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Evaluation of FlexWood concept

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Abbreviations

ALS: Airborne Laser Scanning

BAU: Business as usual (scenario)

CBA: Cost-Benefit Analysis

CEA: Cost-effectiveness Analysis

DBH: Diameter at Breast Height

LCC: Life Cycle Cost

LIDAR: Light Detection and Ranging

MCA: Multi-criteria Analysis

NPV: Net present value

TLS: Terrestrial Laser Scanning

WP: Work Package

WSC: Wood Supply Chain

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1. Executive Summary

Objectives

The overall objective of the FlexWood project is to develop and to build a novel logistic system, incorporating better information on wood resources and enhanced optimisation models, to respond more efficiently and adequately to the demands of industrial sectors. In other words, the aim is to reach a better matching between supply and demand and to provide a Wood Supply Chain (WSC) driven by demand, where requirements of industries pull the activity of the rest of supply chain, until the forest exploitation (and not the opposite, as still often observed today). Finally, this increased flexibility and the better knowledge of resources must create value throughout the WSC.

In this context, the Deliverable 8.2 aims to evaluate the FlexWood concept. More specifically, it is to assess the ability of new technologies (mainly LIDAR) and optimized planning systems to make the Wood Supply Chain more flexible and more efficient at an acceptable cost.

In order to provide such analysis, the evaluation is based on four demonstration sites where new technologies and new practices have been implemented in the framework of the Task 8100 ("*Use case implementation and testing of FlexWood system*"). These demonstration sites are located in France, Germany, Sweden and Poland.

The approach

The chosen approach for doing the evaluation of the FlexWood concept combines qualitative and quantitative analysis.

The qualitative analysis consists mainly of the comparison of the Business as usual scenario and the FlexWood scenario on key points of the WSC (resource inventory, stand allocation, harvesting, logistics, production and communication infrastructure) and of the analysis of main changes, in particular in terms of technologies used and process. Based on this description, the objective is to point out the advantages (already observed or expected), disadvantages and limits to the implementation of the FlexWood concept.

In addition to the qualitative analysis, we have sought to quantify some effects of the Flexwood concept (in particular, the LIDAR technology) through indicators in terms of economic performance, organization efficiency and customer satisfaction. These indicators have been calculated both in BAU and FlexWood scenario.

Obtained results

The evaluation methodology has been implemented in the four Use cases, where the FlexWood concept has been tested (France, Germany, Poland and Sweden). If these four sites have common characteristics (managed and productive forests), they present also differences, in particular in terms of surface, species and homogeneity of the forest resource.

At first, **the qualitative analysis** has confirmed that **LIDAR can enhance the resource information, on both the volume and quality.** In addition, LIDAR allows an automation of data gathering (saving time) and a better homogeneity of the data collected. In particular, ALS is the best data source to estimate the geographic position of a tree, which gives information on how many trees that are found within a harvest area. ALS gives also accurate estimates for tree size including height and diameter (DBH) for the detected trees. TLS is especially effective to estimate the diameter (DBH) and the stem taper. Finally, TLS is the best method (with the harvester's measurements) to define the external properties of the tree, that can be used to predict with models information about the inner quality of the stem.

Nevertheless, **the LIDAR technology has also shown some limits**. In particular, that is not effective to provide data on tree age and tree species. ALS could be an alternative approach for detecting tree species, but not as a stand alone mean for data collection as is often means to be combined with other methods (for data collection and processing). Furthermore, the Use cases in Germany and Poland have pointed out that, with LIDAR, it is difficult to gain reliable information in case of very heterogeneous forests.

Better information of the forest resource alone is not sufficient to improve the entire WSC. **Optimize the use of the new data collected implicates also changes and improvements at the different stages of the WSC** (stand allocation, harvesting, logistics, demand requirements). **Some Use cases have developed novel solutions at the other stages of the WSC in order to benefit from the enriched data on forest resource and to reach a better adequation between supply and industrial demand**. The Swedish Use case has focused on developing an integrated optimization model to enhance bucking simulations and harvesting operations. The French Use case has worked to develop enhanced round wood specifications that industrial users could use to express their expectations. Combined with LIDAR data, they have been integrated in a bucking simulator to test harvesting scenarios. If the developed models have still to be improved, they are today operational.

Concerning **the quantitative analysis**, **except for the Swedish Use case, the implementation of LIDAR implicates higher inventory costs than those in BAU**. **All the other indicators, in contrast, are improved** (or expected to be improved) in the FlexWood scenario. The best results are obtained for the "*time deliver*" with an important decreasing of the time needed (around – 10 days) to deliver the customer between the BAU and the FlexWood scenario for all Use cases. Other indicators should be significantly enhanced according to the Use cases: in the Swedish Use case, the "*productivity*" is increasing (from 2 hours/100 m3 to 1 hour/100 m3), thanks to optimization models implemented in the planning systems, as pointed out in the qualitative analysis. Concerning the indicator "*monetary optimisation of product mix*", the FlexWood concept should represent high potential to get better value out the forest, in particular for the forest owners. In the French Use case, the both indicators reflecting the "*customer satisfaction*" are also expected to be significantly improved, that confirms the capacity of FlexWood concept to allow a better adequation between supply and demand. Concerning the "*storage rate*", just a slight improvement is expected in the FlexWood scenario, as the congestion may not be completely avoided compared to BAU.

The results of the evaluation for LIDAR and FlexWood concept can be summarized in the following SWOT Matrix:

Strengths	**Weaknesses**
Better resource information (volume and quality) Useful in monocultural forests (e.g. pine forests) Enable the mapping of large areas in a short time (ALS) Lower unit costs for forest inventory based on ALS at a large scale implementation (e.g. Swedish Use case – 16000 ha) Enhance the predictability along the value chain thanks to more accurate data and optimization models Better productivity for stand allocation operations and for planning harvesting Decrease of storage rate in the forest and at roadside Better customer satisfaction Enhanced product mix	Difficulties to detect species through LIDAR technology Difficulties to gain reliable information for very heterogeneous forests (e.g. German Use case) High costs of LIDAR implementation for small areas (e.g. German Use case – 2000 ha) New technology which still requires improvements for collecting and processing the data
Opportunities	**Threats**
LIDAR data collection could be a collective dynamic within the forest sector or with others actors (agriculture, water management ?) One component in strategy to respond to possible future wood shortage and/or price increase Supply-related jobs could become more attractive	Existing personnel might be reluctant to adapt to new technologies and/or new methods Non-optimal implementation of LIDAR technology if the information tools and planning systems are not able to be adapted to the integration of LIDAR data Non-optimal implementation of LIDAR technology if the other stages of the WSC are not also improved (logistics, wood specifications from industrial actors, communication…)

From a global point of view, the FlexWood concept and its different components (enhanced resource inventory, optimization models for improved harvesting planning, enhanced round wood specifications…) have shown their capacity to increase the predictability along the WSC and to provide better adequation between supply and demand. Improvements are still needed but models and new practices have been developed in the framework of the FlexWood project and they are today operational.

Nevertheless, the Use cases have underlined also that the LIDAR technology is not relevant for each situation, depending on the forest surface area and the homogeneity of the resource.

Due to a central place in the project, an important part of the evaluation focused on the LIDAR. Based on obtained results, we can make some recommendations for the implementation of LIDAR technology and the development of the FlexWood concept in the WSC:

- The airborne LIDAR **is relevant mainly in case of large areas with a homogeneous forest resource**. In such situation, this technology is cost-effective and provides valuable information for a better resource knowledge;
- In contrast, for basic information, LIDAR is not relevant for small areas due to high costs of data collection;
- Currently, LIDAR technology is **not well adapted to heterogeneous forests** (need for research);
- **The technology is still new and needs to be improved;**
- LIDAR technology will be **more relevant in combination with other remote sensing technologies** (e.g. TLS + Photography);
- **Optimize the use of LIDAR data implicate also changes and improvements in the information and planning systems at the different stages of the WSC** (logistics, wood specifications from industries…);
- A solution related to high costs of LIDAR implementation could be to share them with others public and private actors, even actors outside the forest sector. Nevertheless, it is necessary that these actors have comparable needs;
- **The social acceptance of the new technologies and new practices has to be taken into account early in the projects**. It will be facilitated through mutual awareness between stakeholders, building trust in the new estimates and training programs for practioners.

Finally, even if generalizable results can not be given in terms of evaluation of innovations included in the FlexWood project, we can propose a **list of criteria** that have to be considered in such evaluation. More precisely, decide the relevance or not of LIDAR must take into account (see Figure 1):

- The objectives of the project (what type of data are needed, for which use… ?);
- The forest area (surface, homogeneity of the resource, forest ownership…);
- The financial capacity of the actors involved (in particular, the project leaders);
- The existence of service providers;
- The existence of externalities (public effort, other private projects, even outside the sector);
- The existence of processing and optimization models;
- The social acceptance of the actors (existing personnel, clients, suppliers…).

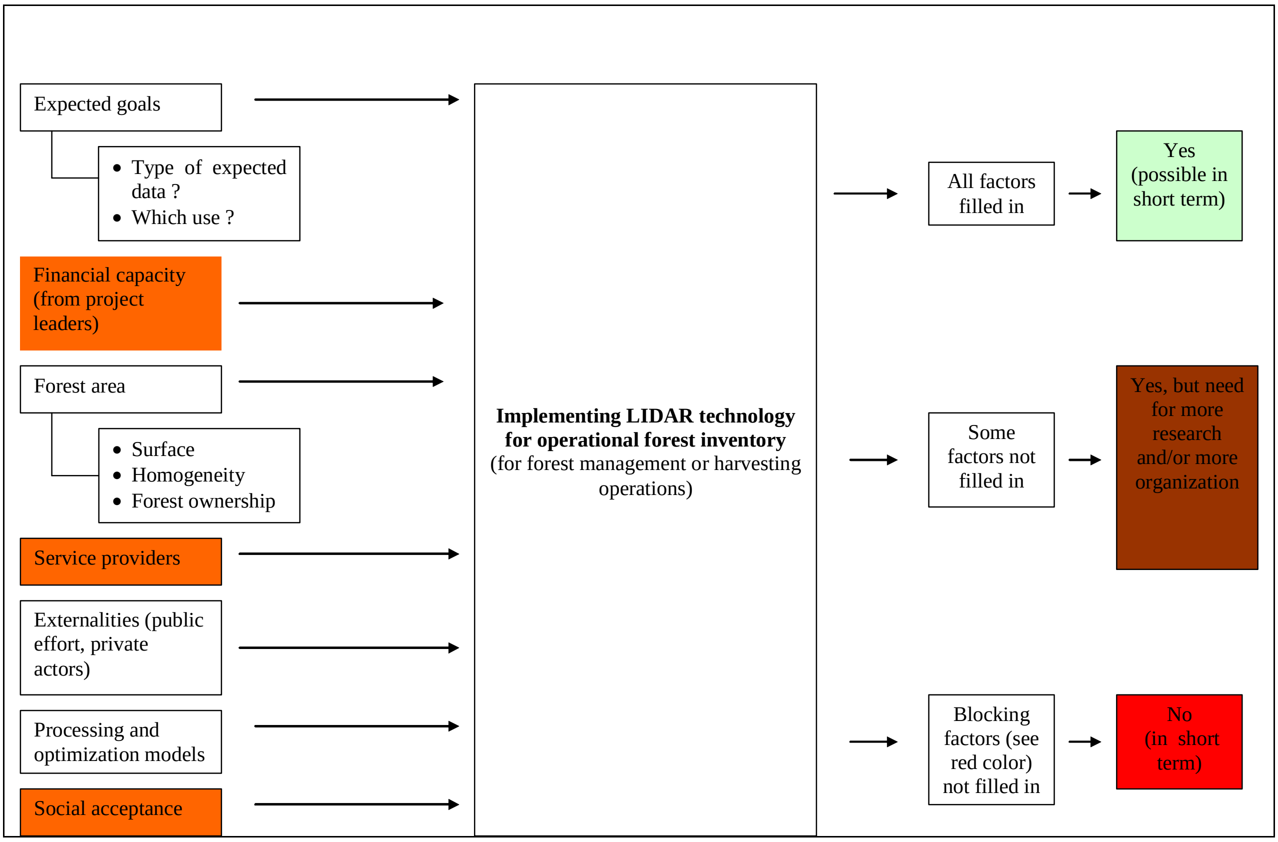


Figure: Decision criteria for implementing LIDAR technology

2. Introduction

The overall objective of the FlexWood project is to develop and to build a novel logistic system, incorporating better information on wood resources and enhanced optimisation models, to respond more efficiently and adequately to the demands of industrial sectors. In other words, the aim is to reach a better matching between supply and demand and to provide a wood supply chain (WSC) driven by demand, where requirements of industries pull the activity of the rest of supply chain, until the forest exploitation (and not the opposite, as still often observed today). Finally, this increased flexibility and the better knowledge of resources must create value throughout the WSC (see Figure 1).

In addition, the growing needs (including through the development of wood energy) and the requirements of sustainable development in Europe make efficient use of the resource even more important.

