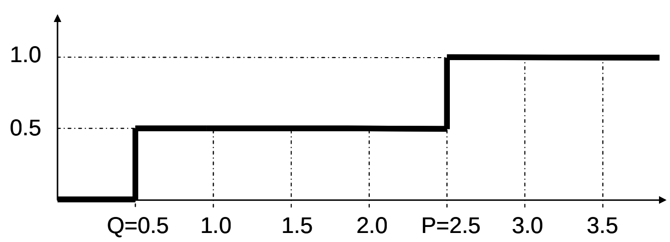


Fig. 2 Example of preference functions (taken from Decision Lab® Guide)

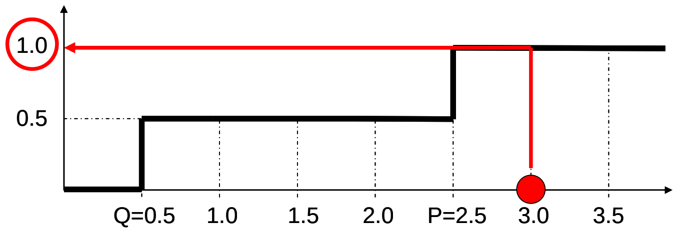
Each shape depends on up to two thresholds:

- the indifference threshold Q represents the largest difference that is considered negligible by the decision maker,
- the preference threshold P represents the smallest difference that is considered as decisive by the decision maker (P > Q).

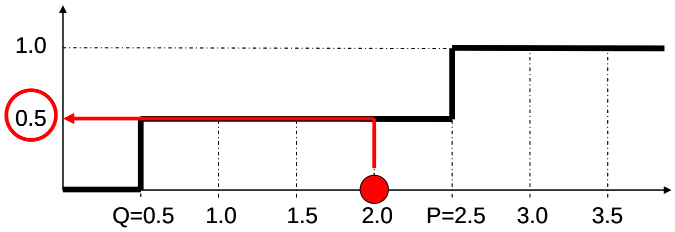
To illustrate the use of preference function we will take the example of the "Level" shape with Q and P thresholds, which is suitable for criteria that require qualitative scales. Let's take Q = 0.5 and P = 2.5 and assume that the criterion has to be maximized, i.e. actions with higher values are preferred.



If the value of the criterion for the action A1 is 1 and the value for the action A2 is 4, then the difference (A2-A1) equals 3. So A2 is preferred to A1 with a preference of 1 (100%) and A1 is preferred to A2 with a preference of 0.



If the value of the criterion for the action A1 is 1 and the value for the action A2 is 3, then the difference (A2-A1) equals 2. So A2 is preferred to A1 with a preference of 0.5 (50%) and A1 is preferred to A2 with a preference of 0.



If the value of the criterion for the action A1 is 2 and the value for the action A2 is 2, then the difference (A2-A1) equals 0. So A2 is preferred to A1 with a preference of 0 (0%) and A1 is preferred to A2 with a preference of 0.

It should be noticed that preference functions are symmetrical. So if the value of the criterion for the action A1 is 3 and the value for the action A2 is 1, then the difference (A2-A1) equals -2. So A2 is preferred to A1 with a preference of 0 (0%) and A1 is preferred to A2 with a preference of 0.5 (50%).

Similar calculations to convert deviations between the evaluations of two actions into preference degrees are made for all criteria, giving for example the table 2.

Tab.2 Example of preference table

Pure pine			**Criteria**	**75% pine – 25% eucalypt**		
preference	deviation	value		preference	deviation	value
0.5	-2	1	Plantation costs (minimize)	0.0	2	3
0.5	1	3	Biomass yield (maximize)	0.0	-1	2
0.5	-1	2	Water use (minimize)	0.0	1	3
0.0	-3	1	Biodiversity value (maximize)	1.0	3	4

Then the different preference degrees are calculated as the average per column.

For "Pure pine" with respect to "75% pine – 25% eucalypt":

$$Mean\ preference = \frac{0.5 + 0.5 + 0.5 + 0.0}{4} = 0.375$$

For "75% pine – 25% eucalypt" with respect to "Pure pine":

$$Mean\ preference = \frac{0.0 + 0.0 + 0.0 + 1.0}{4} = 0.25$$

So the balance is in favour of "Pure pine".

1.2.3. Weights

However in most decision problems not all criteria are considered equal. Decision-makers can indicate the importance they give to a criterion by specifying its weight.

In our example, forest managers may want to put more emphasis on environmental issues. The weights could be fixed as follows in Table 3. It should be noted that weight are often expressed in percentage; their sum is equal to 100%.

Tab.3 Example of criterion's weights

Criterion	Weight
Plantation costs	10
Biomass yield	20
Water use	30
Biodiversity value	40

Mean preferences are then calculated as weighted means:

For "Pure pine" with respect to "75% pine – 25% eucalypt":

$$Mean\ preference = \frac{0.5 \times 10 + 0.5 \times 20 + 0.5 \times 30 + 0.0 \times 40}{100} = 0.30$$

For "75% pine – 25% eucalypt" with respect to "Pure pine":

$$Mean\ preference = \frac{0.0 \times 10 + 0.0 \times 20 + 0.0 \times 30 + 1.0 \times 40}{100} = 0.40$$

In this case the balance is in favour of "75% pine – 25% eucalypt".

1.2.4. Preference flows

Using the preference functions (they can be different for each criterion), one can compare systematically each action one-to-one with the others. To summarize the results of all these comparisons, preference flows are calculated.

