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Illustration of sustainability effects from allocation.
Results from EFORWOOD case studies on:
- Corrugated boxes of fibres from Västerbotten, Sweden.
- Sawn products and biofuel in South Scotland.

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Illustration of sustainability effects from allocation

**Results from EFORWOOD case studies on
- corrugated boxes of fibres from Västerbotten
- sawn products and biofuel in South Scotland**

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[1] Innventia Report No.: 34
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1   Summary

The allocation of suitable materials to mills, processes and products is crucial for the sustainability of the forestry wood chains. All aspects of sustainability are influenced: environmental, economic and societal. If unsuitable material is allocated to a process, this will normally lead to use of more material, energy, increased waste, etc. Product functionality and customer satisfaction may also be compromised. In this report, sustainability effects from raw material allocation are illustrated in two case studies. The first case study which is related to fibre-based products was carried out by Innventia, and the second-case which is related to wood-based products was carried out by Forest Research. The cases are for illustration of the processes and concepts only and should not be used as a basis for decision making.

The fibre-based products case deals with the production, use and recycling of boxes from corrugated materials. The product chain starts in the forest of Västerbotten. Kraft pulp and kraftliner is produced and shipped to a converting plant in Germany. Boxes are produced, distributed, used and collected for recycling. Two alternatives of allocation were defined, providing more suitable wood from which better kraft pulp is produced. From the better kraft pulps, the mill may produce kraftliner with better or the same properties at lower cost. Two alternatives were defined for each allocation case: a) The production of lighter kraftliner from the improved kraft pulp, b) kraftliner with the same grammage and properties, but with some kraft pulp replaced with recycled fibre from Germany brought to Västerbotten. The four resulting alternatives were compared with the current situation as a reference, in relation to the consumption of materials and examples of indicators connected to transportation, emissions, economy and society.

The solid wood-based products case had the purpose of examining current management plans and potential modifications to the allocation system. This included altering how the timber is cut, which sawmill the material is sent to, and increasing the harvesting of material for biomass. A product allocation model was used to compare different log breakout scenarios and predictions were made of the average stem form within the stand and the wood stiffness of the trees. Within the different scenarios, log product proportions were adjusted based on the log diameter, stem straightness and stiffness of the timber. The final result was a prediction of the volumes of logs that will become available for different end uses (structural timber, pallet wood, and biomass) using different allocation strategies. The impacts of the alternative allocation scenarios were measured using four key indicators: Gross Value Added, total transport distance (miles), total greenhouse gas emission (kg CO_2), and total employment (person years).

The measures of sustainability in the two cases were analysed using the Tool for Sustainability Impact Assessment (ToSIA) developed in the EU 6th Framework project EFORWOOD (http://www.eforwood.net), complemented with data, models and tools from Innventia and Forest Research. The analysis showed that the results will change appreciably when different perspectives, constrains, etc. are applied and it is not possible to give general answers. Several of the process models in ToSIA were found to

be too simplistic and a lot of specific expertise on processes, products, logistics and markets is needed to reach realistic results. Such expertise and information are required to properly define the case, describe precisely the processes, specify interactions and limitations, add detail and implement modifications. More specific and dedicated tools would be useful, but ToSIA provides models and data which are an important starting point and serve as a roadmap for the holistic approach needed in the assessment of sustainability.

INNVENTIA

2 Introduction

2.1 A holistic perspective on sustainability

The sustainability of our actions and the products we use, can seldom be judged from a single narrow perspective. A product may look favourable because less energy is used when it is produced, but in the end it creates waste problems. It may seem attractive to set aside an area for conservation, but the consequence may be that local people are deprived of their source of livelihood and is, therefore, not sustainable from their point of view. Therefore, sustainability is defined against three categories:

- Environment
- Economy
- Society

In a true analysis of sustainability it is also necessary to involve "all changes related to different alternatives along the whole chain of processes"

A true sustainability analysis will therefore become quite complex, which creates a need for tools and databases to support. The EFORWOOD project has taken on the challenge to develop this framework for the forest-based sector.