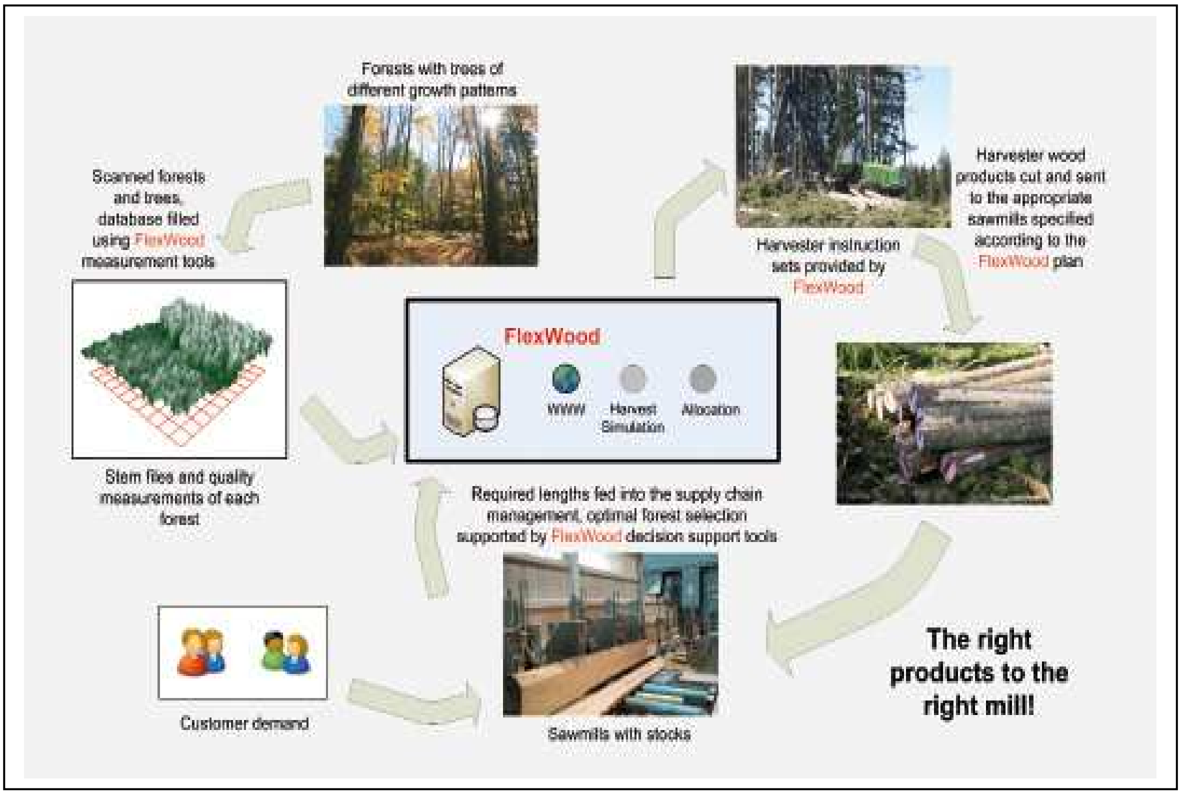


Figure 1: Towards a demand-driven WSC

2.1 Objectives of the Deliverable

In this context, the Deliverable 8.2 aims to evaluate the FlexWood concept. More specifically, it is to assess the ability of new technologies (like LIDAR) and enhanced planning systems to make the Wood Supply Chain more flexible and more efficient at an acceptable cost. The WSC considered here includes each stage from forest management to the mills (sawmills...).

In order to provide such analysis, the evaluation is based on four demonstration sites where innovative solutions have been implemented in the framework of the Task 8100 ("*Use case implementation and testing of FlexWood system*").

One of the objectives in this Deliverable is also to provide, in conclusion, some recommendations for the implementation of new technologies and new operational process defined in the FlexWood concept according to the types of forest sites.

2.2 Links to other FlexWood Work Packages

The FlexWood project analyzes through several Work Packages the implications of the new technologies (LIDAR) and new process implemented at every stage of the WSC: forest resource assessment, stand allocation, harvesting, logistics, specification of industrial requirements, communication infrastructure. The evaluation of the FlexWood concept (WP8200) arrives at the end of the project and uses data and results obtained in the previous WP, in particular:

- The definition of industrial requirements in terms of wood raw material qualities (WP 3000) ;
- Information about data that can be provided by new technologies like LIDAR (ALS and TLS) for describing forest resource (WP 4000) ;
- The implementation and testing of the FlexWood concept on demonstration sites (WP8100).

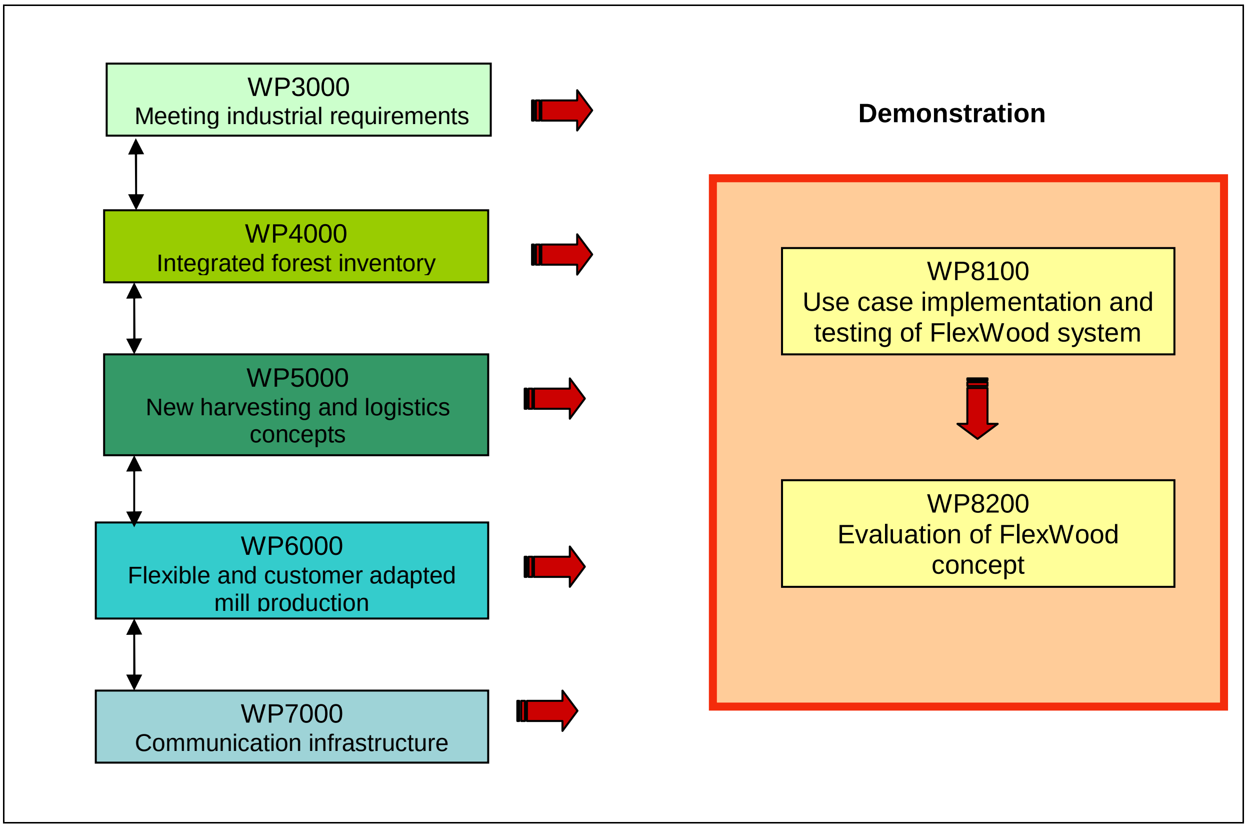


Figure 2: WP8200 as a user of information from other WPs

2.3 Structure of the Deliverable

The Deliverable 8.2 is structured as follows: at first, we explain the methodology chosen to evaluate the FlexWood concept (3). Secondly, we present the results obtained in the demonstration sites (4). A brief review of other studies realised outside FlexWood project will complement and extend this analysis (5). In conclusion, we propose some recommendations for the implementation of FlexWood concept and new technologies associated (6). A more detailed presentation of each Use case is given in Annex.

3. The Approach

3.1 The rationale

In Task 8200, the expected goal is to assess the capacity of remote sensing technologies for collecting data (mainly LIDAR) and of enhanced planning systems to make the WSC more efficient in terms of:

- more flexibility ;
- better adequation between supply and demand ;
- added-value creation for the different actors of the WSC.

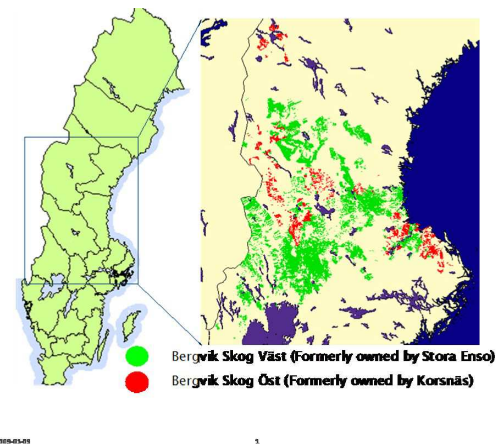
This evaluation will be based on results obtained on demonstration sites (or Use cases) in the framework of the Task 8100.

3.2 Description of the Use cases

The four sites where the FlexWood concept has been tested and evaluated are located in France, Germany, Sweden and Poland.

France

Sweden



Germany Poland

Figure 3: Location of the Use cases

The four Use cases have common characteristics. Mainly, these are managed forests with a production objectives (according to the Use cases).

On the other hand, the implementation sites present differences, in particular in terms of surface, species and homogeneity of the forest resource.

Table 1: Characteristics of the Use cases

	France	Germany	Poland	Sweden
Location	South West	Central Europe	Eastern Europe	Northern Europe
Area (ha)	6 000	2 200	6 400	16 000
Species (in the area)	Maritime Pine	Beech (40 %) Scots Pine (60 %)	Pine (72 %), Beech (7 %), Oak (6,5 %), Alder (5 %)…	Scots Pine (50 %), Norway Spruce (40 %), Birch (10 %)
Homogeneity/ Heterogeneity (in the stand)	Homogeneous	Relatively heterogeneous	Relatively homogeneous	Relatively homogeneous

Table 1 shows, at first, an important difference in the surface of the sites, from around 2 000 hectares for the smallest (Germany) to 16 000 ha for the largest (Sweden). The species are also different according to the Use cases with a predominance of conifers (France, Sweden and Poland). Finally, if the forest resource is rather homogeneous in France, Sweden and Poland, the German site is characterized by a relatively heterogeneous structure, representative of many typical natural Central European forests.

Concerning the overall objectives, the four Use cases seek, at first, to improve the knowledge of the forest resource thanks to the LIDAR technology. They want to test the performance of LIDAR to enhance the resource information. Some Use cases seek also to develop new models and planning systems integrating the new data in order to enhance the stand allocation and harvesting operations, and therefore the adequation between supply and demand (see Table 2).

Table 2: Components of the FlexWood concept tested in the Use cases along the WSC

France South West	**Resource inventory**	**Stand allocation**	**Harvesting**	**Logistics**	**Production**	**Communi-cation infrastructure**
Objectives	Enhance forest resource knowledge (volume and quality)		Simulation of different harvesting scenarios based on enhanced forest resource and round wood specifications		Define enhanced round wood specifications	Web-application to present the newly available information
Technologies/tools implemented	TLS (mainly) ALS		Bucking simulator			Communication interface
Actors involved	Wood supply companies				Mills	Wood supply companies

Germany Central Europe	**Resource inventory**	**Stand allocation**	**Harvesting**	**Logistics**	**Production**	**Communi-cation infrastructure**
Objectives	Enhance forest resource knowledge (volume and quality)					
Technologies/tools implemented	Combination of TLS and ALS					
Actors involved	Public forest agent					

Poland Eastern Europe	**Resource inventory**	**Stand allocation**	**Harvesting**	**Logistics**	**Production**	**Communi-cation infrastructure**
Objectives	Enhance forest resource knowledge (volume and quality)					
Technologies/tools implemented	TLS					
Actors involved	State Forest officers					

Sweden Northern Europe	**Resource inventory**	**Stand allocation**	**Harvesting**	**Logistics**	**Production**	**Communi-cation infrastructure**
Objectives	Enhance forest resource knowledge (volume and quality)	Build an advanced decision support system for scheduling harvest activities: Implement functionality in VSOP-software (wood operating planning system) to benefit from better forest data (ALS data) in order to enable enhanced bucking simulations and harvest instructions.				
Technologies/tools implemented	ALS (mainly) TLS Hyperspectral images	Optimization model				
Actors involved	Foran (ALS data provider) TreeMetrics (TLS data provider)	Korsnäs (forest company) Logica (provider of VSOP-software) Logging contractors Transport companies				

3.3 Methodology of evaluation

3.3.1 Brief review of methodologies

Evaluation of projects can be made by different methodologies. The most common used quantitative methods in terms of economic evaluation are Cost-Benefit Analysis (CBA), Cost-effectiveness Analysis (CEA) and also Life Cycle Cost (LCC). The *Cost-Benefit Analysis* compares all the costs and benefits of a project, including economic, social and environmental aspects, in a common unit (monetary terms). The results can be presented in form of a Net present value (NPV), an Internal rate of return (IRR) or a Benefit-cost ratio (BCR). If this method of valuation allows an exhaustive assessment of impacts (positive and negative) of a project, an important difficulty related to it is to give monetary value to impacts for which a market value doesn't exist (e.g. benefits of a good air quality). Therefore, when effects are difficult or inappropriate to monetize, a *Cost-effectiveness Analysis* can be done. In this case, the evaluation calculates the costs associated to an effect or objective measured in a physical unit (e.g. costs per unit of emissions reduction). Finally, the *Life Cycle Cost* focuses on the costs of a project or a product during its complete life cycle from raw material to the end of life.

