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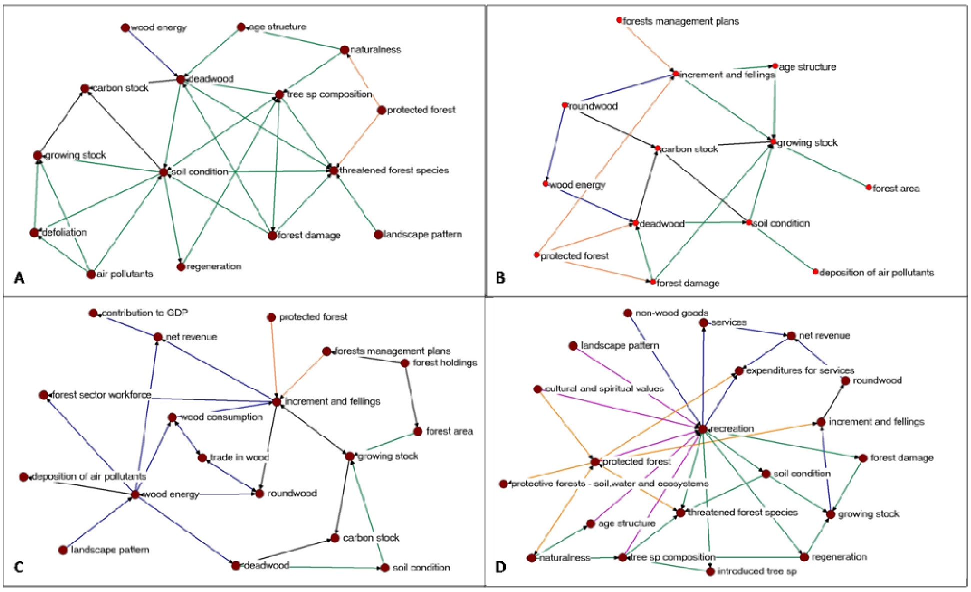
EUROPEAN FOREST INSTITUTE

Mapping the complex interactions of Sustainable Forest Management: an indicator based network approach

Master thesis supervised by Dr. Aljoscha Requardt (EFI)
and followed by Dr. Franck Lecocq (APT-ENGREF)



Sofie BLANCHART **FIF 17 - forest engineering curriculum 2006-2010** **September 2010**

Figure of the front cover: Four thematic indicator networks, **source:** Sofie Blanchart, **software**: Ucinet, Netdraw

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Observatory for European Forests of the European Forest Institute, EFI - OEF

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FICHE SIGNALETIQUE D'UN TRAVAIL D'ELEVE DE LA FIF

Formation des ingénieurs forestiers de l'ENGREF AgroParisTech	**TRAVAUX D'ÉLEVES**
TITRE : Mapping the complex interactions of Sustainable Forest Management: an indicator based network approach.	**Mots clés** : criteria, indicators, network analysis, sustainable forest management, cognitive mapping, participatory modelling.
AUTEUR : Sofie Blanchart	Promotion : **17-18**
Caractéristiques : 1 volumes ; 89 pages ; 23 figures ; 13 tableaux ; 4 annexes ; 1 bibliographie.	

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Abstract

Although the notion of Sustainable Forest Management (SFM) is crucial in all national and international forest dialogues, the exact definition or explanation of what this notion embraces is not always clear. Currently, efforts towards more sustainable forest management are mainly embodied by the various criteria and indicator (C&I) processes developed in all regions around the globe to monitor and report on progress towards SFM.

The present study investigates the use of the pan-European C&I set as a basis to investigate and map the complex mechanisms involved in SFM, following an indicator network approach. Several methods and applications will be detailed to find out how this approach can enhance the communication and understanding of SFM but also support decision-making processes.

Résumé

Même si elle est cruciale dans tous les dialogues nationaux et internationaux, la notion de gestion durable des forêts n'est pas toujours facile à définir ou expliquer en termes exacts. Actuellement l'effort principal envers une gestion forestière plus durable est représenté par la mise en place de sets de critères et indicateurs de gestion durable dans toutes les régions du monde pour évaluer et rendre compte de l'évolution de l'état des forêts.

La présente utilise les critères et indicateurs paneuropéens comme base pour étudier et visualiser les mécanismes complexes de la gestion durable des forêts, selon une approche par réseaux d'indicateurs. Différents protocoles et applications seront détaillés afin de vérifier comment ces méthodes permettent de favoriser l'appréhension du concept de gestion forestière durable l'appui à la décision politique.

Acknowledgements

Working on this topic and writing of the thesis were really interesting and enriching experiences and that is partly thanks to the support of many helpful people.

First of all I would like to address thanks to my supervisor Dr. Aljoscha Requardt, executive manager of the Observatory of European Forests (OEF) of the European Forest Institute (EFI), who has given me the most valuable insight in the world of European forest policy research and has been available for questions and support over the whole duration of my stay at the OEF. His expertise on the subject and his encouragements have greatly facilitated my work there. I am also grateful to Dr. Franck Lecocq deputy director of the Laboratory of Forest Economics and my supervisor from AgroParisTech, who, in spite of his very busy schedule, took some time for validating my work. His remarks were always very pertinent and helpful.

Many thanks also to the whole team of the OEF, in particular Paul Rougieux for his helping hands with the administrative issues and Anna Stier who has been helping me out with the literature research. The nice team spirit and cheery atmosphere reigning in the office were another great motivation for my work.

Finally big thanks to Remy Picavet and Darren Brown who have spent many hours reading and commenting on this thesis, which probably wasn't the most exciting thing to do during those summer days.

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List of Acronyms

C&I: Criteria and Indicators

CICI 2003: Conference on the Contribution of Criteria and Indicators for Sustainable Forest management, Guatemala city in 2003

DPSIR framework: Driving force - Pressure - State - Impact – Response framework

EEA: European Environment Agency

EFI: European Forest Institute

EU: European Union

FAO: Food and Agriculture Organization of the United Nations

FMU: Forest Management Unit

FRA: Global Forest Resources Assessment programme of the FAO.

ICP: International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests

IFF: Intergovernmental Forum on Forests

INRA: French National Institute for Agricultural Research

IPF: Intergovernmental Panel on Forests

ITTO: International Tropical Timber Organization

MCDM: Multi-Criteria Decision Making

MCPFE: Ministerial Conference on the Protection of Forests in Europe, recently grouped under the name of Forest Europe

OECD: Organization for Economic Co-operation and Development

OEF: Observatory for European Forests

PSR scheme: Pressure State Response scheme

SFM: Sustainable Forest Management

SoEF report: the State of Europe's Forests report published by the MCPFE.

UNCED : United Nations Conference on Environment and Development

UNECE: United Nations Economic Commission for Europe

UNFF: United Nations Forum on Forests

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Introduction

Different views on, and concepts of Sustainable Forest Management (SFM) have been developed in all regions of the world, influenced by different contexts and stakeholders. Therefore the formulation of a common definition of SFM and its evaluation is complex and challenging. In Europe, the Ministerial Conference on the Protection of Forests in Europe (MCPFE) developed and adopted a common definition of SFM (MCPFE, 1993). Based on this, pan-European Criteria and Indicators (C&I) were developed as a common policy instrument for evaluating and reporting on progress towards SFM at the pan-European and national levels. At the fourth MCPFE in 2003, six pan-European criteria and a revised set of 35 quantitative indicators were adopted (MCPFE, 2003).

Until now the main purpose of these pan-European C&I has been to monitor and report on the "State of Europe's Forests", which is a key document for each MCPFE (see the 2007 report (MCPFE, UNECE, & FAO, 2007)). Nevertheless, in the last few years, C&I have also been used as an instrument for developing, comparing and evaluating forest management concepts and practices at different levels, particularly in research and management projects. These studies have led to new perceptions of the role and purpose of C&I, and recently, reinforced the vision of C&I as an analytic tool to describe and better understand SFM and its various components and mechanisms (Requardt, 2007). This new role attributed to the C&I sets is particularly interesting as there is a great need for enhancing and harmonising the understanding and conceptualisation of what SFM really refers to (Pokorny & Desmond, 2004).

For a long time, SFM was reduced to a static framework, but this picture has never been truly satisfying, as only a dynamic system approach can reveal the full complexity involved. The visualisation of SFM as a network of many interconnected components, through the analytic C&I network approach, allows the investigation of this dynamic system. The pan-European indicator framework can support this analytical effort at European scale and contribute to enhance the understanding of SFM complexity within different stakeholder perspectives or policy scenarios (Requardt, 2007), (Wolfslehner, Vacik, & Lexer, 2005), (Mendoza & Prabhu, 2006).

The aim of this work is to carry out, based on the pan-European C&I set, several network analyses as adapted from social sciences (Hanneman & Riddle, 2005). The study investigates the possible implementations of these methods in order to better describe SFM as a dynamic system. Individual thematic network building and participatory methods are successively applied and compared; the pros and cons of both are discussed. For each of these methods, the benefits of the network approach are considered regarding three main goals: enhancing the overall understanding of SFM, facilitating communication and cross-sectoral discussions on SFM and supporting the policy related monitoring and decision-making processes.

I. Background of the study

A. Political and institutional background

1. Definition of sustainable forest management at the international level.

Although it is commonly accepted that the concept of sustainability has been present more or less transparently for centuries (Freerk Wiersum, 1995), in the context of the general degradation of the environment and growing scarcity of natural resources, sustainable development has become an increasingly crucial issue over the last century. Because of the intensified transnational exchanges and the global nature of these problems, the need for reasoning natural resource management has become an issue to be addressed at the international level.

In the forestry field the issue of promoting sustainable forest management (SFM) was properly addressed for the first time at the global level during the United Nations Conference on Environment and Development (UNCED), or earth summit in Rio de Janeiro in 1992. Main outcomes of the conference were the adoption of Agenda 21 and of the Statement of Principles for the Sustainable Management of Forests. The fifteen principles defined during the conference set some general rules for forest management, in a "holistic and balanced" approach, "within the overall context of environment and development, taking into consideration the multiple functions and uses of forests" (United Nations, 1992).

The concept of sustainable forestry has continually evolved since then, in accordance with ongoing international dialogues, mainly represented by the Intergovernmental Panel on Forests (IPF), created in 1995 as part of the follow up of the UNCED, and its successor the Intergovernmental Forum on Forests (IFF) and more recently, since 2000, the United Nations Forum on Forests (UNFF) (Bauer & Guarin Corredor, 2006). SFM has thus been developed as a dynamic concept that adapts to the evolution of society's perceptions and valuation of the different functions of forests (Requardt, 2007). The essence of SFM however remains unchanged: managing forests in a way that respects the equilibrium between their economic, environmental and socio-cultural functions at a relevant scale.

In Europe:

The Ministerial Conference on the Protection of Forests in Europe (MCPFE) has deepened this dialogue in Europe and has been a key driver in the development of the concept of SFM on the continent. Resolution H1, signed during the second ministerial conference in Helsinki in 1993, proposes a pan-European definition of sustainable forest management as: "the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems" (MCPFE, 1993).

The principles of sustainable forest management and forest multifunctionality, as defined by UNCED and MCPFE, are central in the EU forest strategy adopted in December 1998. In this strategy, the council of the EU emphasizes "the importance of the multifunctional role of forests and sustainable forest management based on their social, economic, environmental, ecological and cultural functions for the development of society and, in particular, rural areas and emphasizes the contribution forests and forestry can make to existing Community policies" (European Commission, Council resolution of 15 December 1998 on a forestry strategy for the European Union, 1999).

2. Implementation of criteria and indicators for SFM

As stressed in Agenda 21, one of the main requirements for the enhancement of sustainable forest management is the agreement on relevant guidelines and sound criteria to evaluate forest management against. To answer this need, a range of regional and national initiatives for the establishment of criteria and indicator (C&I) sets have emerged (Simula, 2003). In a monitoring perspective Criteria and Indicators are part of a more global hierarchy defined as follows (Ritchie, McDougall, Haggith, & Burford de Oliveira, 2000):

- Principles are the ***fundamental truths or laws*** that define our vision of SFM, forming the umbrellas under which all Criteria, Indicators and Verifiers fall.
- Criteria are ***standards*** by which our progress towards meeting the Principles can be judged, they are less abstract and more meaningful.
- Indicators are the ***components or variables*** of the forest or management system that imply or indicate the state or conditions required by a Criterion
- Verifiers are the ***data*** or information needed for assessing an Indicator. They define the specific details that would show the evolution of an indicator.

The major international C&I initiatives are: the International Tropical Timber Organization (ITTO) C&I (1992), the MCPFE, Helsinki process (1994), the Montreal process (Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests outside Europe -1995), the Tarapoto proposal (C&I for sustainability of the Amazonian Forest - 1995), the C&I for SFM in Dry Zone Africa (1995), the Principles, Criteria and Indicators of the African Timber Organization (1996), the C&I for SFM in the Near East (1996), the Central America process of Lepaterique (1997) and finally the Dry Forest Asia initiative (1999). The common goal of all of these initiatives is to select and implement locally adapted criteria and indicators in order to monitor, assess and report progress towards sustainable forest management in the regions. They are all however, at different stages of progress. In this context and in order to facilitate both the international dialogue on C&I and the transregional knowledge transfer, several intergovernmental expert consultations were organized. During one of these, the International Conference on the contribution of Criteria and Indicators for Sustainable Forest Management (CICI) held in 2003 in Guatemala, the participants agreed for the first time on the following 7 thematic areas of SFM, common to all of the processes (FAO, 2003) :

(1) extent of forest resources,

(2) biological diversity,

(3) forest health and vitality,

(4) productive functions of forest resources,

(5) protective functions of forest resources,

(6) socio-economic functions,

(7) legal, policy and institutional framework.

The criteria composing the different C&I sets are the reflection of these thematic areas. More than that, the agreement on this list demonstrates a global consensus on a framework for the establishment of C&I and, at the same time, it represents another step towards an agreement on a definition of sustainable forest management.

3. Adoption of a pan-European C&I set

Ever since the first pan-European set of C&I for SFM was developed and adopted at the MCPFE Expert Level Meeting in Geneva in 1994, the MCPFE, recently renamed Forest Europe process, has taken the lead of the pan-European C&I process. This first set was accepted as an official framework for international reporting in Europe by the third Ministerial Conference in Lisbon in 1998 (Requardt, 2007). In this context, understanding the importance of having a solid C&I set was crucial, the international experts launched a discussion on the improvement of the existing C&I. The improvements were based on both the experience of the European countries with C&I and on the results of the other regional processes, taking also into account the topical European dialogues on climate change, biodiversity and socio-economic services of forests (MCPFE, 2002). An advisory group representing relevant European level organizations was constituted to work on the improved set of indicators. Workshops were organized and studies have been conducted in order to assess the usefulness, strength, weaknesses and feasibility of the selected indicators. The improved set of 6 quantitative criteria and 35 indicators (Table 1) was adopted during the MCPFE expert level meeting in 2002 in Vienna (MCPFE, 2003). The detailed list of the indicators together with their official definition is given in Annex I of this document.

The adopted C&I were improved with the aim of becoming a common European policy instrument or tool to monitor, evaluate and report progress towards SFM on the continent. One of the main current applications of this C&I set is the publishing of the Sate of Europe’s Forests (SoEF) report every 4 or 5 years which compiles and synthesises the European country’s national forest reports (MCPFE, UNECE, & FAO, 2007). However, the whole process remains voluntary and until now no legally binding agreement exists to compel the European countries to adjust and adopt the C&I set in their countries.

More detailed information on the C&I such as measurement units, scope of the indicators, international data providers as well as underlying definitions are compiled and detailed in a supplementary document: “Background Information for Improved Pan-European Indicators for Sustainable Forest Management” (MCPFE, 2002).

Improved Pan-European Indicators for Sustainable Forest Management		
Criteria	***Indicators***	
C1. Maintenance and proper enhancement of Forest resources and their contribution to global carbon cycles	Forest area	1.1
	Growing stock	1.2
	Age structure, diameter distribution	1.3
	Carbon stock	1.4
C2. Maintenance of Forest ecosystem health and vitality	Deposition of air pollutants	2.1
	Soil condition	2.2
	Defoliation	2.3
	Forest damage	2.4
C3. Maintenance and Encouragement of Productive functions of forests (wood and non wood)	Increment and felling	3.1
	Round wood	3.2
	Non-wood goods	3.3
	Services	3.4
	Forests under management plans	3.5
C4. Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems	Tree species composition	4.1
	Regeneration	4.2
	Naturalness	4.3
	Introduced tree species	4.4
	Deadwood	4.5
	Genetic resources	4.6
	Landscape pattern	4.7
	Threatened forest species	4.8
	Protected forest	4.9
C5. Maintenance and appropriate enhancement of protective functions in forest management (notably soil and water)	Protective forests - soil, water and other ecosystem functions	5.1
	Protective forests - infrastructure and managed natural resources	5.2
C6. Maintenance of other socio-economic functions and conditions	Forest holdings	6.1
	Contribution of forest sector to GDP	6.2
	Net revenue	6.3
	Expenditures for services	6.4
	Forest sector workforce	6.5
	Occupational safety and health	6.6
	Wood consumption	6.7
	Trade in wood	6.8
	Energy from wood resources	6.9
	Accessibility for recreation	6.10
	Cultural and spiritual values	6.11
Qualitative indicators:	A : Overall policies, institutions and instruments for sustainable forest management	A1 - A5
	B: Policies, institutions and instruments by policy area	B1 - B12

Table 1: list of the improved pan-European C&I *(MCPFE, 2003)*

4. Applications of C&I: primary roles and new concepts

a. *C&I for monitoring, assessment and reporting on SFM*

C&I have been implemented in several national and international reporting processes such as the global Forest Resources Assessment (FRA), led by the Food and Agriculture Organization of the United Nations, and the State of Europe's Forests report published by the MCPFE. Those reports are produced every five to ten years. In the case of the pan-European reporting process, the assessment of the different indicators over time gives a good overview of the progress of the different countries towards more sustainable forest management practices. C&I allow the identification of fields where progress is made and where there is need for additional measures both at national and regional scales (MCPFE, UNECE, & FAO, 2007).

International expert meetings on C&I are organized by the main international stakeholders in order to favour international dialogue on the improvement of the current C&I implementations. Despite global consensus in discussions on the usefulness of the C&I sets, several obstacles and limitations have been identified in relation to the current C&I sets and their implementation (Simula, 2003; Hendricks, 2003; Pokorny & Desmond, 2004). The outcomes of those discussions reveal a significant lack of coordination amongst the different C&I initiatives. Even though 7 thematic areas have been agreed upon (FAO, 2003), the different C&I sets still have heterogeneous structures, which limits comparisons between the reports or results of different regions. In addition, overlapping reporting processes are conducted in many regions and countries, with multiple data collections and analysis, which is not only a waste of money and time, but also a cause of confusion for the public. The first background paper of the International Conference on the Contribution of Criteria and Indicators for Sustainable Forest management held in Guatemala city (CICI) in 2003 stressed the lack of efficient tools for data pooling and sharing at the international level (Simula, 2003). The development of this kind of tools could facilitate general cooperation as well as data availability and transfer between different reporting and C&I processes. However, more than only being an organisational problem, the homogenisation between the different processes is complicated because of the variability of perceptions on the concepts and definitions involved, reflecting also a need for harmonization at this level.

Inefficient and incomplete data collection is another shortcoming of the current reporting processes. In most of the compiled reports data completeness is only partial. As an example, Annex 2 of the 2007 State of Europe's Forests report (MCPFE, UNECE, & FAO, 2007) gives an overview of the completeness of the compiled data from the different country reports. The data in this document does not concern all indicators of the pan-European set, since not all the indicators must be reported on by the countries - data on indicators such as air pollutants and defoliation, amongst others, is provided by other international data sources. Figure 1 shows how a significant amount of indicators, mainly environmental (e.g. deadwood, threatened species and tree species composition) but also socio-cultural indicators (e.g. cultural and spiritual values) have been reported on by less than 50 % of the countries. There may be many reasons for this as explained in one of the CICI 2003 background papers (Hendricks, 2003). On the one hand the definition of some of the indicators is to be blamed, as not all indicators are easily understandable, quantifiable and there are no clear guidelines for data collection procedures. On the other hand, there are obvious financial issues - human and financial resources are often insufficient to support the additional collection and reporting effort. As a result, the reporting efforts in those cases focus on the indicators that are easy to measure and for which data collection already exist, leaving aside those indicators of more recent concern such as the social and environmental indicators.

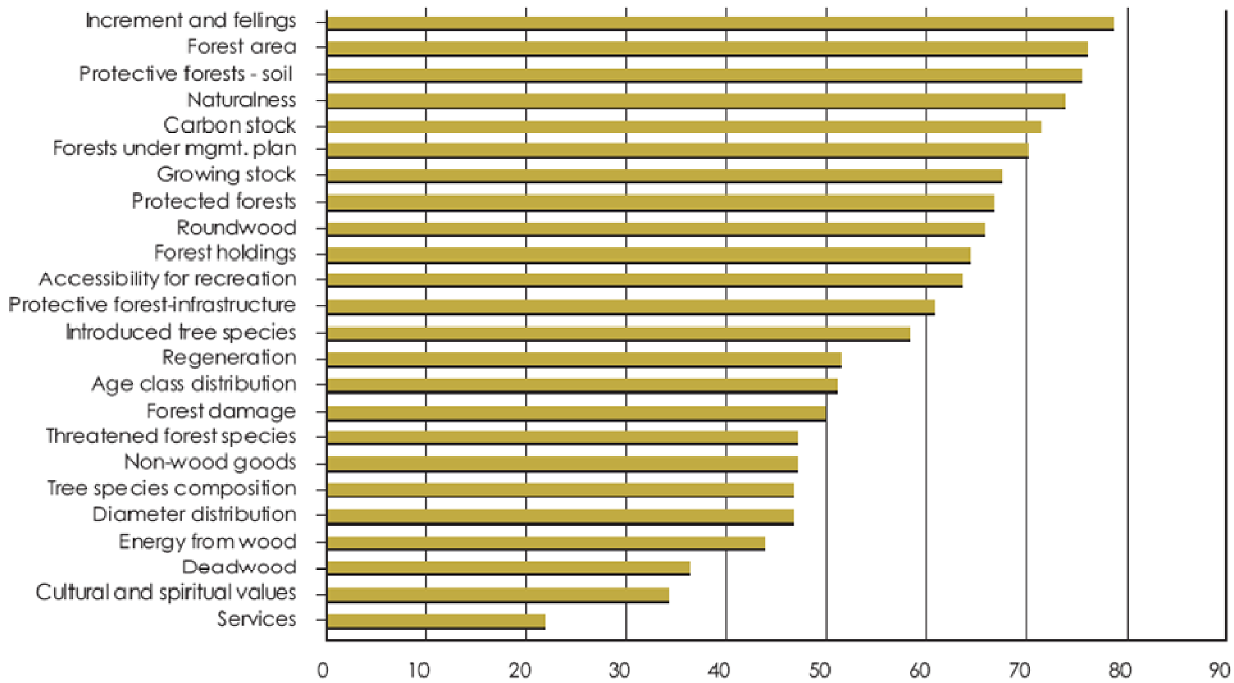


Figure 1: Data completeness, in % of countries, of the pan-European reporting process (*source: SoEF Annex2* (MCPFE, UNECE, & FAO, 2007)*)*

The above-mentioned concerns already raised the importance of clearly defining the C&I, as confusing definitions and delimitations of the criteria and indicators cause an overall lack of transparency in the C&I sets. The exact focus of the indicators isn't always obvious and in some cases the indicators do not really assess what they are supposed to. Indirect political or administrative verifiers can sometimes be used to assess environmental indicators. An example is indicator 5.1 of the pan-European set, characterizing soil and water preservation in forests, which is described as "Area of forest and other wooded land designated to prevent soil erosion, to preserve water resources, or to maintain other forest ecosystem functions, part of MCPFE Class "Protective Functions"" (MCPFE, 2002). The term "designated" illustrates that those indicators are indirect indicators and depend on national standards or on the perceptions of the people who fill in the report. The different administrative standards and classifications as well as the subjectivity of the authors of the national reports can have a significant influence on the reporting results and cause significant differences from one country to another. In a study carried out in the Brazilian Amazon aiming at evaluating the relevance of indicators from various international C&I sets (Pokorny & Adams, 2003), it was established that in general, confusion was also caused by similarities, unclear connections or overlapping indicators. The authors explain the importance of "ensuring a clear hierarchical structure of the C&I sets by checking for repetitions and unclear relations."

All of these concerns or problems highlight the need for harmonisation, intensified analysis and clarification of the C&I sets as well as better understanding and consensus on the meaning of the indicators and the concept of sustainable forest management as a whole. As Pokorno and Adams explain: "in interpreting sustainability as the sum of the assessed C&I, the understanding of sustainability varied strongly between the sets" (Pokorny & Adams, 2003). The network analysis carried out in this study is a first step in this direction, aiming specifically at clarifying the relations between indicators, in the case of the pan-European set allowing another interpretation of SFM.

b. C&I for sustainability assessment and forest certification

In recent years, the uses and applications of C&I have expanded significantly. More than being just a tool for reporting on forest management, C&I have shown to be useful in other contexts, both on the national and international level.

C&I can also be very useful for the evaluation of SFM at a very local scale, meaning at Forest Management Unit (FMU) level. Following the progress of the indicator values enables forest managers to assess the evolution of the state of a forest over time under changing management strategies or changing environment. Local C&I sets are derived from the international sets and in the case of comparison of several local management strategies, the C&I can be used as a basis for **Multi-Criteria Decision Making**. The indicators of the official C&I sets can be used as the "criteria" according to which the different alternatives or strategies are going to be evaluated and ranked, and this technique has been applied in several forest contexts (Mrosek, Balsillie, & Schleifenbaum, 2006).