The positive flow (Φ+) of an action is the preference degree with which this action is preferred on average over other actions. The larger the positive flow, the better the action.

The negative flow (Φ-) of an action is the preference degree with which the other actions are preferred on average over that action. The smaller the negative flow, the better the action.

The net flow (Φ) is the balance between the positive and the negative flows (Φ =Φ+ - Φ-). The larger the net flow, the better the action.

Flows are computed as mean values of pairwise preference values as shown in Table 4.

Tab.4 Example of preference flow

	Pure pine	Pure eucalypt	75% pine – 25% eucalypt	25% pine – 75% eucalypt		**Φ+**	**Φ**
Pure pine		0.4	0.3	0.1	►	0.27	**-0.17**
Pure eucalypt	0.1		0.1	0.1		0.10	**-0.40**
75% pine – 25% eucalypt	0.4	0.5		0.4		0.43	**0.20**
25% pine – 75% eucalypt	0.8	0.6	0.3			0.57	**0.37**
	▼						
Φ-	0.43	0.50	0.23	0.20			

► "Pure pine" preferred over the other forest compositions

▼ Other forest compositions preferred over "Pure pine"

In this example forest compositions would be sorted in the following order of preference:

"25% pine – 75% eucalypt" > "75% pine – 25% eucalypt" > "Pure pine" > "Pure eucalypt"

1.3 Proposal for a Multi Criteria Risk Analysis (MCRA)

One of the main objectives of the Work Package 2.4 in EFORWOOD is to predict the risk of biotic and abiotic damage in European forests under various forest management alternatives. To reach this objective we propose to adapt the approach of MCDA, using a process of analogy to develop Multi Criteria Risk Analysis.

We need to compare the potential effect on forest health of different forest management alternatives (FMAs): it is exactly as if forest managers would have to make a choice between different actions, i.e. decide about which FMA to apply. To make their decision, forest managers will have to consider the risks each FMA might result in. Forest Management Alternatives are designed according to main objectives – or forest functions, such as wood production or environmental services – and are described as a combination of stand management practices (see EFORWOOD D 2.1.3). FMA's objectives can be used to qualify stand exposure to biotic and abiotic hazards. For example, a forest intensively managed to produce the maximum of biomass (FMA "Wood Biomass Production") will experience a greater impact of hazards that reduce wood production such as bark beetles or fire; it is more exposed to these hazards. FMA's practices can be used to estimate stand susceptibility to biotic and abiotic hazards as demonstrated in the EFORWOOD D2.4.3. The interaction between exposure and susceptibility is often defined as vulnerability. To make a decision about FMAs forest managers will have to consider their vulnerability to several main types of biotic and abiotic hazards (pest insects, diseases, wind, fire etc.): we will therefore consider these vulnerabilities as criteria to compare FMAs. But not all of the hazards have the same occurrence in a given area, depending on local climate or intrinsic species dynamics. We will then use the likelihood of a hazard to weight the importance of stand vulnerability to this hazard, just as criteria have weights in Multi Criteria Decision Analysis. Correspondences between MCDA and MCRA approaches are summarized in Table 5.

Tab.5 Correspondences between objectives and vocabulary of Multi Criteria Decision Analysis and Multi Criteria Risk Analysis

MCDA	MCRA
Solve a decision problem	Solve a forest management problem
Rank actions in order of increasing preference according to several criteria	Rank FMAs in order of increasing risk of damage by several hazards
Action	Forest Management Alternative
Criterion	Vulnerability = (Susceptibility ×Exposure) to one hazard
Weight	Likelihood of the hazard

2. Procedure for a Multi Criteria Risk Analysis (MCRA) using Decision Lab® and Excel®

In this chapter we will describe how to perform a MCRA using Excel as spreadsheet and Decision Lab as analytical and graphical tool.

The MCRA exercise is proposed for the most representative forest types in the EFORWOOD regional cases studies. As an example we will present here the results of a MRCA done for pure stands of maritime pine (*Pinus pinaster*) in Aquitaine.

2.1. Document the vulnerability of forest stands to hazard under Forest Management Alternatives

2.1.1. Exposure

Five FMAs have been defined by the EFORWOOD WP2.1 and described in the deliverable D2.1.3.

1. Unmanaged forest nature reserve
2. Close-to-nature forestry (low intervention forestry)
3. Combined objective forestry
4. Intensive even-aged forestry
5. Wood biomass production (short rotation forestry)

In our Work Package 2.4 we have proposed three indicators to qualify forest damage:

1. Tree mortality
2. Tree growth loss
3. Wood quality loss

In each case study (a particular forest type in a particular region) data should be collected from ICP Forest, National Forest Inventories or local Forest Health monitoring schemes to list the main hazards in terms of both occurrence and possible damage. For maritime pine stands in Aquitaine we have retained the following ten biotic and abiotic hazards (thus defining 10 criteria):

Common name	**Species**	**Type**
Pine processionary moth	*Thaumetopoea pityocampa*	pest insect
Pine stem borer	*Dioryctria sylvestrella*	pest insect
Pine bark beetle	Ips sexdentatus	pest insect
Pine weevil	*Hylobius abietis*	pest insect
Armillaria root rot	*Armillaria ostoyae*	pathogen
Annosus root rot	*Heterobasidion annosum*	pathogen
Pine shoot rust	*Melampsora pinitorqua*	pathogen
Deers	*Capreolus capreolus*	game
Wind		wind
Fire		fire

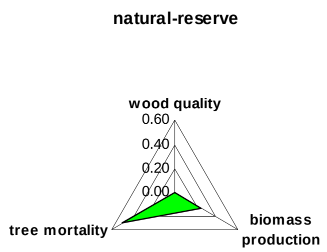
Knowing the damage caused by each hazard in pine stands it is possible to estimate their potential impact on tree mortality, tree growth and wood quality. Given the relative importance dedicated to tree mortality, tree growth and wood quality in each FMA, it is then possible to infer how pine stands would be exposed to the impact of the ten hazards under the five FMAs.