The general objective of EFORWOOD is to develop a tool, ToSIA, for the analysis of sustainability effects on society and industry of forest related activities. It covers the effects of operations all along the chain: from forest establishment to the use and recycling of products, including wood-based and fibre-based products as well as bio-energy. It also includes calculations of the effects on a large number of non-industrial factors such as health, recreation, gender issues, etc.

Towards the end of the project, ToSIA has also been used to illustrate total sustainability effects of a number of scenarios of different natures and scales. The largest-scale study is pan-European and an important and very demanding part of the project has been to compile compatible cross-European data, which in itself will become a very valuable asset for continued work in the field. The project has also provided a very good basis for the further development of dedicated tools for specific issues, regions, industries, etc.

2.2 Importance of good allocation of wood raw materials

The allocation of suitable materials to mills, processes and products is crucial for the sustainability of the forestry wood chains. Wood shows large variation in properties; between species and trees, under different growth conditions and from different parts of the tree. This means that it is possible, but not always economically feasible, to find wood matching a broad spectrum of property specifications for different products and processes. The large variability is, however, also a weakness of wood as a material.

Unwanted property variations lead to reduced yield, increased costs and problems with product quality. If unsuitable material is allocated to a process, this will normally lead to losses in yield and value. The processing will also normally be less efficient, with more material, energy, etc. used per unit produced than is necessary. Unsuitable materials may have to be redirected to other processes or mills, which means increased transportation. In addition the quality, product functionality and customer satisfaction may be compromised.

The two studies carried out were selected to illustrate their relevance to different sectors of the forest-based industry:

1. One example from the fibre-based sector:
    Production of kraftliner from forests in the north of Sweden, export to the European continent, production of corrugated packaging materials and boxes, which are distributed, used and recycled.

2. One example on the solid wood-based and bio-energy sector:
    Production of sawlogs, pallet logs and bio-energy material from Craik Forest in South Scotland was forecast. Different allocation schemes for sending this material to local primary processors have been made to test the impact on different economic, environmental and social indicators.

The scope of the studies was to illustrate that:

*   The correct allocation of raw materials from the forest to specific mills and products is very important in ensuring sustainability

*   Alternatives which are reasonable from an overall point of view may include both positive and negative effects along the chain, which have to be considered, and which in turn makes the analysis of different alternatives complex

*   Tools like ToSIA, which aggregate different sustainability indicators along the wood-chain are useful for assessing the overall impact of different allocation alternatives.

2.3   Prerequisites for allocation

Important prerequisites for successful allocation are:

1. Information about the volumes and properties of:
    + the wood raw materials available for harvesting in the forest
    + the harvested material ready for distribution to different mills and products

2. Knowledge about industrial use:
    + raw material properties needed or preferred for production of various products in mills
    + costs and other negative factors involved in using non-preferential materials

3. Procedures and tools to match what the mill want with what is available in the forest.

Product and property demands, the second issue, have been generally described in the report "Key products of the forest-based industries and their demands on wood raw material properties" (Lundqvist, Gardiner 2007)[1].

The activities in EFORWOOD related to methods for and results from mapping of properties of wood and fibres in forest resources (issue 1 above) have been covered in the reports "Forest Resource Databases – a concept for product-oriented mapping of properties and volumes in forest resources" (Lundqvist et al 2008)[2] and "Mapping of properties in forest resources and models used – Results from EFORWOOD case studies in Västerbotten, Baden-Württemberg and South Scotland" (Lundqvist et al 2009)[3], which also touch on issue 3 and provide references to other work.

Based on the work previously reported on the description and mapping of key wood properties for different end products we are now able in this report to look at different allocation strategies. The variable nature of wood properties within trees, between trees and between forest stands means that inevitably any allocation strategy will be a compromise with "non-ideal" material always being included in the material sent to a particular process. The key is to attempt to ensure the highest levels of "acceptable" material without incurring unacceptable costs (economic, environmental or social).