This kind of local SFM evaluation is encompassed more generally in the so called sustainability impact assessment approach. The aim of Sustainability Impact Assessment (SIA) is to evaluate the impact in terms of sustainability, of certain changes (economic scenarios or policy decisions) on a system, in this case, forest systems. Several large scale projects of SIA in the forest sector have been launched over the last decades. Two main European projects are the SENSOR project and the EFORWOOD project (Lindner, Paivinen, Verkerk, Palosuo, & Suominen, 2009). The SENSOR project (2004-2008) aimed at assessing social, environmental and economic impacts of policy driven land use changes in Europe. The EFORWOOD project focuses on impact assessment of forest industry scenario, evaluating entire forest wood chains.

The main tool used in the EFORWOOD project is called Tool for the Sustainability Impact Assessment (ToSIA) of Forest-Wood-Chains (FWC). In order to be analysed and compared, the FWCs are scrutinised and broken down to individualised processes constituting the different steps (Lindner, Suominen, & Trasobares, 2007). For each process of each WFC, sustainability indicators are established to assess social, environmental and economic impacts. In total, the EFORWOOD tool is based on the collection of 27 main indicators with more than 100 sub indicators. The tool simulates the material flow through the whole FWC. For each process, the ToSIA calculates the value of the corresponding indicators. At the end those values are aggregated for each alternative (each FWC). Cost Benefit Analysis (CBA) or Multi Criteria Analysis (MCA), based on valuation or ranking of the different impacts, can be used to choose the most beneficial of the different alternatives (Prokofieva, et al., 2008). The validity of the model is based on the accuracy of the material flows and indicator calculations, which are complicated by the multiple interactions between the environmental, economic and social sustainability indicators and the corresponding production processes. The integration of an enhanced description of C&I interactivity could contribute to improving the model.

Another essential purpose for sustainability indicators, derived from the previously mentioned applications, is forest certification. Certification schemes are based on the evaluation of forest management and wood trade practices. Indicators are key components of all certification processes since they provide the necessary framework to carry out the evaluation. Certification indicator sets are similar to the international forest reporting C&I sets and cover the same aspects of forest management (PEFC, 2007). The main difference between indicators for certification purposes and the previously mentioned C&I sets is that using C&I for certification requires the establishment of certain rules or thresholds for all of the indicators. In certification procedures, the aim is to decide whether or not the management of a forest is "sustainable enough" according to all the assessed indicators: for each indicator there exists a limit not to be exceeded. This is very different from the C&I for reporting, which are used to describe a situation without "judgment" of the result (Simula, 2003). As we have seen for international C&I processes, the proliferation of certification schemes over the last years has also intensified the need for international coordination. An agreement on a framework for international indicators for certification schemes would be profitable to enhance credibility of the forest certification schemes worldwide.

c. C&I for policy making and explaining SFM through network analysis

The success of the different applications of C&I are dependent on the definition, description and understanding of the C&I frameworks they are based upon. A better description of the interactivity of C&I within SFM systems would be useful not only for those applications, but also for providing a better understanding of sustainable forest management as a whole. Former C&I based descriptions of sustainable forest management tend to be hierarchical, mentioning the three pillars of sustainability and underlying criteria, each with their specific indicators or variables. This description doesn't reflect the reality of SFM, where all dimensions are interlinked and each variable can relate to more than one dimension (see Figure 2). Instead of depicting sustainable forest management as a hierarchical static framework, new approaches address SFM as a dynamic system closer to the panarchy concept which embraces the cross-scale dynamics specific to socio-ecological systems (Janssen, Bodin, Anderies, Elmqvist, & Ernstson, 2006).

Originating from social sciences, network analysis is one attempt to describe the connectivity in a system by investigating and mapping the interactions between its components. Several initiatives have been led in order to apply network analysis approaches to C&I for SFM. Mendoza and Prabhu have conducted a study in Zimbabwe, using soft methodologies - meaning model building methodologies that do not require explicit quantifiable measures - based on a cognitive mapping approach to analyze indicator linkages (Mendoza & Prabhu, 2003). Their work confirmed the utility of network analysis as a participatory tool to discuss, conceptualise and assess SFM in specific contexts. The study provided valuable information on cause-effect schemes and strategic indicators in the C&I set, thereby providing an interesting insight on SFM in the region.

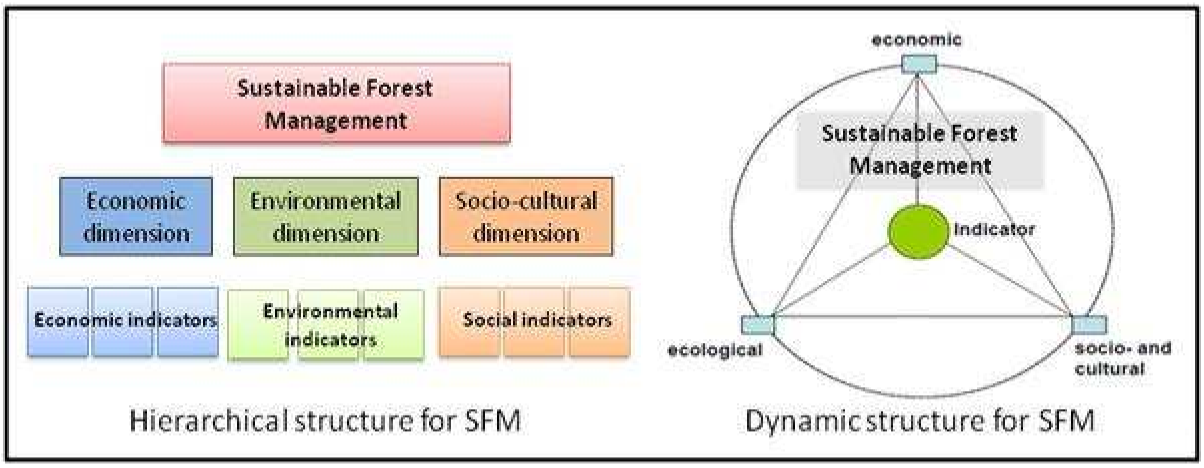


Figure 2: Conceptual frameworks for SFM, ***(source: Requardt, 2007 modified by Sofie Blanchart)***

Similar approaches have been developed in other studies. In a more theoretical context, Requardt has conducted a network analysis of the pan-European C&I. He used the MCPFE background document as source of information concerning the relations between indicators and applied social network analysis methodologies (Figure 3). His study designated core indicators and "left aside" indicators; this classification of the indicators reflects both the real level of connectivity of the indicators in the network but also the subjective point of view of the authors of the MCPFE document (Requardt, 2007). The different methods that can be used for C&I network analysis will be further detailed in part I.0.

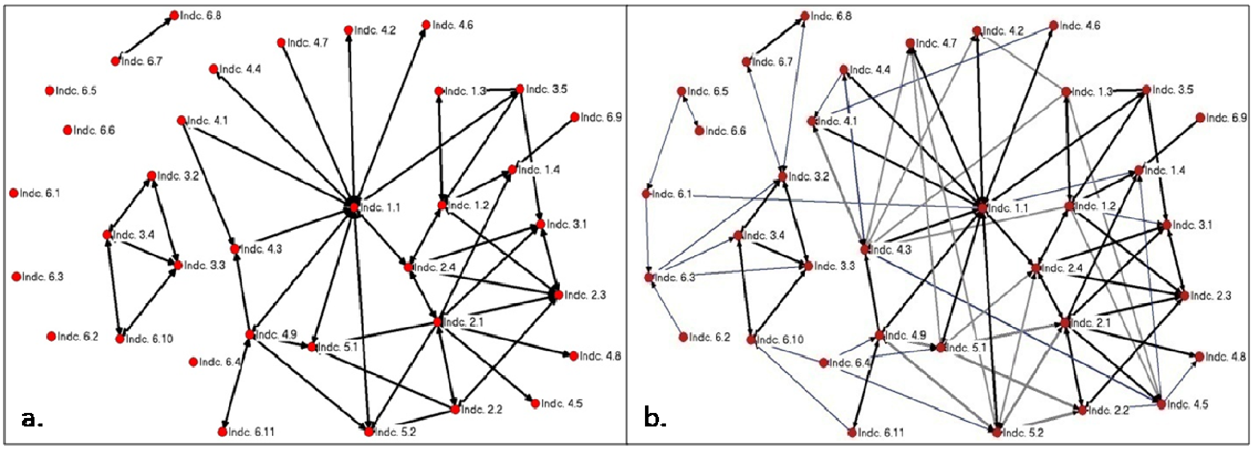


Figure 3: Analytic networks of the pan-European indicators, according to the MCPFE background document (a) then enhanced (b) (Requardt, 2007)

B. Methodological background for network analysis: definitions and tools

The main aim of this study is to investigate best methodologies and tools to illustrate the complexity of the interactions between the various facets constituting multipurpose forest management. The previous paragraph has shown how network approaches can be helpful for achieving this goal. Different network analysis methods exist and can be adapted and used in the context of C&I network analysis (Mendoza & Prabhu, 2006), (Requardt, 2008). Tools and models from other fields such as social sciences, or computer sciences can be studied and adapted to meet the requirement for application in natural resources management. (Janssen, Bodin, Anderies, Elmqvist, & Ernstson, 2006). However, whatever tools are used, one should always keep in mind that the representations used will never truly reflect reality and that "models must be viewed as *problem structuring* tools, rather than *problem solving* methods." (Mendoza & Prabhu, 2006)

The following pages give insight on some methods and conventions about Network analysis and its applications to C&I. The depiction of C&I networks and mapping of the cause effect relations between indicators requires several steps:

1. the identification and description of those relationships
2. the illustration of the network by network drawing
3. the analysis of the depicted network

In this part the choice of the different methodologies that have been used for all of these steps will be explained.

1. Conceptual tools for identifying the interactions of a network

Network data is generally defined by nodes and ties. The nodes correspond to the actors or components of the network and the ties reflect the relationships between those components. In this study the nodes are the pan-European indicators, the ties linking the indicators to each other correspond to the different logical influence paths or cause effect relationships that exist between these. The aim is to describe as accurately as possible the mechanisms at stake in sustainable forest management systems and to break down complex correlations to a succession of direct cause effect relationships.

Different network analysis approaches can be implemented to identify and describe the ties connecting the nodes of a network, (Requardt, 2008) . Several methods can be considered for this study:

a. The DPSIR framework:

The DPSIR (Driving force, Pressure, State, Impact, Response) framework gives one approach to investigate and describe relations between indicators. This method has been used for the classification of environmental indicators by the European Environment Agency (EEA) (Gabrielson & Bosch, 2003) and aims at simplifying the understanding of complex environmental problems.

The DPSIR framework describes environmental systems as causal chains starting from '*driving forces*' (economic, social or demographic developments) through '*pressures*' (physical or biological agents, resources or land use) affecting '*states*' (physical, chemical and biological) causing '*impacts*' on ecosystems, human health and functions, and eventually leading to political (or natural) '*responses*' (prioritization, target setting, indicators). The responses can then have a feedback on all of the previously stated components, as shown in Figure 4. A simplified version is the PSR (Pressure State Response) scheme developed by the Organization for Economic Co-operation and development (OECD).

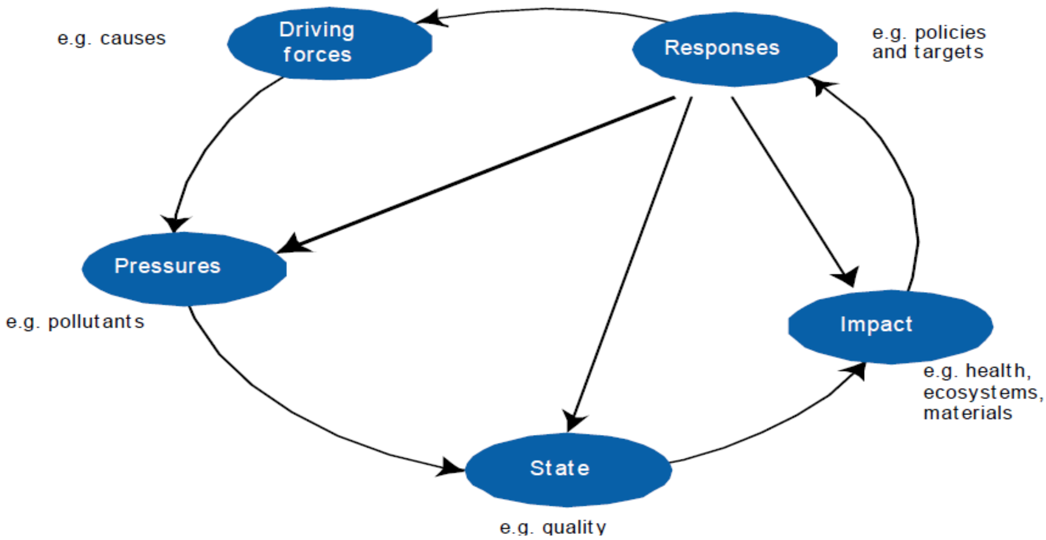


Figure 4: The DPSIR framework for environmental indicators. ***(source: EEA, 2003)***

Advantages and drawbacks of the DPSIR approach:

The DPSIR framework is a quick and easy way to clarify and map the causal interactions between indicators. The five categories are predefined and one only needs to place each indicator into one of those categories. Participatory approaches can easily be conducted, in order to do the classification with a group of actors discussing and agreeing the position of the different indicators in the framework.

Despite its recognition as an interesting tool for synthesising the mechanisms of systems represented by the indicators, criticism has been developed against the DPSIR framework. The oversimplification of complex systems by treating them as simple unbranched cycles cannot reflect the complex interdependencies, synergies or antagonisms of socio-ecological systems. Several authors report that although the DPSIR framework is relevant for illustrating environmental problems and useful for decision making support, "for analytical purposes the scheme is unsatisfying" (Maxim, Spangenberg, & O'Connor, 2009). In some cases the classification of some indicators is quite arbitrary: they could correspond to more than one category, depending on the viewpoint (Ness, Anderberg, & Olsson, 2010).

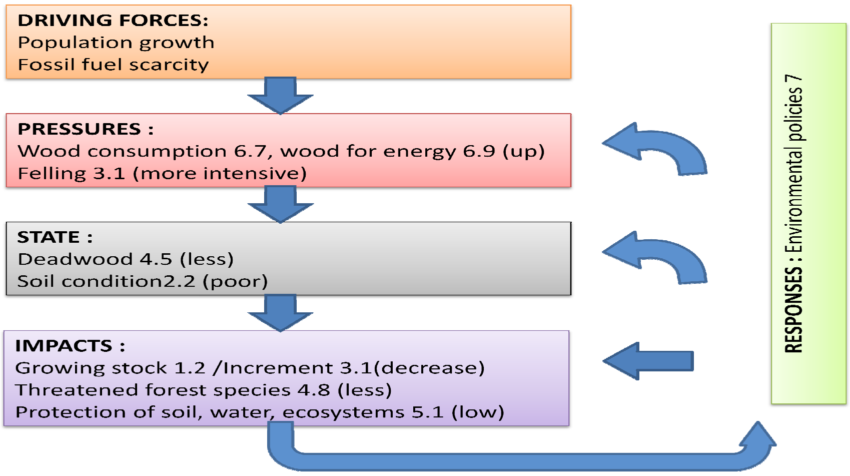
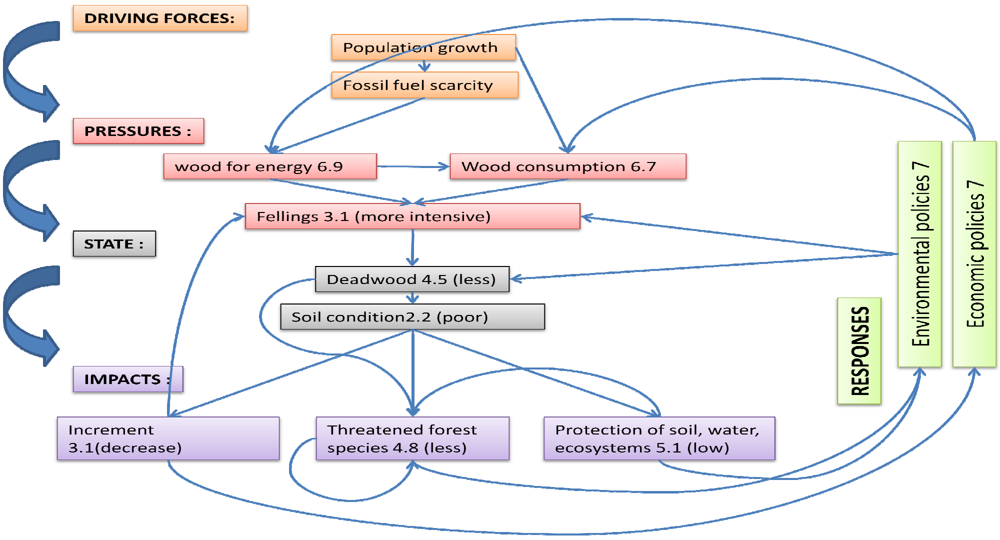


Figure 5: Integrating the indicators linked to "deadwood" in the DPSIR framework

The DPSIR approach can be applied to the pan-European C&I set, for example to deadwood and related indicators as shown in Figure 5 but this picture only represents half the truth. If we dig into the relations between those indicators we can identify more complex interactions, not respecting the linear progression as depicted in "classic" DPSIR frameworks. The inclusion of those additional relations in the previous figure leads to a more complex figure:



Considering in addition that the classification of some indicators in one category or another is purely theoretical and thus subjective, it appears that this method is not really suited to our purposes.

b. Cognitive mapping

Many terms exist to describe the different intuitive techniques that allow the visual illustration of people's mental pictures of a problem or of a system. Whether they are called mind maps, knowledge maps, mental models, causal maps or semantic networks, they all aim to map complex systems by using nodes and arrows. In this document the term cognitive map is used which is defined as follows: a cognitive map is a representation of a person or a group's mental perception of a system and its interactions, in our case applied to SFM.

By definition, cognitive mapping is a very subjective method - the maps reflect the variability of the conceptions people have of a problem (Eden, 2004). They therefore represent a good means to investigate and reveal stakeholders' views and can become an interesting tool for decision making in the forestry field (Tikkanen, Isokääntä, Pykäläinen, & Leskinen, 2006). In the case of this study, cognitive mapping can be associated with the techniques commonly designated as "storytelling" which is generally how the cognitive maps are constructed. To draw the nodes and the ties interlinking them, the most intuitive approach is to tell a story about the concept or system starting with one component and progressively including all other components by "snowball effect", which is how cognitive mapping can be orientated according to a given focus organizing the "story" - limits can also be included in order to keep the story teller on the right "track".

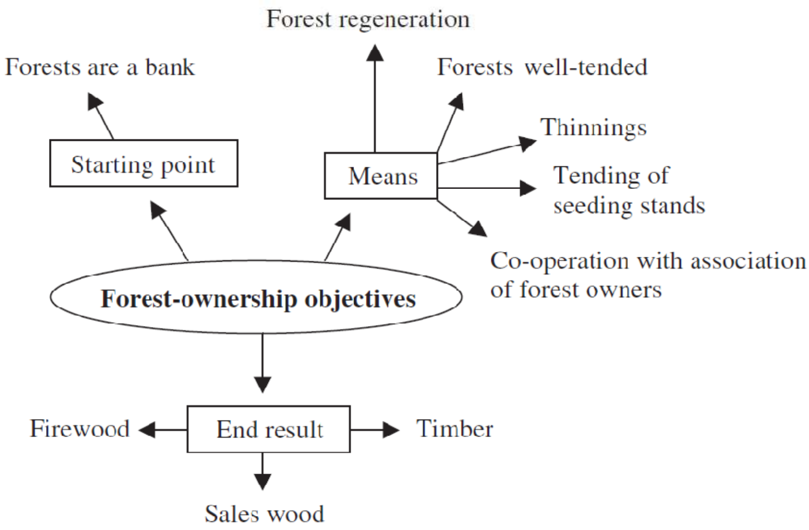


Figure 6: Cognitive map representing forest owners' objectives. (Tikkanen, Isokääntä, Pykäläinen, & Leskinen, 2006)

The maps built by cognitive mapping seem more accurate than the ones obtained within the DPSIR framework; the structure is more complex and closer to reality. However there are many ways of building cognitive maps; Figure 6 is an example of a simple and functional cognitive map organised according to a specific interest, in this case forest ownership objectives, other cognitive maps can be much more abstract and complex when they try to gather all kinds of existing interactions (Figure 3). As a result the main drawback of the cognitive mapping approach is that the final maps can look very different according to who has built them, above all when there were few methodological instructions before starting the story telling. This makes comparison difficult in some cases.

In spite of the previously mentioned shortcomings, the cognitive mapping approach is the one that will serve as a basis to build the C&I networks in this study. Part II.A. details the specific methodology and shows how those shortcomings have been faced.

c. *Using participatory methods*

The two methods detailed above allow to the identification of the interactions existing between components of a network but they are both highly subjective since they are based on the vision of the person who conceives them. Given the complexity of the considered system, one person cannot have a sound and scientifically objective picture of absolutely all the interactions. What is interesting to complete these methods is to take into account as many people as possible in order to have a more global or consensual picture of the system that is described. Workshops and surveys are often the best ways to gather the input of groups of experts.

An interesting tool for example for the participatory classification of the indicators in the DPSIR framework could be the Delphi survey. Delphi surveys are based on an iterative and anonymous discussion process divided in different rounds. A questionnaire is developed and distributed to all the participants in each round of the process, each person fills in the questionnaire and explains his choices. After each round all responses are summarised and reported back to the participants who have the opportunity to revise their judgments in a revised questionnaire, according to the feedback they received. Delphi surveys have been used in the past for defining specific C&I sets (Wolfslehner, Vacik, & Lexer, 2005), (Orsia, Genelettia, & Newton, 2010). On the other hand, for the building of cognitive maps workshops can also be very interesting, an example of workshop applied to the building of participatory networks will be given in part III.A.

d. Data modeling

A completely different alternative to avoid the subjectivity of the cognitive mapping or DPSIR approaches is to use statistical tools. For analysing the maps or networks, especially in a policy making context, quantifying the relationships between the nodes can be very valuable. In order to prioritize the ties in the network and classify the different causal paths, a relative valuation of the ties is necessary. Once the central nodes are identified, data modelling could provide information concerning the strength of the correlation between them (Requardt, 2008). Linear regression and other correlation analyses would be particularly interesting since they allow breaking complex correlations down to individual influences. However, in most cases, not only is there too little data available but moreover, some of the nodes represent very abstract variables that are not really quantifiable. In the case of the pan-European C&I, some of the indicators of criterion 6, grouping social and economic indicators, are not easy to assess with statistical tools. The example of indicator 6.11 assessing cultural and spiritual values of forests can be given: it is not easy to put a note or number on cultural or spiritual values. In summary, while it is true that data modelling could bring some very interesting additional input to the networks in terms of quantifying the interactions, this approach remains very complex. Further developments in this direction can be imagined in the future, based on more robust databases; more thoughts on possible quantitative models will be provided in the outlook of the study (part IV.1.).

2. Networks visualisation tools

The tools that are used for drawing and visualizing the networks are crucial for communication purpose. As stated by (Hanneman & Riddle, 2005): "sometimes the rules and conventions of the language of graphs and mathematics themselves lead us to see things in our data that might not have occurred to us to look for if we had described our data only with words."

a. Matrixes

In general the first step in representing networks is the gathering of the information in form of a matrix. Several types of matrixes exist for network analysis purposes. In this study we will mainly use adjacency matrixes. Adjacency matrixes are square binary matrixes. There are as many rows and columns as there are nodes in the network.

If node B has an influence on node C, the intersection of row B and column C will be filled with a 1, otherwise with a 0 (Table 2Table 1). The adjacency matrix of a directed network is not symmetric.

For valued networks, other matrixes can be used where the 0/1 is replaced by a number illustrating the strength of the relation between B and C (Table 3).

nodes	A	B	C
A	0	0	0
B	0	0	**1**
C	0	0	0

Table 2: Adjacency matrix, example

nodes	A	B	C
A	0	0	0
B	**2**	0	**3**
C	**1**	0	0

Table 3: Matrix of a valued, signed network.

b. Graphs

Graphs allow the visualization of networks - the nodes are represented as dots or circles and the ties between the nodes are visualized by lines or arrows. Graphs can be binary (presence or absence of links) or valued (a value is attributed to the strength of the links often reflected by the thickness of the lines), and they can be directed - in that case the direction of the relation is illustrated by an arrow. In the same way, in a signed graph, each tie is attributed a sign (+ or -) indicating whether the influence is positive or negative. (Hanneman & Riddle, 2005)

The type of graph or its spatial organization can have a significant influence on its interpretation and should therefore be chosen with care. For example, to stress the causal relationships, the nodes which are situated in the beginning of the causal paths can be on one side of the graph and the ones situated in the end or on the right. Other representations put the indicators which are more central in the system in the middle and the others more in periphery, whereas a circular layout is more objective, positioning all the nodes at the same distance from the centre. According to the layout the reader will not notice the same characteristics of the network.

c. *Different software to use*

Several software packages exist, allowing the handling of network matrixes and the creation of graphs. Two software programs have been used in this study: UCINET and VISONE.

UCINET is a social network analysis program distributed by Analytic Technologies (http://www.analytictech.com/ucinet/). UCINET allows the user to import, create and carry out mathematical operations on network matrixes, and to perform specific network analysis, calculating various network descriptive parameters. A program called NETDRAW associated with UCINET is used for visualizing the networks by the creation of different graphs.