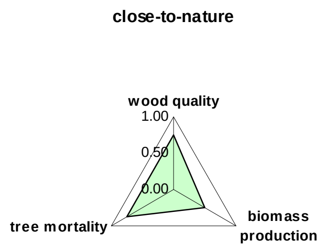
We propose the following procedure to estimate <u>exposure</u>.

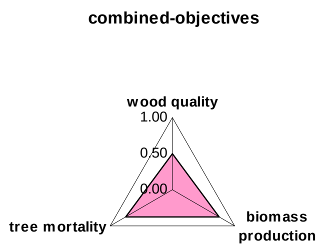
The importance of tree mortality, tree growth and wood quality in each FMA is estimated using the following scale:

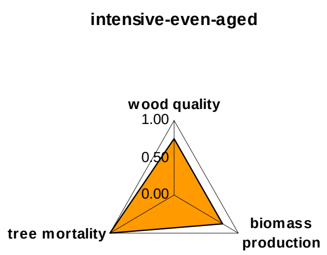
Importance	**Score**
Null	0.00
Low	0.25
Medium	0.50
High	0.75
Very high	1.00

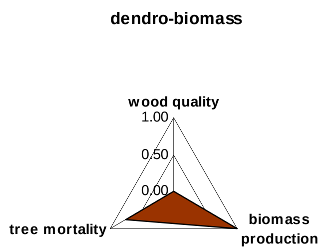
Radar graphs may be useful to figure out and possibly refine importance of the three damage indicators for each FMA.











The impact of hazards on tree mortality, tree growth and wood quality is estimated using the following scale:

Impact	**Score**
Null	0.00
Low	0.25
Moderate	0.50
High	0.75
Very high	1.00

Then for one particular hazard and one particular FMA, exposure is calculated as the product of importance and impact scores:

$\text{EXPOSURE TO}_{\text{tree mortality}} = \text{IMPORTANCE OF}_{\text{tree mortality}} \times \text{IMPACT ON}_{\text{tree mortality}}$

$\text{MEAN EXPOSURE} = (\text{EXPOSURE TO}_{\text{tree mortality}} + \text{EXPOSURE TO}_{\text{tree growth}} + \text{EXPOSURE TO}_{\text{wood quality}}) / 3$

It has to be noted that "Impacts" of different hazards should remain the same irrespective to FMAs whereas "Importance" should change according to FMAs.

In the Aquitaine case study we obtained the following estimates for the 5 FMAs:

Nature Reserve:

		Impact of									
indicator	**importance of**	Pine moth	Pine borer	Pine beetle	Pine weevil	Armillaria	Annosus	Rust	Deer	wind	fire
wood quality	0.00	0	0.75	0.25	0	0.25	0	0.25	0.25	0.25	0.25
growth loss	0.25	0.5	0	0	0	0.25	0.25	0.25	0	0	0
tree mortality	0.50	0	0.25	0.75	0.75	0.75	0.75	0	0.25	0.75	0.75
	exposure wood quality	0	0	0	0	0	0	0	0	0	0
	exposure growth loss	0.125	0	0	0	0.0625	0.0625	0.0625	0	0	0
	exposure tree mortality	0	0.125	0.375	0.375	0.375	0.375	0	0.125	0.375	0.375
	mean exposure	0.0416667	0.0416667	0.125	0.125	0.145833	0.145833	0.02083	0.04167	0.125	0.125

Close to Nature:

		Impact of									
indicator	**importance of**	Pine moth	Pine borer	Pine beetle	Pine weevil	Armillaria	Annosus	Rust	Deer	wind	fire
wood quality	0.75	0	0.75	0.25	0	0.25	0	0.25	0.25	0.25	0.25
growth loss	0.50	0.5	0	0	0	0.25	0.25	0.25	0	0	0
tree mortality	0.75	0	0.25	0.75	0.75	0.75	0.75	0	0.25	0.75	0.75
	exposure wood quality	0	0.5625	0.1875	0	0.1875	0	0.1875	0.1875	0.188	0.1875
	exposure growth loss	0.25	0	0	0	0.125	0.125	0.125	0	0	0
	exposure tree mortality	0	0.1875	0.5625	0.5625	0.5625	0.5625	0	0.1875	0.563	0.5625
	mean exposure	0.0833333	0.25	0.25	0.1875	0.291667	0.229167	0.1042	0.125	0.25	0.25

Combined Objectives:

		Impact of									
indicator	**importance of**	Pine moth	Pine borer	Pine beetle	Pine weevil	Armillaria	Annosus	Rust	Deer	wind	fire
wood quality	0.50	0	0.75	0.25	0	0.25	0	0.25	0.25	0.25	0.25
growth loss	0.75	0.5	0	0	0	0.25	0.25	0.25	0	0	0
tree mortality	0.75	0	0.25	0.75	0.75	0.75	0.75	0	0.25	0.75	0.75
	exposure wood quality	0	0.375	0.125	0	0.125	0	0.125	0.125	0.125	0.125
	exposure growth loss	0.375	0	0	0	0.1875	0.1875	0.1875	0	0	0
	exposure tree mortality	0	0.1875	0.5625	0.5625	0.5625	0.5625	0	0.1875	0.563	0.5625
	mean exposure	0.125	0.1875	0.2291667	0.1875	0.291667	0.25	0.1042	0.10417	0.229	0.2292

Intensive Even-aged:

		Impact of									
indicator	**importance of**	Pine moth	Pine borer	Pine beetle	Pine weevil	Armillaria	Annosus	Rust	Deer	wind	fire
wood quality	0.75	0	0.75	0.25	0	0.25	0	0.25	0.25	0.25	0.25
growth loss	0.75	0.5	0	0	0	0.25	0.25	0.25	0	0	0
tree mortality	1.00	0	0.25	0.75	0.75	0.75	0.75	0	0.25	0.75	0.75
	exposure wood quality	0	0.5625	0.1875	0	0.1875	0	0.1875	0.1875	0.188	0.1875
	exposure growth loss	0.375	0	0	0	0.1875	0.1875	0.1875	0	0	0
	exposure tree mortality	0	0.25	0.75	0.75	0.75	0.75	0	0.25	0.75	0.75
	mean exposure	0.125	0.2708333	0.3125	0.25	0.375	0.3125	0.125	0.14583	0.313	0.3125

Wood Biomass:

		Impact of									
indicator	**importance of**	Pine moth	Pine borer	Pine beetle	Pine weevil	Armillaria	Annosus	Rust	Deer	wind	fire
wood quality	0.00	0	0.75	0.25	0	0.25	0	0.25	0.25	0.25	0.25
growth loss	1.00	0.5	0	0	0	0.25	0.25	0.25	0	0	0
tree mortality	0.75	0	0.25	0.75	0.75	0.75	0.75	0	0.25	0.75	0.75
	exposure wood quality	0	0	0	0	0	0	0	0	0	0
	exposure growth loss	0.5	0	0	0	0.25	0.25	0.25	0	0	0
	exposure tree mortality	0	0.1875	0.5625	0.5625	0.5625	0.5625	0	0.188	0.563	0.5625
	mean exposure	0.1666667	0.0625	0.1875	0.1875	0.270833	0.27083	0.083	0.063	0.188	0.1875

2.1.2. Susceptibility

Evaluating the susceptibility of a stand under a certain Forest Management Alternative relies on the assumption that each silvicultural practice can affect tree sensitivity to hazards. The main silvicultural practices are detailed in EFORWOOD D2.1.3. For consistency and simplicity (it is difficult for example to consider different stand stages), we suggest grouping them according to 8 successive silvicultural operations:

1. Selection of **site conditions** (site fertility, microclimate, elevation, aspect…)
2. Selection of s**ite preparation** (ploughing, fertilizing, draining…)
3. Selection of **stand composition** (tree species assemblages)
4. Selection of **genetic material** (use of improved tree varieties…)
5. Selection of **regeneration type** (natural or artificial regeneration through sewing or planting…)
6. Selection of **cleaning method** (use of mechanical or chemical weed control…)
7. Selection of **thinning or pruning** methods (intensity and frequency of thinning operations)
8. Selection of **harvesting** method (clear-cutting or selection, retention harvesting…)

For each of the 8 operations, few keywords have to be selected to define key practices of each FMA. Then for each operation, it has to be decided whether the application of specific practices would result in increased or decreased stand / tree susceptibility to each hazard. This estimate is based on expert knowledge. We propose using the following scale to quantify the effect of silvicultural practices on susceptibility:

Effect	**Score**
decrease sensitivity greatly	**0.50**
decrease sensitivity moderately	**0.75**
no change	**1.00**
increase sensitivity moderately	**1.25**
increase sensitivity greatly	**1.50**

Then a mean susceptibility score per FMA is calculated from the 8 values of susceptibility associated with one particular silvicultural operation.

In the Aquitaine case study we obtained the following estimates for the 5 FMAs.

The mean susceptibility score was further expressed as change from value 1 (no effect on susceptibility) to provide an opinion on the overall effect of the FMA on susceptibility to one hazard; negative values indicate improvement in stand resistance, positive values indicate increase in stand susceptibility.

Nature Reserve:

	Nature reserve	Defoliator	Stem borer	Scolytids	Hylobius	Armillaria	Heterobas	Rust	Deers	wind	fire
site conditions	sand dune	1.25	0.75	1	1	1.25	0.75	0.75	1	0.5	0.5
site preparation	no	1	0.75	1.25	0.75	1	1	1.25	0.5	1	1.25
stand composition	mixed	0.5	0.75	0.75	0.75	0.75	0.5	1.25	0.5	1	0.75
genetic material	no	1	1	1	1	1	1	1	1	1	1
regeneration type	natural	1	0.75	1	0.5	1	1	1.25	0.5	0.75	1.25
cleaning	no	0.75	0.75	1.25	0.75	1	1	1.25	1	1	1.5
thinning-pruning	no	1	0.75	1.25	1	1	0.5	1	1	0.75	1.5
harvesting	no	0.75	1	0.75	0.75	1	0.5	1	1	1.25	1.25
	mean susceptibility	0.90625	0.8125	1.03125	0.8125	1	0.78125	1.09375	0.8125	0.906	1.125
	change	-9%	-19%	3%	-19%	0%	-22%	9%	-19%	-9%	13%