2.4 Simplified analysis for illustration

Due to the prioritisations necessary during the EFORWOOD project, ToSIA has been adapted to primarily make possible the larger scale and less detailed case studies related to policy scenarios on the European or national level. It is currently less suited to investigate issues related to regional or local conditions and more detailed aspects of specific products, technical issues and fine scale allocation of forest resources. We hope that there will be possibilities after the EFORWOOD project has been finalised, to address such questions and develop/adapt tools for the benefit of mills, companies and regional organisations, based on the large experience and data gathered within the EFORWOOD project.

In the absence at this stage of a tool available for regional or forest level allocation purposes and mill issues, the two simplified studies reported have been performed based on results and data from EFORWOOD and individual models and data from Forest Research and Innventia. It is, however, important to acknowledge that the analysis presented here is for illustrative purposes only. It calculates values all along the chain from forest to recycled product, but the calculations are based on simplifications and assumptions. The results produced at this stage cannot be used as a basis for decisions to change policies or production strategies, but will hopefully throw some light on the importance of applying holistic approaches when discussing sustainability.

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[1] Based on EFORWOOD Deliverable PD3.1.2
[2] Based on EFORWOOD Deliverable PD3.1.5
[3] Based on EFORWOOD Deliverable PD3.1.8

3   Case kraftliner and corrugated packaging

The imaginary setting of the fibre-based study is that a producer of kraftliner wants to investigate what opportunities follow from making better use in his manufactured products of the wood raw material available in the region. The producer has high standards regarding sustainability and decides that positive and negative consequences of different alternative all along the chain from the forest to the recycled final product will be included in a study. The producer is not dominant in the market. Therefore, this study is limited to the investigation of the effects of the producer's own actions and will not include indirect effects on other parts of the forest-based sector.

The study is based on modelled mill characteristics and does not reflect conditions of any specific mill in the regions named. The purpose is to illustrate what can be done and to give some examples. It is a limited effort based on simplifications. It does not include investment costs and the results cannot not be used as a basis for decisions. Precise results that are necessary for decision making can only be achieved through an enlarged study, based on detailed specific information on mills and products. Such studies have not been within the scope of the EFORWOOD project, but they can be performed based on use and the further development of models and data applied in this study.

3.1   The product

The product chain investigated provides boxes of corrugated materials to users on the European continent, here represented by Germany. The boxes serve the purpose of protecting a range of goods and facilitating their transport. The goods can vary from heavy machines to food and delicate products like liquors and perfume, and is illustrated in the boxes for fruit shown in *figure 1*. The boxes are often printed to display the product inside.

The corrugated materials from which the boxes are produced are multiple layer constructions: two flat outer layers of liner and a corrugated sheet of fluting in between (see *figure 2)*. Sometimes the structure is repeated with more layers. This is a way to reach high stiffness of the material and good protection of the goods but with a very low material use. After use, a large proportion of the boxes are recycled.

Figure 1. Boxes made from corrugated material in a grocery store.

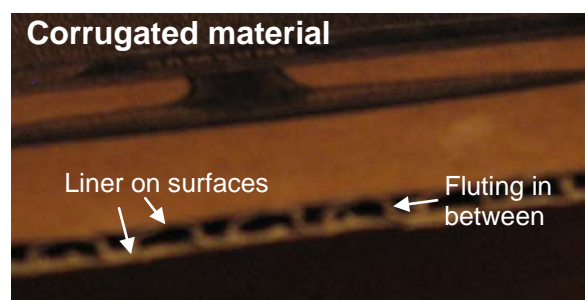**Corrugated material**

Liner on surfaces

Fluting in between

Figure 2. Corrugated material: Exterior sheets of liner with a corrugated sheet of fluting between.

The fluting itself is often produced from recycled material. The demands on the fluting material are generally less pronounced than those for liner. In this study, quality effects of fluting are excluded.

There are two types of liner: Testliner produced from recycled fibres, often in a mill close to the user, and kraftliner, with better properties, produced predominantly from virgin fibres in a mill close to the wood resource. Kraftliner dominates in more demanding packaging applications. Through repeated recycling, the fibres are gradually worn out. A stable level of properties in testliner is maintained, as new fibres from boxes made of kraftliner enter the recycling loop, while worn fibres are "lost" to energy generation or waste.