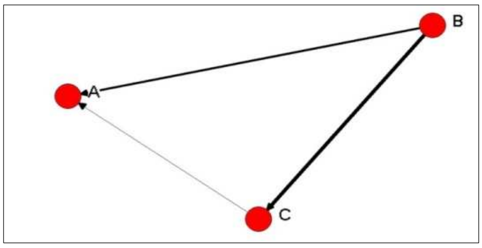


Figure 7: Directed graph for the network of table 4, *(UCINET)*

VISONE is a freeware for non-commercial use, accessible online: http://visone.info/about. VISONE both allows the manipulation of the data and matrixes and visualizing the networks. If UCINET is very efficient for manipulating and analyzing the data matrixes, VISONE contains some interesting visual representations. A circular display mode allows the visualisation of attributes of the indicators within the network, the indicators' position in the graph is determined for example by their centrality, most central indicators placed in the centre of the graph. Modification of node and tie attributes is also facilitated in the VISONE software.

3. Network analysis tools

It was mentioned earlier that the cognitive maps can be interpreted as networks; the tools we will use to analyse them are therefore adapted from the methodologies created for social network analysis. In social sciences the need for studying the structure of networks and the interactions between actors has lead to the development of an adapted and thorough framework including different tools and specific vocabulary.

The notions and measures are defined here based mainly on the California Riverside University's online textbook (Hanneman & Riddle, 2005):

a. *Describing the network as a whole:*

Networks size (Ns) corresponds to the numbers of actors or nodes forming part of a network.

$$Ns = \sum nodes$$

Network density (Nd) corresponds to the proportion of ties depicted by the network as compared to all possible ties; density equals 1 when all the nodes are connected to one another. In a valued network the density is the sum of all the tie values divided by the maximum number of ties.

$$Nd = \frac{\sum ties}{2 \times Ns \times (Ns - 1)} \%$$

b. Describing nodes' position in the network

Centrality is a notion reflecting how central or important one actor is within the network. Studying the centrality of the nodes of a network aims to assess how strategic their position in the network is. Different centrality measures exist:

The **degree** of a node corresponds to the number of direct ties one node has with all the others around it. The degree is limited by the size of the network: in a directed network one can distinguish **indegree**, corresponding to the number of ties received from the other nodes, and **outdegree** corresponding to the ties sent by the considered node.

$$Degree = Indegree + Outdegree$$

The degree calculation takes into account only the relations with directly neighbouring nodes, this approach can be criticized, as centrality should be seen at the network scale and not only locally at the level of one node and its neighbours. If we also want to take into account indirect connections with nodes situated further in the network, we can use the **eigenvector**. The eigenvector is a more complex measure obtained by factor analysis and reflects the centrality of the node within the entire network.

Betweenness centrality is based on the proportion of times that a node of the network is "between" other nodes on the causal paths. The betweenness reflects how many relations depend on this particular node. Betweenness can also be expressed as a percentage of the maximum possible betweenness of a node in the considered network.

c. Describing the relations between 2 nodes

A **path** from node A to node B is the succession of ties and nodes to go from A to B, using each node or tie only once.

Reachability between A and b describes whether or not you can reach B from A or not. If the network is undivided, reachability between any of the nodes is 1.

Point connectivity reflects the number of nodes of the network to be deleted to destroy the connection between nodes A and B. The higher the point connectivity between A and B, the more A and B are connected.

The **geodesic distance** between nodes A and B corresponds to the number of successive ties constituting the shortest path from A to B.

II. Part 1: Constructing and analysing thematic C&I networks.

A. Methodology

1. General objective

The main objective of this part of our study is to investigate the cognitive mapping method and map a first description of the interactions between the different indicators of the pan-European C&I set. One of the prior assumptions is that cognitive mapping is strongly subjective and dependant on personal point of view or focus (Requardt, 2007), (Eden, 2004). In addition multifunctional forest management, is far too complex to be approached with only one "story", the multiplicity of goals and interests represented in SFM is too great. In order to take into account these two assumptions, four networks will be successively drawn, according to different focuses, centred on indicators or thematic areas defined beforehand. The chosen indicators serve as main entry points to "start the stories". Analysis and comparison of the different networks will be carried out in order to discuss the identified relations and to illustrate the subjectivity of the method. A final attempt will be made to aggregate the information contained in each of the thematic networks to find out how this different perspectives can be put together into a global picture.

2. Choice of the focus of the different thematic networks

The choice of the focus to be given to the networks was made according to multiple aspects. The first priority was to tell stories that are relevant to current international priorities; therefore the most relevant issues in the current political context in Europe were investigated. However another important aspect was to correlate the position of they of the indicators in the network with the results of previous classifications according both to data availability, reporting efforts (MCPFE, UNECE, & FAO, 2007) as well as to the results of the previous network analysis (Requardt, 2007). The aim was to check consistency between the results of this study and the previous findings of other works. Therefore it was necessary to select a wide range of indicators from both the top and the bottom of the previous classifications based on data availability and network centrality.

a. Identification of policy relevant topics

In order to identify which indicators were most relevant in the current international policy context, the working pillars or priorities set by some of the main European policy making institutions were analysed. The following information has been gathered:

- main domains of interest of Forest Europe, the former MCPFE process described on the website,
- research programs and the underlying research directions of the European Forest Institute (EFI)
- the Strategic Plan for the UNECE/FAO integrated program of work on timber and forestry 2008-2013 (FAO & UNECE, 2008),
- The European Commission's Forest Action Plan (European Commission, 2006)

The most recurrent themes in all these documents were **wood for energy**, climate change and **carbon sequestration**, closely followed by **biodiversity** and enhancement of the **use of wood**. Once those general themes identified, specific indictors were chosen for each theme to orientate the "stories" according to their data availability and network centrality as given by the State of Europe's Forests report and Requardt's study.

b. Questioning of data availability for the different indicators

Data completeness is treated in the annex 2 of the Sate of Europe's Forests report (MCPFE, UNECE, & FAO, 2007) (Figure 1). The detail of this document reveals very high variability according to data reporting effort with indicators having:

- high data completeness of more than 75% : indicator 3.1 increment and fellings, indicator 1.1 forest area and indicator 5.1 Protective forests - soil, water and other ecosystem functions,
- high data completeness between 70 and 75 %: indicator 3.5 forests under management plans, indicator 1.4 carbon stock and indicator 4.3 naturalness,
- very low data availability, less than 45% completeness: indicator 6.9 energy from wood resources (44%), indicator 6.11 Cultural and spiritual values (34%), indicator 4.5 deadwood (22%) and indicator 3.4 services (20%).

Although the reasons for this unbalanced reporting efforts are not always evident (lack of interest, complex monitoring of some indicators or delay in the development of a monitoring system), it is obvious that the reporting in 2007 was not really consistent with the thematic priorities outlined above. Deadwood which is one of the most relevant indicators for biodiversity is in second last position as far as completeness of the reporting is concerned. Wood for energy, highlighted as a main issue by all the four investigated European institutions is in fourth last position, with only 44% completeness. It would be interesting to focus specifically in this study on those two indicators and try to explain this paradox.

c. Investigation of indicators' network centrality based on former studies

Previous studies have already established classifications of the pan-European indicators based on their network centrality values by applying network approach to the C&I set (Requardt, 2007). The results of Requardt's work based on the mapping of the indicators' interactions as described by the MCPFE background document give interesting input for us. According to the background document, most central indicators by indegree are: forest area, forest growing stock, defoliation and forest damage. Most central indicators by outdegree are: forest area, deposition of air pollutants, defoliation, forest damage and protected forests.

Other indicators were clearly isolated, mainly the socio-economic indicators (indicators 6.1 to 6.6 see Table 1: list of the improved pan-European C&I *(MCPFE, 2003)*). It is clear according to these results that the MCPFE background document lays the stress more on production indicators and forest damage and health indicators, which have historically been the most important issues, at the expense of the more recent socio-economic and biodiversity indicators. Again this is not really consistent with the identified policy priorities.

d. Final selection of themes and corresponding indicators:

According to the previous results and remarks, the different thematic networks that were chosen are the following: 1) a thematic network about biodiversity centred on indicator 4.5 deadwood, 2) network about wood markets focusing on indicator 6.9 energy from wood resources, 3) a network about climate change mitigation mainly based on forest carbon stocks and finally 4) a network about the social values of forests built around indicator 6.10 accessibility for recreation.

3. Construction of the thematic networks

For each of previously selected themes, a network was created; in order to avoid additional bias all four networks were built by one and the same person. The networks were created as cognitive maps built around the pan-European indicator previously defined. The story telling started with that indicator and from there on the development of the entire network was based on a snowball effect: telling the story of one indicator includes the stories of those indicators directly and strongly linked with that first one, and so forth until the story can be considered complete. Once identified, the relations were reported into a contingency matrix as ones and zeros. For each theme, confirmation of the identified relations as well as complementary information was provided by specific scientific literature review (Annex2), the sources of which were reported in a database. The relations remaining unsure after this review were deleted from the network.

The data compiled in the matrixes was then imported in the UCINET or in the Visone software for further analysis and network visualisation. For each case, a visual analysis was conducted completed by statistical analysis of the network size and density calculations and of the main centrality measures comprising Freeman's in and outdegree and betweenness centrality measures. After analysing the results at indicator level the networks and centrality measures were interpreted at the criteria level.

The final goal of the exercise was to depict the inherent cause effect mechanisms at stake in SFM systems. However, the construction of the following thematic networks and the establishment of the ties reflecting the interactions between the indicators depend highly on the interpretation and meaning given to the different indicators. In this study the idea was to stick as much as possible to the definitions and descriptions of the indicators as given by the MCPFE background document (MCPFE, 2002). In addition, because of the complex entanglement of the environmental, social and economic aspects, all the indicators are somehow correlated to each other by more or less direct connexions, however one of the main difficulties of the methodology was to break the complex and numerous relations down to a limited number of essential direct interactions describing as accurately as possible the exact cause effect mechanisms.

4. Choice and meaning of the network analysis measures

The different notions used here are defined in part I0.

The analysis of the networks is mainly based on network size and density measures when the aim is to evaluate the overall complexity of the network, and on betweenness centrality measures as well as Freeman degree centrality when one wants to assess a node's strategic position within the network.

Network size corresponds to the amount of nodes composing the network. In the following networks it was decided to define the size of the network considering only the nodes directly used in each of the networks. Network size is therefore always less than 35 for the thematic networks never include all of the 35 pan-European indicators. After determining network size, one of the first measures to be calculated for each network is network density. The higher the density the more the network is complex with an increasing amount of interactions. Similarly, the complexity increases with network size. However, since network size depends rather directly on the operator's estimation of where the story ends, network density is a more reliable complexity measure. Comparing the complexity of the different thematic networks reveals which of the international priorities will be most difficult to address and might need more input in terms of research and resources.

Analysing centrality measures can be very interesting for comparing the monitoring need of all the indicators. Generally one can state that indicators with a high centrality need more intense monitoring. Centrality measures are also very valuable in a decision making context; a high in-degree measure gives some valuable information about which indicators are easily influenced and thus very sensitive to changes in the system (high indegree), and which indicators on the opposite have a higher inertia (low indegree). On the contrary, a high outdegree reveals influential indicators that impact many others; those indicators can be interesting since modifying them allows to significantly adjust the system, but they can also be very tricky since they compromise the stability of the whole system.

It is important to note here that in the following the degree is calculated with differentiation of incoming and outgoing ties, if an arrow is two headed, then this tie will be counted twice for calculating the degree, once as an incoming arrow and once as an outgoing tie. As a result, a degree equalling 10 doesn't mean that the node is related to 10 other indicators but that the sum of received and sent ties is 10.

5. Description of the network merging approach

Once all the networks have been analysed separately, additional information can be obtained by merging networks together. These combined networks are obtained by adding the matrixes of different individual networks; the tie values sum up and the resulting value of tie strength represents the repetition of this particular relation in all the networks. Two by two merging of networks can be of interest to study specific questions dealing with problems that affect two of the themes in case of confrontation of two interests on a specific topic. Merging all the networks together is one way to approach the full picture of SFM integrating all different views.

In addition, in order to simplify the network and have a more synthetic view, the information contained in the indicator networks can then also be aggregated at criteria level. Therefore the values of the matrix obtained by summing the thematic networks, were summed again within each criterion, a new matrix sizing 6 by 6 is obtained describing the merged SFM network aggregated at criteria level. The value of the tie between criteria A and B corresponds to the sum of all the ties going from one indicator of criterion A to one indicator of criterion B.

B. Results

1. The thematic networks

The different networks were built according to the four chosen indicators corresponding to the four different policy relevant themes. Although cognitive mapping was initiated by one particular indicator, the story telling procedure quickly lead to the inclusion and even in some cases a progressive shift of the focus, towards other indicators that were relevant in the story. Concretely, the "telling of the stories" often corresponded to asking some basic questions starting with the initial indicator. I am interested in the amount of deadwood in the forests, how can I increase this amount of deadwood, what will be the result of this increasing on other indicators? What will then be the effect of the increase of those other indicators? The snowball effect leads to the drawing of an entire picture that ends when there are no more significant effects to be added.

According to their focus the networks were not all equally easy to construct. While the interactions involving deadwood and environmental indicators, as well as the mechanisms ruling carbon stock evolutions, are explained by physical interactions that are easy to establish, network b. shifts the focus more towards the economic aspects, with more complex interactions. Economic and market mechanisms can be very complex and unsteady and often they are also integrated in more global economic systems. Therefore it is unrealistic to pretend to reflect those interactions accurately within the limits imposed by the use of the pan-European C&I set. Some relevant aspects of forest economics are not described by the indicators, non-energy wood products for example are not represented by any indicator, therefore the competition between wood energy and other wood products is not visible and the picture is simplified. The definition of the indicators as given by the MCPFE background document is not always precise as to the interpretation of the indicators in a market context. Trade of wood refers for example both to importations and exportations, that is why this interaction cannot be reduced to a simple cause effect relationship and appears in this network with two-headed arrows. To tell a coherent economic story, it was chosen that, in this network, indicator 3.2 roundwood would approximate the supply function and indicator 6.7 wood consumption, the demand function. The last network described in this paragraph is devoted to the interactions concerning the social values of forests which can be hard to describe in terms of functional interactions. As compared to economic and production interactions or to biological mechanisms, social values are hardly quantifiable and assessable and therefore their evaluation is highly subjective. However, recent studies investigating the main drivers of forest recreation have been published lately, (Hilger & Englin, 2009) (Rusterholz, Bilecen, Kleiber, Hegetschweiler, & Baur, 2009) (Zandersen, Termansen, & Jensen, 2007) providing additional input for identifying the relations drawn in this picture (Figure 8).

As a result of this variability, the four stories result in the creation of diverse networks with different shapes and structures as shown in Figure 8: Thematic pan-European indicator networks. Software: UCINET6, Netdraw

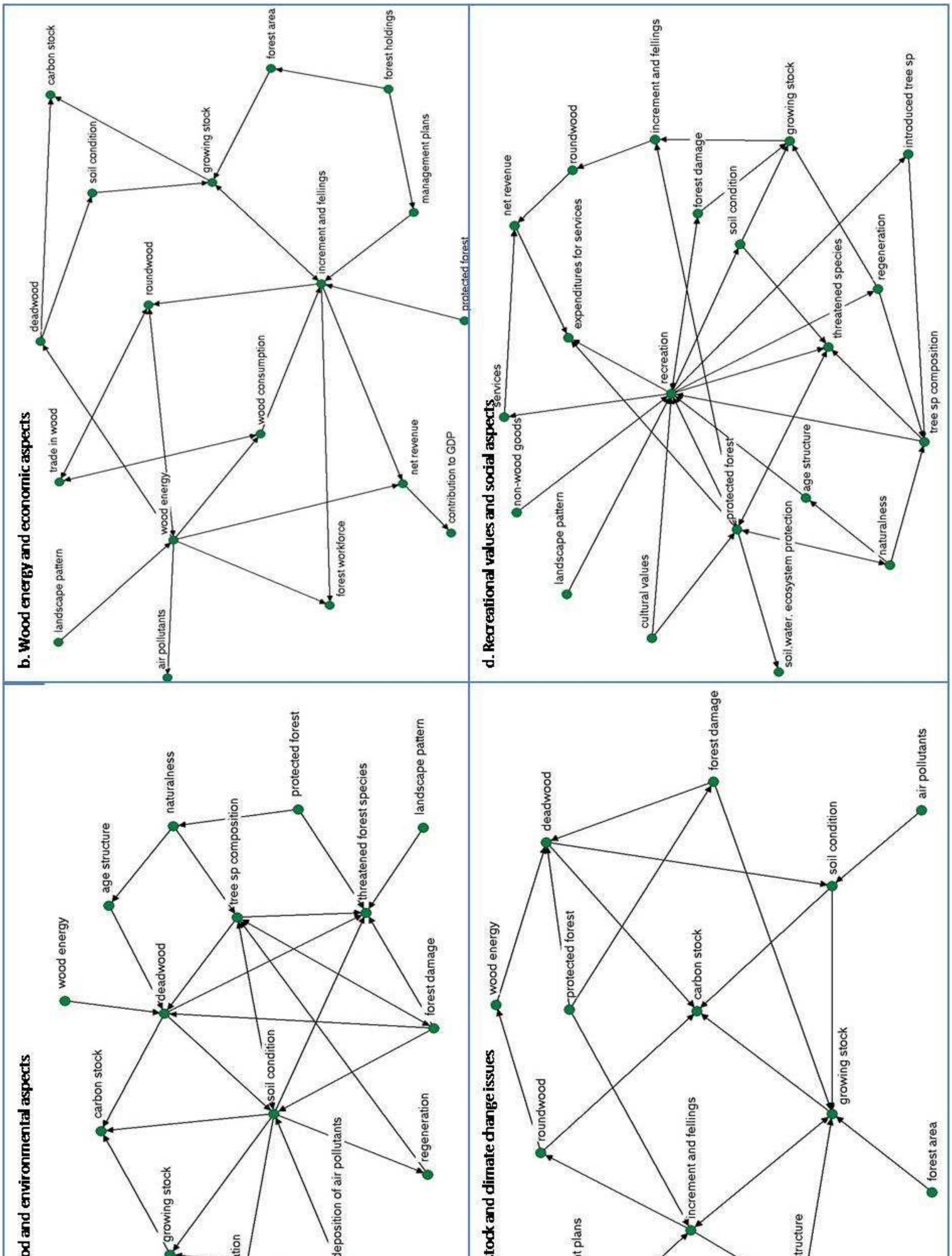


Figure 8: Thematic pan-European indicator networks. Software: UCINET6, Netdraw

The complexity of these networks as given by their size and density is also relatively variable, some themes naturally include much more indicators than others as it is the case for example for the network focusing on recreation and social values contradicting previous results mentioning that recreation wasn't a very central indicator. The density obtained for the networks is situated between 9 and 14 % (Table 4) these figures reveal that even though the graphs seem quite complex, only a limited number of direct connections are made. All indicators are connected but, as in most networks or systems, most of the indicators are not linked by direct influence but following more complex cause-effect paths involving several other indicators. The network revealing the highest density and thus the highest level of entanglement is network a focusing on deadwood and environmental values. On the contrary the carbon stock story is a quite simple one. Since carbon storage is the ultimate goal in this scenario and is therefore clearly situated in the end of the causal path, the building of this story simply consisted of tracking back the factors influencing carbon stock evolutions. The existence of a wide range of clear and recent literature on this subject, allows drawing a quite clear and simple picture of the main mechanisms. However, the significance of some of those relations still remains to be discussed; only the solidly attested ones are reported in this network.

	Network a. (deadwood)	Network b. (wood energy)	Network c. (carbon stock)	Network d. (recreation)
Network size	15	18	13	20
Network density	14.3 %	9.1 %	13.5 %	9.5 %

Table 4: Recap tab of thematic network complexity measures

2. Indicator centrality in the networks

As mentioned earlier the networks described in this part are simplifications of reality, one should always be careful with the interpretation of the centrality measures when these models are only a simplification of reality.

Network a. deadwood and biodiversity aspects:

In Figure 8.a. it can be easily noted that not all the indicators have similar positions and roles in the network. The importance of the different indicators was assessed by different centrality measures, the results are given in Table 5.

N°	indicator	Degree	Betweenness (%)	Indegree	Outdegree
2.2	soil condition	10	38.60	4	6
4.1	tree sp composition	8	28.77	4	4
4.5	deadwood	7	19.82	4	3
4.8	threatened forest species	6	0.00	6	0
2.4	forest damage	5	0.00	1	4
1.2	growing stock	4	1.58	3	1
2.1	air pollutants	3	0.00	0	3
1.4	carbon stock	3	0.00	3	0
2.3	defoliation	3	0.00	2	1
4.3	naturalness	3	9.47	1	2
1.3	age structure	2	1.75	1	1
4.9	protected forest	2	0.00	0	2

4.2	regeneration	2	0.00	1	1
4.7	landscape pattern	1	0.00	0	1
6.9	wood energy	1	0.00	0	1

Table 5: Deadwood network, indicator centrality values, source: *Visone*

Most central indicators according to both degree and betweenness centrality are respectively indicators 2.2 soil condition, 4.1 tree species composition and 4.5 deadwood. It is interesting to notice that deadwood, which was the starting point of the storytelling, is not in first position, showing that the final structure of the network does not depend entirely on the choice of the indicator initiating the story. In this case two other indicators appeared as core indicators. Soil condition has both a high indegree and a high outdegree, meaning that it has a lot of influence on the related indicators but also that it is influenced by many indicators. This is confirmed by a high betweenness, the indicator being situated on a high number of paths between other indicators.

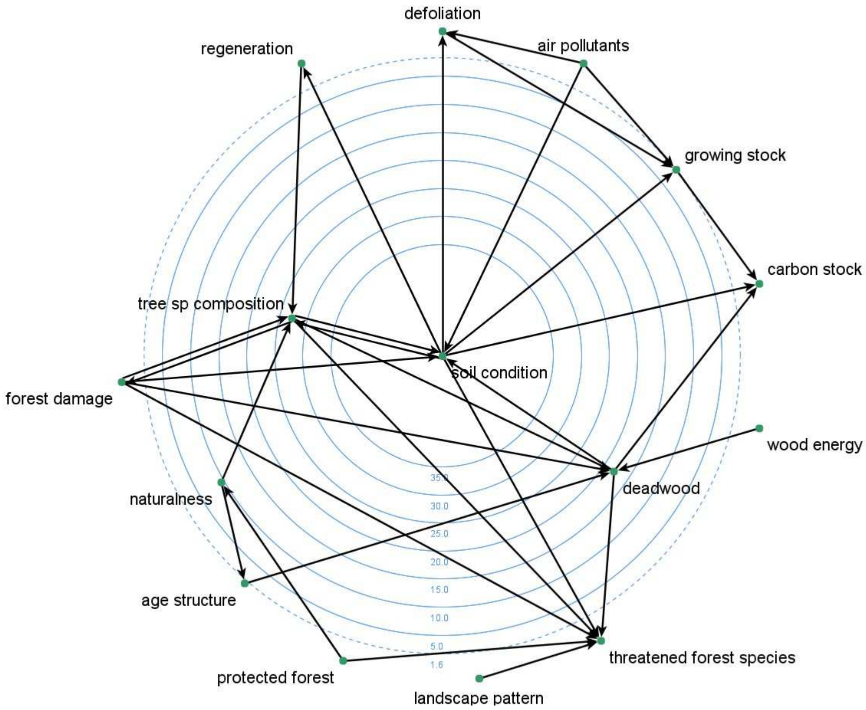


Figure 9: deadwood network display centred on betweenness centrality, Visone

A closer look at the in- and outdegrees of the indicators shows that some indicators are situated rather in the beginning or at the end of the causal paths. The indicator “threatened forest species” for example has a very high indegree and a zero outdegree, this means that many factors have an influence on this indicator but that it has no influence on other indicators, in this particular case. On the contrary, deposition of air pollutants has a very high outdegree, this factor affects many other indicators, but it is not affected by other indicators. Those indicators with an overall high betweenness centrality, such as soil condition, both influenced by and influencing a high number of other indicators, are very strategic, they are very important both in system regulation and in system monitoring perspectives. Information on in and out-degrees can be very valuable for evaluating the indicators in a decision making approach. Indicators with a high outdegree and a low indegree, such as air pollutants in this case, can cause problems since they affect the state of many other indicators but there are few alternatives for regulating them. In the network we are considering, if the policy aim is to have a positive impact on threatened species, several solutions exist according to the schemes drawn by this network. One scenario would be to increase the amount of deadwood, another scenario could consist of establishing a protected area in a specifically threatened area, or of encouraging the maintaining of high tree species diversity by setting new rules for forest harvesting.

The notions of in and outdegree are however not always that simple. One can consider that a high indegree is positive since it means that there are many ways to have an impact and thus to regulate a given indicator A. On the other hand a high indegree also means that once the indicator has reached a satisfying value, an intervention on another indicator B in the system has higher probability to impact also indicator A, with a possible negative impact. As a result, system regulation as a whole becomes very complex. The above-mentioned indicators are essential for understanding the mechanisms at stake, as far as deadwood and biodiversity are at stake, and should therefore be a priority in the monitoring processes. However, when examining the State of Europe's Forests report (MCPFE, UNECE, & FAO, 2007) it appears that those indicators are far from being in the centre of the monitoring efforts. Both dead wood and tree species composition are amongst the indicators with lowest completeness rates (Figure 1) with respectively 36 and 47 % for the entire MCPFE region. Data for soil condition was not provided by the countries but by the ICP, the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests of the UN, and data completeness of this indicator is therefore not reported in the report.

Completeness data shows on the other hand that other biodiversity indicators such as protected areas and naturalness have significantly higher data completeness. It's interesting to note that those indicators are not assessing the state of biodiversity but only quantify the classifications of the forests and the measures taken, without considering their efficiency. Data concerning this kind of indicators is easy to collect since they are included in the management plans. It is regrettable to see that data collection effort is based more on difficulty of the collection than on relevance of the indicators themselves.