In addition to purely economic evaluation methods, we find in the literature other methods of valuation like the *Multi-criteria Analysis* (MCA). The MCA is a tool to evaluate different alternatives considering several criteria (technical, economic, environmental, social) that can be in conflict. The quantification of criteria is given in different units (physical, monetary) depending on each criterion. The final result is presented in form of a performance score for each alternative/project.

All these methods are quantitative methods. This means that the result of the evaluation is given in form of numerical results that can be compared between different projects.

Nevertheless, a quantitative evaluation of a project is not always easy or possible to implement. Indeed, such evaluation requires enough data to estimate indicators and to calculate ratios. If such data are not available, the solution can be to perform a qualitative analysis in order to point out in literary form the main contributions and also limits of the project.

Table 3: Examples of methods for evaluating projects

Methods	Principle	Advantages	Disadvantages
Cost-Benefit Analysis	Calculate all the costs and benefits of a project (including economic, social and environmental aspects) in a common unit (monetary terms). The final result is expressed in a net present value (NPV), an internal rate of return (IRR) or a benefit-cost ratio (BCR).	• Exhaustive method : all impacts are considered (positive and negative) • Assessment in a common unit (monetary terms) • Considers the societal perspective of a project, including economic, environmental and social impacts.	• Time consuming • Difficulties to give a monetary value to certain impacts • Need a lot of data
Cost-effectiveness Analysis	Calculate the costs associated to an effect or objective (e.g. costs per unit of pollution avoided).	• Useful when effects are difficult to monetize (e.g. in the fields of Health or Environment) • Assessment in a common unit	• Need a lot of data
Life Cycle Cost	Calculate the costs of a project or product during its complete life cycle from raw material to the end of life.	• Take into account the complete life cycle of a product/project • Assessment in a common unit	• Focused on the costs • Need a lot of data
Multi-criteria Analysis	Compare different alternatives considering several criteria (technical, economic, environmental, social)	• Take into account several criteria that can be in conflict (e.g. costs/quality) • Assessment in a common unit	• Evaluation based for a part on a subjective analysis from experts • Need a lot of data
Qualitative analysis	Point out in literary form the main contributions and also limits of a project	• Useful when not enough data are available • Complementary approach to quantitative analysis	• Subjective approach • Make more difficult the comparison between different projects

The aim of both quantitative and qualitative analysis is the same: evaluate if a project is relevant or not, by comparing between several alternatives or between a Business as usual scenario (BAU) and a Project scenario, in order to support decision making with a tool and therefore help the actors in their strategic choices.

Finally, the choice of an evaluation method depends on several criteria, mainly:

- Objectives of the evaluation
- Time budget and resources affected to the evaluation
- Availability and quality of the data

3.3.2 Constraints related to the Task 8200

The Task 8200 includes three main constraints. At first, the time budget allocated to the task is limited, while the implementation of a quantitative evaluation like CBA is time consuming. Secondly, the Flexwood concept is still new and has been tested in the Use cases not always in real conditions. It will also probably require adjustments and improvements. In this context, it is not certain that all consequences of the concept can be identified at this stage of the project. Finally, and linked to this second point, the availability of data is a strong constraint to conduct the evaluation in the framework of this Task.

3.3.3 Choice of a methodology

Considering the objectives and the constraints related to the Task 8200, we develop an evaluation method that combines qualitative and quantitative analysis and that compares, for each of them, a BAU scenario and a FlexWood scenario.

The same methodology has been implemented by each Use case through a questionnaire (see Annex). It can be described as follows:

1st step: define a BAU scenario and a FlexWood scenario

For each Use case, it is necessary to define two alternative scenarios. The first one is the Business as usual (BAU) scenario, where the WSC is considered from the forest to industrial use without implementation of the Flexwood concept. It describes the current situation, including realistic future expectations of the WSC.

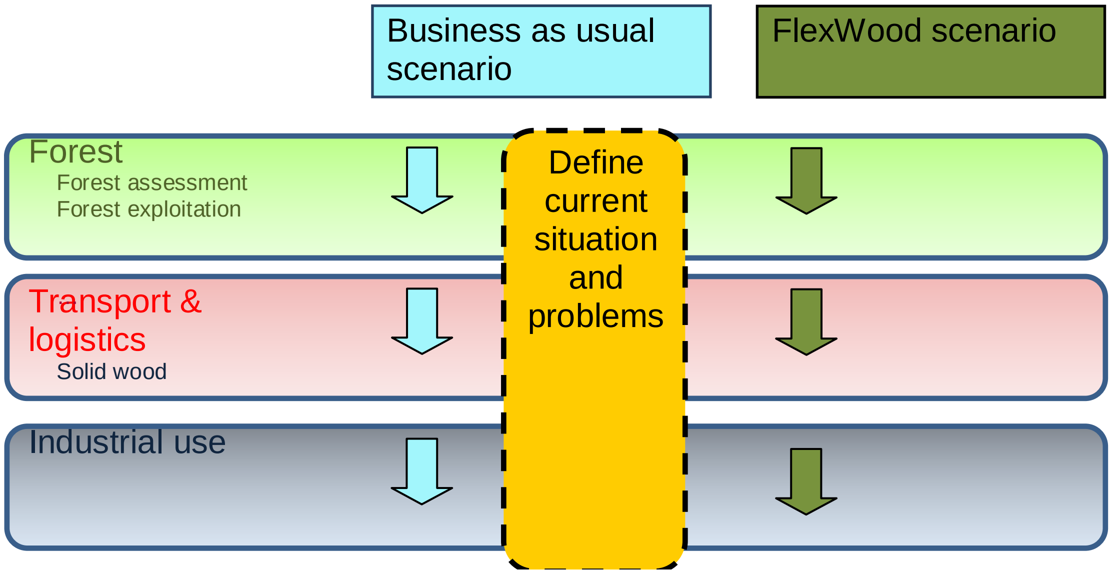


Figure 4: Define a Business as usual scenario

The FlexWood scenario describes, for each of the Use cases, the implementation of the FlexWood concept, as well as its impacts on the WSC. In order to streamline the work, and respect the budgetary constraints, a focus on the incremental changes (focus on differences between two scenarios) is made.

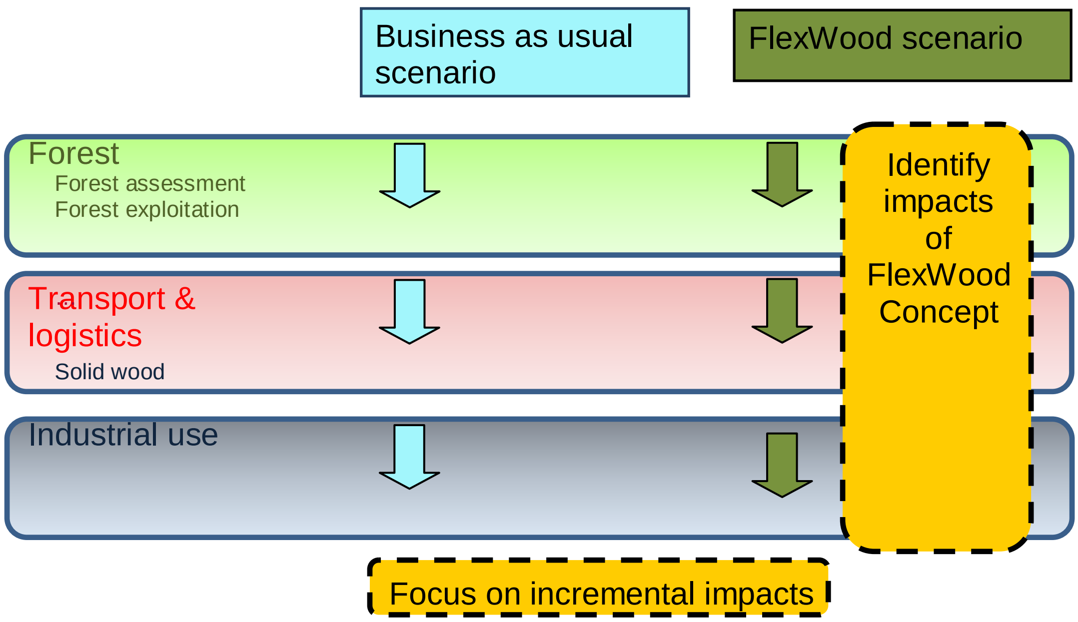


Figure 5: Define a FlexWood scenario

2nd step: perform the qualitative analysis

The qualitative analysis consists mainly of the comparison of the Business as usual scenario and the Flexwood scenario on key points of the WSC (resource inventory, stand allocation, harvesting, logistics, production and communication infrastructure) and of the analysis of the main changes, in particular in terms of technologies used and process. Based on this description, the objective is to point out the advantages (already observed or expected), disadvantages and limits to the implementation of the Flexwood concept.

3rd step: perform the quantitative analysis

In addition to the qualitative analysis, we have sought to quantify some effects of the Flexwood concept (in particular, the LIDAR technology) through indicators. These indicators are not exhaustive but they are key indicators to catch the impacts of the Flexwood concept, considering also the data availability and the feasibility of calculating.

In total, six indicators have been defined at different stages of the WSC according to three categories:

- 2 indicators which measure the economic performance of the current and new technologies/process (including inventory costs) ;
- 2 indicators related to the efficiency of organization within the supply companies ;
- 2 indicators which assess the service provided to the client (mills).

These indicators have been obtained through calculation based on observed data, estimations or experts' opinion and have been gathered from the Use cases. A more detailed description is available in Table 4 (see next page).

4th step : propose a SWOT Matrix

To conclude, a SWOT matrix gathers for each Use case the main results of the qualitative and the quantitative analysis. This will provide information for proposing some recommendations in the conclusion of the Deliverable.

Table 4: Definition of quantitative indicators

Indicators	Definition	WSC stage	Category of indicator	Calculation	Impact captured
Inventory costs	Costs due to forest resource inventory (quantity and quality)	Resource inventory	Economic performance	Flexwood scenario : data collection costs, including LIDAR (euros/hectare) + processing BAU scenario : expenditures to inventory the forest resource both in quantity and quality (field trips in the forest, measurement…) (euros/hectare)	Costs of new technologies like LIDAR.
Productivity	Time spent by the forest manager / m3 to plan the answer to a client's demand : identify the appropriate block where the targeted product mix could be harvested, find the combination human resources/machine to do bucking/harvesting operations, send instructions for the operations.	Resource inventory and Stand allocation	Efficient organization	Difference in productivity between. BAU scenario and Flexwood scenario in m3 (e.g. according to an expert). If not possible, indicate the evolution of productivity bet. the two scenarios with a trend (++, +, =, -, --).	Productivity evolution of order management. Indirect indicator of the evolution of order management costs.
Time before delivery	Time deliver to respond to customer (sawmills) demand.	Production sawmill	Customer satisfaction	Time in days between the order (from customer) and the delivery (to customer) both in BAU scenario and Flexwood scenario.	Measure changes in flexibility and quality of customer service.
Perfect order fulfilment	Customer (sawmills) satisfaction related to order fulfilment.	Production sawmill	Customer satisfaction	Evaluation by customer (sawmills) of their satisfaction related to how delivery meets initial demand, in %, both in BAU scenario and Flexwood scenario. Rejection and Downgrading rates could also be a way to quantify the order fulfilment notion	Measure the quality of customer services and the adequation bet. supply and demand.
Level of congestion / Storage rate	Level of congestion in platforms in forest and roadsides.	Harvesting	Efficient organization	Average rate of congestion (in %) in platforms in forest and roadsides, both in BAU scenario and Flexwood scenario. Congestion due to by-products which are not yet allocated to a client	Indirect indicator of storage costs.
Produce to monetary Value	Monetary Value of different product mix	Stand allocation and Harvesting	Economic performance	Difference in value bet. BAU scenario and Flexwood scenario in % (e.g. according to an expert).	Measure potential monetary optimisation of product mix

4. Results from Use cases

In this section, we present the synthesis of the results obtained by the implementation of the FlexWood concept in the four Use cases. The detailed description of each Use case is available in Annex.