Close to Nature:

	Close-to-Nature	Defoliator	Stem borer	Scolytids	Hylobius	Armillaria	Heterobas	Rust	Deers	wind	fire
site conditions	sand dune	1.25	0.75	1	1	1.25	0.75	0.75	1	0.5	0.5
site preparation	harrowing	1	1	1	0.75	1.25	1	0.75	1.25	1	0.75
stand composition	mixed	0.5	0.75	0.75	0.75	0.75	0.5	1.25	0.5	1	0.75
genetic material	no	1	1	1	1	1	1	1	1	1	1
regeneration type	natural + seeding	1	0.75	1	0.5	1	1	1.25	0.5	0.75	1.25
cleaning	mechanical	1.25	1	1	1	1.25	1	1	1	1	0.75
thinning-pruning	selective	1	1	1	1	1	1.25	1	1	1.25	1.25
harvesting	shelterwood > 80 years	1.25	1	1.25	1.25	1	1.25	1	1	1.25	1.25
	mean susceptibility	1.03125	0.90625	1	0.90625	1.0625	0.96875	1	0.90625	0.969	0.9375
	change	3%	-9%	0%	-9%	6%	-3%	0%	-9%	-3%	-6%

Combined Objectives:

	Combined-objectives	Defoliator	Stem borer	Scolytids	Hylobius	Armillaria	Heterobas	Rust	Deers	wind	fire
site conditions	sand dunes	1.25	0.75	1	1	1.25	0.75	0.75	1	0.5	0.5
site preparation	strip ploughing, harrowing, low fertilization, weed control	1	1.25	0.75	0.75	1.25	1	1.25	1.25	1	0.5
stand composition	pure - even-aged	1.5	1.25	1.25	1.25	1.25	1.5	0.75	1.5	1	1.25
genetic material	no	1	1	1	1	1	1	1	1	1	1
regeneration type	seeding + planting	1	1.25	1	1.25	1	1	1	1.25	1.25	0.75
cleaning	thinning	1.25	1.25	0.75	1	1.25	1	1	1	1	0.5
thinning-pruning	3-4 thinnings, removing 30% of trees, pruning	1	1.5	0.75	1	1.25	1.5	1	1	1.5	0.75
harvesting	clear cut at 80 years	1.25	1	1.25	1.5	1.25	1.5	1	1.25	1.25	0.75
	mean susceptibility	1.15625	1.15625	0.96875	1.09375	1.1875	1.15625	0.9688	1.15625	1.063	0.75
	change	16%	16%	-3%	9%	19%	16%	-3%	16%	6%	-25%

Intensive Even-aged:

	Intensive even-aged	Defoliator	Stem borer	Scolytids	Hylobius	Armillaria	Heterobasi	Rust	Deers	wind	fire
site conditions	mesophylous podzols	0.75	1.25	0.75	1	1	1	1.25	1	1.25	1.25
site preparation	full ploughing, harrowing, drainage, cleaning, fertilization	1	1.5	0.5	0.75	1.5	1.25	1.25	1.25	0.75	0.5
stand composition	pure, even-aged	1.5	1.25	1.25	1.25	1.25	1.5	0.75	1.5	1	1.25
genetic material	improved varieties	1	1.25	0.75	1.25	1	1	1	1	1.25	1
regeneration type	planting 1250t/ha	1	1.5	0.75	1.25	1	1	0.75	1.5	1.5	0.75
cleaning	chemical, before thinnings	1.25	1.25	0.75	1	1.25	1	1	1	1	0.5
thinning-pruning	pruning, 3-4 thinnings, removing 33% of trees	1	1.5	0.5	1	1.25	1.5	1	1	1.5	0.5
harvesting	clear cut at 45 years	1.5	1	1.25	1.5	1.25	1.5	1	1.25	1.5	0.5
	mean susceptibility	1.125	1.3125	0.8125	1.125	1.1875	1.21875	1	1.1875	1.219	0.7813
	change	13%	31%	-19%	13%	19%	22%	0%	19%	22%	-22%

Wood Biomass:

	Wood-Biomass	Pine moth	Pine borer	Pine beetle	Pine weevil	Armillaria	Annosus	Rust	Deer	wind	fire
site conditions	most fertile	1	1.5	0.5	1	1	1	1.5	1	0.75	1.25
site preparation	full ploughing, harrowing, drainage, cleaning, fertilization	1	1.5	0.5	0.75	1.5	1.25	1.25	1.25	1.25	0.5
stand composition	pure, even-aged	1.5	1.25	1.25	1.25	1.25	1.5	0.75	1.5	1	1.25
genetic material	improved varieties	1	1.25	0.75	1.25	1	1	1	1	1.25	1
regeneration type	planting 2500t/ha	1	0.75	1.25	1.25	1.25	1.25	1.25	1	0.75	1.25
cleaning	mechanical, chemical	1.25	1.25	0.75	1	1.25	1	1	1	1	0.5
thinning-pruning	1-2 heavy thinnings	1	1.25	0.5	1	1.25	1.25	1	1	1.5	0.75
harvesting	clear cut at 15-30	1.5	1	1.25	1.5	1.5	1.5	1	1.25	1.5	0.5
	mean susceptibility	1.15625	1.21875	0.84375	1.125	1.25	1.21875	1.094	1.125	1.125	0.875
	change	16%	22%	-16%	13%	25%	22%	9%	13%	13%	-13%

2.1.3. Vulnerability

Stand vulnerability to one particular hazard under on particular FMA is then calculated as the product of the mean score of susceptibility by the mean score of exposure.