Network b. Wood energy and economic aspects

In this network, the two most central indicators according to degree are indicator 3.1 increment and fellings and indicator 6.9 wood energy (Table 6). They both have the same degree but indicator 3.1 has a higher betweenness centrality, meaning that it is involved in more causal paths between other indicators, whereas wood energy has a low indegree but a higher outdegree and is thus situated rather at the beginning of the causal paths. This can be rather surprising; while wood energy is considered mostly as a goal to achieve, the results of this network approach reveal that wood energy mainly has an influence on many other aspects of forest management. We can mention for example the effect on biodiversity through the decrease of deadwood. However, one should keep in mind that a low indegree does not necessarily mean that there are no means to regulate this indicator. Actually it only means that within the indicators set that we are studying there are little indicators directly impacting wood energy. There are however other means to do so, for example political decisions can have an important impact on wood energy, as well as national or local recommendations or programmes that promote the utilisation of wood for energy purposes with specific subsidies.

Other important indicators, according to centrality measures are 1.2 growing stock and 3.2 roundwood. In comparison with the deadwood and biodiversity network the two most central indicators are very clearly isolated in this network.

N°	Indicator	Degree	Betweenness (%)	Indegree	Outdegree
3.1	increment and fellings	8	27.63	4	4
6.9	wood energy	8	17.83	2	6
1.2	growing stock	5	12.46	3	2
3.2	roundwood	5	18.60	3	2
6.8	trade in wood	4	2.60	2	2
6.7	wood consumption	4	3.21	2	2
4.5	deadwood	3	5.26	1	2
6.3	net revenue	3	4.32	2	1
1.4	carbon stock	2	0.00	2	0
1.1	forest area	2	0.66	1	1
6.1	forest holdings	2	0.00	0	2
6.5	forest sector workforce	2	0.00	2	0
3.5	forests management plans	2	3.65	1	1
2.2	soil condition	2	3.77	1	1
6.2	contribution to GDP	1	0.00	1	0
2.1	deposition of air pollutants	1	0.00	1	0
4.7	landscape pattern	1	0.00	0	1
4.9	protected forest	1	0.00	0	1

Table 6 : Wood energy network, indicator centrality values, source: Visone

Monitoring efforts should therefore be intensified especially on those two very central indicators. In the case of increment and fellings, we have seen in the background chapter that it is the indicator with the best reporting results as far as the MCPFE State of Europe's forests reporting is concerned (Figure 1) with 79% of data completeness. In this particular case this intense monitoring effort seems justified in the light of the centrality measures of the indicator. On the other hand, monitoring on energy from wood indicator could still be improved since data completeness is only 44%. One of the reasons why reporting on wood energy can be difficult is that in some places the high rates of auto consumption cause the indicators to be hard to assess, in general even for those countries who report on the indicator the uncertainty level is very high.

According to the betweenness of the different indicators in this network, increment and felling appears as the most efficient way of regulating the development of wood energy. And if we follow the causal chain one step more, we find there are several ways of modifying increment and fellings: enhancing the growing stock, improving the management plans, boosting wood energy consumption and modifying the surface or the regulations of protected areas. The most relevant solutions can be selected amongst those alternatives. In the networks presented here the relations' strength is not characterized, in more sophisticated models the integration of tie strength would allow also to choose which alternatives are more efficient.

If we then want to look at the effects that the enhancement of wood energy systems will bring about, the high outdegree value of the wood energy indicator shows that many other variables are likely to be affected by this change. Some indicators are rather at the margin of the network such as air pollution and to a certain extend deadwood also, but what is interesting to notice is that there are also some feedback loops for example with an influence of wood energy on wood consumption and then back on increment and fellings. This feedback loop explains how, to a certain extend the increasing of wood energy will be auto sustained; the demand will increase with the spread of wood energy installations and projects. The identification of these complex feedback mechanisms is crucial for understanding and managing the system.

Network c. Forest carbon stocks

The two most central indicators in this network are indicator 1.2 growing stock, in first position according to total degree and indicator 3.1 increment and fellings most important indicator according to its betweenness centrality measure with a value of 26 % (Table 7). Indicator 1.2 has a remarkable high indegree and a low outdegree, as a matter of fact shows that this indicator is directly influencing carbon stock and is thus in penultimate position in the chain. Carbon stock itself is situated only in fourth position according to its degree and has a zero betweenness centrality due to the lack of outgoing ties; once again the indicator initiating the story is not preponderant in the final network.

N°	Indicator	Degree	Betweenness (%)	Indegree	Outdegree
1.2	growing stock	7	23.89	5	2
3.1	increment and fellings	6	26.43	3	3
4.5	deadwood	5	11.78	3	2
1.4	carbon stock	4	0.00	4	0
2.2	soil condition	4	12.10	2	2
3.2	roundwood	3	14.65	1	2
2.4	forest damage	3	0.32	1	2
4.9	protected forest	3	0.00	0	3
1.3	age structure	2	0.00	1	1
6.9	wood energy	2	10.83	1	1
2.1	deposition of air pollutants	1	0.00	0	1
1.1	forest area	1	0.00	0	1
3.5	forests management plans	1	0.00	0	1

Table 7: carbon stock network, indicator centrality values, source: Visone

Growing stock is thus definitely a crucial node in the network to be reported on thoroughly in order to evaluate forest carbon stock changes. Especially as we know that not only it is the most central indicator in the network but it also represents in most cases the highest proportion of carbon stored by the forest sector – if we put aside soil carbon whose current stocks and variations are tricky to asses – exceeding carbon stored in roundwood, deadwood (Goodale, et al., 2002). This information of the relative strength of the relations, which unfortunately our non valued network approach cannot transmit, reinforces the conclusions given by the centrality analysis. Once again if we report to Figure 1 it can be seen that the reporting effort on this indicator is already relatively high with a data completeness of 72 %, this effort should be maintained and enhanced. The importance of indicator 3.1 increment and fellings, already mentioned in previous networks is confirmed again here.

As to the means for enhancement of carbon stocks, growing stock is definitely an important trigger, the high indegree means that there are several options as shown in Figure 8: increasing forested areas and promoting tree plantations (indicator 1.1 forest area); implementing more dynamic sylvicultural techniques (indicators 3.1 increment and fellings and 1.3 age structure and diameter distribution), combating forest and soil degradation (indicators 2.4 forest damage and 2.2 soil condition). Decoding the network in more detail can give more input as to how those different alternatives are related and how they can be established. Similarly to the wood energy network, in this case we can see that, on the other hand, the pan-European indicators are insufficient to take into account the long term effects of carbon stock enhancement.

Network d. Recreational values and social aspects

At a first glance in Figure 8 it can be noted that this particular network has a very star-shaped layout, with indicator 6.10 forest recreation in the centre and most of the others radiating from there. As a result Indicator 6.10 is obviously ahead of the other indicators according to the centrality measures given in Table 8, the indicator has both a high in and outdegree resulting in a high betweenness centrality. This result clearly contradicts some results of former studies. A previous network analysis of the pan-European C&I set (Requardt, 2007), describing relations between the indicators based on the information given in the MCPFE background document (MCPFE, 2002), classified indicator 6.10 with a very low centrality, connected to only 2 other indicators within the network. The picture drawn in our network strongly refutes that idea. Given the high outdegree of recreational values in this network, this factor can have a significant influence on other systems and requires appropriate monitoring. The reporting effort on this specific indicator on European scale described in Figure 1 shows that actual monitoring is rather high with a 64 % of data completeness, matching the high centrality described here. Another indicator appearing as particularly central in this network is indicator 4.9, protected forests with a high outdegree. Protected forests have a direct influence on forest recreation but also on many other aspects and can therefore play a crucial role in system regulation.

N°	Indicator	Degree	Outdegree	Betweenness (%)	Indegree
6.10	accessibility for recreation	14	7	32.07	7
4.9	protected forest	9	6	19.39	3
4.8	threatened forest species	5	1	13.75	4
4.1	tree sp composition	5	2	8.48	3
1.2	growing stock	4	1	3.87	3
4.3	naturalness	4	3	4.11	1
6.4	expenditures for services	3	0	0.00	3
2.4	forest damage	3	2	1.53	1
3.1	increment and fellings	3	1	5.37	2
6.3	net revenue	3	1	1.15	2
4.2	regeneration	3	2	2.34	1
2.2	soil condition	3	2	1.53	1
1.3	age structure	2	1	0.74	1
6.11	cultural and spiritual values	2	2	0.00	0
4.4	introduced tree sp	2	1	0.81	1
3.2	roundwood	2	1	1.93	1
3.4	services	2	1	2.94	1
4.7	landscape pattern	1	1	0.00	0
3.3	non-wood goods	1	1	0.00	0
5.1	protective forests - soil,water and ecosystems	1	0	0.00	1

Table 8: recreation and social values of forests, indicator centrality values, source: Visone

The high number of indicators involved and the high indegree of the indicator for forest recreation make it rather complex to take concrete decisions about how to enhance recreational values in forests, too many options exist and complementary analysis focusing on weighing the relations would be particularly useful in this case. The same goes for the effects of increased recreational activities in the forests. A simplified view on a criteria basis will in this case give clearer information.

3. Centrality and relative importance of the criteria in the networks

Another interesting point for investigation concerns the representation of the different criteria in the networks. Figure 11 shows which criteria are involved in the story on deadwood and biodiversity. According to the number of indicators, biological diversity is in first position as expected, since almost half of the indicators are part of criterion 4. Criterion 2, health and vitality, is in second position, thereby highlighting the strong correlation between forest vitality and biodiversity indicators. With only 27% of the indicators for 32% of total degree, indicators of criterion 2 appear to have a very crucial role in the network. A more detailed analysis based on in and outdegrees reveals that if we consider only the network's indegrees, representation of criterion 3, forest resources, becomes more significant (Figure 10.c.). Criterion 3 takes the second position with 24% of the total indegree meaning that forest production is seriously affected by changes in biodiversity. On the contrary, when taking into account only the outdegree, indicators of criterion 2 Health and vitality gain importance and are preponderant with 47% of total outdegree (Figure 10 d.) revealing this time how forest health and vitality has a clear impact on the forests' diversity; in the perspective of this network health and vitality indicators appear to play a key role to monitor and to try to limit biodiversity loss. This criteria approach gives a clearer picture on how the main facets of forest management (represented by the criteria) are represented in the network. For example by revealing how health and vitality influences biodiversity or by showing how biodiversity loss can have an impact on forest productivity. This visual representation could make stakeholders realize how crucial it is to preserve biodiversity not only for conservation issues but only for economic and sanitary reasons.

In a wood energy scenario such as in network b. more criteria are involved in the network, wood energy and forest economics appear in Figure 11 as more cross-sectoral issues at the crossroads of social, financial, production, sanitary and environmental concerns. Indeed, more criteria are involved even though the criteria distribution is still not really balanced. The socio-economic indicators remain dominant, not only because the focus is laid on an economic indicator but probably also because this criterion is most represented in the C&I set ((MCPFE, 2003). It's interesting to note that although biodiversity indicators are significantly represented in number, when it comes to the degree they are less important, meaning that although several biodiversity indicators are involved in this story, they are rather marginal in the system. On the contrary both according to in and outdegree the productivity indicators appear as very relevant with respectively 29 and 25 % of the total, highlighting the high interconnection between the economic and production indicators in the wood energy context.

Figure 13 corresponding to the carbon sequestration scenario shows a more balanced representativeness of the different criteria. All criteria are represented in this network excepted criterion 5: maintenance and appropriate enhancement of protective functions in forest management. Once again we can see that the system is interweaving closely indicators from various criteria, and is very cross-sectoral. As can be seen in Figure 13**Erreur ! Source du renvoi introuvable.**, the three preponderant criteria in this network are criterion 1 related to forest resources, criterion 2 related to health and vitality and criterion 3 related to productive functions. As mentioned earlier, the implication of socio-economic factors, appearing as rather insignificant in the diagrams, might be underestimated in this picture, again because of the long term effects of climate change on people and on the economy, which are not included here. When focusing on the indegree (Figure 13.c.) Forest resources comprising carbon stock are clearly dominating, with 48% representativeness, meaning that they are subject to many influences; on the other hand, according to the outdegree, productive functions are taking more importance. As a result, in the context of regulating forest carbon stocks, efforts for monitoring the evolutions of the system should be focused on forest resources indicators whereas the domain of production indicators might be more suitable for intervention in order to regulate the system. Once more one shouldn't forget that not all the aspects of the question are reflected since the long term effects of carbon storage on economics in the perspective of the global carbon market are not reflected in this network. In the long run carbon storage has also a positive effect on climate change and thus on forest health and vitality. However, those effects are at a too large scale, both in space and time, to be taken into account in this work.

Finally Figure 12 shows for the only time a network including all the criteria, although their distribution is far from being balanced. This consolidates the previous statement that recreation and social values are very strongly interconnected with all of the other criteria. Biological diversity indicators are prevalent in this story, according to the number of indicators in the first place, with 35 % of the indicators involved in the network, but even more according to the degree with 40% of the total degree. With a high cumulated indegree as well as a high cumulated outdegree biodiversity indicators are related as much with the drivers of forest recreation as with the positive or negative consequences. Second most important criterion in the recreation context, according to number of relations established, is criterion 6, related to socio-economic functions with 35 % of all ties for only 20% of indicators. Given the higher indegree, socio economic indicators seem to be connected more to the consequences of forest recreation activities than to the drivers in this system. If we take a closer look at the interactions between biodiversity and recreation, it's easy to imagine that while the impacts of biodiversity on recreation value are probably rather positive, with people preferring more natural stands (Zandersen, Termansen, & Jensen, 2007), the overall impact of recreation in forests on biodiversity is rather negative as shown by (Leung & Marion, 2000) and (Blanc, Marion, & Granet, 2007). This means there is a negative feedback loop which is very important to take into account to implement efficient measures for enhancing recreation. If this feedback effect is not taken into account there is a risk that the actions that are implemented cancel each other out, the presence and specific management of some specifically well-liked species causes in some cases over frequentation of the habitat resulting in habitat destruction and lower population levels which then again takes the recreation value down. For this kind of interpretation it is important to consider whether the interactions between the indicators are positive or negative.

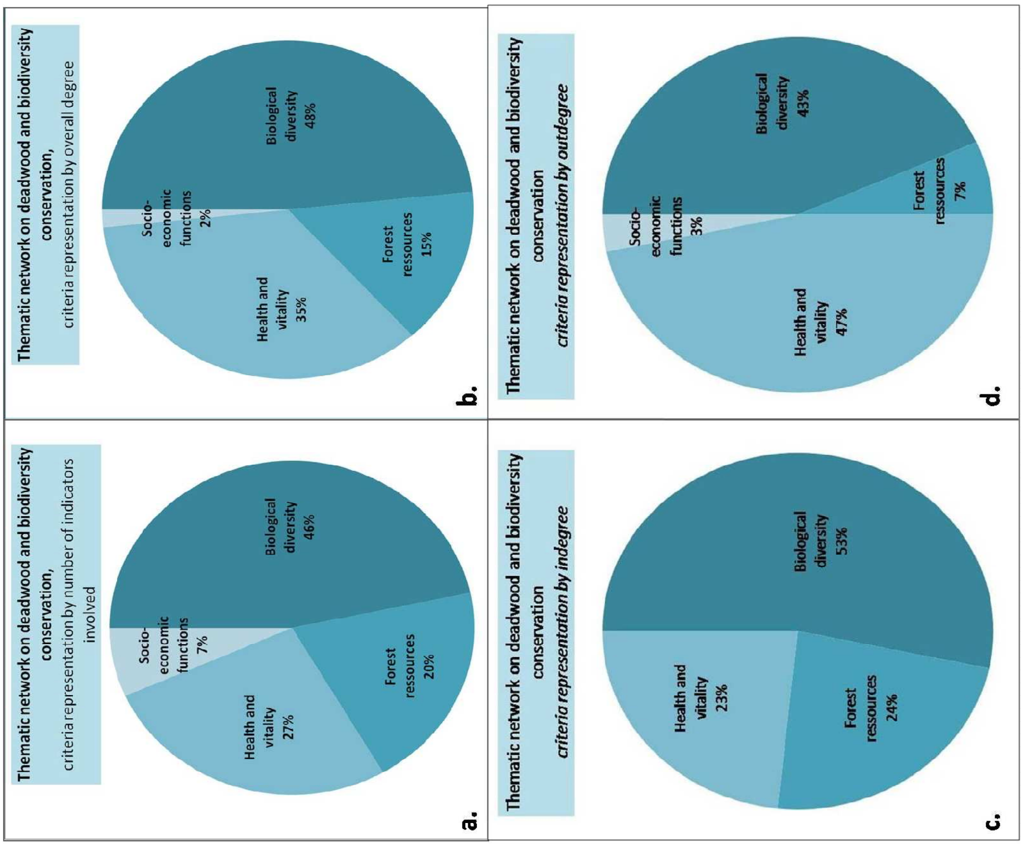


Figure 11: Criteria representation in network a. on deadwood and biodiversity conservation

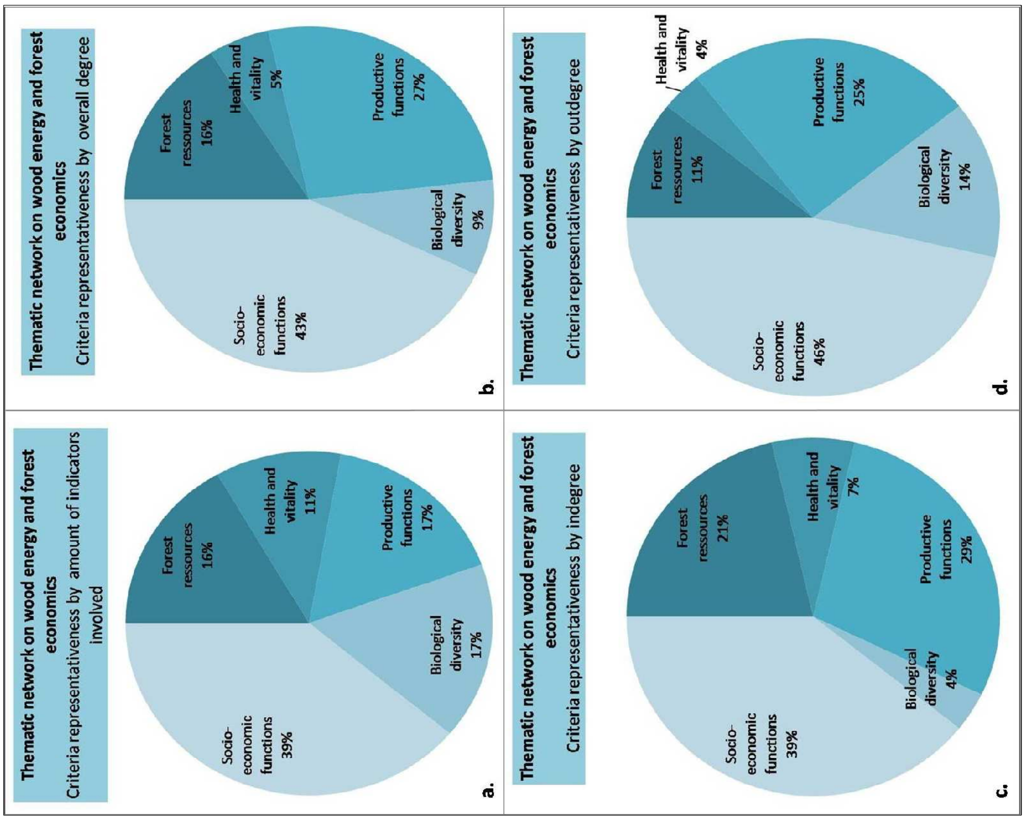


Figure 10: Criteria representation in network b. on wood energy and forest economics

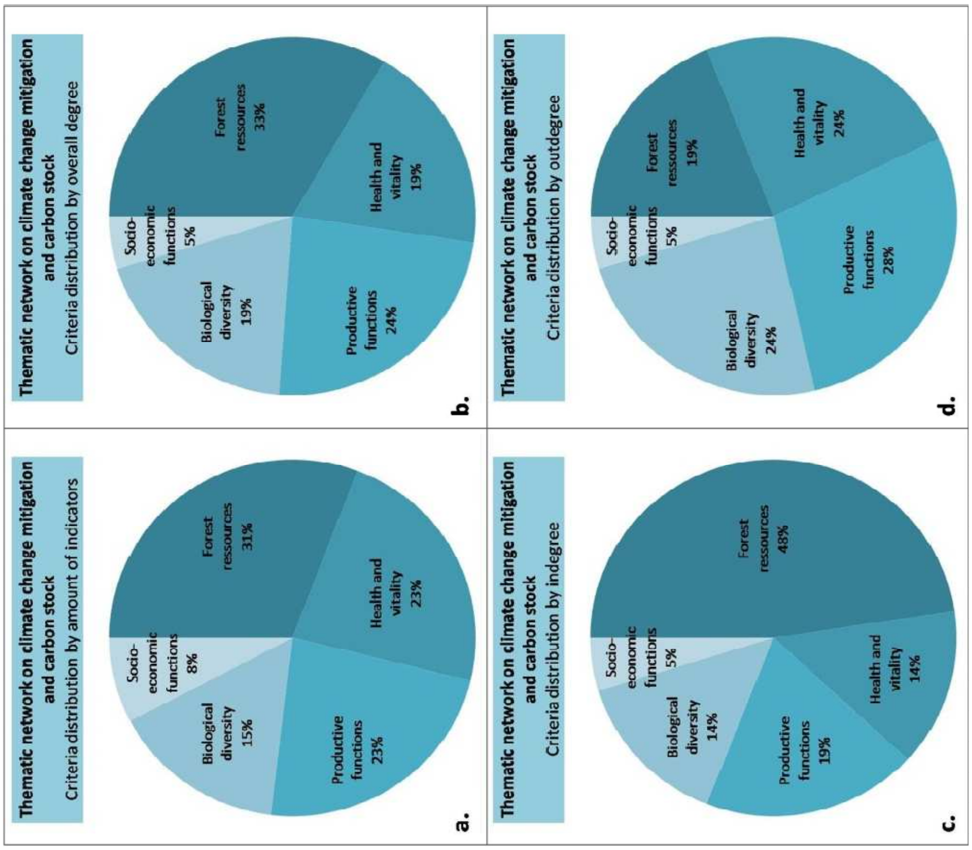


Figure 13: Criteria distribution in the thematic network on climate change mitigation and carbon stock.

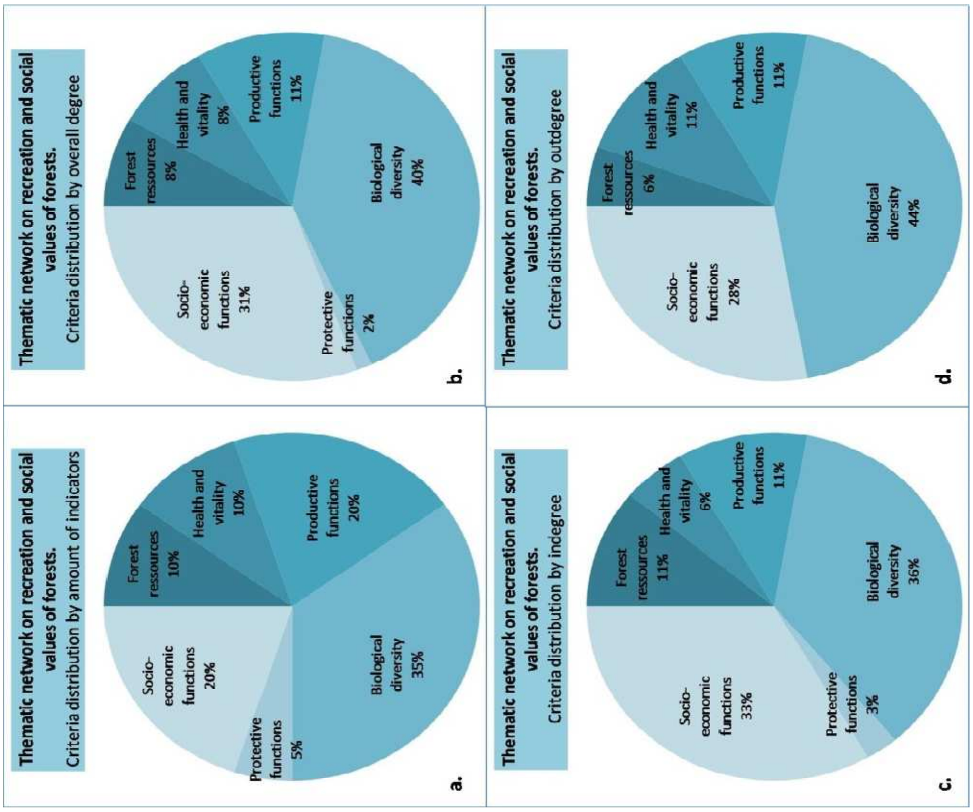


Figure 12: Criteria distribution in the thematic network on forest recreation and other social values.

4. Merging of the thematic networks,

The previous thematic networks have given interesting input for discussing several aspects that are part of sustainable forest management. Actually they can be considered as pieces of a puzzle and when they fall into place their compilation draws a picture that approaches a holistic concept of sustainable forest management. In the following paragraphs we will investigate how those thematic networks can be merged together and what are the applications and limits of this process.

a. Confrontation of thematic networks in a stakeholder dialogue perspective

According to the problems one is confronted with, some of the thematic networks can be compiled in order to "build" a new one which answers specifically the questions of interest in the given context. Figure 14 for example illustrates the combination of the network focused on wood energy and forest markets (green) with the biodiversity oriented one (blue).