4.1 The qualitative analysis

Enhance the knowledge of the forest resource is a common objective shared by each Use case. Nevertheless, a better resource information, alone, is not sufficient to improve the entire WSC. Optimize the use of the new data collected implicates also changes and improvements at the different stages of the WSC. Indeed, looking for additional information on resource is not worth the effort if, for example, the forest manager is not able to integrate it in its planning system. Therefore, the FlexWood concept aims not only to enhance the resource knowledge but also to improve logging and harvesting operations, to specify better industrial requirements and to optimize logistics.

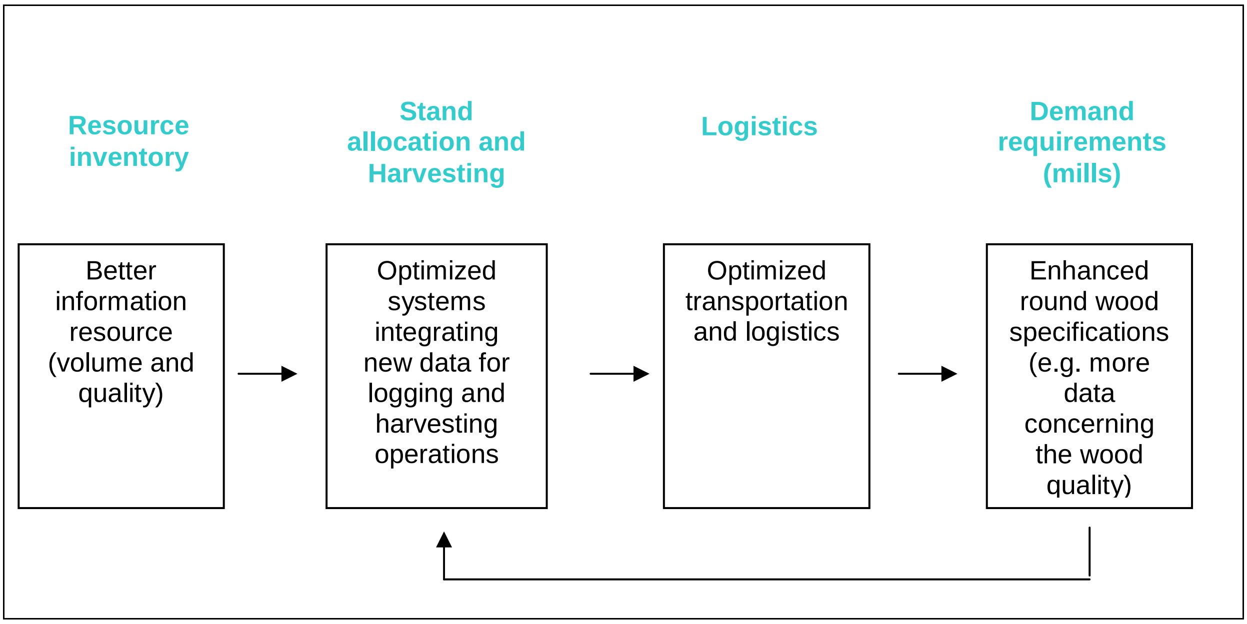


Figure 6: Conditions for an optimized WSC

4.1.1 Enhance the knowledge of resource

What is tested in the FlexWood project is, at first, the ability of LIDAR technologies to provide more and better data in comparison to a BAU scenario, in order to respond better to the demand of clients. Indeed, WP 3000 has shown the importance of the wood quality properties for the industrial clients (sawmills, pulp and paper, bio-energy). Sometimes, these properties are shared among sectors (e.g. species), but most of the time, their relative importance vary (e.g. age). Typical requirements of sawmills are higher than those of bio-energy producers. In pulp industry, requirements are higher for mechanical than for chemical pulping[1].

[1] For more details, see the Deliverable 3.1: “*Industrial requirements, gaps and improvements needs*”.

There are still gaps and improvement needs for characterizing wood properties. Indeed, today, requirements of industrials are still mainly expressed in terms of volume and dimensions, due in part to limited information on forest stands. The question is to know if the FlexWood concept and, in particular, the LIDAR technology (by distinguishing between ALS and TLS) can contribute to enhance the knowledge of the resource in terms of specifications.

In general, the literature on LIDAR shows a lot of benefits from this technology compared to traditional resource inventory. Thanks to LIDAR, the forest inventory is more accurate, more detailed and faster. More precisely, Aerial LIDAR (ALS) allows to obtain rapidly an overview of the forest resource for large or very large scales. Terrestrial LIDAR (TLS) provides a more accurate information at the level of the individual tree.

In the framework of the FlexWood project, the Use cases have sought to determine and to test the contributions of the LIDAR compared to other methods. Table 5 shows the best methods to provide forest data in some Use cases.

Table 5: Best data sources to provide forest data according to different approaches

	Airborne Remote sensing		**Measurements from the ground**			**Other models**
Use cases	ALS	Optical sensors	TLS	Manual Stand inventory	Harvester	
South West (France)						
Total tree height	X		(X)	(X)		(x)
1.30 circumference	(X)		X	X		(x)
Height of 1st live branch	(X)		X	(X)		
Height of 1st dead branch			X	(X)		
Total taper			X			(x)
Sweep			X			
Average stem volume	(X)		X	(X)		(x)
Age				X		
Central Europe (Germany)						
Tree height	**X**			(X)		
Crown base height	**X**		X	(X)		
Crown radius/diameter	**X**		(X)	(X)		
Diameter (DBH)			**X**	X		
Diameter at height 7m (D7)			**X**	X		
Taper			**X**			
Sweep			**X**			
Branch height			**X**	(X)		
Branch base diameter			**X**	(X)		
Species	(X)		(X)	**X**		

Northern Europe (Sweden) / Stem level						
Geographic position	X		(X)			
Diameter (DBH)	X		X			
Stem taper			X			(X)
Height	X					
Tree age				X		
Tree species	(X)	X		(X)	(X)	
External properties			X		X	(X)

X / X : indicates the preferred data sources
(X) : indicates alternative approaches
Source : Vauhkonen *et al*. (2012) ; Vuillermoz *et al*. (2012)

According to the results on the Use case of Northern Europe, ALS is the best data source to estimate the geographic position of a tree, which gives information on how many trees that are found within a harvest area. ALS gives also accurate estimates for tree size including height and diameter (DBH) for the detected trees. TLS is especially effective to estimate the diameter (DBH) and the stem taper. Finally, TLS is the best method (with the harvester's measurements) to define the external properties of the tree, that can be used to deduce information about the inner quality of the stem when it is combined with external predictive models.

In the French Use case, TLS has also been useful to detect the height of the first live branch and the height of the first dead branch. This information on branchiness is valuable because it can be used as input for a quality model capable of predicting anatomic characteristics of maritime pine.

From a global point of view, the four Use cases have confirmed that LIDAR can enhance the resource information, on both the volume and quality. In addition, LIDAR allows an automation of data collection and processing which saves time but also implies a better homogeneity of the collected data.

Nevertheless, LIDAR technology has also shown some limits. In particular, that is not effective to provide data on tree age and tree species. ALS could be an alternative approach for detecting tree species, but not as a stand alone mean for data collection as is often means to be combined with other methods (for data collection and processing). Furthermore, the Use cases in Germany and Poland have pointed out that, with LIDAR, it is difficult to gain reliable information in case of very heterogeneous forests.

4.1.2 Other components of the FlexWood concept

Some Use cases (mainly Sweden and France) have tried to implement novel solutions in planning systems to optimize the logging operations and to improve the bucking simulations and harvest instructions. Furthermore, the French Use case has worked to develop enhanced round wood specifications that industrial users could use to express their expectations.

4.1.2.1 Optimize harvest instructions (Swedish Use case)

In the Swedish Use case, an important goal of the FlexWood project was also to enhance bucking simulations and harvest instructions by integrating new data from enriched resource inventory. This was possible by implementing new functionality in the planning system for harvesting that is already used in the Swedish case (VSOP). Doing that, it allows to build an advanced decision support system for scheduling harvest activities and therefore to reach a better adequation between supply and industrial demand. The optimization model developed in the framework of the FlexWood project has been tested in real conditions resulting in harvesting instructions[2].

4.1.2.2 Enhance round wood specifications (French Use case)

In the French Use case, a module of the FlexWood project was dedicated to enhance round wood specifications that clients (e.g. sawmills) could use to express their demand. In particular, the integration of quality aspects in the definition of round wood specification has been studied. This has resulted in a better description of the product, including anatomic characteristics.

In a second step, bucking simulations in framework of harvesting scenarios have been tested by integrating the enriched data from LIDAR and the enhanced round wood specifications. Even if the developed models have to be improved, they are today operational.

Finally, the French Use case has tested different allocation scenarios in a web-application to select the best one[3].

4.1.3 Process of operations in the Wood Supply Chain

Finally, the implementation of the FlexWood concept implicates changes in terms of operational process along the WSC. Indeed, the FlexWood scenario is characterized by an automation of data collection thanks to the LIDAR technology (TLS and ALS), while in the BAU, the inventory of the resource is mainly based on manual field measurement. That has implications on the other stages of the WSC like Stand allocation and Harvesting, that can be based on better knowledge of the forest resource (enriched data, more homogeneous and more accurate). This optimisation is reinforced by the development of models for processing these new data. Another main difference between the FlexWood scenario and the BAU concerns the production stage. Indeed, as the resource information may be better and richer, the clients can define more precise requirements (see Table 6).

[2] A more detailed description of the Swedish Use case is available in Möller J. *et al.* (2012).

[3] More information about the French Use case can be found in Vuillermoz et al. (2012).

Table 6: Main changes in the process of the WSC between BAU and FlexWood scenario

<table>
<tr><th></th><th>Resource inventory</th><th>Stand allocation</th><th>Harvesting</th><th>Logistics</th><th>Production sawmill</th></tr>
<tr><td>BAU</td><td>Traditional field inventory (mainly manual)</td><td colspan="3">Mainly manual planning systems based on limited information.</td><td>Specifications mostly quantitative a. dimensional

quality assessment based on classification standard</td></tr>
<tr><td>FlexWood</td><td>Inventory completed by TLS/ALS means (automation of data collection and processing, enriched information)</td><td colspan="3">Allocation and harvesting instructions based on enriched information / integrated optimization models</td><td>Enhanced specifications with more precise requirements in quantity and quality, including inner wood quality

Tools for processing new data</td></tr>
</table>

4.2 The quantitative analysis

In addition to the qualitative analysis, we have sought to calculate some indicators for each Use case, reflecting the impacts of the FlexWood concept. This section will analyse the results obtained, at first, for the inventory costs and then for the other indicators.

4.2.1 Inventory costs

Inventory costs are defined in our study as expenditures to collect and process the data needed for resource inventory. A distinction between ALS costs and TLS costs has been made.

Inventory costs from ALS (Aerial LIDAR)

The ALS costs consist of fixed costs and variable costs. Fixed costs represent the main part of total costs. They mainly include the flight and equipment. In this context, large forest areas can benefit from scale economies (e.g. Swedish Use case). In contrast, small areas suffer from higher unit costs (German Use case).

Furthermore, the costs depend also on the complexity of the field to be scanned. More the terrain is rugged and the resource is heterogeneous, higher are the costs because more precise information (in terms of points/m2) is required.

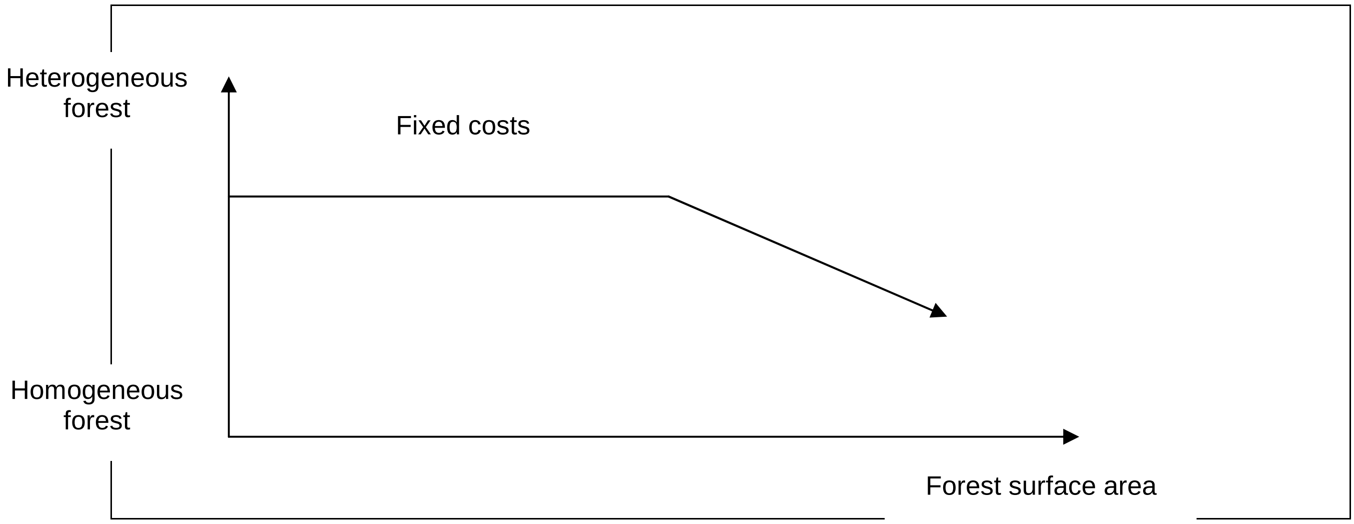


Figure 7: ALS unit costs

Inventory costs from LIDAR compared to BAU

The following table shows some results for inventory costs obtained in the Use cases by different methods. It should be noted here that it is difficult to compare the costs between the different Use cases (because of differences in calculation methods[4]). Only the numerical comparison between methods for each Use case is really relevant (BAU versus FlexWood scenario).