In the Aquitaine case study we obtained the following estimates for the 5 FMAs.

FMAs	Pine moth	Pine borer	Pine beetle	Pine weevil	Armillaria	Annosus	Rust	Deer	wind	fire
	Criteria									
Nature reserve	0.04	0.03	0.13	0.10	0.15	0.11	0.02	0.03	0.11	0.14
Close-to-Nature	0.09	0.23	0.25	0.17	0.31	0.22	0.10	0.11	0.24	0.23
Combined-objectives	0.14	0.22	0.22	0.21	0.35	0.29	0.10	0.12	0.24	0.17
Intensive even-aged	0.14	0.36	0.25	0.28	0.45	0.38	0.13	0.17	0.38	0.24
Wood-Biomass	0.19	0.08	0.16	0.21	0.34	0.33	0.09	0.07	0.21	0.16

2.1.4. Weights = Hazard likelihood

Any kind of information has to be collected to estimate likelihood of the main hazards in a particular forest type of a particular area. We suggest estimating the mean percentage of affected trees by a particular hazard per hectare and per year. Due to temporal variations of hazards' occurrence one may try to average the percentage of affected trees over a long period of time, the last fifty years for example.

This is what we did in Aquitaine to come up with the following estimates:

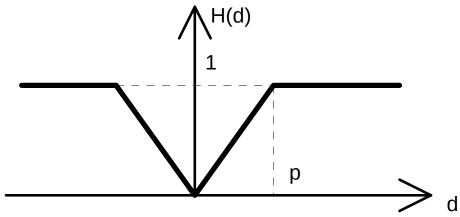
weight	Pine moth	Pine borer	Pine beetle	Pine weevil	Armillaria	Annosus	Rust	Deer	wind	fire
	Criteria									
% affected tree/ha/year	15	15	0.05	0.03	0.1	0.15	0.01	0.01	0.1	0.2
relative weight	0.4894	0.4894	0.0016	0.0010	0.0033	0.0049	0.0003	0.0003	0.0033	0.0065

Relative weights have been calculated by dividing specific likelihoods by the sum of all likelihoods as required by standard MCDA.

2.2. Ranking Forest Management Alternatives according to associated risks with Decision Lab®

2.2.1. Preference functions

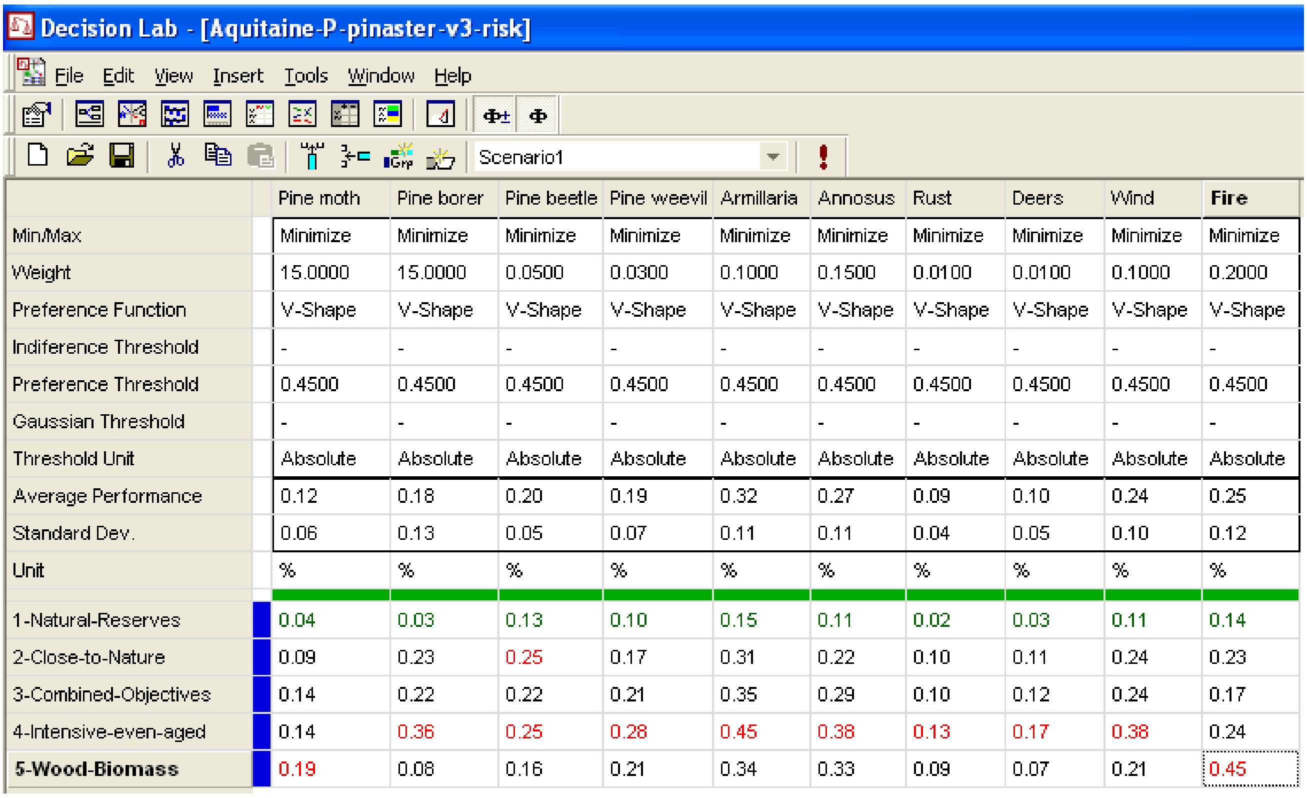
A key issue in MCDA is to choose the shape and threshold values of preference functions. In our MCRA approach we suggest using V-shape preference functions which vary linearly from 0 to 1 when the difference (d) between the criterion values of two compared actions varies from 0 to a maximum threshold (P).