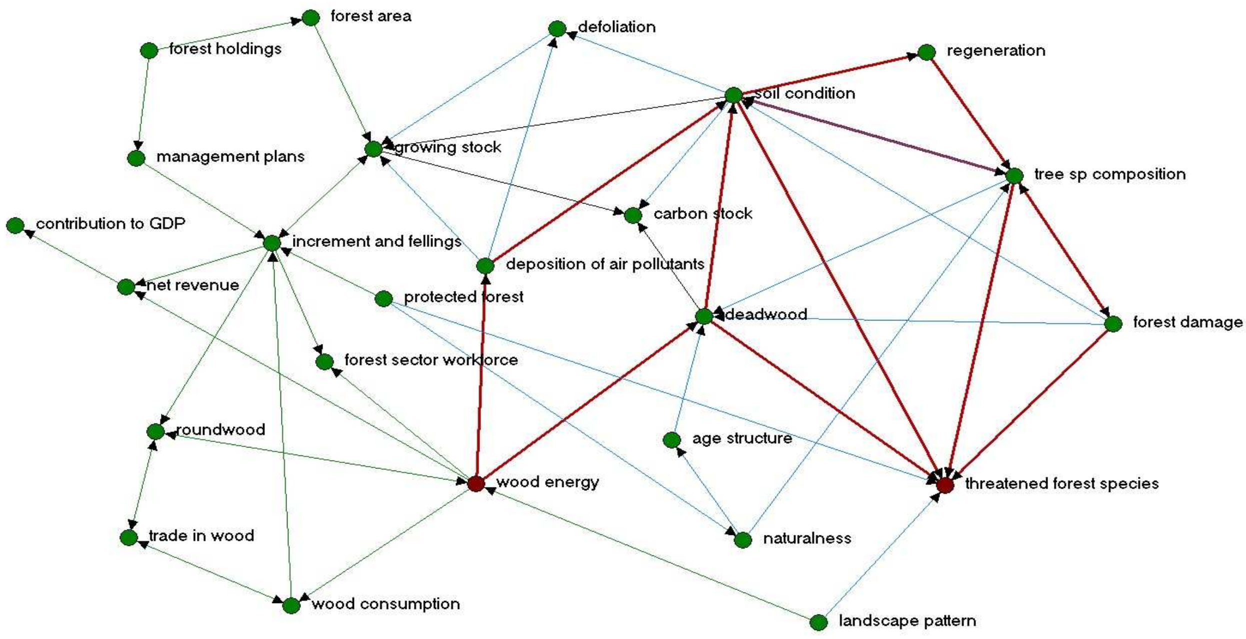


Figure 14: Composite network combining wood energy and biodiversity issues

This network is of interest for example when we want to estimate the different ways how the enhancement of wood energy can impact threatened forest species. The different paths leading from indicator wood energy to indicator threatened forest species are coloured in red in the picture. The information given by the network, combined with some deeper characterizing of the identified paths, can be very helpful to try to anticipate the possible effects of the first on the latter. Of course the validity of the newly composed network should be considered at the light of the approximations of the initial networks.

Moreover the story of the interaction of two concerns cannot always be boiled down to the sum of the individual stories. In our example, some relations might be missing between the two indicators we are interested in. Not only does the development of wood energy affect threatened forest species through the decrease of forest deadwood (Verkerk, Lindner, Zanchi, & Zudin, 2009) or, to a lesser extent, through the emission of air pollution (Forsberg, 2000) but it can be argued that the higher wood demand and the resulting higher felling rates also have a direct effect on threatened species because of the additional disturbance of the species' habitats. This interaction was, wrongly or rightly, not considered significant in the two stories individually and is therefore absent in the merged network, but becomes relevant when the two interests are confronted.

Once the individual networks are merged into one, a specific stakeholder analysis can be carried out to find out whether the objectives of different actors are compatible. In this case, if the government advocates on one hand an increase of 20% in the production of wood energy and on the other hand environmental NGOs recommend an increase of tree species composition, the different connexions between those indicators can give some answers as to the compatibility of those 2 objectives. Once again determining the negative or positive nature of the ties, as well as their relative strength would be an important step towards the implementation of this kind of investigation.

b. Merging all the networks to approach a global view of SFM

As mentioned before, each of the four previously described networks represents one main concern of sustainable forest management today; the network obtained by merging them together draws a picture of SFM in a more general perspective. This merged network is illustrated in Figure 15. In the graph tie strength is represented by the width and the darkness of the arrows. The size of the nodes on the other hand reflects their degree, taking into account the amount as well as the values (number of repetitions) of the relations involving one node. For keeping the visibility the nodes with a very low degree (less than 5) have all the same size. Nodes coloured in orange are those that were used as starting points for the construction of the networks, it can be seen that those are not necessarily the most central ones.

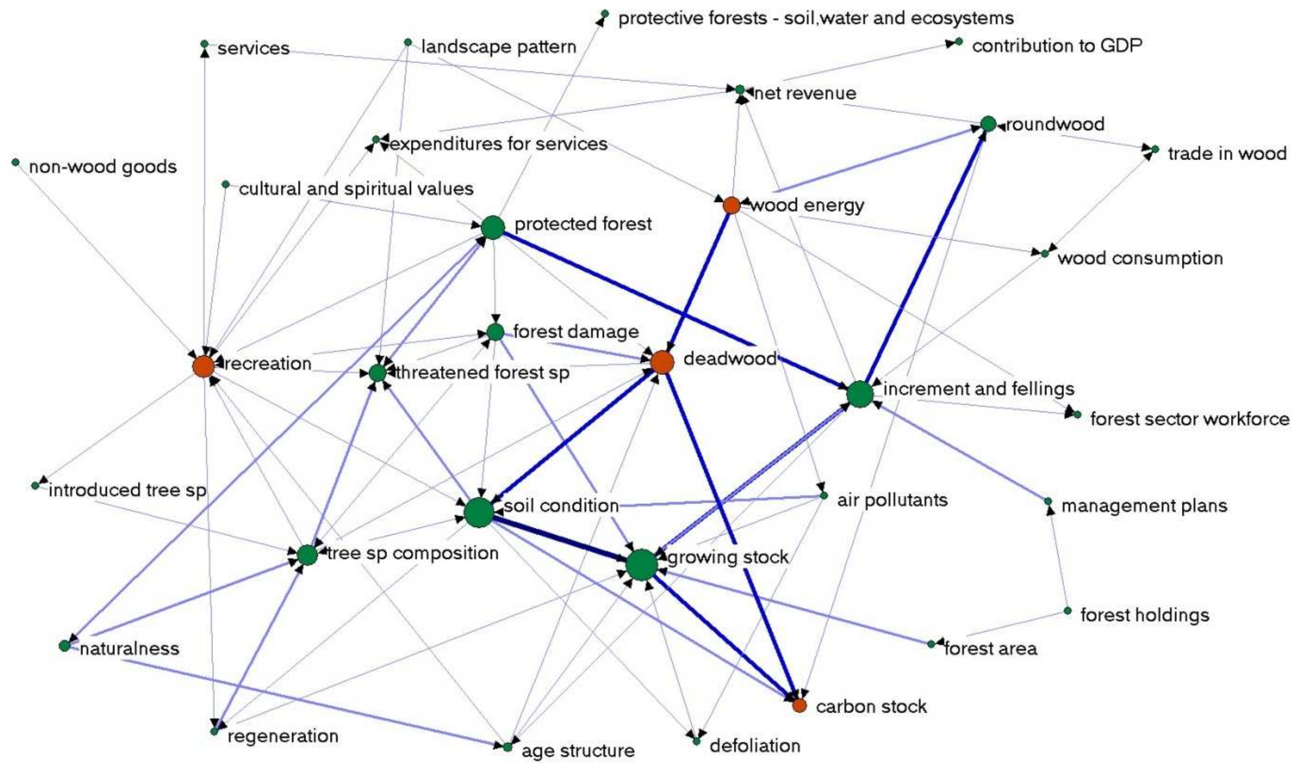


Figure 15: Overall network resulting from the compilation of the 4 thematic networks.

Description of the network:

When merging the networks almost all the indicators of the pan-European C&I set get to be included in the network. Only three indicators are missing namely indicator 4.6 genetic resources, indicator 5.2 protective forests for infrastructure and managed resources and indicator 6.6 occupational safety and health. The absence of these specific indicators does not mean that they are not in any way linked to the other indicators, but rather that, considering the focuses of the different thematic networks, they did not seem particularly relevant to the person who built the networks. Probably they could have been included by adding additional thematic networks based on other stories.

Figure 15 shows how the accumulation of information in the network makes the picture less readable; while gaining in completeness, the network loses visibility. It is however still interesting to try to understand which relations are repeated in the different stories and why. The only relation that is present in all four of the networks is the effect of soil condition on growth. Other recurrent relations are the effect of fellings on roundwood, the effect of wood energy on deadwood, the participation of deadwood and growing stock in carbon storage, the effect of deadwood on soil condition and the impact of protection status on fellings. Those relations are transcending the scope of one specific story and therefore describe a more global view of SFM; they are however not sufficient to describe SFM.

Centrality analysis

If, because of the more important size and complexity, the network's visual representation is maybe less interesting, the statistical approach on the other hand reveals some interesting information. The results gathered in the three first columns of Table 9 correspond to the degree of the different indicators, calculated taking into account the amount of ties sent or received, modulated by the strength of the relations. According to the resulting classification based on overall degree, most central indicators are growing stock, soil condition, increment and fellings, protected forests and deadwood.

For comparing those results to previous studies additional information was added in the table. The last column compiles the data completeness of the reporting for the State of Europe's Forests (SEF) report and the three penultimate columns the information from the network analysis based on the description of the pan-European C&I as given by the MCPFE background document. (Requardt, 2007) The five first positions in each classification were highlighted in the tab.

It is easy to notice that the results of the different analysis are not consistent, the most central indicators as identified by storytelling in our study are not corresponding to the ones identified with the analysis of the MCPFE experts' background document, and the reporting efforts are centered on even different indicators. While centrality in our merged SFM network is based on the position of the indicators within the cause-effect chains of the different stories describing some aspects of sustainable forest management, the importance of the indicators by report data completeness is mainly based on difficulty and cost of the information collection. The reporting is efficient on those indicators that are already well known and studied in forest inventories, mainly economic and production indicators and forest surfaces and types. On the other hand the relations described in the MCPFE background document and that are at the origin of the centrality degree calculated by A.

Requardt are very much orientated by political issues and topical concerns at the time of the writing of the document, revealing once more the subjectivity of this kind of analysis.

N°	indicator	Merged SFM network			MCPFE background doc			SEF report
		indeg	outdeg	degree	indeg	outdeg	degree	reporting level (%)
1.2	growing stock	14	6	20	5	4	9	68
2.2	soil condition	8	11	19	2	4	6	-
3.1	increment and fellings	9	8	17	4	3	7	79
4.9	protected forest	3	12	15	2	5	7	67
4.5	deadwood	8	7	15	1	0	1	36
6.10	recreation	7	7	14	2	2	4	64
4.1	tree sp composition	7	6	13	1	2	3	47
2.4	forest damage	3	8	11	5	5	10	50
4.8	threatened forest species	10	1	11	1	0	1	47
6.9	energy from wood	3	8	11	0	1	1	44
3.2	roundwood	5	5	10	2	2	4	66
1.4	carbon stock	9	0	9	3	1	4	72
4.3	naturalness	2	5	7	3	1	4	74
1.3	age structure	3	3	6	2	1	3	51/47
6.3	net revenue	4	2	6	0	0	0	-
2.1	deposition of air pollutants	1	4	5	4	9	13	-
4.2	regeneration	2	3	5	1	1	2	52
6.7	wood consumption	2	2	4	1	1	2	-
6.8	trade in wood	2	2	4	1	1	2	-
2.3	defoliation	2	1	3	5	5	10	-
4.7	landscape pattern	0	3	3	0	1	1	-
6.4	expenditures for services	3	0	3	0	0	0	-
1.1	forest area	1	2	3	11	10	21	76
3.5	forests management plans	1	2	3	1	4	5	70
6.5	forest sector workforce	2	0	2	0	0	0	-
6.1	forest holdings	0	2	2	0	0	0	64
4.4	introduced tree sp	1	1	2	1	1	2	58
6.11	cultural and spiritual values	0	2	2	1	1	2	34
3.4	services	1	1	2	3	3	6	22
6.2	contribution to GDP	1	0	1	0	0	0	-
5.1	protective forests - soil, water and ecosystems	1	0	1	4	1	5	76
3.3	non-wood goods	0	1	1	3	3	6	47
4.6	genetic resources	0	0	0	1	1	2	-
5.2	protective forests, infrastructure and managed resources	0	0	0	4	1	5	61
6.6	occupational safety and health	0	0	0	0	0	0	-

Table 9: Merged SFM network, indicator centrality values, source: Excel, (Requardt, 2007)g

The results allow the identification of specific problems with some rather central indicators having a very low reporting level such as indicator 4.5 for deadwood and indicator 4.1 tree species composition. On the other hand it is also interesting to notice that, as noted already in some of the thematic networks, many of the social indicators are very low in the centrality classifications. Those indicators are not yet really integrated in the SFM stories. Whether they are not really relevant for reaching SFM or whether they are too recent or too complex issues to be clearly present in the mental images we construct about SFM remains unsure. Sometimes the indicators which would be the bridge between those indicators left out here and the ones that are included in the network do not exist in the C&I set. In other cases another story could have been merged in this network in order to include those indicators. For example, occupational safety and health is definitely related to total forest sector workforce. So if one would tell a story about forest sector employment and wellbeing, these 2 indicators would be linked. However, in the story about wood energy this issue wasn't really relevant.

On the other hand, the fact that those indicators are not closely interlinked in the network, does not necessarily mean that the aspect they treat is not relevant in the story, sometimes it is the definition of the indicator itself that does not fit. For example the genetic resources refer to "area managed for conservation and utilisation of forest tree genetic resources (in situ and ex situ gene conservation) and area managed for seed production" (MCPFE, 2003), this is not really involved in the deadwood and biodiversity network, what would have been linked is the evolution of genetic resources of forests, but that is not what this indicator measures. A similar example is for protective forests for infrastructure and managed natural resources, defined by the MCPFE experts as "area of forest and other wooded land designated to protect infrastructure and managed natural resources against natural hazards, part of MCPFE Class "Protective Functions"" (MCPFE, 2003). The classification of these areas depends highly on political decisions, but the *efficiency* of forests for protecting infrastructure would be strongly correlated with many indicators describing forests stands, such as growing stock, age distribution and others.

5. Aggregation of the network information at criteria level

criteria	C1	C2	C3	C4	C5	C6	outdegree	overall degree
C1. Forest resources and global carbon cycle	6	0	3	1	0	1	11	38
C2. Forest ecosystem health and vitality	**10**	5	0	**8**	0	1	24	38
C3. Productive functions of forests	4	0	5	0	0	**8**	17	33
C4. Biological diversity in forest ecosystems	6	6	3	**17**	1	5	38	**71**
C5. Protective functions in forest management	0	0	0	0	0	0	0	1
C6. Socio-economic functions and conditions	1	3	5	7	0	**9**	25	**49**
indegree	27	14	16	33	1	24		

Table 10: Matrix of the by criteria agregated global network

Table 10 is the matrix containing the same information as contained in the earlier networks but this time the information is summarized and reported at criteria level. Unlike the previous matrixes the values in the diagonal are not null, they correspond to the sum of the relations between indicators belonging to the same criterion. It can be seen in the matrix that many of the interactions are involving indicators of the same criterion.

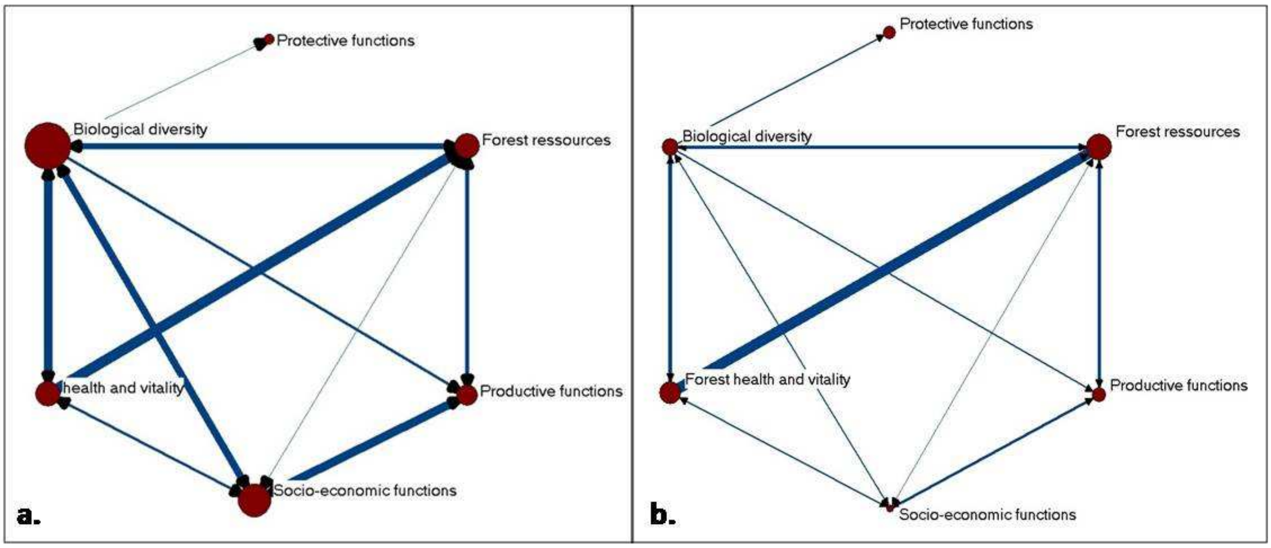


Figure 16: Visual representation of the by criteria aggregated global network.

As shown in Figure 16, the aggregation at criteria level allows to draw simple and easily interpretable networks, contrary to the networks drawn in part II.B.4. The width of the ties reveal tie strength and the size of the nodes reveals node centrality degree. Biodiversity appears in network a. in the most central position, it is the only node which is linked to all of the criteria constituting the pan-European C&I set. In second position are the socioeconomic indicators. This is not really a surprise; these 2 criteria are the ones that have the highest amount of indicators, which obviously influences the amount of connexions. Therefore the values can be standardized.

In order to compensate the fact that the criteria are very unbalanced as to the amount of indicator, the previous matrix was thus corrected by dividing the value in each cell by the maximum of possible connections and the connectivity between criteria is given in % of all possible connections. This approach changes significantly the results of the analysis. The tie linking forest health and vitality to forest resources and carbon stock reinforces its leading position, and in comparison all the other ties seem insignificant. This analysis thus highlights the very high interdependence of forest resources and forest health and vitality, this result should however be taken with caution because of the many approximations that add up over the whole process. The extreme simplification and the numerous stages necessary to obtain this final network cause it to be rather far from reality, while the method remains interesting as well as the results in a statistical perspective, the purpose of explaining and understanding SFM is not really achieved here. The final network doesn't really tell any story at all about SFM anymore... This experience illustrates how the different methodologies should be chosen with care, always keeping in mind the prior objectives.

6. Overall results of the thematic network building

The construction of several networks according to different themes was chosen here because it greatly facilitates the building up of the network by storytelling methods. Telling a story of SFM as a whole would have required a really accurate overview and a very high degree of analytic and synthetic skills. It has been mentioned already that even the thematic networks have many shortcomings partly since they are already an approximation as the fruit of the reflection of one single person. Some first conclusions as to the role of the different indicators can still be drawn and above all they allow the illustration of the methodology and investigation of the applications of the network analysis approach.

Adequacy of the reporting processes to the centrality of the indicators

Although most of the results according to centrality of the different indicators in the networks and according to the role and importance of the different relations are relatively evident some additional information has been provided by the network approach. The high correlation of the social values (in particular recreation) with the other criteria has been demonstrated in network d. The tool also provides a visual approach that can be valuable for supporting decision makers who do not have an overview of the different components of forest management.

In addition the network analysis allows the investigation of the consistency between indicators centrality for SFM, data availability and current reporting efforts. Table 9 shows that in some cases, such as for indicators 1.2 growing stock and 3.1 increment and fellings, the current reporting efforts match rather well the importance of the indicators in an SFM system approach, as given by their centrality measures. But other indicators such as both tree species composition and dead wood, although their centrality is high in the merged network (Table 9), are amongst the indicators with lowest completeness rates (Figure 1) with respectively 36 and 47 % for the entire MCPFE region, pointing out that still a lot is to be done for enhancing the reporting on those crucial biodiversity indicators. The same goes for indicator 6.9, energy from wood resources, the reporting level is not yet living up to the strategic importance of the current development of wood energy.

Overall the different parts of the study also showed that most of the socio-economic indicators are still left aside in the network approach. This might be due to the high amount of indicators but also to the fact that those indicators are not clearly associated to the other aspects in the mind of today's foresters. It can be seen in Figure 16.b. that the connexion between criterion 6 and the others are rather weak.

Limitations of the pan-European C&I set regarding its application for network building

Cases of incomplete networks or oversimplification of the systems because of the absence of appropriate indicators have been reported repeatedly in some of the thematic networks. As a matter of fact the C&I set is limited for the sake of concision and monitoring feasibility, in this perspective only the most relevant indicators were selected. As a consequence the set is not always adapted to the network building purpose. As mentioned in part II.B.1 concerning the network on wood energy, some economic indicators are less relevant while others, for example "other wood products", are missing. That is why the network cannot fully reflect the market mechanisms and the competition of different wood products regarding the resource supply. Another aspect which is clearly missing - particularly in the networks concerning carbon storage for climate change mitigation and recreation - concerns the political and social demands transmitted by political instruments, meaning mainly legislative or financial incentives for developing forest services or products. Within the pan-European C&I set an additional group of qualitative indicators has been established specifically for assessing the countries' major political measures and instruments. Unfortunately, since they are not listed as definite indicators but as open questions (MCPFE, 2003) these qualitative indicators couldn't be integrated in the networks. Some aspects such as wood energy markets with high subsidies, or by legislation defined protected areas, are strongly influenced by those political instruments, and therefore the integration of those qualitative indicators into the network would be necessary for reflecting the interactions more closely. Finally in the case of climate change mitigation the beneficial impact of carbon storage is not easily taken into account, there is no indicator for CO_2 concentration in the atmosphere or for temperature. The benefits provided by forest carbon storage can therefore not be reflected in the network. Those benefits are too indirect, time dependant and complex to be reflected in the networks that are built here. The same is true for the effect of wood energy in a climate change context; although the positive impact of the development of wood energy in terms of reduction of fossil fuel consumption is real, it cannot be described only with the MCPFE indicators.

Comments on the methods used

As described in the methodology, the different thematic networks were built by one person and even though additional literature research was carried out in order to address possible knowledge gaps this can be considered as one of the weaknesses of the method. Keeping or eliminating the ties is not always an obvious choice, significance of the interactions can be fairly hard to evaluate. We can take as example the effect of recreation on introduced tree species. Literature confirms (Leung & Marion, 2000) that high frequentation rates are likely to lead to the introduction of invasive species, such as the appearance of non endogenous bryophytes on climbing routes or hiking trails. However in the specific case of tree species this effect is likely to be similar but has not been studied in detail and is probably less significant, since tree species are less easily disseminated and thus less likely to be introduced by accident. Therefore the relation between the indicator accessibility for recreation and the indicator introduced tree species is not very strong, nevertheless, on the basis of the article it was decided to keep this tie. The definition of the strength of the relations as a whole is problematic; we will try to address this issue in the outlook of this study.

In addition to the significance of the interactions, the issue of their exact sequencing is also crucial. In theory, the ties of the network describe the direct relations between two nodes or indicators. A succession of ties from one indicator to the next creates a path. If A is connected to B and B is connected to C, than as a result there is a causal path leading from A to C. This relation is an indirect relation which, for this reason, should not be materialized by a tie in the network. In practice, the exact sequence of causes and effects is often badly or not known, leading to the jumping of some steps and thus to inaccurate ties in the network. For example in the wood energy approach network, storytelling was trying to answer the question of which factors influence on the proportion of wood used in European energy supply. In the first stages it was found that protected forests are partly "responsible" since the higher the amount of protected forests, the less forests are left for more intensive biomass extraction and as a consequence for providing wood energy. However, while digging deeper into this relation one realizes that this is not a direct relation. Actually, the establishment of more protected forests, with associated felling or biomass extraction restrictions, causes global felling rates to decrease, inducing a change in the availability of roundwood resulting in a decrease in the supply of wood energy, as illustrated in Figure 17. In some cases, careful review of the networks allows the correction of the mistakes, but this is not always possible, above all in contexts where the exact mechanisms are not known.

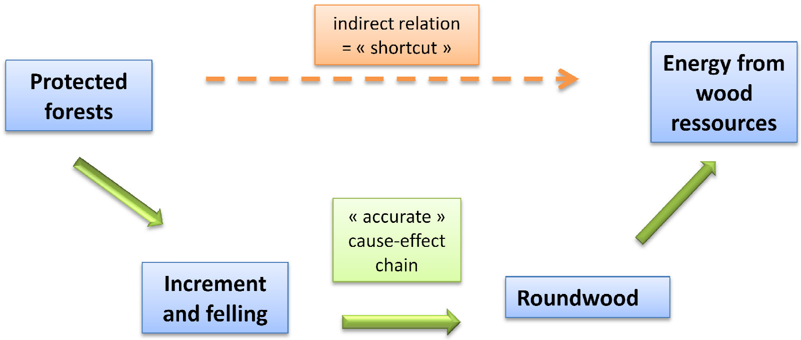


Figure 17: example of indirect relation between protected forests and wood energy

To sum up, the work carried out in this first part of the study reveals some interesting results regarding the application of the network approach. For the purpose of building objective functional models for policy decision making support, the methods need to be improved on several points, but the different methods for merging and aggregating the information contained in the matrixes have shown to give some valuable additional insight. Although they can be criticised for not giving an objective picture of the mechanisms at stake in forest management systems, the cognitive mapping methods are very useful to provide a subjective picture of the understanding of one person or a group of persons of SFM in a given context. The second part of this study will focus more on the use of network building and analysis as a communication and discussion tool to support a better understanding of the concept of sustainable forest management.

III. Part2: Participatory network construction; a case study

A. Methodology

One main criticism against the previous networks was that they depicted SFM according to the perception of one person alone. If we want the models to be legitimate in a given context, they should be based on the input and viewpoints not of one person but of as many stakeholders as possible. The cognitive mapping theories are perfectly adapted to the implementation of participatory approaches that is why in this part of the study we will experiment and describe an example of participatory network building.