Table 7: Inventory costs in FlexWood versus BAU scenario

	BAU	ALS	TLS
French Use case (6000 ha)	Reference situation	n.a.	- (1)
German Use case (2200 ha)	22 155 € (2) (35€/plot)	16 200 – 17 300 € (2)	12 660 – 15 825 € (2) (20-25€/plot)
Poland Use case (6400 ha)	10-15 €/ha (3)	2-3 €/ha	15-20 €/ha (3)
Swedish Use case (16 000 ha)	150 €/ha (4) 12 €/ha (5)	6 €/ha (4) 4 €/ha (5)	6 600 € (58 plots) (6)

BAU scenario | FlexWood scenario

(1) Projected result: for the French Use case, no monetary value is available. The sign – indicates that experts estimate the LIDAR costs higher than those from BAU (therefore, this is less performance in the FlexWood scenario).
(2) Gathering and processing costs
(3) Costs for data collection
(4) Measurement of diameter and height for all trees
(5) Inventory of average diameter, height and volume
(6) The Swedish Use case has made a TLS inventory but so far the data have not been integrated in the analysis.

[4] For example, some Use cases include in their calculation the taxes, while other Use cases do not.

In the German Use case, the combination of ALS and TLS data implicates much higher costs than those in the BAU. This is due mainly to the small area scanned and the fact that the use case is more a research study (with thorough data collection and processing) than attempt for industrial implementation (at this stage). In Poland, the LIDAR costs are also higher compared to the BAU scenario.

In Sweden, ALS data are enough to replace the BAU methods, even if they plan to combine ALS and TLS data. In this case, the implementation of the LIDAR technology (airborne) allows obtaining lower costs for forest inventory. This is mainly due to the large scale implementation combined with a homogeneous resource.

Therefore, except for the Swedish Use case, the implementation of LIDAR implicates higher costs than those in BAU. The question is to know if these costs can be offset by benefits.

4.2.2 Other indicators

In addition to the inventory costs, we have tried to calculate other indicators summarized in the following table (see Table 4 for calculation method).

Table 8: Quantitative indicators for evaluating the FlexWood concept (1)

Indicators	**Definition (2)**	**WSC**	**French Case**		**German Case**		**Swedish Case**	
			BAU	**FlexWood**	**BAU**	**FlexWood**	**BAU**	**FlexWood**
Productivity	Time spent by the forest manager / m3 to plan the answer to a client's demand	Resource inventory and Stand allocation	n.a.	n.a.	*2 hours/ 100 m3*	*1,7 hours/ 100 m3*	**2 hours/ 100 m3**	**1 hour/ 100 m3**
				+		+		**++**
Time before delivery	Time deliver to respond to customer (mills) demand	Production (saw)mill	n.a.	n.a.	*28 days*	*17-20 days*	**30 days**	**20 days**
				++		++		**++**
Perfect order fulfilment	Measure the customer satisfaction	Production (saw)mill	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
				++		n.a.		**+**
Storage rate	Level of congestion in platforms in forest and roadsides	Harvesting	n.a.	n.a.	*10 %*	*5 %*	**12 %**	**8 %**
				+		+		**+**
Produce to monetary value	Monetary value of different product mix	Stand allocation and harvesting	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
				+		+		**++**

Police code : **observed** ; *projected estimation*

Note: if the numerical estimation is not possible, the evaluators indicate the evolution of indicators bet. the two scenarios with a trend (++, +, -, --). BAU is the reference situation, + indicates an improvement of the indicator and – indicates a degradation. In some cases, both information numerical value and trend is given.

(1) no value for the Polish Use case is available. Nevertheless, some comments concerning the evolution of the indicators can be found in the detailed description of the Use case (see Annex).
(2) for a more detailed definition, see Table 4
(3) n.a. : not available

The results are relatively homogeneous between the different Use cases : all indicators are improved (or are expected to be improved) in the FlexWood scenario. The best results are obtained for the "*time deliver*" with an important decreasing of the time needed (around – 10 days) to deliver the customer between the BAU and the FlexWood scenario for all Use cases. Other indicators should be significantly enhanced according to the Use cases: in the Swedish Use case, the "*productivity*" is increasing (from 2 hours/100 m3 to 1 hour/100 m3), thanks to optimization models implemented in the planning systems, as pointed out in the qualitative analysis. Concerning the indicator "*monetary optimisation of product mix*", the FlexWood concept should represent high potential to get better value out the forest, in particular for the forest owners. In the French Use case, both indicators reflecting the "*customer satisfaction*" are also expected to be significantly improved, that confirms the capacity of FlexWood concept to allow a better adequation between supply and demand. Concerning the "*storage rate*", just a slight improvement is expected in the FlexWood scenario, as the congestion may not be completely avoided compared to BAU.

5. Enlargement and Discussion

LIDAR technology development has increased since the early 1990s with today various fields of application: topography, agriculture, forest management, coastal protection, urban development and infrastructure projects, energy management, communications, archaeology...

Some studies have analysed the impacts of this technology in terms of advantages and disadvantages. In the forest sector, a few studies have been found whose results give some complementary information.

Costs and benefits of LIDAR

In Sweden, Skogforsk has analysed and quantified in a study from 2008 the benefits that the SingleTree method from FORAN can offer to the forest industry. SingleTree (available since 2006) is a method for ALS-based forest inventory with high resolution, so that individual trees can be measured. Compared to the traditional methods, the study shows that a forest inventory based on ALS technology gives added value along the whole supply chain from forest management to the wood industries (see Table 9).

The conclusion of the study is that data capture with pulse intense laser scanning combined with planning tools and procedures provides added value to justify the cost of the method. In the slightly longer term, the added values are likely to increase significantly if methods and planning systems are developed to better utilize the high-resolution data.

Table 9: Benefits from ALS inventory in terms of added value

Operations the WSC	**Added value provided by the SingleTree method (ALS inventory) compared to traditional methods**
Strategic planning (forest management)	5-15 €/ha
Sales of standing forests	5 €/ha
Enhanced planning of silviculture/cleaning activities	0,5 €/ha
Enhanced *in situ* harvest planning	4-6 €/ha
Exchange of timber assortments	3 €/ha
Enhanced timber utilization in further steps of WSC	1-30 €/ha

Source: Skogforsk (2008)

Outside Europe, a study conducted by the Tropical Forest Foundation of Indonesia (R. Behrendt ; A. Klassen, 2011) shows that Aerial LIDAR can be of a great interest for the Indonesian forest concessions by providing a large variety of valuable information: detailed terrain maps, canopy height, canopy closure, hydrological flow, tree height maps... In addition, at large scale, this technology is cost-effective. Indeed, for an area larger than 50 000 hectare, a LIDAR collection costs less than 3 US$ per hectare (compared to 5-6 $ from a standard method). These results are comparable with those obtained in the Swedish Use case from the FlexWood project.

Finally, a research team of the Agricultural University of Norway (T. Eid ; T. Gobakken ; E. Naesset, 2004) has tried to compare inventories for large areas based on photo-interpretation and laser-scanning by means of cost-plus-loss analysis. The principle of this approach is to take into account, in addition of inventory costs, also net present value losses, which are expected economic losses resulting from future incorrect decisions due to errors of measurements. Doing that, they show that the total costs (inventory costs + NPV losses) are for photo-interpretation around twice as high as for laser-scanning. This study enlarges the cost approach by integrating direct and indirect costs of inventory methods. It shows that taking into account these indirect costs (in form of economic losses resulting from measurement errors) may change the comparative evaluation of the total costs between different inventory methods.

These different studies confirm the fact that for large forest areas, the airborne LIDAR is cost-effective and can offer benefits for all the actors of the WSC. Nevertheless, to optimize these benefits, it is necessary to develop systems and optimization models enable to process the new data at the different stages of the WSC.

Human factors and social acceptance

Social acceptance is an important question when new technologies or new methods are implemented. Indeed, existing personnel might be reluctant to adapt to new process/tools and formation is necessary in order to make the implementation of the technology successful. This point has not been studied deeply in the Use cases but it has been pointed out as a factor of potential obstacle if it is not taken into account by actors involved in the change.

Furthermore, during the final seminar of the FlexWood concept, a panel of experts has confirmed the need to consider the human factors in the implementation of innovations analyzed in the FlexWood. They have also given some recommendations for a better acceptance by the actors :

- Need to build trust in the new system and the estimates provided between the stakeholders ;
- Importance of communication and mutual awareness between the stakeholders ;
- Need for proper dissemination and training for personnel.

6. Conclusion

Aim of this Deliverable was to synthesize and to analyze the results obtained through the LIDAR implementation and novel solutions in the WSC in four demonstration sites, located in Germany, Sweden, France and Poland. To do that, the chosen approach was to combine a qualitative and a quantitative evaluation that was applied by each Use case.

The main results observed in the four Use cases can be summarized in the following SWOT Matrix:

Table 10: SWOT Analysis for LIDAR and FlexWood concept

Strengths	**Weaknesses**
Better resource information (volume and quality) Useful in monocultural forests (e.g. pine forests) Enable the mapping of large areas in a short time (ALS) Lower unit costs for forest inventory based on ALS at a large scale implementation (e.g. Swedish Use case – 16000 ha) Enhance the predictability along the value chain thanks to more accurate data and optimization models Better productivity for stand allocation operations and for planning harvesting Decrease of storage rate in the forest and at roadside Better customer satisfaction Enhanced product mix	Difficulties to obtain precise species through LIDAR technology Difficulties to gain reliable information for very heterogeneous forests (e.g. German Use case) High costs of LIDAR implementation for small areas (e.g. German Use case – 2000 ha) New technology which still requires improvements for collecting and processing the data
Opportunities	**Threats**
LIDAR data collection could be a collective dynamic within the forest sector or with others actors (agriculture, water management ?) One component in strategy to respond to possible future wood shortage and/or price increase Supply-related jobs could become more attractive	Existing personnel might be reluctant to adapt to new technologies and/or new methods Non-optimal implementation of LIDAR technology if the information tools and planning systems are not able to be adapted to the integration of LIDAR data Non-optimal implementation of LIDAR technology if the other stages of the WSC are not also improved (logistics, wood specifications from industrial actors, communication…)

From a global point of view, the FlexWood concept and its different components (enhanced resource inventory, optimization models for improved harvesting planning, enhanced round wood specifications…) have shown their capacity to increase the predictability along the WSC and to provide better adequation between supply and demand. Improvements are still needed but models and new practices have been developed in the framework of the FlexWood project and they are today operational.

Nevertheless, the Use cases have underlined also that the LIDAR technology is not relevant for each situation, depending on the forest surface area and the homogeneity of the resource.

Due to a central place in the project, an important part of the evaluation focused on the LIDAR. Based on obtained results, we can make some recommendations for the implementation of LIDAR technology and the development of FlexWood concept in the WSC:

- The airborne LIDAR **is relevant mainly in case of large areas with a homogeneous forest resource**. In such situation, this technology is cost-effective and provides valuable information for a better resource knowledge ;
- In contrast, for basic information, LIDAR is not relevant for small areas due to high costs of data collection ;
- Currently, LIDAR technology is **not well adapted to heterogeneous forests** (need for research) ;
- **The technology is still new and needs to be improved ;**
- LIDAR technology will be **more relevant in combination with other remote sensing technologies** (e.g. TLS + Photography) ;
- **Optimize the use of LIDAR data implicate also changes and improvements in the information and planning systems at the different stages of the WSC** (logistics, wood specifications from industries…) ;
- A solution related to high costs of LIDAR implementation could be to share them with others public and private actors, even actors outside the forest sector. Nevertheless, it is necessary that these actors have comparable needs.
- **The social acceptance of the new technologies and new practices has to be taken into account early in the projects**. It will be facilitated through mutual awareness between stakeholders, building trust in the new estimates and training programs for practioners.

Finally, even if generalizable results can not be given in terms of evaluation of innovations included in the FlexWood project, we can propose a **list of criteria** that have to be considered in such evaluation. More precisely, decide the relevance or not of LIDAR must take into account (see Figure 8):

- The objectives of the project (what type of data are needed, for which use… ?);
- The forest area (surface, homogeneity of the resource, forest ownership…);
- The financial capacity of the actors involved (in particular, the project leaders);
- The existence of service providers;
- The existence of externalities (public effort, other private projects, even outside the sector);
- The existence of processing and optimization models;
- The social acceptance of the actors (existing personnel, clients, suppliers…).