To select the P value we propose to use the maximum observed value of stand vulnerability. It is equal to 0.45 in the Aquitaine case study.

The last decision is about minimizing or maximizing criteria. In the MCRA the objective is to find the FMA that minimize risk of damage so for all criteria, i.e. hazards, we will select "minimize".

After entering vulnerability data produced in the Excel file, estimated weights (likelihoods) and attributes of preference functions, we get an Evaluation Table as following:



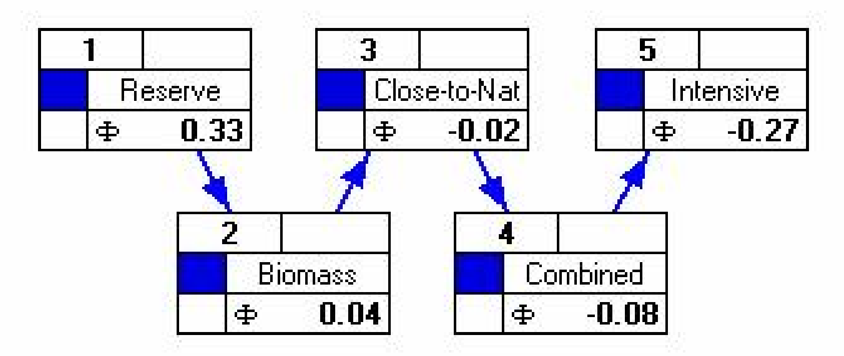
	Pine moth	Pine borer	Pine beetle	Pine weevil	Armillaria	Annosus	Rust	Deers	Wind	Fire
Min/Max	Minimize	Minimize	Minimize	Minimize	Minimize	Minimize	Minimize	Minimize	Minimize	Minimize
Weight	15.0000	15.0000	0.0500	0.0300	0.1000	0.1500	0.0100	0.0100	0.1000	0.2000
Preference Function	V-Shape	V-Shape	V-Shape	V-Shape	V-Shape	V-Shape	V-Shape	V-Shape	V-Shape	V-Shape
Indiference Threshold	-	-	-	-	-	-	-	-	-	-
Preference Threshold	0.4500	0.4500	0.4500	0.4500	0.4500	0.4500	0.4500	0.4500	0.4500	0.4500
Gaussian Threshold	-	-	-	-	-	-	-	-	-	-
Threshold Unit	Absolute	Absolute	Absolute	Absolute	Absolute	Absolute	Absolute	Absolute	Absolute	Absolute
Average Performance	0.12	0.18	0.20	0.19	0.32	0.27	0.09	0.10	0.24	0.25
Standard Dev.	0.06	0.13	0.05	0.07	0.11	0.11	0.04	0.05	0.10	0.12
Unit	%	%	%	%	%	%	%	%	%	%
1-Natural-Reserves	0.04	0.03	0.13	0.10	0.15	0.11	0.02	0.03	0.11	0.14
2-Close-to-Nature	0.09	0.23	0.25	0.17	0.31	0.22	0.10	0.11	0.24	0.23
3-Combined-Objectives	0.14	0.22	0.22	0.21	0.35	0.29	0.10	0.12	0.24	0.17
4-Intensive-even-aged	0.14	0.36	0.25	0.28	0.45	0.38	0.13	0.17	0.38	0.24
5-Wood-Biomass	0.19	0.08	0.16	0.21	0.34	0.33	0.09	0.07	0.21	0.45

2.2.2. Perform the comparison

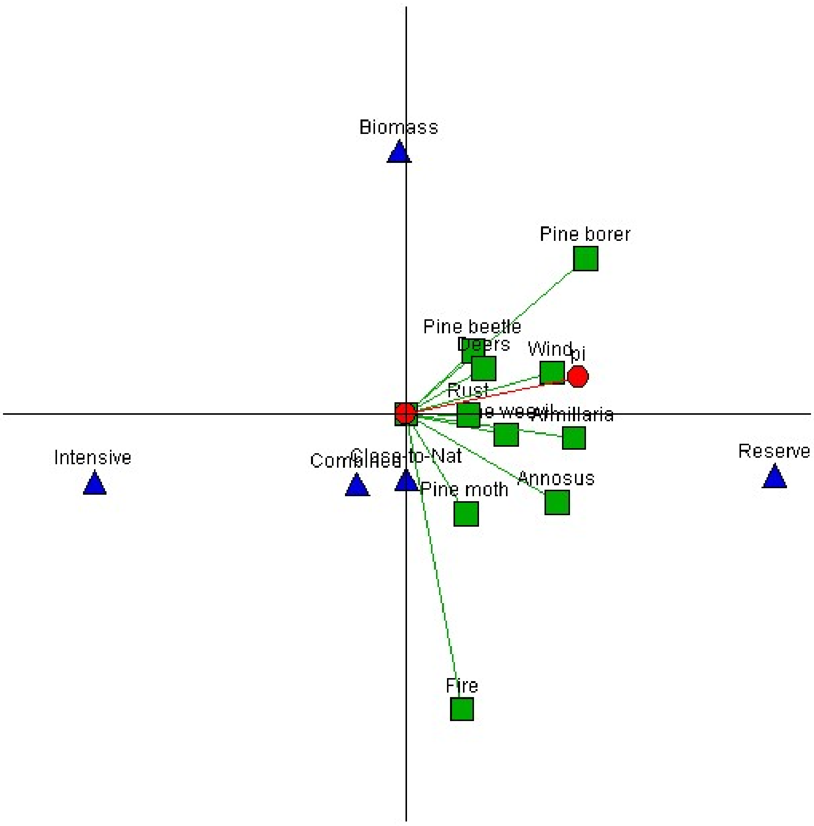
Once we have all the requisite information we can start comparing the actions, i.e. the FMAs. Decision Lab provides several types of results. We will only present the most important.