1. Organisation of a workshop on the mapping of SFM complexity

After a first network building approach based on storytelling conducted by one person only, the aim of the second part of this study was to try to build more exhaustive networks by gathering the input of a large group of people.

The organization of an international PhD course on international forestry and global issues, jointly organized by the French National Institute for Agricultural Research (INRA) together with the European Forest Institute (EFI), provided the ideal opportunity to sample a group of researchers with different professional forest related backgrounds. The course took place in Champenoux from May 17th to May 21st and on the 20th a specific workshop was organized in collaboration with Dr. Aljoscha Requardt on the mapping of SFM complexity using C&I. The aim was on the one hand to inform the participants about the network approach for analyzing SFM system complexity and its applications in the forestry field and on the other hand to gather their input for the analysis conducted in this study.

The participants of the workshop were all either PhD students or young researchers from various research institutions. They were working on a wide range of issues reaching from forest economy to climate change or forest ecology; the different backgrounds represented a clear advantage for drawing a holistic picture of SFM.

2. Proceedings of the workshop

Policy scenario	Number of participants
1. maximizing carbon storage in forests	6
2. Wood energy promotion and sustainable timber supply	3
3. Increasing value of non marketed goods and ecosystem services	(3)
4. Adapting to climate change and protecting forest health and vitality	3
5. Protecting and enhancing forest biodiversity	4
6. Increasing competitiveness of the forest industry	4
7. Increasing society awareness and recreational use of forests	3

Table 11: workshop's policy scenarios and participants

As in part I of this study, the network construction was based on storytelling methods. First of all, the participants were divided into 7 groups; a specific policy scenario was attributed to each group so as to orientate their SFM story. The different policy scenarios and the number of participants are described in Table 11. The participants received together a presentation on the methods and theory of network analysis as applied to C&I for SFM, after that, the exercise was divided into two parts.

The first network was to be built individually without consulting other members of the group. Each person was asked to select some of the indicators from the pan-European C&I set (between 10 and 25) and to build one network about SFM as suggested by their policy scenario. The detailed handout of this part of the exercise is attached in Annex 3.

After this first step, the participants from one group were asked to gather in order to confront and discuss their networks and finally propose a consensus and draw a “group network”. The exercise then continued with some role playing where each group had to defend their network and propose some concrete management orientations for a specific forest based on their policy scenario and on the main cause effect relations they identified.

3. Proceedings of the analysis of the collected data

At the end of the workshop, the sheets containing the individual networks of all the participants were gathered and the data was transformed into contingency matrixes, processed with the Ucinet software, drawn as networks and analysed. Supplementary analysis has been carried out in excel as well. Regrettably, because of some methodology problems some participants’ output didn’t have the required format and could not be included in the analysis that will be developed here. The results of group 3 for example have for this reason been excluded. In total 23 networks have been analysed.

The results were studied, first individually, then all together, per group, and finally between the groups, in order to investigate the divergences and similarities within and between the groups, according to the policy scenarios.

In order to measure the “group effect” and to verify whether the policy scenario given to the members of the groups really makes them build similar networks, the variability of the indicator degree measures within and across policy scenario groups were compared by additional data processing. The different calculations are illustrated in Figure 18. For each group, a data sheet gathers the degree values obtained from all the participants for all the indicators. For each indicator the mean degree value as well as the standard deviation is calculated within the group. Then the mean standard deviation is calculated by averaging the standard deviations of all the indicators. This value reflects the average variability, for the members of one group, of their evaluation of the indicators. The second step is to calculate for each indicator the standard deviation between the mean degrees of the 6 groups and to average this over all the indicators. The obtained value reflects the variability of centrality measures between the groups corresponding to the policy scenarios. Comparing the variability intergroup and the variability within the groups will reveal whether the networks drawn within the groups are really more consistent.

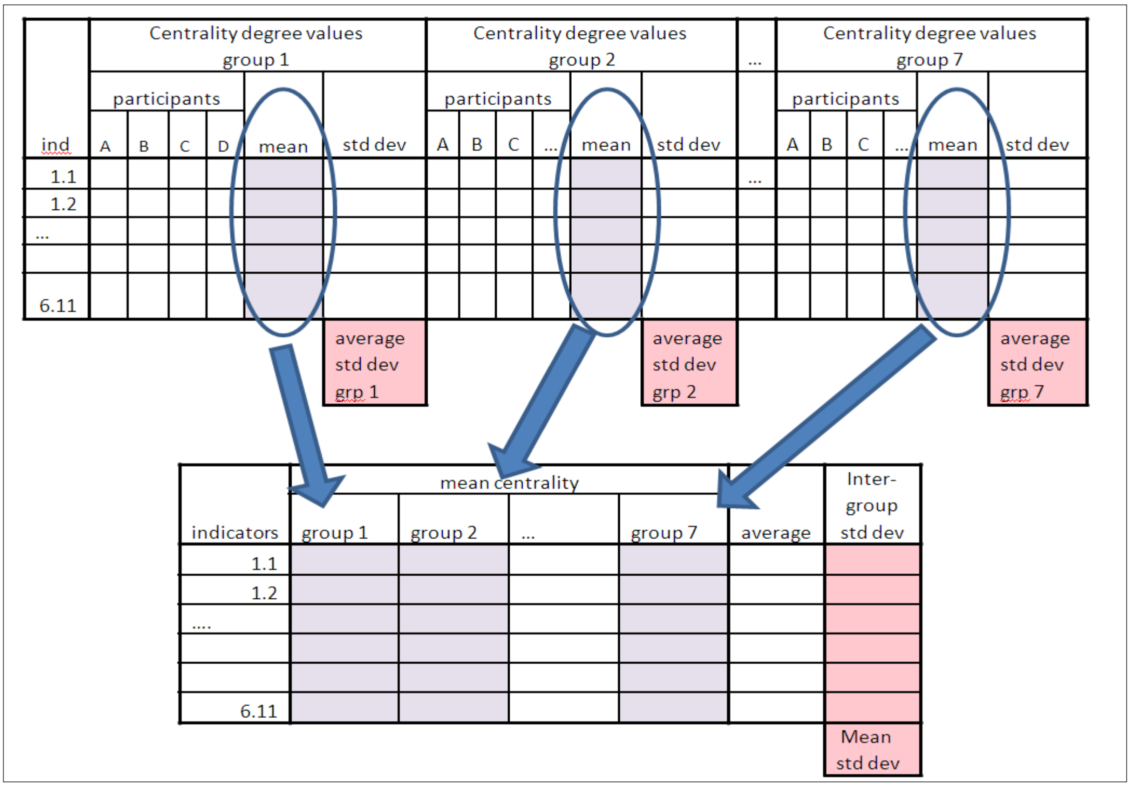


Figure 18: Degree variability analysis

B. Results

1. Structure and centrality analysis of the global resulting network

First step of the analysis consisted of studying the responses of the different participants as a whole. The different matrixes containing the individual networks of the participants were summed in order to obtain one merged network containing the views of all the participants without policy scenario distinction. As shown in Figure 19, the obtained network is extremely complex; we can notice that all the indicators of the pan-European C&I set have been included in the network at least once meaning that they were all considered relevant by at least one of the participants. Many relations have been identified, the density of this network, based on the amount of ties and not on their strength, amounts to 31%, which is a lot higher than in the previously studied networks. The summing of the individual networks, not only contributes to strengthen the relations but also added a great variability in the identified relations. The diversity of links drawn in the different networks illustrates in how far people's personal views disagree.

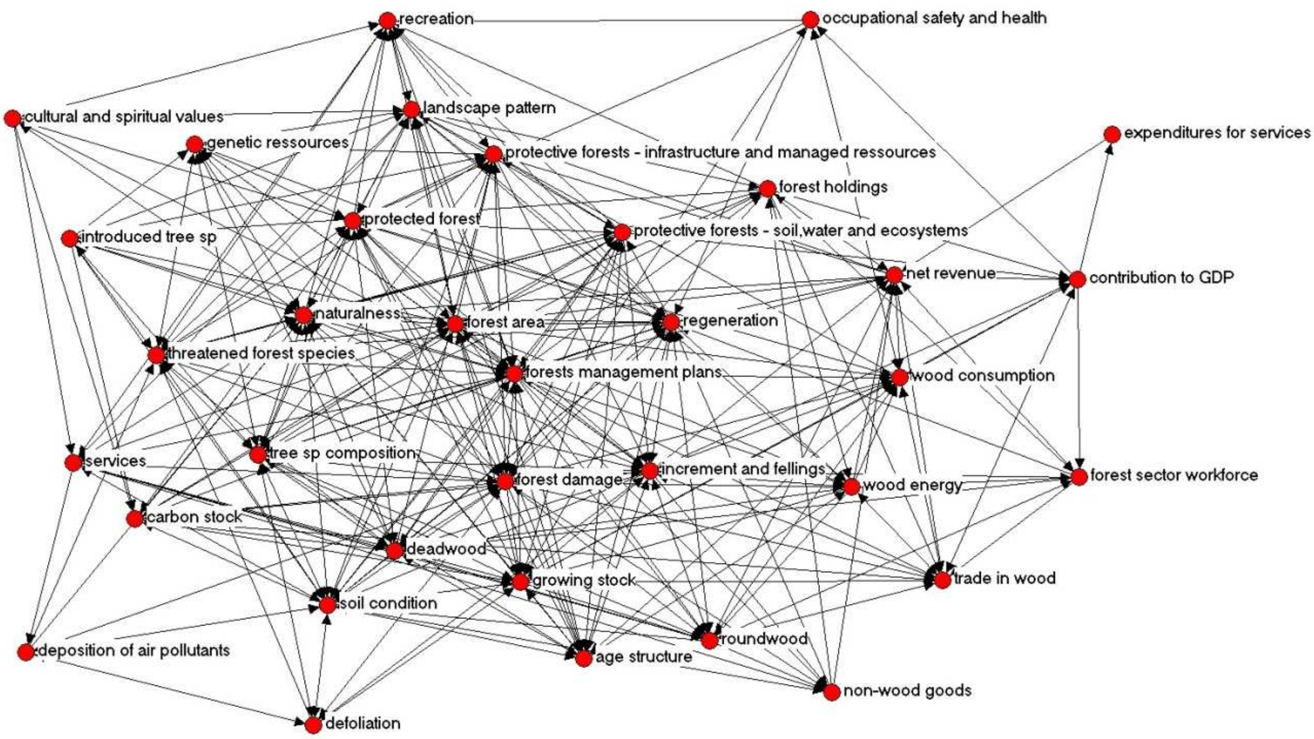


Figure 19: Network resulting from the sum of individual input of all the workshop participants

The results compiled in the merged matrix can however be filtered, according to given thresholds, one can decide for example that only the relations stated by at least two people are considered relevant in the analysis. In addition the Netdraw software allows to rank the ties according to their strength, and thus to illustrate clearly which relations are the most recurrent ones. Furthermore the indicators or nodes can be classified according to their centrality degree, reflected by the node size. The resulting network is shown in Figure 20, processing the data this way allows to clarify the picture significantly.

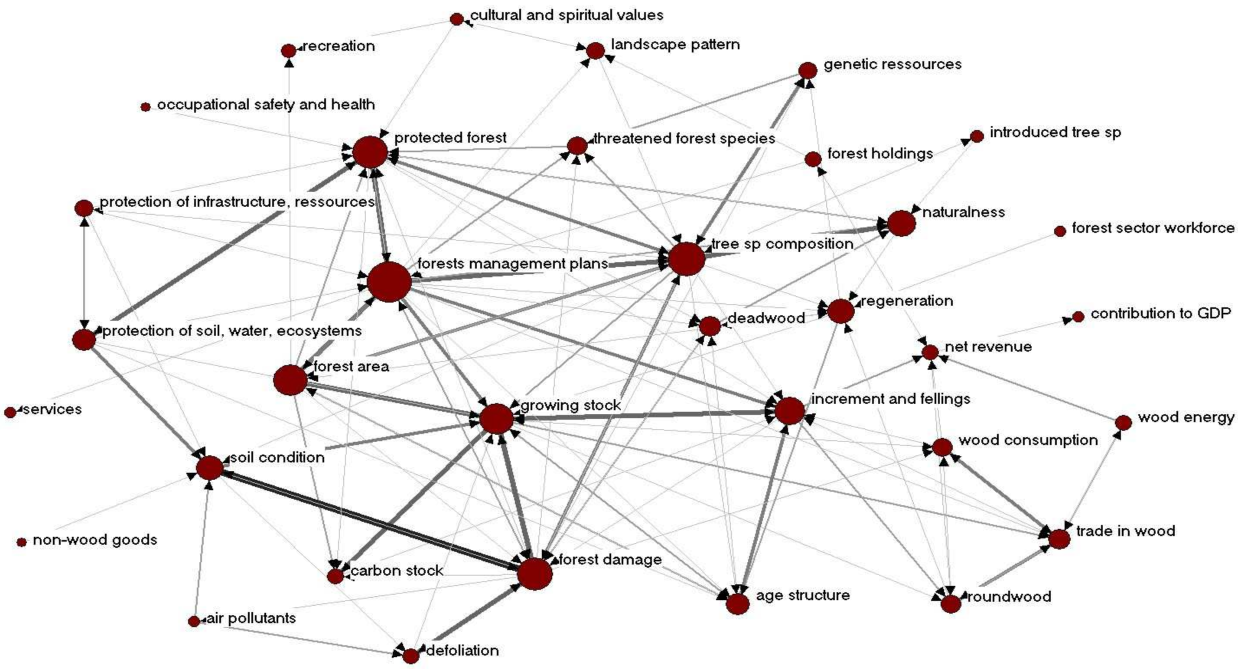


Figure 20: condensed network resulting from the sum of individual input of all the workshop participants

The most significant interactions

The analysis revealed which interactions were identified by the greatest number of participants. The interaction which was quoted in the most networks was the effect of soil condition on forest damage, in total this interaction was present in 6 of the studied networks, meaning by one fourth of the participants. Even though this is the best score, it still only represents a small part of the participants, once again this reveals that there are no really evident relations and that, considering SFM, there is no real consensus on any obvious interactions. The following most important relations, cited by at least 5 people, are:

- the influence of forest area on growing stock,
- the influence of forest area on forest management plans,
- the influence of growing stock on carbon stock
- the influence of growing stock on increment and fellings
- the influence of increment and fellings on growing stock
- the influence of forest management plans on tree species composition
- the influence of forest management plans on protected forests
- the influence of tree species composition on naturalness
- the influence of protection of soil, water and ecosystems on protected forests

None of the relations cited here involve any of the socio-economic indicators, most involved are the forest resources indicators closely followed by biodiversity and production indicators.

Indicators' degree centrality

		Workshop results			Merged thematic networks			**MCPFE background doc network** (Requardt, 2007)			**SEF report** (MCPFE, UNECE, & FAO, 2007)
N°	**indicator**	**In-degree**	**Out-degree**	**degree**	**In-degree**	**Out-degree**	**degree**	**in-degree**	**out-degree**	**degree**	**Data completeness (%)**
3.5	forests management plans	28	55	83	1	2	3	1	4	5	70
4.1	tree sp composition	32	36	68	7	6	13	1	2	3	47
2.4	forest damage	29	37	66	3	8	11	5	5	10	50
4.9	protected forest	34	30	64	3	12	15	2	5	7	67
1.1	forest area	24	37	61	1	2	3	11	10	21	76
1.2	growing stock	39	22	61	14	6	20	5	4	9	68
3.1	increment and fellings	30	25	55	9	8	17	4	3	7	79
4.3	naturalness	29	19	48	2	5	7	3	1	4	74
4.2	regeneration	25	22	47	2	3	5	1	1	2	52
2.2	soil condition	23	22	45	8	11	19	2	4	6	-
5.1	protective forests - soil,water and ecosystems	13	27	40	1	0	1	4	1	5	76
1.3	age structure	18	19	37	3	3	6	2	1	3	51/47
6.8	trade in wood	19	16	35	2	2	4	1	1	2	-
4.5	deadwood	19	15	34	8	7	15	1	0	1	36
6.7	wood consumption	16	16	32	2	2	4	1	1	2	-
3.2	roundwood	18	14	32	5	5	10	2	2	4	66
4.8	threatened forest species	22	10	32	10	1	11	1	0	1	47
4.7	landscape pattern	14	15	29	0	3	3	0	1	1	-
5.2	protective forests - infrastructure and managed ressources	13	16	29	0	0	0	4	1	5	61
4.6	genetic ressources	16	12	28	0	0	0	1	1	2	-
1.4	carbon stock	19	5	24	9	0	9	3	1	4	72
2.3	defoliation	12	10	22	2	1	3	5	5	10	-
6.3	net revenue	14	8	22	4	2	6	0	0	0	-
6.1	forest holdings	6	16	22	0	2	2	0	0	0	64
6.9	energy from wood	11	11	22	3	8	11	0	1	1	44
6.10	recreation	14	6	20	7	7	14	2	2	4	64
4.4	introduced tree sp	5	11	16	1	1	2	1	1	2	58
6.11	cultural and spiritual values	6	10	16	0	2	2	1	1	2	34
2.1	deposition of air pollutants	3	9	12	1	4	5	4	9	13	-
6.5	forest sector workforce	6	6	12	2	0	2	0	0	0	-
6.2	contribution to GDP	7	5	12	1	0	1	0	0	0	-
3.4	services	8	4	12	1	1	2	3	3	6	22
6.6	occupational safety and health	3	6	9	0	0	0	0	0	0	-
3.3	non-wood goods	3	6	9	0	1	1	3	3	6	47
6.4	expenditures for services	1	1	2	3	0	3	0	0	0	-

Table 12: Centrality results for the indicators of the workshop's merged network

Table 12 clearly shows that indicator 3.5 forest management plans is the most central one here, it has a degree of 83. This can be explained by the fact that the reflexion was orientated in terms of policy scenarios and the management plans are often the tool which is the basis of the implementation of the management strategies and thus the most direct way to transpose policy changes in the field. The following indicators according to their degree are indicator 4.1 tree species composition with a degree of 68 followed by indicator 2.4, forest damage having a degree of 66, indicator protected forests having a degree of 64, indicator 1.1 forest area and indicator 1.2 growing stock both with a degree of 61 followed by indicator 3.1 increment ad fellings with a degree of 55. Table 12 recaps the full results of the centrality measures including degree indegree and outdegree of this network as compared to the centrality results of the other studies.

The centrality results of this compiled network and the classification of the indicators according to their centrality is again clearly different from the previous results. The variability of most central indicators (orange cells in the tab) seems however greater than for the least central indicators (blue cells) for which there is a greater consensus with a majority of socioeconomic factors. One of the other reasons why the results from part II and part I of this study are not really consistent can also be related to the fact that, due to some organisational issues, the groups were not really balanced and even the choice of the policy scenarios, although they were chosen with care, wasn't perfectly balancing all aspects of SFM either, so not all the indicators had the same weight in the final network. We can state for example that the indicators for recreation and wood energy have a lower ranking in the merged workshop network than in the merged thematic network because the policy scenario groups focusing on those issues were composed only by 3 students.

Criteria centrality and interdependence:

A specific pivot analysis was carried out to assess the average indicator degree for each criterion. Using the average allows to limit the bias of the size of the different criteria.

$$Average\ degree\ criterion\ A = \frac{\sum degrees\ of\ the\ indicators}{number\ of\ indicators\ in\ the\ criterion}$$

The results of the pivot chart are compiled in Figure 21; socio-economic indicators are significantly less central than other indicators in the network. This time the low representation of the criterion cannot be attributed to the focus of the policy scenarios since several of them are about socio-economic indicators, for example policy scenario 7 on recreation or policy scenario 2 on wood energy. Another explanation could be given by the research background of the participants, however, examination of the field of research of the different participants shows that a significant proportion is working on socio-economic or policy topics (Annex 4). As a result, the very low degree of the socio-cultural indicators probably corresponds to a reality which is that according to common perception, the socio-economic aspects are still rather isolated and are not strongly intertwined neither with the other aspects nor between themselves. As to the other 5 criteria, it can be noted that the share is rather balanced, forest resources being slightly dominant as in previous networks. This reveals that the aggregated picture of the interactions between indicators, given by this group is rather balanced which is rather positive. None of the criteria seems to be significantly more central than the others: a vision consistent with the common perception of sustainable forest management.

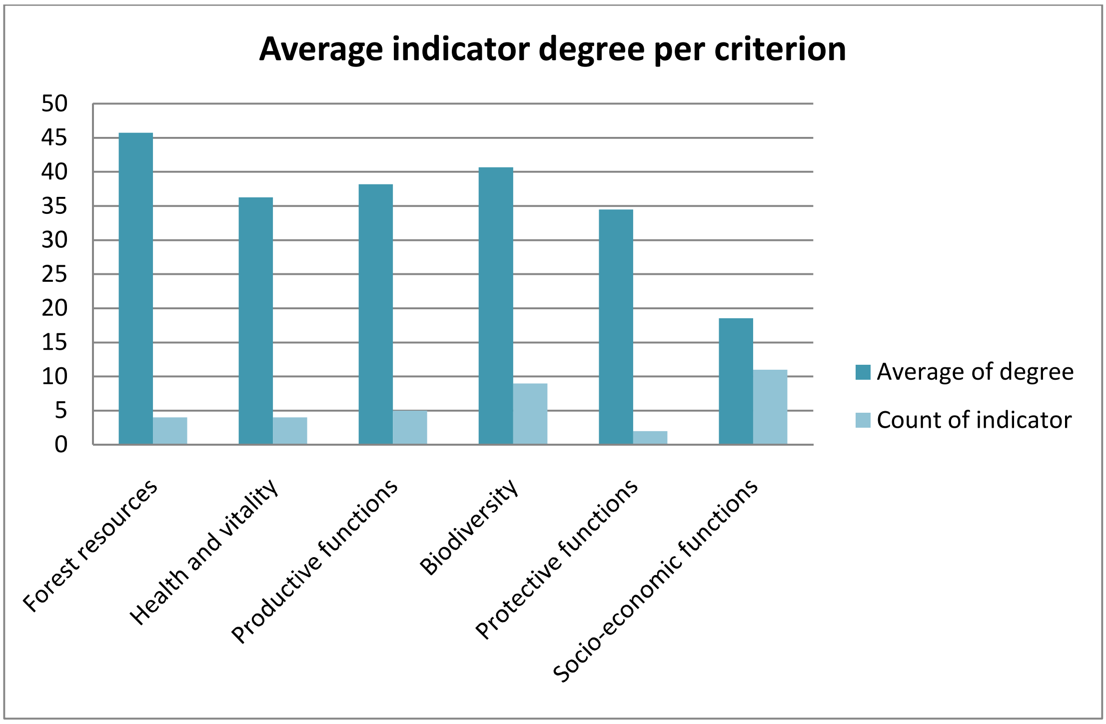


Figure 21: Graph illustrating the average indicator degree per criterion

2. Analysing inter- and intra-group variability of network structure.

After noting earlier that the individual networks are not always agreeing as to the main relations or most central indicators, the question that remains is whether this variability can be explained by the orientation the different policy scenarios give to the networks within the groups.

Table 13 gathers the values of the standard deviations representing the variability of the degree of the different indicators within and between the different groups. The results collected in the tab are to be interpreted with care since the small and variable size of the groups doesn't allow very robust results. However, the figures seem to show that the variability between groups isn't really higher than within the groups, meaning that the centrality estimations are in average not more consistent between the members of one group than between the groups. So, even when people are given a same policy scenario, the inter-individual variation remains important and in this case as much as the variability between the groups. Between the groups the inter-individual variability has already been smoothed when meaning the degree measures for each group, partly explaining how in the end the standard deviation can be relatively low.

	Standard deviation within the groups						Standard deviation between the groups
	grp1	grp2	grp4	grp5	grp6	grp7	
N	6	3	3	4	4	3	6
mean value	1.6921	1.2036	1.2850	1.9523	1.8076	1.3446	1.371801

Table 13: Standard deviation of the average indicator centrality degree within and between the different groups.

It could be interesting to deepen this kind of study with bigger and more balanced groups in order to have more sound results and more reliable interpretations. Although the samples are not robust enough to have statistically significant results, the tendencies that are observed still show that the personal interpretation of the indicators and their relations cannot be streamlined by asking people to stick to a specific context, or in this case, to a policy scenario. Personal perceptions cannot easily be harmonized above all when we consider such a complex system as SFM. This means that the story told by each group cannot be simply considered as the story of the policy scenario that was attributed to the group but should rather be seen as the sum of the personal viewpoints of the members of the group according to the given policy scenario.

3. Participants' feedback on the network building workshop

We have previously detailed the output of the workshop as far as the content of the networks and the centrality analysis of the indicators and the criteria are concerned. However, gathering data for this study was not the only purpose of this workshop; the network building exercise also aimed to give the participants the opportunity to analyse, enhance and confront their perceptions of sustainable forest management. Therefore it was particularly interesting after the exercise to gather the feedback from the participants on the methodology, the results and the usefulness of the exercise. Different points were mentioned by one or more of the participants. In the first place many of the participants admitted never having considered SFM this way, meaning as a dynamic system with a certain amount of components that interact constantly. Most of them agreed that it was a very interesting experience which clarified and furthered their conception of sustainable forest management and of the underlying mechanisms.

Moreover, the confrontation of the different individual networks within the groups and the discussions that followed in order to agree on one group network, revealed the difficulties both of the interpretation of the indicators and their definitions and of the understanding of the relations. Often the underlying ideas were similar for all the participants but their way to express them based on the C&I set were different. The understanding of the indicators are frequently different from one person to another, and the sequencing of the cause effect chains were not always equivalent. The high amount of indicators in the set also caused some participants to select different indicators to describe similar interactions. Some people selected for example the growing stock indicator to reflect the increase of forest wood resource in their story; others used the indicator increment and felling, putting the emphasis on the "increment" aspect. A third category of participants considered increment and fellings as an indicator for the sylvicultural interventions, laying the stress on the "fellings" aspect. These disagreements are basically caused by the structure of the C&I set and the confusion concerning the definition of some of the indicators. Other confrontations were caused by the divergence between the different perceptions on SFM, those were more interesting to observe. The identification and priority of the different mechanisms fluctuated within the groups, triggering very enriching discussions; these discussions especially allowed examination and enhancement of the participants' conceptualisation of SFM.