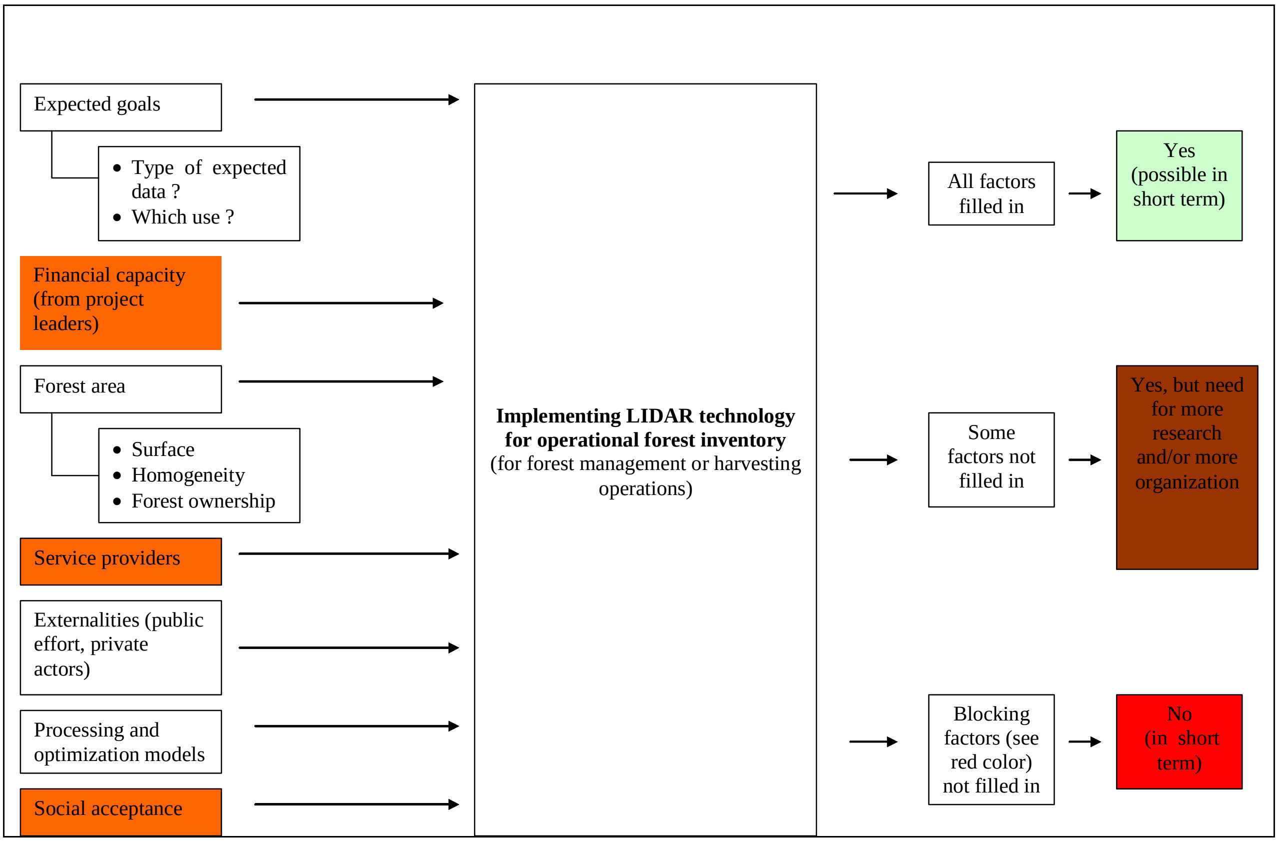


Figure 8 : Decision criteria for implementing LIDAR technology

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Annexes

Use case 1: France
Author: Morgan Vuillermoz (FCBA)

Use case 2: Germany
Authors: Martin Opferkuch (ALU-FR FobAwi), Ursula Kretschmer (ALU-FR IWW)

Use case 3: Sweden
Author: Tobias Jonmeister (FORAN), with the contribution of Andreas Barth (Skogforsk)

Use case 4: Poland
Author: Krzysztof Jodlowski (IBL)

French Use case

Author : Morgan Vuillermoz (FCBA)

See also Flexwood D8.1 „French Flexwood study case : demand-driven supply in Aquitaine", FCBA October 2012. 23 pages.

1. Description of case study

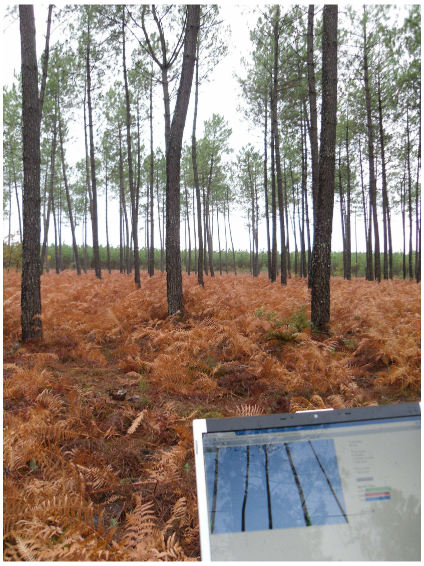
1.1 General questions

Location of the implementation and demonstration site
Surface of the forest (ha)

- Location : South-west France near Saint Symphorien (F-33113)
- Area *:* 6 000 ha of forest with a Focus on stand > 35 old

Description and structure of local forest resource

Pinus pinaster (PNPN) private-owned plantations on flat sandy terrain with a dense road network. During the last decade, the whole region was hit by 2 storms and the annual wood harvest will be reduced in the 5 up-coming years, hence supply issues.



Actors

Wood mobilization is covered by multiple actors from wood supply companies, to forest cooperatives or industrial users who integrate logging operations, hence fierce competition.

Main markets

Numerous forest-based industries (solid-wood, pulp & paper, energy) implanted in the region currently process PNPN only and request round wood with both quantity and quality specifications.

1.2 Characteristics of case study

Demand – driven organization of logging operations

- The case study is centered on s*upply companies* and their dedicated role in the local supply chain:
  - Supply round wood to local mill with specific demand (depending on their process line)
  - Organize logging operations in the forest stand in which they acquired standing trees to be harvested
  - Provide their sub-contractors with relevant instructions so that stand are harvested and produce logs in adequacy with clients' demands

- The purpose is to evaluate how novel solutions can contribute to optimize supply operations in accordance to client's demand

FLEXWOOD	Round wood specification	Resource Inventory	Supply chain modeling	Harvesting optimization	IT infrastructure
Application Output	Quality-enhanced round wood specifications	Block description including inner-wood information on the Stem level	Description of the local supply chain Input for SWOT analysis	Simulation of different product-mixes	Web-application to present the newly available info

1.3 Scenarios definition

Business as usual scenario (BAU)

– Supply companies acquire rights to harvest in several stands on which they have limited information on the standing timber. In parallel, their industrial clients (mostly sawmills and pulp mills) order round wood supply from them.

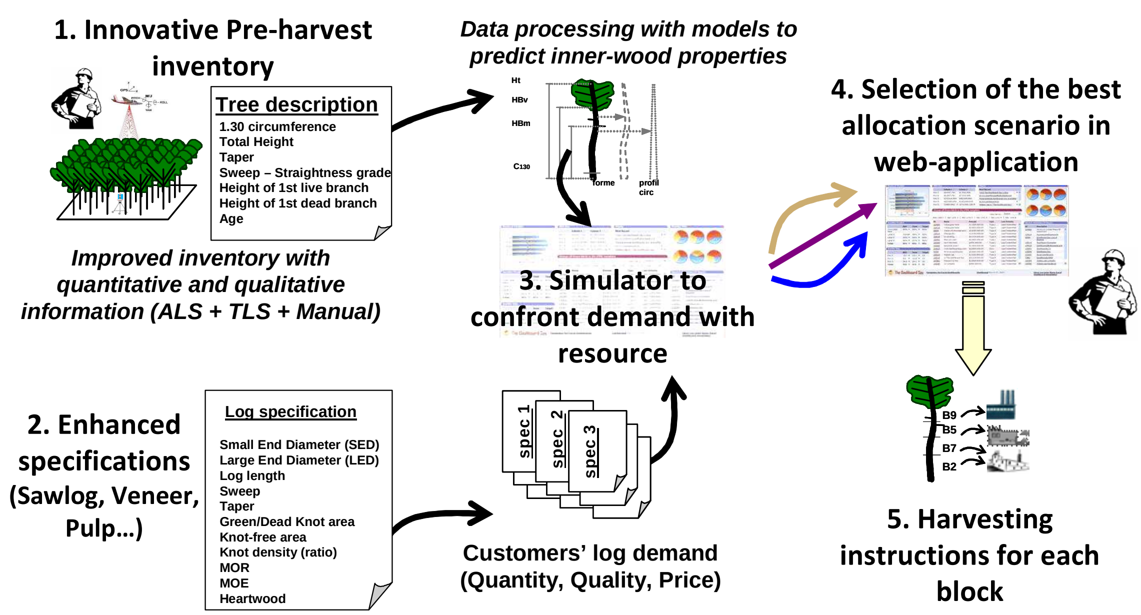
– Harvesting instructions on a given stand are designed according the most urgent demand and by-products are allocated to remaining needs without much consideration on what could have been the best product-mix to be cut from the same stand

FlexWood scenario

– Techno. or method to be implemented: LIDAR for automatic and enhanced information on a given stand; Model to link inner-wood characteristics to dendrometric ones ; IT interface to visualize & process the collected data, integrate demand and support decision making.

– Expectations: at the time when a supply company would try to plan future logging operations (stand allocation, harvesting instructions for the machine…) the decisions would be easier to make with an easy access to enhanced stand description and demand (see also figure)

Figure : Illustration of the FlexWood scenario



2. Qualitative analysis

BAU scenario

BAU	**A. Resource inventory**	**B. Stand allocation**	**C. Harvesting**	**D.**	**E.Mill Round wood specificat°**	**F. Communica-tion infrastructure**
Techno and process *	Manual inventory (DBH and height)	Manual allocation with limited information on resource	On-board computers to integrate and apply harvesting instructions		Mostly quantitative specificat°	Information on resource is collected in GIS
Skills required by Actors **	Empirical analysis by wood supplier	Empirical analysis by wood supplier	Empirical analysis by wood supplier to create Harvesting instruction		Empirical analysis by Mill	

* : What technologies and process are used ? What are the main difficulties and constraints ?

FlexWood scenario

Flexwood scenario	**A. Resource inventory**	**B. Stand allocation**	**C. Harvesting**	**D.**	**E. Mill Round wood specificat°**	**F. Com- infrastructure**
Technologies and process *	ALS TLS Improved manual inventory Models	Knowledge-based allocation of block (product mix prediction)	Knowledge-based harvesting instruction		Enhanced specificat° including inner wood quality	IT dashboard to provide access to stand information and clients' demands
Consequences for the Actors **	• new organisation for the manual inventory • Offer from new service providers (Lidar)	• training needs related to new tools for decision making • Integration of new specification from Mills	• Full adoption of APT files & Co by the actors		• Willingness to specify needs differently (Mill) • Same language on spec for Mills and Suppliers	• new IT products to be offered by service providers

* : main differences with BAU scenario ? What are the realised or expected impacts (positive / netagive) ?
** : What changes in the activities and skills of employees ? Entry of new actors ?...

In the French case, it was determined that several organizational issues and technical topics should be addressed and solved before this business case could be effectively adopted by the actors and widely spread in day to day practices:

- Training should be thought through (user guide, training session…) in order to secure the efficient integration of a potential Flexwood system in the process by smoothing its adoption by the future users ;

- Forest stakeholders need to find a way to pool collection means for LIDAR data to be available on significant scale and to be up-dated over time
    - Share costs with other non-forestry users – e.g in France, ALS is currently collected for topography purposes only and over very specific areas (flooded shores, riverbanks…) ;
    - Rely on service providers (Data collection + Processing + Delivery of information) with an acceptable business offer ;

- Improving wood allocation before harvesting is only worth the effort if WSC actors manage to improve their logistics. Without reflection and collective solutions (which local stakeholders are now trying to launch), the advantage gained might not be valorized later down the chain.

- Inter-operability is a major challenge for any new system relying on ICT modules and dealing with electronic data exchange between companies. E.g. Harvesting instructions designed with a FLEXWOOD system should be compatible with onboard computers of logging machines. This brings up the importance of standardization (e.g. StandforD or Papinet) and confirms the need to connect the results of this specific research initiative done in Aquitaine with other running collective initiatives like EXPLOTIC or eMOBOIS in France.

3. Quantitative analysis

Evaluation was based on results from the data processing. Expert opinion was combined with feedback from Professional users.

Indicators	Definition	WSC	French Case	
			BAU	FlexWood
Inventory costs	Costs due to forest resource inventory (quantity and quality)	Resource inventory	Reference situation	–
Productivity	Time spent by the forest manager to plan the answer to a client's demand	Resource inventory and Stand allocation	Reference situation	+
Time before delivery	Time deliver to respond to customer (mills) demand	Production (saw)mill	Reference situation	++
Perfect order fulfilment	Measure the customer satisfaction	Production (saw)mill	Reference situation	++
Storage rate	Level of congestion in platforms in forest and roadsides	Harvesting	Reference situation	+
Produce to monetary value	Monetary value of different product mix	Stand allocation and harvesting	Reference situation	+

Color code : blue (observed) ; green (projected estimation)
Note : if the numerical estimation is not possible, the evaluators indicate the evolution of indicators bet. the two scenarios with a trend (++, +, -, --). BAU is the reference situation, + indicates an improvement of the indicator and – indicates a degradation. In some cases, the information both numerical value and trend is given.