First we can make complete ranking of FMAs using PROMETHEE 2 method. All the FMAs are ranked from the best one to the worst one.

In our example, Natural Reserve is the best FMA, the one which reduce at most risk of damage, the Intensive Even-aged forestry is the worst.



Second Decision Lab can produce the GAIA (Graphical Analysis for Interactive Assistance) plane which provides the decision-makers with a comprehensive graphical image of the decision problem.

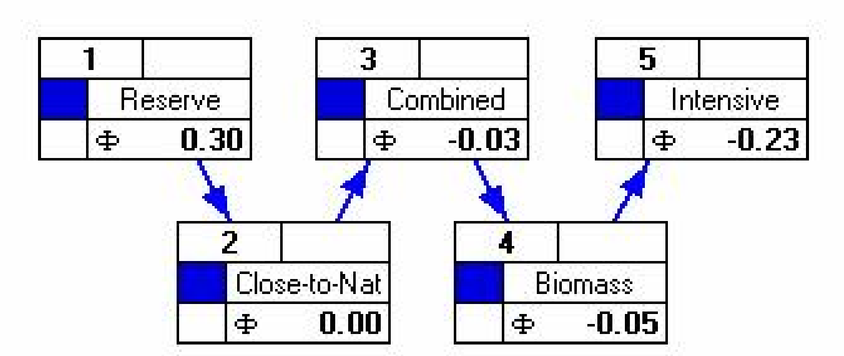


Each action (FMA) is represented by a blue triangle and each criterion by a green axis.

- The orientation of the criteria axes indicates which criteria are in agreement with each other (such as Pine borer, Pine beetle, Deers and Wind) and which are conflicting (such as Fire and Wind).
- The position of the FMAs indicates what are the strong and weak features of each FMA. The farther a FMA is located in the direction of a criterion, the better it is on that criterion. If it is located in the opposite direction, it means that its performance on that criterion is below average. For example Fire risk is particularly important with the Wood-Biomass.

Third Decision Lab allows testing the robustness of the ranking by testing the effect of changing weights. A Walking Weights window is available in which one can change the weight of a particular criterion and observe the effect on ranking. One can also set all weight equal to test the effect of equal weights for all criteria.

In our example setting all weight equal would have resulted in different preference flows and a slightly different ranking but Nature Reserve is still the best and Intensive Even-aged the worst, indicating a robust classification.



2.2.3. Using Multiple Scenarios

In one MCDA, criteria evaluations, preference functions, threshold values, weights have been entered by one group of decision makers, corresponding to one "scenario". However another group of decision makers might have chosen other values for the same problem. Decision Lab allows considering different "scenarios", providing that they have in common the set of actions and criteria. Several tools are available:

- The pairwise comparison of scenarios with the display of complete PROMETHEE 2 rankings side by side,
- The GAIA – Criteria planes with a projection of actions and criteria in which each criterion axis is an aggregate of the different scenarios,

- The aggregation of scenarios with the ranking of actions taking into account all points of views.

We propose to use this multiple scenarios approach in our MCRA to compare risks associated with EFORWOOD FMAs across different cases studies, i.e. several main European tree species in different regions. This combined analysis will provide the opportunity to possibly detect general patterns at the European level.

In the EFORWOOD WP2.4 we propose to develop MCRAs and combine them for the following case studies:

Forest Management Alternatives (FMAs)	**Criteria = Hazards**	**European Region**	**Tree species**
	At least five hazards:	Portugal	Eucalyptus
1. Unmanaged forest nature reserve	1. insect pest	Aquitaine	Maritime pine
2. Close-to-nature forestry	2. pathogen	Baden Wurttemberg	European beech
3. Combined objective forestry	3. game/grazer	Scotland	Sitka spruce
4. Intensive even-aged forestry	4. fire	Silesia	Scots pine
5. Wood biomass production	5. wind	Austria	Norway spruce

References

Brans J.P. Mareschal B. et al (1984). “PROMETHEE: a new family of outranking methods in multicriteria analysis”. In J. P. Brans, editor, Operational Research, 477-490

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

Brans J.P. and Mareschal B. (2002). PROMETHEE-GAIA. Une Méthodologie d'Aide à la Décision en Présence de Critères Multiples. Ellipses, Paris, France.

Decision Lab 2000 (2003). Getting Started Guide. Visual Decision Inc. Montreal, Canada.