Finally, despite the various disagreements, all of the groups managed to agree on a final network, and to present their view on SFM in the specific policy context to the other groups. The implementation of the network building techniques showed to be a very efficient way to explain, defend and enrich one's personal view on sustainable forest management, and to better understand other people's viewpoints.

IV. Outlook for further research

In the two distinct parts of this study similar remarks arise about the importance of the characterisation and the nature of the ties between the different indicators. In this paragraph we will present some further ideas on how these aspects can be better integrated in the networks.

1. Evaluation of the strength of the network ties:

Defining the strength of the interactions between the indicators : a crucial question

The previous paragraphs of this study have shown how the network analysis can give valuable input for supporting the implementation of sustainable forest management. However this role of the C&I network approach could be enhanced if, instead of depicting the sole presence or absence of interactions between the indicators, the networks would also represent tie strength. The valuation of the ties in the network would enable the ranking of the different alternatives in a decision making context.

Until now, in this study, the only means to value the ties was to merge several networks together and sum of the individual tie values. This method is however not sufficient: the fact that a relation is mentioned by all the members of a group does not mean that all the members of this group consider this relation is the most important. To note the limits of this method one can also imagine a case where several relations have been identified by all the members of the group. In that case there is no way to rank those relations one against another. Moreover, for explaining sustainable forest management, this approach, at least as it is implemented here, is not really adapted; the merged network itself is less meaningful because it does not tell one coherent story anymore. I any case, the interpretations should be made carefully, taking into account the approximations and assumptions that were made while building the individual networks.

Two additional methods can be investigated to address the challenge of integrating the tie strength in the system: qualitative participatory methodologies or statistical data modelling techniques.

The use of participatory methods

For implementing some qualitative valuation techniques, once again participatory methods can be used, the methods based on workshops, and discussion rounds or Delphi surveys could be adapted to the valuation of the ties. The aim would be to ask a group of stakeholders to give their personal valuations of the importance of the relationships and discuss them together in order to obtain a consensus; this approach allows globally accepted results that are adapted to the specific context one is working in. Once the valuation is carried out, additional methods can be used to transform the system into a more sophisticated fuzzy dynamic model. (Mendoza & Prabhu, 2006) have detailed in their paper a specific methodology allowing the creation of a fuzzy model that can simulate changes and policy scenarios. However the implementation of this methodology requires an in depth knowledge of the system which does mostly not exist when we talk about sustainable forest management.

The use of data modelling techniques

Data modelling on the other hand corresponds to a whole different philosophy, the methods used until now were based on physically- or knowledge-based modelling whereas data modelling corresponds to a data driven modelling approach. Although the approach is radically different, the data modelling could be interesting to shed new light on the models. Those quantitative methods involve more specific requirements especially as to the availability of adapted data sets. Linear regression techniques could allow to find which indicators influence most significantly one specific indicator A, and to establish the strength of the interaction given by the regression coefficients. However, because of the high level of correlation between many of the variables, very thorough data sets would be necessary to be able to obtain a correct sequencing of the complex mechanisms and to lead from basic correlations to the effective causalities.

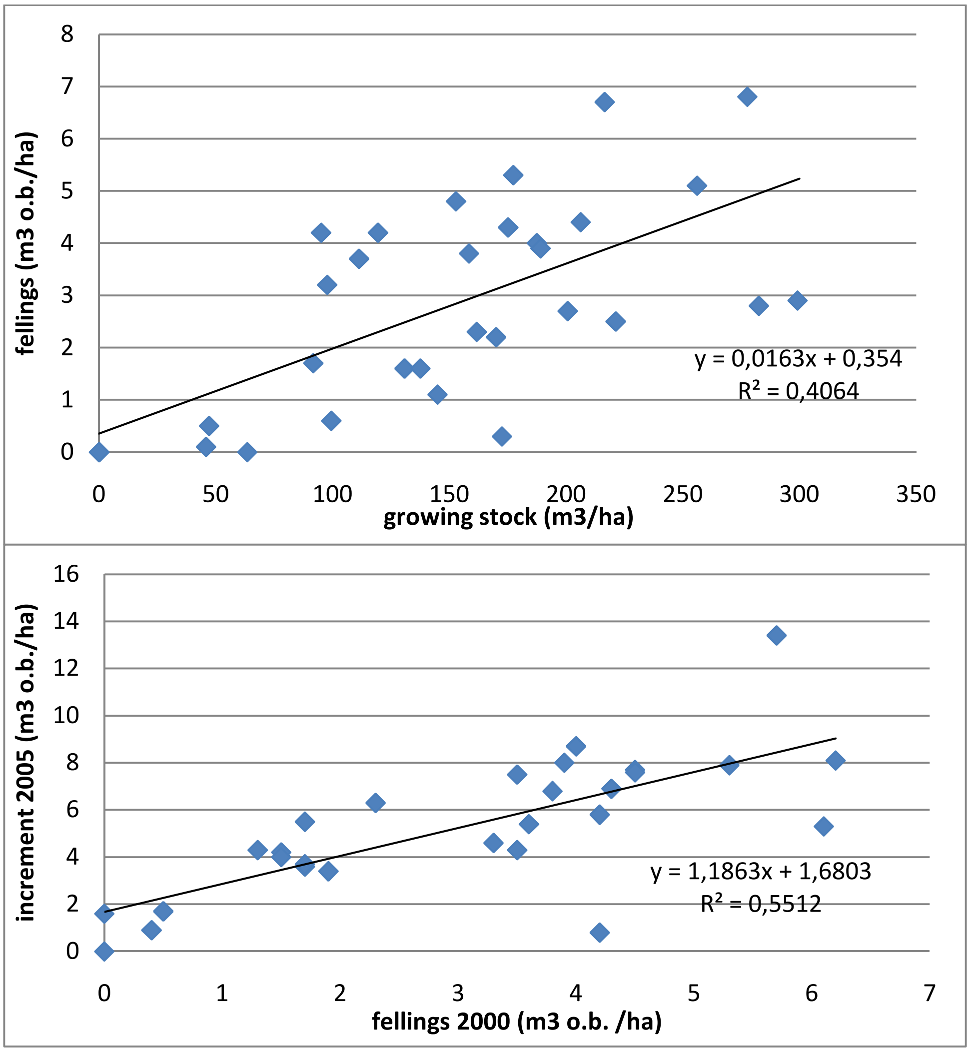


Figure 22: Graphic representations of the correlation between indicators growing stock and fellings and between fellings and increment. Data source: (MCPFE, UNECE, & FAO, 2007)

One available data set is provided by the State of European Forests report (MCPFE, UNECE, & FAO, 2007) where for each pan-European country the values of all the indicators of the C&I set are given. However the significant information gaps of the reporting process reduces its potential for data modelling almost to zero. And, even when all the countries would report perfectly on the whole indicator set, the number of countries and the variability represented by those countries would probably be too low to have satisfying results with linear regressions. With the existing data set only some visual representations and interpretations can be carried out in order to verify the supposed interactions as described with the cognitive mapping approach.

Figure 22 illustrates correlations between three indicators of the pan-European C&I set, revealing some trends in the data, confirming that there is a relation between the indicators. This information however doesn't allow us to conclude that there is a direct cause effect relationship, a lot of other indicators could be in between, and neither does this graph give any information on the direction of the relations. As an example, the second graph illustrates a trend between the indicator fellings and the indicator increment. Two hypothesis can be drawn: first one could suppose that the high felling rates stimulate the tree growth and results in higher increment, on the other hand it could also be that the increment is higher in some, more fertile stands, as a consequence the fellings are higher. The graphs cannot conclude which of these hypotheses is correct; the real reason for the correlation could even be different.

2. Proposition of typology to characterize the nature of the network ties.

Another question emerged during the building and interpretation of the different networks : which kind of relation do we want to depict? What is the real significance of the ties linking the different indicators? Has the tie connecting soil condition and tree growth the same meaning as the one connecting protected forests to the fellings? This issue of qualifying the nature of the ties in network has already been mentioned before. A text by, (Janssen, Bodin, Anderies, Elmqvist, & Ernstson, 2006) highlights this by stating "because links can be of different sorts in the same network, e.g., human-human links and human-species links, we understand that we will face problems of link comparability in the structural analysis".

In order to address these aspects a little more, the different thematic networks of part I have been studied in detail again in order to identify the difference between the ties and to find out whether those relations can be classified into specific categories. Since one of the main goals of the network analysis is the support for policy making, the classification that was chosen for the ties, is orientated towards a policy decision focus. As a result the classification of a tie doesn't actually reflect its real nature but rather to in how far this interaction can be modulated by the decision makers.

A colour typology was established: the different colours correspond to :

- Green colour was chosen for the physical and biological relations; meaning necessary interactions that are obeying the laws of nature and are therefore almost impossible to change.
- Blue colour was chosen for the economic interactions based on market mechanisms, in theory those are ruled y the fluctuations of the markets, however they can be, in a certain extend, influenced by decision makers through specific market regulations for example by subsidies, or specific trade barriers.
- Orange colour was chosen to illustrate the policy based interactions, meaning those influences that are directly linked to policy decisions mostly through the existence of some official protection status or management document like a forest management plan which imposes specific

rules. Policy makers can directly enhance or reduce those influences by modifying the regulations or by establishing new ones. The amount of orange ties is relatively low in the networks we use in this study since the quantitative C&I set we used does not include all the qualitative policy evaluation indicators.

– Dark red colour finally was chosen to reflect the society induced interactions, meaning those effects that are directly based on people's perceptions and preferences. Policy makers can have an indirect impact on those relations through communication and awareness building campaigns.

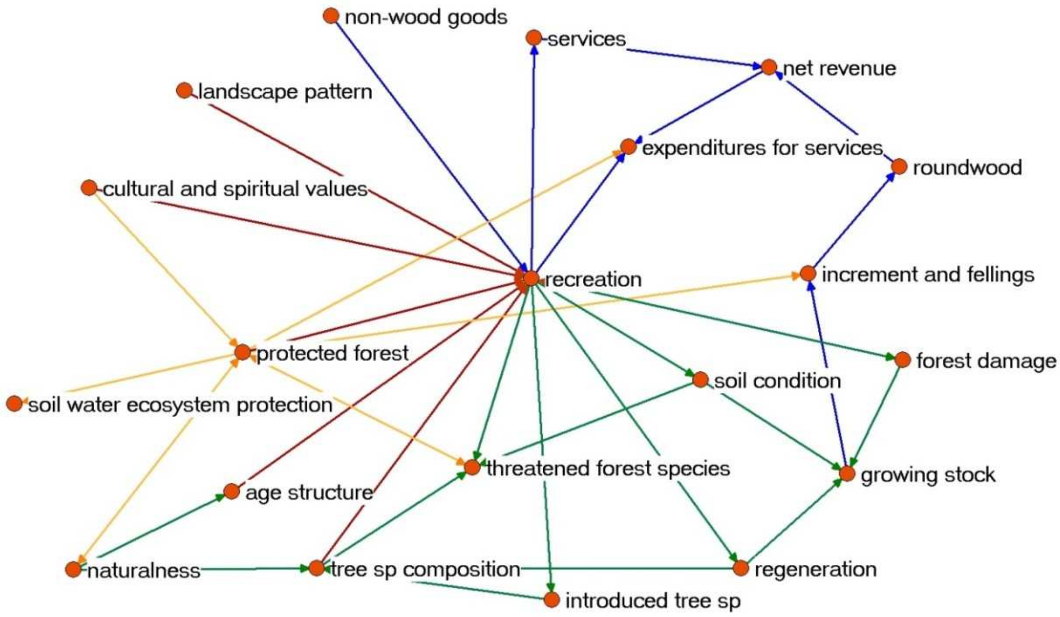


Figure 23: Application of the tie typology to thematic network on recreation; *software: Netdraw*

Figure 23 illustrates the application of this typology to the thematic network on recreational values. The graph clearly shows how the different types of ties are represented in a network. This methodology can be interesting for stakeholder to visualize how they can act on the system in order to regulate it. However, the objectivity of the classification of the ties can also be discussed, in many cases the relations have more than one meaning and could be classified in more than one category. In other cases for two headed arrows, the classification of the tie changes according to the direction. That is why sometimes an arbitrary decision has to be made as to which colour should be attributed to the tie. In the case of recreation, it is clear that there are many different ways to act on forest recreation: this can be achieved by regulation (by changing the regulation in protected areas), market measures (by giving subsidies for services that attract the public to the forests) or by promoting the diversity, the cultural values of forests.

The methodology that was tested here seems interesting but could probably be improved and participate to the creation of more elaborated models for policy support in the field of forestry. One idea for improvement could be to use a third dimension by creating different layers that can be overlaid which would allow to have different types of interaction for the same tie.

V. Discussion

A. The different applications of the C&I network approach

Many networks have been drawn and analysed throughout the study, according to different perspectives and methodologies; each of them providing more or less relevant information regarding the objectives set in the introduction of this paper. However, the different networks depicted agree on the idea that, when describing SFM, all the pan-European indicators are connected more or less directly to one another, regardless of the criteria they belong to. These observations differ greatly from the picture of the hierarchically structured indicator concepts where all indicators are segregated within criteria that are independent and disconnected from each other (refer to Figure 2). The high level of connectivity observed between the indicators in this study clearly demonstrates the relevance of the network approach when compared to the purely hierarchical models as far as the representation and analysis of SFM systems are concerned. In addition to this general statement concerning its legitimacy, the network approach has been shown to provide answers to different issues of importance in the forestry field (Pokorny & Desmond, 2004).

In the outcome of this study, as well as in previous studies (Requardt, 2007), (Wolfslehner & Vacik, 2010) the usefulness of the network representation of SFM for communication and assessment of progress towards SFM is shown. What is more questionable is how to build the networks. The methods used in this study to build the networks are based on cognitive mapping. This approach has been chosen because it is simple to implement and adapted to participatory network building (Mendoza & Prabhu, 2003). Storytelling automatically involves a high level of subjectivity; these methods will never bring about a scientifically sound objective network, as the networks can only reflect the diversity of people's perceptions and ideas. The shape of the network also depends on which type of relations one decides to depict, which can be "physical" cause-effect relations or more complicated interactions linked to economic mechanisms or human preferences. Subjectivity can be inconvenient when the aim is to identify the most central indicators or most important relations in order to evaluate the monitoring of SFM more objectively at European level. However, the compilation, confrontation and discussion around those subjective networks can allow the creation of a synthetic network resulting from the consensus of a group of individuals, which can then be considered as legitimate in the given context. Each situation and each group of actors will thus be able to build their own network to work on in this specific context.

While the relevance of the different existing centrality measures (Hanneman & Riddle, 2005) can also be discussed, the different analyses show that these measures are still a useful means of estimating the position of the indicators within each of the networks. Even though the centrality measures are not clearly objective, the information they provide can be used for evaluating the monitoring of SFM. In some cases most central indicators, or indicators situated on the most important causal paths, can be considered to require more intense monitoring efforts since they are crucial in many mechanisms composing SFM. The examples shown in this document reveal that the current state of SFM monitoring does not seem very consistent with the indicators' centrality results as given in the different networks. Some of the environmental and social indicators are often still left aside in the monitoring process as the reporting completeness date of Figure 1 show (MCPFE, UNECE, & FAO, 2007). The results of the successive network analyses of both parts II and III of this study show that this is not justified regarding the crucial position of some of those indicators in the cause effect chains. Table 12 shows how for example indicators 4.1 tree species composition and 4.5 deadwood but also 6.9 wood energy have very low data completeness rates while they are having a high centrality degree either in the participatory or the thematic networks. This is particularly striking in the case of the biodiversity indicators since biodiversity has been presented as a priority on the main international forestry agendas in recent times. Also the absence in many people's mental pictures about SFM, of most of the socio-cultural values as shown by the really low centrality degrees of indicators such as 6.5 workforce, 6.6 occupational safety and health, 6.9 recreation or 6.11 cultural and spiritual values of forests in the group networks (Table 1Table 12) is very telling. These observations regarding both monitoring and common perceptions on SFM reveal a need for more efficient communication on social and environmental values of the forests. While those results are important and interesting one should keep in mind that they are reflecting one specific hypothesis stating that most central indicators are "more important" than the others, which is adopted in this study. However this point of view originates from the first applications of network analysis in social sciences, were the amount of relations is directly correlated to importance of power of the actors. On the opposite, in the case of socio-environmental systems isolation can also give a certain importance to indicators. Some people could argue for example that the fact that cultural and spiritual values are disconnected from other indicators makes them even more important because it is the only way to monitor these aspects of SFM.

An even more interesting achievement of this study concerns the very positive outcomes of both the thematic network analysis and the participatory network building workshop in terms of the implementation of network building techniques for discussing and explaining SFM as a dynamic system. The progression of the study and the confrontation of the different networks successively lead to the evidence that there is not one SFM system but there are as many SFM systems as there are contexts or actors. The very simple and visual methods that are used here allow each actor or stakeholder to depict clearly his own view on sustainable management and to explain and share it with an assembly. Their implementation is very fruitful for both the designer of the network and the recipient of the message. As shown by the participants' feedback on the network building workshop, the creation of such a network requires analytic effort and causes people to explore and conceptualize their personal understanding of SFM. In the same time, the person to whom the network is explained also gets an insight in the other participants' vision on SFM and can learn from the external perspective he discovers. Rather than being a problem solving method the network approach is thus a problem structuring method allowing the enhancement of the understanding between stakeholders from different backgrounds. These methods can therefore be adapted to facilitate not only the cross-sectoral interactions between forest stakeholders but also the communication on SFM towards the public.

From a more technical point of view, the network approach stays also a very valuable tool for modelling the different mechanisms involved in the SFM systems in order to simulate how decision makers can impact those mechanisms. Network analysis can help to evaluate the sensitivity of the different indicators to system changes through the in- and outdegree measures, and to identify the main and most important causal paths involving the indicators one is interested in. This information gives decision makers the opportunity to regulate the system in a more considerate way. Understanding the complex underlying mechanisms as accurately as possible is in this case crucial for making correct decisions and obtaining satisfactory results. Although the cognitive mapping approach has the clear advantage of being easy and fast to implement in comparison with more elaborate simulation models, its limitations in terms of subjectivity and accuracy of the interactions are problematic. More precise characterisation of the relations is crucial: the methodology detailed in the outlook of this study, with a specific classification of the different types of relation gives some more input in this direction. The visual characterisation of the interactions can significantly facilitate the decision-making process by revealing the different cause effect chains and how they can be influenced. Further research on this kind of tool could be carried out in order to adapt the whole network approach for modelling purposes.

B. Suitability of the pan-European C&I for network building purposes

Another subject for discussion concerns the suitability of the pan-European C&I set for the network analysis purposes. It is clear from the beginning that the current pan-European C&I set as adopted in 2002 (MCPFE, 2003) was not really meant for this kind of theoretical analysis on the concept of sustainable forest management. The indicators were compiled in a monitoring perspective, and have been selected not only to cover the whole range of forest goods and values but also for their ease of measurement and assessment over time (FAO, 2004). As a result, some indicators are not particularly relevant for assessing the various values of forests, and other, potentially more useful indicators are missing. In order to improve the C&I networks, it would be necessary to find a way to include the qualitative pan-European indicators since they reflect important aspects of SFM in particular some of the regulation mechanisms which are missing in the networks of this study, as explained in part II.B.6. Those qualitative indicators are part of the pan-European C&I set as adopted in 2002 (MCPFE, 2003) but couldn't be included in the network building since their format is not adapted to this exercise.

In addition, although the regional C&I sets are supposed to be the result of the consensus of experts from different fields, they are not really balanced according to the different values of forests. The unbalanced sets cause problems for people to give the same level of importance to all values in the network they build. Whereas the absence of some political indicators limits the explanation of some policy driven mechanisms in the networks, the socio-economic indicators are almost too abundant. This may contribute to explain why the environmental and socio-economic indicators, which are regrouping a higher amount of indicators in the pan-European C&I set, were given lower centrality by the participants in the network building workshop.

Finally the feedback on the workshop also revealed certain confusion about the indicators themselves as described in part III.B.3. Again, the definition of the indicators was driven by the monitoring purpose and therefore not really adapted to a wider public and a more conceptual use. The positioning of the different indicators in the network depends highly on the interpretation of their definition, and often this definition is not precise enough to limit the deviation of this interpretation. Hence, depending on how the indicators are understood and used, it can occur that the same idea is expressed in different ways in the network. For the group that participated in the participatory network building there was some confusion as regards the nature of the indicators, which are in the C&I set parameters to measure and not the actions or values that they measure. This was the case in particular about forest management plans, which were considered all important as they determine everything. This is more or less the case in the real world, but in the indicator system, the presence or absence of a management plan only indicates whether or not the forest is being managed and not its achievements. This illustrates how crucial it is to clarify the wording and definition of the indicators for improving the quality of the result of the network building exercises.

In spite of the previously mentioned limitations, until now the existing C&I sets remain the most suitable means for carrying out network analysis. According to the previous remarks, the conclusions drawn from this study suggest some adaptations to be made to the current C&I set in order to facilitate its use for network building and storytelling in particular. In general it is worth considering in each case which kind of set would be more adapted to the situation. Because of the European scope of the reflection of this work, only the pan-European C&I set was used in this study but this might is not the most appropriate one for all of the applications. FMU level C&I, which are more adapted to local contexts and in some cases easier to comprehend for the public, could suit better the network building purpose, particularly for stakeholder dialogue on local problems. One could imagine, if time is available setting up a specific local C&I set adapted to the purpose of the network analysis, with a deepened work on definition and scope of each indicator.

VI. Conclusion

Although the first C&I processes were launched almost twenty years ago, until very recently the applications of criteria and indicators for sustainable forest management were very limited, mostly reduced to monitoring purposes. This study supports remarks by other researchers concerning the possibilities of broadening the spectrum of application of C&I and the pan-European set in particular (Mendoza & Prabhu, 2003). The C&I network approach which is detailed in this document is an example of one of these other uses of C&I sets. This study has demonstrated the benefits of the network approach both for enhancing understanding of SFM and for supporting the policy related monitoring and decision-making processes.

Thematic network building was carried out in order to show the wide range of possible networks that can be built according to the focus of interest and to illustrate how the roles and positions of the indicators can change. In a second step, participatory networks were also built and analysed by a group of forest researchers during a group workshop. The different analyses highlighted the marginalisation of some mainly socio-economic and environmental indicators - for example wood energy and deadwood indicators - both in the monitoring processes and in the participatory networks (Table 12). On the other hand, the thematic networks in part II clearly showed that those very same indicators can have a very strategic role in specific contexts or according to different sensibilities. These results reveal the lack of information, communication and reporting on the role of those specific components of SFM.

Although the primary goal of the study, meaning obtaining an accurate description of the complexity of interaction constituting SFM, might have been too ambitious, the progression of the study reached even more interesting conclusions regarding other objectives. Indeed, the complexity of SFM shouldn't be overlooked - the individual and participatory cognitive mapping approaches give no accurate answers to those questions - but these same tools can be even more helpful by providing valuable support to structure and foster discussion and debate on SFM. This facilitating of the dialogues and discussions will be an essential step for eventually leading local and global stakeholders to the implementation of new measures for developing Sustainable Forest Management in the future.

As to the use of these tools for the development of existing or the creation of more sophisticated models for SFM, the methods described in this study and particularly in the outlook, can provide useful input. More research would be necessary to investigate all the possibilities. The first methodologies implemented here, which lead to the building of purely qualitative networks, could potentially be enhanced in order to integrate some valuation of the interactions between the different components of the system. Quantifying the interactions would be an important step towards transforming the purely theoretical SFM conceptualisation tool towards a SFM simulation tool which would be even more efficient for supporting policy decision making.

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ANNEXES

I. List and definitions of the 35 pan European quantitative indicators
II. Thematic networks literature and contingency matrixes
III. C&I workshop handout
IV. Participants research backgrounds

ANNEX I: List and definitions of the 35 pan European quantitative indicators

The following definitions are extracted from the leaflet on Improved Pan-European Indicators for Sustainable Forest Management as adopted by the MCPFE Expert Level Meeting 7-8 October 2002, Vienna, Austria (MCPFE, 2003).
Downloadable on www.mcpfe.org

Criterion 1: Maintenance and Appropriate Enhancement of Forest Resources and their Contribution to Global Carbon Cycles

1.1 Forest area
Area of forest and other wooded land, classified by forest type and by availability for wood supply, and share of forest and other wooded land in total land area
1.2 Growing stock
Growing stock on forest and other wooded land, classified by forest type and by availability for wood supply
1.3 Age structure and/or diameter distribution
Age structure and/or diameter distribution of forest and other wooded land, classified by forest type and by availability for wood supply
1.4 Carbon stock
Carbon stock of woody biomass and of soils on forest and other wooded land

Criterion 2: Maintenance of Forest Ecosystem Health and Vitality

2.1 Deposition of air pollutants
Deposition of air pollutants on forest and other wooded land, classified by N, S and base cations
2.2 Soil condition
Chemical soil properties (pH, CEC, C/N, organic C, base saturation) on forest and other wooded land related to soil acidity and eutrophication, classified by main soil types
2.3 Defoliation
Defoliation of one or more main tree species on forest and other wooded land in each of the defoliation classes “moderate”, “severe” and “dead”
2.4 Forest damage
Forest and other wooded land with damage, classified by primary damaging agent (abiotic, biotic and human induced) and by forest type.