SWOT analysis

	Helpful to the Flexwood objectives	**Harmful to the Flexwood objectives**
Internal factors	**Strengths** • Supply-related jobs to become more attractive • Interesting results from impact indicator on the Company level	**Weaknesses** • Existing personnel might be reluctant to adapt (fondness for the old way) • Implementation costs if LIDAR data collection was not pooled with others or had to become too frequent?
External factors	**Opportunities** • LIDAR data collection should be a collective dynamic, within the sector or with others (Agriculture, Communities, State…) • Electronic Data Exchange is under dev. in the sector and could boost Flexwood application • Towards a more transparent relationship with the forest own if resource estimation relies on pooled data collection and collective method to analyze it.	**Threats** • Existing actors could fear new competitors who would like to settle in the field of supply if the business becomes easier to operate ? • Logistics need to be improved in a collective approach before a concept like Flexwood can have a real impact on the WSC.

4. Conclusion

Main recommendations for implementation of FlexWood concept at large scale :

- Training and adoption facilitators should be considered
- Pooling of efforts is mandatory
- Connection with other ICT inspired tools and methods developed for forest-based actors in a collaborative approach (e.g. in France: EXPLOTIC, éMOBOIS…) is needed
- Standardization (e.g. wood product description) should be integrated to guaranty proper data exchange and interoperability

German Use case

Authors : Martin Opferkuch (ALU-FR FobAwi), Ursula Kretschmer (ALU-FR IWW)

1. Description of case study

1.1 General questions

Location of the implementation and demonstration site
Surface of the forest (ha)

The implementation and demonstration site of the Central European use case is located in an area close to the city of Karlsruhe in south-western Germany.
The surface of the forest is approximately 2200 ha.

Description and structure of local forest resource

The forest resource in the Central European use case includes a variety of mixed stands either dominated by broad-leaved species, mainly European Beech (FASY), or by Scots Pine (PNSY). With their heterogeneous structure, these stands are thus representative of many typical natural Central European forests.

Actors

Forest Ownership: Public forest represents the largest proportion of the Central European demonstration site. It is managed by forest agents.
A little proportion of the area is small non-industrial private forest (NIPF), some owners are organized in forest owner cooperatives.
In the vicinity of the project area, there are a number of small and medium to large sawmills, as well as pellet industries and biomass heat and power plants are present.
Industry purchases most of the forest raw material on road side.
Harvesting is done both by state forest loggers and by contractors depending on species and assortment; transport is realized by small hauling companies on a contract base.

Main actors implicated in the local WSC

	Forest owners	Forest managers	Wood procurement companies	Cooperatives	Logging contractors	Transport companies	Sawmill	Other …
Main role	Selection of harvest stands	Selection of harvest stands	Purchase of raw wood on roadside	Organisation of raw wood harvesting and sales	Harvesting and forwarding of raw wood by order	Hauling of raw wood by order	Purchase of raw wood on roadside	
Complementary role	Harvesting and forwarding	Allocation of raw material to industry demand	Stumpage purchase				Purchase free mill	

Main markets

- The main main markets are the sawing industry and wood fuel production (pellets, wood chips) or direct energy use in (industrial) heat (and power) plants or households.
- Structure of demand is heterogeneous with both large and small sawmills.
- Due to the heterogeneity of the wood products industry, there exists a large diversity of customer demand towards the raw material regarding assortment specifications, quality preference and required volume. Generally spoken, smaller sawmills are rather used to the long wood system, whereas larger sawmills tend to prefer CTL logs. This is true both for hard- and softwood species. The largest quality demand is in the range of class B and C of the European Standard EN-1316 and EN-1927 respectively and volume demand per lot ranging from less than one truck load (25m^3) to several hundred m^3.

1.2 Characteristics of case study

What stages of the supply chain are involved in the case study ?
What are the main actors concerned by the case study ?

	A. Resource inventory	B. Stand allocation	C. Harvesting	D. Logistics	E. Production	F. Communication infrastructure
Case study	X	X	X	X	X	
Main actors involved	Public forest agent	Public forest agent	Public forest loggers; harvest contractors	Small haulage companies	Sawmill; Bioenergy industry	

1.3 Scenarios definition

Business as usual scenario (BAU)

Public forest agents organize selective cutting with main focus on silvicultural aspects. There is limited to no exact information on the forest resource (volume and quality) before formation of the sales contract and subsequent harvesting. Final roundwood allocation to customers is thus done after volume and quality assessment on roadside based on National and European Standards.

FlexWood scenario

Terrestrial (TLS) and Aerial (ALS) Lidar are implemented to enhance information on the forest resource (volume and quality) on stand level to support or replace traditional forest inventory measurements. With more precise definition and formulation of industrial demand (dimension and quality) – supported by additional information from CT scanning of logs - this is expected to improve round wood allocation.
Where the application of these technologies faces essential burdens (e.g. small forest ownership – NIPF) it is being assessed how they can be included in the advanced Flexwood supply chain.

2 Qualitative analysis

BAU scenario

BAU scenario	A. Resource inventory	B. Stand allocation	C. Harvesting	D. Logistics	E. Production sawmill	F. Communica-tion infrastructure
Technolo-gies and process *	Manual sample (plot) inventory (species, dbh, (height)),		Chainsaw or harvester depending on species and assortment		Purchase on road side, volume based; quality assessment based on classification standard	Telephone, Fax, E-mail, Mail
Actors (activities, skills of employees)	Forest agent; Public Forest inventory; Forest service companies		Public forest loggers or harvest contractors	Small haulage companies on individual contract base	Wood purchasers	

* : What technologies and process are used ? What are the main difficulties and constraints ?

FlexWood scenario

FlexWood scenario	A. Resource inventory	B. Stand allocation	C. Harvesting	D. Logistics	E. Production sawmill	F. Communica-tion infrastructure
Technolo-gies and process *	ALS, TLS; Comprehension of quality assessment in manual inventory	IT tools and infrastructure to support decision on resource allocation to demand			CT Scanning of logs; Formulation of specific requirements on raw material	
Actors **	Adaptation of manual inventory (include quality assessment); ALS and TLS service providers.	Forest agents, (Wood purchasers)	Assortment definition		Sawmill personnel; wood purchasers	Forest agents, Customer personnel

* : main differences with BAU scenario ? What are the realised or expected impacts (positive / negative) ?
** : What changes in the activities and skills of employees ? Entry of new actors ?...

3 Quantitative analysis

3.1 Inventory costs

Scenario	Area (ha)	Number of plots	Costs per plot (€)	Total costs without tax (€)
BAU (Conventional way)	2 200	633	35	22 155
ALS costs (Flexwood scenario)	2 200			
Gathering costs				14 000
Processing costs				1 - 1,5 € / ha
TLS gathering and processing costs (Flexwood scenario)	2 200	633	20-25	12 660 - 15 825

3.2 Other indicators

Indicators	Definition	WSC	German Case	
			BAU	FlexWood
Productivity	Time spent by the forest manager to plan the answer to a client's demand	Resource inventory and Stand allocation	2 hours/ 100 m3	1,7 hours/ 100 m3
				+
Time before delivery	Time deliver to respond to customer (mills) demand	Production (saw)mill	28 days	17-20 days
				++
Perfect order fulfilment	Measure the customer satisfaction	Production (saw)mill	n.a.	n.a.
				n.a.
Storage rate	Level of congestion in platforms in forest and roadsides	Harvesting	10 %	5 %
				+
Produce to monetary value	Monetary value of different product mix	Stand allocation and harvesting	n.a.	n.a.
				+

- Color code : blue (observed) ; green (projected estimation)
- Note : if the numerical estimation is not possible, the evaluators indicate the evolution of indicators bet. the two scenarios with a trend (++, +, -, --). BAU is the reference situation, + indicates an improvement of the indicator and – indicates a degradation. In some cases, the information both numerical value and trend is given.
- n.a. : not available

4 SWOT analysis

Strengths	**Weaknesses**
Better resource information (vol. & qual.) More precise demand information.	High costs for information acquisition Difficulty to gain reliable information for very heterogeneous forests
Opportunities	**Threats**
One component in strategy to respond to possible future wood shortage and/or price increase	Costs higher than added value in comparison to BAU.

5 Conclusion

LIDAR technology is, at the moment, only feasable for large areas with homogenous forest. On the German test site it is not advisable as it is also too small. But here, for a research project, on a small area different kinds of questions can be tackled.

Swedish Use case

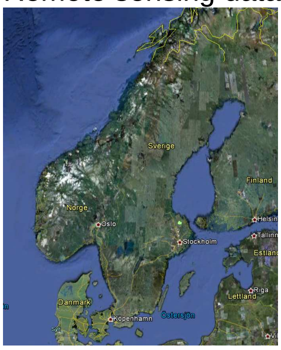
Authors : Tobias Jonmeister (FORAN), with the contribution of Andreas Barth (Skogforsk)

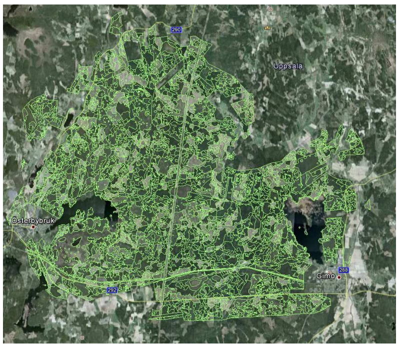
1. Description of case study

1.1 General questions

Location of the implementation and demonstration site
Surface of the forest (ha)

Osterbybruk area located approx. 100km north of Stockholm in central Sweden. Remote sensing data covers about 16000 hectars area.





Description and structure of local forest resource

Managed boreal forest in a flat terrain on moraine soils. Dominated by Scots pine and Norway spruce. Other main species are deciduous species, mainly birch. The road network are dense.

Actors

Private owned forest by Bergvik Skog. Korsnäs is responsible for harvesting operations and deliver timber both to own pulp mills and to several saw mill costumers in middle Sweden.

Main actors implicated in the local WSC

	Forest owners	Forest managers	Wood procurement companies	Cooperatives	Logging contractors	Transport companies	Sawmill	Other…
Main role	Bergvik Skog	Korsnäs	Korsnäs	No	Several companies	Several companies	Several sawmills	Pulp mills (Korsnäs)
Complementary role	Other private forest owner	Bergvik Skog						Bioenergy heating plants

Main markets

Saw timber, pulp- and paper as well as energy.
A large variation in demands from different customers.
Customer expect delivery of contracted volumes on assortment and species.

Normally 3-6 assortments per species. Saw timber normally length distribution demand per diameter class (2-3 cm). In total at least 10 assortments per object with delivery to 6-10 different industries.

1.2 Characteristics of case study

What stages of the supply chain are involved in the case study ?
What are the main actors concerned by the case study ?

	A. Resource inventory	B. Stand allocation	C. Harvesting	D. Logistics	E. Production sawmill	F. Communication infrastructure
Case study	YES	YES	YES	YES	NO	NO
Main actors involved	Foran, TreeMetrics	Korsnäs (Logica as a provider of software)	Korsnäs and logging contractors	Korsnäs and transport companies		

1.3 Scenarios definition

Business as usual scenario (BAU)

Korsnäs is using VSOP for the operational harvest planning which includes selection of stands to be harvested and scheduling the machine resources. VSOP is a wood operating planning system from Logica. Today Korsnäs do prognosis of log product recovery on each stand that is suggested to be harvested within about one year ahead. Information about stands available for harvesting is registered in a database, either by Bergvik or by Korsnäs when standing timber is contracted from other private forest owners. To get a good forecast of the outcome a bucking simulation is done in VSOP (Silvia Sim) for each stand. The simulations are based on the current price lists and demand information from the industries. Bucking simulation gives a forecast of the log product distribution into log tallies, value per log product and an overall value. Based on the results from bucking simulations and a timber delivery plan the production manager schedules the harvesting activities. Stands are selected for harvesting and are scheduled to match the demanded volumes of wood to each mill defined in the delivery plan. Operationally this demand is defined at the district level of Korsnäs wood supply organization. Today the bucking simulation is based on stand registry data which include average DBH, species distribution, volume per ha and the stand area . Based on the registry data VSOP creates a list of trees to describe each stand. Properties of each tree is given from typical trees in terms of damage, quality classes and diameter distributions.

New technologies implemented:

- Improve the description of the forest based on LIDAR and remote sensing data (ALS+TLS+hyperspectral images) considering better resolution (diameter and height distribution per species) higher accuracy (volume).
- Implement functionality in VSOP-software to benefit from better forest data in order to enable enhanced bucking simulations and harvest instructions..
- Test a model to improve stand allocation for harvesting in VSOP by using description of forest, industry demand and machine resources.

2. Qualitative analysis

BAU scenario

BAU scenario	**A. Resource inventory**	**B. Stand allocation**	**C. Harvesting**	**D. Logistics**	**E. Production sawmill**	**F. Communica-tion infrastructure**
Technolo-gies a. process *	Manual stand inventory	Bucking simulation and manual planning	Harvest instructions		-	-
Actors (activities, skills of employees)	Forest owner Bergvik or wood supplier Korsnäs	Wood supplier at Korsnäs			-	-

* : What technologies and process are used ? What are the main difficulties and constraints ?

FlexWood scenario

FlexWood scenario	A. Resource inventory	B. Stand allocation	C. Harvesting	D. Logistics	E. Production sawmill	F. Communica-tion infrastructure
Technolo-gies a. process *	ALS TLS Empirical harvester data	Bucking simulation and optimized stand allocation	Harvester instructions		-	-
Actors **	New service provider (Foran, TreeMetrics)	Wood supplier at Korsnäs with improved decision support system			-	-

* : main differences with BAU scenario ? What are the realised or expected impacts (positive / negative) ?
** : What changes in the activities and skills of employees ? Entry of new actors ?...

Impacts to the interconnections of the supply chain

No critical impacts at interconnections of the WSC, but there is many possibilities for improvements in the chain.

3. Quantitative analysis

3.1 Inventory costs

	BAU	**ALS**
Single Tree-measurement : measure diameter for all trees, estimate height for all trees	150 €/ha	6 €/ha
Stand inventory : Average diameter, height and volume	12 €/ha	4 €/ha

TLS
6 600 €* (58 plots)

* : data collection costs (without processing costs) but including taxes

3.2 Other indicators

Indicators	Definition	WSC	Swedish Case	
			BAU	FlexWood
Productivity	Time spent by the forest manager to plan the answer to a client's demand	Resource inventory and Stand allocation	2 hours/ 100 m3	1 hour/ 100 m3
				++
Time before delivery	Time deliver to respond to customer (mills) demand	Production (saw)mill	30 days	20 days
				++
Perfect order fulfilment	Measure the customer satisfaction	Production (saw)mill	n.a.	n.a.
				+
Storage rate	Level of congestion in platforms in forest and roadsides	Harvesting	12 %	8 %
				+
Produce to monetary value	Monetary value of different product mix	Stand allocation and harvesting	n.a.	n.a.
				++

Color code : blue (observed) ; green (projected estimation)
Note : if the numerical estimation is not possible, the evaluators indicate the evolution of indicators bet. the two scenarios with a trend (++, +, -, --). BAU is the reference situation, + indicates an improvement of the indicator and – indicates a degradation. In some cases, the information both numerical value and trend is given.

4. SWOT analysis

Strenghs	Weaknesses
Better adaptation to industry demand (lower storage, higher revenues). Better control and description of the wood flow. Better description of the forest. Lower cost for forest inventory at a large scale implementation.	If planned area differ from area cut. Lack of accurate information from external forest land owner.
Opportunities	**Threats**
Better knowledge about what is in the forest (assortments based on bucking simulations) might enable the forest owner to find the best paying buyer and get better value out of the wood when harvesting. Opportunity for industry to find fulfil its need at lower cost due to less surplus of unwanted assortments.	

5. Conclusion

ALS-data are enough in the Swedish Use case to replace BAU, even if it is planned to combine ALS and TLS data.
In the Swedish Use case, ALS technology allows obtaining a lot of benefits (more accurate quantitative data, qualitative data, lower costs inventory…) with positive impacts for the entire WSC (better utilization of the resource, better predict the output from a harvesting site, better value out of the forest, especially for the forest owners…).
No threats have been identified for an implementation of the LIDAR in that site.
Nevertheless, the benefits are likely to increase significantly if planning systems are developed to better make use of high resolution data.

Polish Use case

Author : Krzysztof Jodlowski (IBL)

1. Description of case study

1.1 General questions

Location of the implementation and demonstration site
Surface of the forest (ha)

Eastern European Use Case site is located in north-western part of Poland, with the total area of forest amounting to 6,380 ha.

Description and structure of local forest resource

Main species, homogeneous versus heterogeneous resource…

Forest type: Coniferous, mixed and decidious forests.

Species composition: Pine 72,2%, Beech 7,2%, Oak 6,5%, Alder 5,3%, Birch 2,4%, Spruce 2,1%, Larch 1,5%, others 2,8%

Such a species composition is quite common for many forest stands in Poland.

Actors

Forest ownership structure - 100% state forests
Forest inventory – usually done by state company.
Forest are managed by **state officers**.
No sawmills on project area or its vicinity – all wood is transported at least 80 km away.
Wood is harvested by **private forestry** contractors in moto (harvesters) or moto-manual (chain saw + mechanical extraction) way.
Harvested wood is sold on road side after electronic auctions. 90-95% of wood is sold via Internet.

Main actors implicated in the local WSC

	Forest owners	Forest managers	Wood procurement companies	Cooperatives	Logging contractors	Transport companies	Sawmill	Other…
Main role		Pre-harvest assessment; Selection of forest stand (Matching forest compartments with industry demand); Measurement of harvested wood			Performing of harvest and extraction operations (contractors are paid by State Forests local district)	Performing hauling operations	Purchase of wood on Internet auctions	
Complementary role		Supervising of harvest operations					Arranging companies for wood hauling	

Main markets

The main markets are sawmilig and pulp&paper industries. Some amount of wood is sold as a fuel wood (households).

Structure of demand is heterogenous in terms of dimensions and species. Wood is sold in form of logs or long wood pecies.

Wood trading is based on so-called ‘technical requiremets’ which are result of agreement between State Forests National Holding and wood industries in Poland. Technical requirements are adaptation of EU standards to specifics Polish conditions. Most demanded quality classes are C and B. Volume ranges from small quantities (a truck load) for small sawmills to several thousands of cm^3.

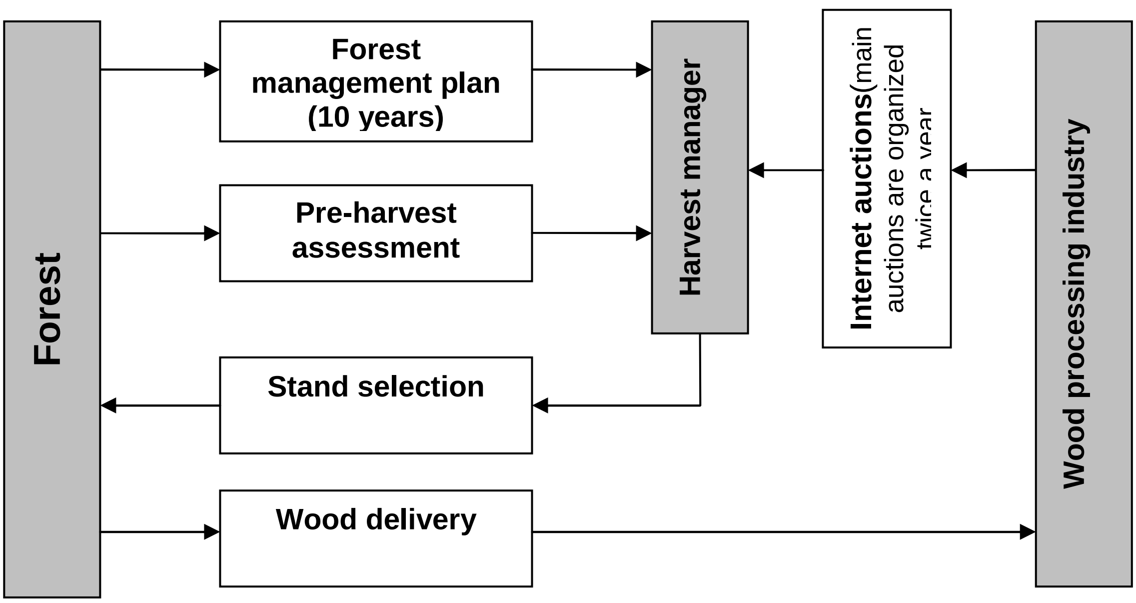
1.2 Characteristics of case study

What stages of the supply chain are involved in the case study ?
What are the main actors concerned by the case study ?

	A. Resource inventory	B. Stand allocation	C. Harvesting	D. Logistics	E. Production sawmill	F. Communication infrastructure
Case study	X	X	X			
Main actors involved	State Forests officers	State Forests officers	State Forests officers			

1.3 Scenarios definition

Business as usual scenario (BAU)



FlexWood scenario

TLS are used for quality and volume calculation. Results are compared with pre-harvest assessment and post-harvest data.

2. Qualitative analysis

BAU scenario

BAU scenario	A. Resource inventory	B. Stand allocation	C. Harvesting	D. Logistics	E. Production sawmill	F. Communica-tion infrastructure
Technolo-gies a. process *	Manual, based on sample plots	Manual, using existing data bases	Mechanised or moto-manual ; Volume and quality determined by State Forests officers during extraction or on road side.		Volume based purchase on road side after Internet auctions	Internet platfors, e-mails, phones, faxes,
Actors (activities, skills of employees)	State company	Harvest manager (State Forests officer)	Private forestry contractors	Department or responsible persons at sawmills; sometimes managers at hauling companies.	Departments/ responsible persons at sawmills	

* : What technologies and process are used ? What are the main difficulties and constraints ?

FlexWood scenario

FlexWood scenario	**A. Resource inventory**	**B. Stand allocation**	**C. Harvesting**	**D. Logistics**	**E. Production sawmill**	**F. Communica-tion infrastructure**
Technolo-gies a. process *	TLS; volume and quality assessment					
Actors **	TLS service providers.					

* : main differences with BAU scenario ? What are the realised or expected impacts (positive / netagive) ?
** : What changes in the activities and skills of employees ? Entry of new actors ?...

3. Quantitative analysis

Indicators	**Calculation**	**Category of data**	**Impact captured**
Inventory costs	FlexWood scenario: acquisition costs of LIDAR data (euros/hectare) **TLS: 15-20 euro/ha (there are no numerous TLS devices in Poland so costs were calculated basing on rates of hiring/sub-contracting)** **ALS + aerial photo: 2÷3 euros per hectare** BAU scenario : expenditures to inventory the forest resource both in quantity and quality (field trips in the forest, measurement…) (euros/hectare) **10÷15 euro/hectare, depending on terrain/forest category.** **Pre-harvest assessments (determination of volume and quality classes composition befor cutting): 50-60 euro/hectare**	**Experts**	Implementation costs of new technologies like LIDAR. **TLS data collection is not a major problem, the problem is data processing. Implementation costs should be enlarged by that category.**
Productivity	Difference in productivity between. BAU scenario and Flexwood scenario in % (e.g. according to an expert). If not possible, indicate the evolution of productivity bet. the two scenarios with a trend (++, +, =, -, --). **This question is difficult to answer since it assumes comparable results (in terms of information) from BAU and FlexWood concept. One can assume two scenarios:** **1/ <u>stands with simplified vertical structure (e.g. even aged stands or one stratum stand)</u>** **Using TLS, ALS and aerial photos one can achieve similar result to BAU inventory in**	**Experts**	Productivity evolution of order management. Indirect indicator of the evolution of order management costs.

	terms of tree height, DBH, species composition (using spectral analysis). **In such a case the productivity using novel technology should be higher: + But only in volume terms.** **2/ stands with complex vertical structure (multi-aged forest stands, multi-strata forest stand).** **In such a stands LIDAR technologies do not provide the same data set as classic forest inventory. E.g. distinguishing of tree species is very difficult.** **General question is determining of standing wood quality. If we want the FlexWood concept be useful for industry it should detect such a wood failures like open and enclosed knots, sweeps, rot and presence of bracket fungi. It is essential to select stands containing grade A and B. And also distinguish C form D. New technologies do not offer such solutions, neither classic inventory.** **That's why pre-harvest assessments are done in Poland, offering very detailed info on wood resources. So for the experienced harvest manager matching client's order with appropriate forest sub-compartment can take 2-3 hours (including stand visit to verify the selection). It can cost 20-30 Euro.**		
Time before delivery	Time in days between the order (from customer) and the delivery (to customer) both in BAU scenario and Flexwood scenario. **Time in BAU is usually up to 1 week, depending on volume and harvesting technology.**		Measure changes in flexibility and quality of customer service. **No major improvements are expected.**
Perfect order fulfilment (Customer satisfaction)	Evaluation by customer (sawmills) of their satisfaction related to how delivery meets initial demand, in %, both in BAU scenario and FlexWood scenario. Rejection and Downgrading rates could also be a way to quantify the order fulfilment notion		Measure the quality of customer services and the adequation bet. supply and demand.
Level of congestion / Storage rate	Average rate of congestion (in %) in platforms in forest and roadsides, both in BAU scenario and FlexWood scenario. Congestion due to by-products which are not yet allocated to a client		Indirect indicator of storage costs for forest managers.
Produce to monetary Value	Difference in value for forest managers bet. BAU scenario and Flexwood scenario in % (e.g. according to an expert).		Measure potential monetary optimisation of product mix

4. SWOT analysis

Strenghs	Weaknesses
Useful in monocultural forests – e.g. pine forests with very limited understorey.	Problems to obtain information from mixed forests.
Opportunities	**Threats**
Interesting decision support tool for harvest managers.	High costs of implementation.