Criterion 3: Maintenance and Encouragement of Productive Functions of Forests (Wood and Non-Wood)

3.1 Increment and fellings
Balance between net annual increment and annual fellings of wood on forest available for wood supply
3.2 Roundwood
Value and quantity of marketed roundwood
3.3 Non-wood goods
Value and quantity of marketed non-wood goods from forest and other wooded land
3.4 Services
Value of marketed services on forest and other wooded land
3.5 Forests under management plans
Proportion of forest and other wooded land under a management plan or equivalent

Criterion 4: Maintenance, Conservation and Appropriate Enhancement of Biological

Diversity in Forest Ecosystems

4.1 Tree species composition

Area of forest and other wooded land, classified by number of tree species occurring and by forest type

4.2 Regeneration

Area of regeneration within even-aged stands and unevenaged stands, classified by regeneration type

4.3 Naturalness

Area of forest and other wooded land, classified by “undisturbed by man”, by “semi-natural” or by “plantations”, each by forest type

4.4 Introduced tree species

Area of forest and other wooded land dominated by introduced tree species

4.5 Deadwood

Volume of standing deadwood and of lying dead-wood on forest and other wooded land classified by forest type

4.6 Genetic resources

Area managed for conservation and utilisation of forest tree genetic resources (in situ and ex situ gene conservation) and area managed for seed production

4.7 Landscape pattern

Landscape-level spatial pattern of forest cover

4.8 Threatened forest species

Number of threatened forest species, classified according to IUCN Red List categories in relation to total number of forest species

4.9 Protected forests

Area of forest and other wooded land protected to conserve biodiversity, landscapes and specific natural elements, according to MCPFE Assessment Guidelines

Criterion 5: Maintenance and Appropriate Enhancement of Protective Functions in Forest Management (notably Soil and Water)

5.1 Protective forests – soil, water and other ecosystem functions

Area of forest and other wooded land designated to prevent soil erosion, to preserve water resources, or to maintain other forest ecosystem functions, part of MCPFE Class “Protective Functions”

5.2 Protective forests – infrastructure and managed natural resources

Area of forest and other wooded land designated to protect infrastructure and managed natural resources against natural hazards, part of MCPFE Class “Protective Functions”

Criterion 6: Maintenance of Other Socio-Economic Functions and Conditions

6.1 Forest holdings

Number of forest holdings, classified by ownership categories and size classes

6.2 Contribution of forest sector to GDP

Contribution of forestry and manufacturing of wood and paper products to gross domestic product

6.3 Net revenue

Net revenue of forest enterprises

6.4 Expenditures for services

Total expenditures for long-term sustainable services from forests

6.5 Forest sector workforce

Number of persons employed and labour input in the forest sector, classified by gender and age group, education and job characteristics

6.6 Occupational safety and health

Frequency of occupational accidents and occupational diseases in forestry

6.7 Wood consumption

Consumption per head of wood and products derived from wood

6.8 Trade in wood

Imports and exports of wood and products derived from wood

6.9 Energy from wood resources

Share of wood energy in total energy consumption, classified by origin of wood

6.10 Accessibility for recreation

Area of forest and other wooded land where public has a right of access for recreational purposes and indication of intensity of use

6.11 Cultural and spiritual values

Number of sites within forest and other wooded land designated as having cultural or spiritual values

Annex II: Thematic networks literature and contingency matrixes

Thematic network on deadwood and biodiversity aspects

Literature used for validating the network

Augustaitis, A., & Bytnerowicz, A. (2008). Contribution of ambient ozone to Scots pine defoliation and reduced growth in the Central European forests: A Lithuanian case study. Environmental Pollution , 155, 436-445.

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Bütler, R., Angelstam, P., Ekelund, P., & Schlaepfer, R. (2004). Dead wood threshold values for the three-toed woodpecker presence in boreal and sub-Alpine forest. Biological Conservation , 119 (3), 305-318.

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Jabin, M., Mohr, D., Kappes, H., & Topp, W. (2004). Influence of deadwood on density of soil macro-arthropods in a managed oak-beech forest. Forest Ecology and Management , 194, 61-69.

Juknys, R., Vencloviene, J., Stravinskiene, V., Augustaitis, A., & Bartkevicius, E. (2003). Scots pine (Pinus sylvestris L.) growth and condition in a polluted environment: from decline to recovery. Environmental Pollution , 125, 205-212.

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Mathers, N. J., Mendham, D. S., O'Connell, A. M., Grove, T. S., Xu, Z., & Saffigna, P. G. (2003). How does residue management impact soil organic matter composition and quality under Eucalyptus globulus plantations in southwestern Australia? Forest Ecology and Management , 179, 253-267.

Mc Neely, J. A. (1994). Protected areas for the 21st century: working to provide benefits for society. Biodiversity and Conservation , 3, 390-405.

Palosuo, T., Peltoniemi, M., Mikhailov, A., Komarov, A., Faubert, P., Thürig, E., et al. (2008). Projecting effects of intensified biomass extraction with alternative modelling approaches. Forest Ecology and Management , 255 (5-6), 1423-1433.

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Verkerk, P., Lindner, M., Zanchi, G., & Zudin, S. (2009). Assessing impacts of intensified biomass removal on deadwood in European forests. Ecological Indicators , In Press, Corrected Proof.

<u>Contingency matrix:</u>

		1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.1	5.2	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	6.1.	6.11
Forest area	1.1																																			
Growing stock	1.2				1																															
Age structure, diameter distribution	1.3																		1																	
Carbon stock	1.4																																			
Deposition of air pollutants	2.1		1				1	1																												
Soil condition	2.2		1		1			1							1	1						1														
Defoliation	2.3		1																																	
Forest damage	2.4						1								1				1			1														
Increment and fellings	3.1																																			
Roundwood	3.2																																			
Non-wood goods	3.3																																			
Services	3.4																																			
Forests under managzmt plans	3.5																																			
Tree species composition	4.1						1		1										1			1														
Regeneration	4.2														1																					
Naturaleness	4.3			1											1																					
Introduces tree species	4.4																																			
Deadwood	4.5				1		1															1														
Genetic ressources	4.6																																			
Landscape pattern	4.7																					1														
Threatened forest species	4.8																																			
Protected forest	4.9																1					1														
Protective forests - soil, water and other ecosystem functions	5.1																																			
Protective functions - infrastructure and managed natural ressources	5.2																																			
Forest holdings	6.1																																			
Contribution of forest sector to GDP	6.2																																			
Net revenue	6.3																																			
Expenditures for services	6.4																																			
Forest sector workforce	6.5																																			
Occupational safety and health	6.6																																			
Wood consumption	6.7																																			
Trade in wood	6.8																																			
Energy from wood resources	6.9																		1																	
Accessibility for recreation	6.1																																			
Cultural and spiritual values	6.11																																			

Thematic network b. On wood energy and economic aspects.

Literature used for validating the network:

Berndes, G., Hoogwijk, M., & van den Broek, R. (2003). The contribution of biomass in the future global energy supply: a review of 17 studies. Biomass and Bioenergy , 25, 1-28.

Bernetti, I., Fagarazzi, C., & Fratini, R. (2004). A methodology to anaylse the potential development of biomass-energy sector: an application in Tuscany. Forest Policy and Economics , 6, 415-432.

Forsberg, G. (2000). Biomass energy transport. Analysis of bioenergy transport chains using life cycle inventory method. Biomass and Bioenergy , 19, 17-30.

Korhonen, J. (2001). Regional industrial ecology: examples from regional economic systems of forest industry and energy supply in Finland. Journal of Environmental Management , 63, 367-375.

Palosuo, T., Peltoniemi, M., Mikhailov, A., Komarov, A., Faubert, P., Thürig, E., et al. (2008). Projecting effects of intensified biomass extraction with alternative modelling approaches. Forest Ecology and Management , 255 (5-6), 1423-1433.

Raulund-Rasmussen, K., Hansen, K., Katzensteiner, K., Loustau, D., de Jong, J., Gundersen, P., et al. (2007). Deliverable 2.2.2. Synthesis report on impact of forest management on environmental services. EFORWOOD .

Türker, M. F., Ayaz, H., & Kaygusuz, K. (1999). Forest biomass as a source of renewable energy in Turkey. Energy Sources , 21 (8), 705-714.

van Riet, C. (2005). Sustainable use of wood for products and energy: conflict or opportunity. Les cahiers scientifiques du bois , 3, 1-12.

Verkerk, P., Lindner, M., Zanchi, G., & Zudin, S. (2009). Assessing impacts of intensified biomass removal on deadwood in European forests. Ecological Indicators , In Press, Corrected Proof.

Contingency matrix:

		1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.1	5.2	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	6.10	6.11
Forest area	1.1		1																																	
Growing stock	1.2				1					1																										
Age structure, diameter distribution	1.3																																			
Carbon stock	1.4																																			
Deposition of air pollutants	2.1																																			
soil condition	2.2		1																																	
defoliation	2.3																																			
forest damage	2.4																																			
Increment and fellings	3.1		1								1																	1		1						
Roundwood	3.2																																1	1		
Non-wood goods	3.3																																			
services	3.4																																			
forests under managmt plans	3.5									1																										
tree species composition	4.1																																			
regeneration	4.2																																			
naturaleness	4.3																																			
introduces tree species	4.4																																			
deadwood	4.5				1		1																													
genetic ressources	4.6																																			
landscape pattern	4.7																																	1		
threatened forest species	4.8																																			
protected forest	4.9									1																										
protective forests - soil, water and other ecosystem functions	5.1																																			
Protective functions - infrastructure and managed natural ressources	5.2																																			
forest holdings	6.1	1												1																						
contribution of forest sector to GDP	6.2																																			
Net revenue	6.3																										1									
Expenditures for services	6.4																																			
forest sector workforce	6.5																																			
occupational safety and health	6.6																																			
wood consumption	6.7									1																							1			
trade in wood	6.8										1																					1				
energy from wood resources	6.9					1					1								1									1		1		1				
accessibility for recreation	6.10																																			
cultural and spiritual values	6.11																																			

Thematic network c. Carbon stocks and climate change aspects.

Literature used for validating the network:

Berndes, G., Hoogwijk, M., & van den Broek, R. (2003). The contribution of biomass in the future global energy supply: a review of 17 studies. Biomass and Bioenergy , 25, 1-28.

Bernetti, I., Fagarazzi, C., & Fratini, R. (2004). A methodology to anaylse the potential development of biomass-energy sector: an application in Tuscany. Forest Policy and Economics , 6, 415-432.

Forsberg, G. (2000). Biomass energy transport. Analysis of bioenergy transport chains using life cycle inventory method. Biomass and Bioenergy , 19, 17-30.

Korhonen, J. (2001). Regional industrial ecology: examples from regional economic systems of forest industry and energy supply in Finland. Journal of Environmental Management , 63, 367-375.

Palosuo, T., Peltoniemi, M., Mikhailov, A., Komarov, A., Faubert, P., Thürig, E., et al. (2008). Projecting effects of intensified biomass extraction with alternative modelling approaches. Forest Ecology and Management , 255 (5-6), 1423-1433.

Raulund-Rasmussen, K., Hansen, K., Katzensteiner, K., Loustau, D., de Jong, J., Gundersen, P., et al. (2007). Deliverable 2.2.2. Synthesis report on impact of forest management on environmental services. EFORWOOD .

Türker, M. F., Ayaz, H., & Kaygusuz, K. (1999). Forest biomass as a source of renewable energy in Turkey. Energy Sources , 21 (8), 705-714.

van Riet, C. (2005). Sustainable use of wood for products and energy: conflict or opportunity. Les cahiers scientifiques du bois , 3, 1-12.

Verkerk, P., Lindner, M., Zanchi, G., & Zudin, S. (2009). Assessing impacts of intensified biomass removal on deadwood in European forests. Ecological Indicators , In Press, Corrected Proof.

Contingency matrix:

		1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.1	5.2	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	6.10	6.11
Forest area	1.1		1																																	
Growing stock	1.2				1					1																										
Age structure, diameter distribution	1.3		1																																	
Carbon stock	1.4																																			
Deposition of air pollutants	2.1						1																													
soil condition	2.2		1		1																															
defoliation	2.3																																			
forest damage	2.4		1																1																	
Increment and fellings	3.1		1	1							1																									
Roundwood	3.2				1																													1		
Non-wood goods	3.3																																			
services	3.4																																			
forests under managmt plans	3.5									1																										
tree species composition	4.1																																			
regeneration	4.2																																			
naturaleness	4.3																																			
introduces tree species	4.4																																			
deadwood	4.5				1		1																													
genetic ressources	4.6																																			
landscape pattern	4.7																																			
threatened forest species	4.8																																			
protected forest	4.9								1	1									1																	
protective forests - soil,water and other ecosystem functions	5.1																																			
Protective functions - infrastructure and managed natural ressources	5.2																																			
forest holdings	6.1																																			
contribution of forest sector to GDP	6.2																																			
Net revenue	6.3																																			
Expenditures for services	6.4																																			
forest sector workforce	6.5																																			
occupational safety and health	6.6																																			
wood consumption	6.7																																			
trade in wood	6.8																																			
energy from wood resources	6.9																		1																	
accessibility for recreation	6.1.																																			
cultural and spiritual values	6.1																																			

Thematic network d. On recreation values and social aspects.

Literature used for validating the network:

Blanc, F., Marion, G., & Granet, A.-m. (2007). Les impacts écologiques de la fréquentation. Les rendez-vous techinques de l'ONF , 16, 79-84.

Hilger, J., & Englin, J. (2009). Utility theoretic semi-logarithmic incomplete demand systems in a natural experiment: Forest fire impact on recreational values and use. Resource and Energy Economics , 31, 287-298.

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Leung, Y.-F., & Marion, J. L. (2000). Recreation impacts and management in wilderness: a state-of-knowledge review. USDA Forest Service Proceedings , 5, 23-48.

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MCPFE. (2002). Background information for improved pan-European indicators for sustainable forest management. MCPFE expert level meeting. Vienna: MCPFE Liaison Unit.

Rusterholz, H.-P., Bilecen, E., Kleiber, O., Hegetschweiler, K. T., & Baur, b. (2009). Intensive recreation activities in suburban forests a method to quantify the reduction in timber value. Urban Forestry &Urban greening , 8, 109-116.

Zandersen, M., Termansen, M., & Jensen, F. S. (2007). Evaluating approaches to predict recreation values of new forest sites. Journal of forest Economics , 13, 103-128.

Contingency matrix:

		1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.1	5.2	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	6.10	6.1
Forest area	1.1																																			
Growing stock	1.2									1																										
Age structure, diameter distribution	1.3																																		1	
Carbon stock	1.4																																			
Deposition of air pollutants	2.1																																			
soil condition	2.2		1																			1														
defoliation	2.3																																			
forest damage	2.4		1																																1	
Increment and fellings	3.1										1																									
Roundwood	3.2																											1								
Non-wood goods	3.3																																		1	
services	3.4																											1								
forests under managmt plans	3.5																																			
tree species composition	4.1																					1													1	
regeneration	4.2		1												1																					
naturaleness	4.3			1											1								1													
introduces tree species	4.4														1																					
deadwood	4.5																																			
genetic ressources	4.6																																			
landscape pattern	4.7																																		1	
threatened forest species	4.8																						1													
protected forest	4.9									1							1					1		1					1						1	
protective forests - soil,water and other ecosystem functions	5.1																																			
Protective functions - infrastructure and managed natural ressources	5.2																																			
forest holdings	6.1																																			
contribution of forest sector to GDP	6.2																																			
Net revenue	6.3																												1							
Expenditures for services	6.4																																			
forest sector workforce	6.5																																			
occupational safety and health	6.6																																			
wood consumption	6.7																																			
trade in wood	6.8																																			
energy from wood resources	6.9																																			
accessibility for recreation	6.10						1		1				1			1		1				1							1							
cultural and spiritual values	6.11																						1												1	

Annex III: C&I workshop handout

Name:

Institution:

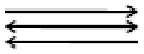
Field of research and expertise:

1

Objective: Please tell a story of SFM and draw a network of main system and causal relationships according to your understanding of SFM , using pan-European indicators.

Time: 45'

- Go through the list of indicators, read the definitions and select a limited number of indicators for the SFM story you want to build (between 10 and 25) (sheet 3)
- Draw the causal interlinkages (cause-effect relations) between these indicators according to your understanding of SFM on sheet 6. Please limit the number of relations to only direct relations. Please indicate the number of each indicator.
- Indicate direction of relationship/impact:



- Identify and explain (sheet 7):
  - the 2 most important relations of your SFM network,
  - which are the most central indicators in your network and why?
- Please describe briefly which problems you faced building your network and SFM story (sheet 8).

2

MCPFE C&I for SFM

C1	Forest Resources & Carbon
1.1	Forest area
1.2	Growing stock
1.3	Age structure and/ or diameter distribution
1.4	Carbon stock

C2	Health & Vitality
2.1	Deposition of air pollutants
2.2	Soil condition
2.3	Defoliation
2.4	Forest damage

C3	Productive Functions
3.1	Increment and fellings
3.2	Roundwood
3.3	Non-wood goods
3.4	Services
3.5	Forests under management plans

C4	Biodiversity
4.1	Tree species composition
4.2	Regeneration
4.3	Naturalness
4.4	Introduced tree species
4.5	Deadwood
4.6	Genetic resources
4.7	Landscape pattern
4.8	Threatened forest species
4.9	Protected forests

C5	Protective Functions
5.1	Protective forests – soil, water and other ecosystem functions
5.2	Protective forests – infrastructure and managed natural resources

C6	Socio-Economic Functions
6.1	Forest holdings
6.2	Contribution of forest sector to GDP
6.3	Net revenue
6.4	Expenditures for services
6.5	Forest sector workforce
6.6	Occupational safety and health
6.7	Wood consumption
6.8	Trade in wood
6.9	Energy from wood resources
6.10	Accessibility for recreation
6.11	Cultural and spiritual values

3

Criterion 1:Maintenance and Appropriate Enhancement of Forest Resources and their Contribution to Global Carbon Cycles

1.1 Forest area
Area of forest and other wooded land, classified by forest type and by availability for wood supply, and share of forest and other wooded land in total land area
1.2 Growing stock
Growing stock on forest and other wooded land, classified by forest type and by availability for wood supply
1.3 Age structure and/or diameter distribution
Age structure and/or diameter distribution of forest and other wooded land, classified by forest type and by availability for wood supply
1.4 Carbon stock
Carbon stock of woody biomass and of soils on forest and other wooded land

Criterion 2:Maintenance of Forest Ecosystem Health and Vitality

2.1 Deposition of air pollutants
Deposition of air pollutants on forest and other wooded land, classified by N, S and base cations
2.2 Soil condition
Chemical soil properties (pH, CEC, C/N, organic C, base saturation) on forest and other wooded land related to soil acidity and eutrophication, classified by main soil types
2.3 Defoliation
Defoliation of one or more main tree species on forest and other wooded land in each of the defoliation classes "moderate", "severe" and "dead"
2.4 Forest damage
Forest and other wooded land with damage, classified by primary damaging agent (abiotic, biotic and human induced) and by forest type

Criterion 3:Maintenance and Encouragement of Productive Functions of Forests (Wood and Non-Wood)

3.1 Increment and fellings
Balance between net annual increment and annual fellings of wood on forest available for wood supply
3.2 Roundwood
Value and quantity of marketed roundwood
3.3 Non-wood goods
Value and quantity of marketed non-wood goods from forest and other wooded land
3.4 Services
Value of marketed services on forest and other wooded land
3.5 Forests under management plans
Proportion of forest and other wooded land under a management plan or equivalent

Criterion 4:Maintenance, Conservation and Appropriate Enhancement of Biological Diversity in Forest Ecosystems

4.1 Tree species composition
Area of forest and other wooded land, classified by number of tree species occurring and by forest type
4.2 Regeneration
Area of regeneration within even-aged stands and uneven-aged stands, classified by regeneration type
4.3 Naturalness
Area of forest and other wooded land, classified by "undisturbed by man", by "semi-natural" or by "plantations", each by forest type
4.4 Introduced tree species
Area of forest and other wooded land dominated by introduced tree species
4.5 Deadwood
Volume of standing deadwood and of lying dead-wood on forest and other wooded land classified by forest type

4

4.6 Genetic resources
Area managed for conservation and utilisation of forest tree genetic resources (in situ and ex situ gene conservation) and area managed for seed production
4.7 Landscape pattern
Landscape-level spatial pattern of forest cover
4.8 Threatened forest species
Number of threatened forest species, classified according to IUCN Red List categories in relation to total number of forest species
4.9 Protected forests
Area of forest and other wooded land protected to conserve biodiversity, landscapes and specific natural elements, according to MCPFE Assessment Guidelines

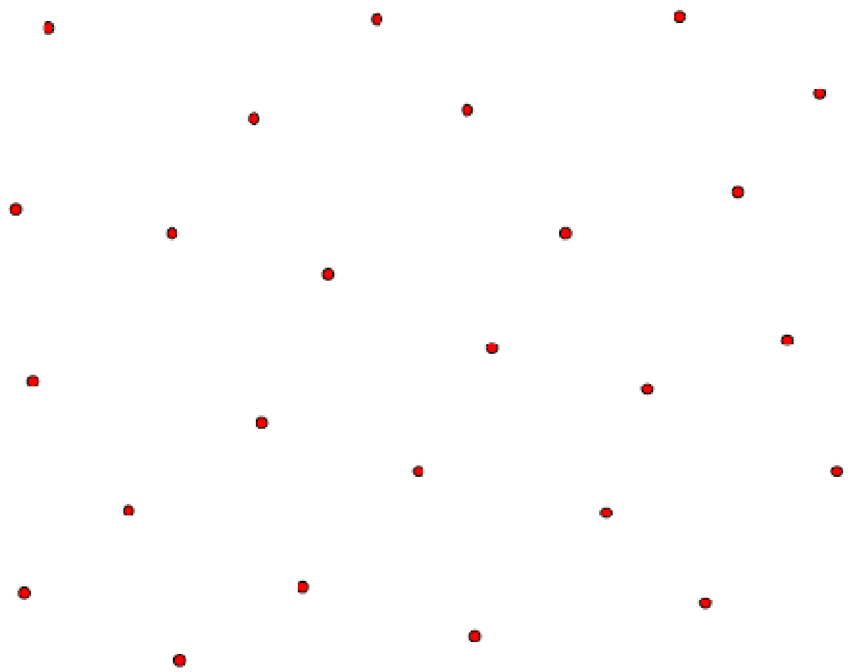
Criterion 5: Maintenance and Appropriate Enhancement of Protective Functions in Forest Management (notably Soil and Water)

5.1 Protective forests – soil, water and other ecosystem functions
Area of forest and other wooded land designated to prevent soil erosion, to preserve water resources, or to maintain other forest ecosystem functions, part of MCPFE Class "Protective Functions"
5.2 Protective forests – infrastructure and managed natural resources
Area of forest and other wooded land designated to protect infrastructure and managed natural resources against natural hazards, part of MCPFE Class "Protective Functions"

Criterion 6: Maintenance of Other Socio-Economic Functions and Conditions

6.1 Forest holdings
Number of forest holdings, classified by ownership categories and size classes
6.2 Contribution of forest sector to GDP
Contribution of forestry and manufacturing of wood and paper products to gross domestic product
6.3 Net revenue
Net revenue of forest enterprises
6.4 Expenditures for services
Total expenditures for long-term sustainable services from forests
6.5 Forest sector workforce
Number of persons employed and labour input in the forest sector, classified by gender and age group, education and job characteristics
6.6 Occupational safety and health
Frequency of occupational accidents and occupational diseases in forestry
6.7 Wood consumption
Consumption per head of wood and products derived from wood
6.8 Trade in wood
Imports and exports of wood and products derived from wood
6.9 Energy from wood resources
Share of wood energy in total energy consumption, classified by origin of wood
6.10 Accessibility for recreation
Area of forest and other wooded land where public has a right of access for recreational purposes and indication of intensity of use
6.11 Cultural and spiritual values
Number of sites within forest and other wooded land designated as having cultural or spiritual values

5



6

Describe and explain briefly the 2 most crucial relations in your network:

In your network, which are the most central indicators and why?

7

Which problems did you face to build your network and SFM story?

8

Annex IV Participants research backgrounds

group	participant	field of research and expertise
1	1.A	tropical forest ecology
1	1.B	biomass production, forest ecophysiology
1	1.C	forest ecology and management
1	1.D	soil use and land management
1	1.E	forest ecology and carbon sinks
1	1.F	forest policy
2	2.A	remote sensing and dendrochronology
2	2.B	GIS remote sensing
2	2.C	genetics, microbiology
2	2.D	plant physiology, energy and carbon emissions
3		policy development
3		plant physiology
3		forest biology
3		tree provenances and climate change
4	4.A	forest entomology
4	4.B	socio-economics
4	4.C	fire management (biodiversity and wildlife)
5	5.A	wood energy mobilisation
5	5.B	forest policy and economics
5	5.C	forest policy and economics
5	5.D	forest policy nature conservation
6	6.A	sylviculture, sustainable forest management
6	6.B	nature conservation and forest policy
6	6.C	wood quality
6	6.D	C&I and network analysis
7	7.A	wood products and wood consumption
7	7.B	forest ecology
7	7.C	forest policy and economics, socuial functions of forests

Abstract

Although the notion of Sustainable Forest Management (SFM) is crucial in all national and international forest dialogues, the exact definition or explanation of what this notion embraces is not always clear. Currently, efforts towards more sustainable forest management are mainly embodied by the various criteria and indicator (C&I) processes developed in all regions around the globe to monitor and report on progress towards SFM.

The present study investigates the use of the pan-European C&I set as a basis to investigate and map the complex mechanisms involved in SFM following an indicator network approach. The network approach, by representing the interactions between the indicators, gives a new insight on the complexity of SFM. Several methods and applications will be detailed to find out how this approach can enhance the communication and understanding of SFM but also how it can evaluate and support decision-making processes.