3.2   Key properties of corrugated boxes, liner and fibres

The question to answer in the study is if the functionality of the intermediate materials (kraftliner) and ready products (boxes) can be reached in more favourably, if wood and fibres with more uniform and suitable properties for each type of products may be supplied from the forest. The products have to fulfil a number of specifications related to mechanical properties, dimensional stability, printability, etc., which are dependent on their end-use. The intermediate materials have to meet demand regarding properties, runnability and quality in papermaking, converting, printing, etc. We will now discuss the property demands of the products and how they are related to fibre properties.

A crucial mechanical property for boxes is compression and stability when many boxes are stacked on top of each other for storage and transport. The sides of the boxes should ideally keep their dimensions and flatness under the pressure from above and not bulge. For this high compression strength and bending stiffness are important. The bending stiffness is achieved by exterior sheets of kraft liner with high tensile stiffness and a separation between them, established by the fluting, which gives very efficient material use. The dimensional stability is particularly hard to fulfil at high and varying humidity, for instance when boxes are moved in and out of cold transportation and storage or shipped overseas. The corrugated material should also be reasonably persistent to puncture and possible to cut and fold without problems.

Often the boxes are printed to provide information of different forms. This adds demands for reasonably high printability, which is related to surface smoothness and other surface properties. The top layer for appearance and printing may be brown, mottled or white depending on its intended use. White top liner, with bleached pulp in the uppermost layer of the sheet, is often used in products to be printed.

These properties are in turn related

- to the fibres used: fibre dimensions in the wood raw material, linked to their origin in the forest, and the content of recycled fibres

- the processing: cooking, refining and the layout and operation of the paper-machine

Generally, one may say that all the properties mentioned are improved if there are many bonds between fibres in the sheet. For liner with a specified grammage, the properties would generally be improved by the use of thin-walled fibres which are easy to collapse from "stiff pipes" with open lumen to "flexible bands" and also many per gram. Differences between fibres and wood from different sources are illustrated in *figure 3 and 4* (Lundqvist et al 2008). This indicates that, in this case, pulpwood should be better than sawmill chips, and pulpwood from thinnings better than pulpwood from the final cut. However, fibre length is also important and needs to be taken into account.
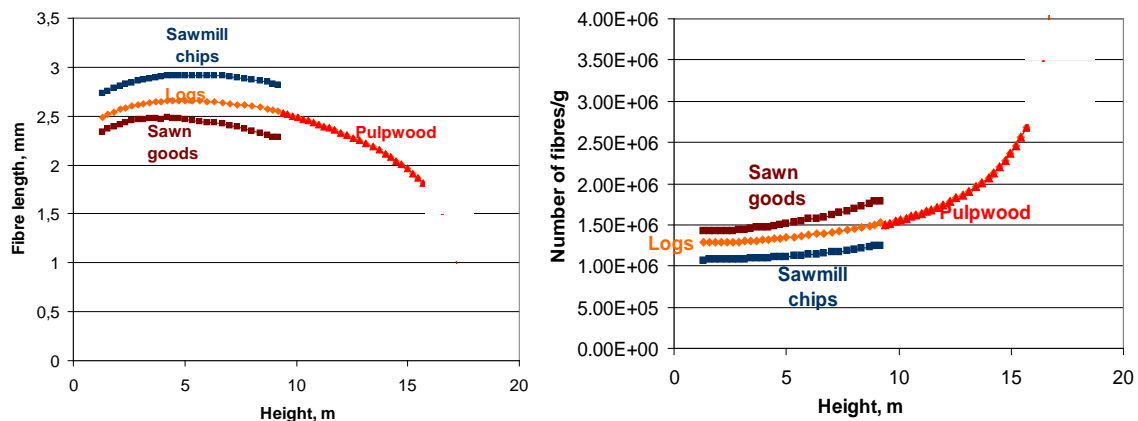
Figure 3. Fibre length and number of fibres per gram versus height above ground (left) or all internodes in a pine tree. Timber limit: diameter 14 cm. Data from the high detail Forest Resource Database for Västerbotten (Lundqvist et al 2008)
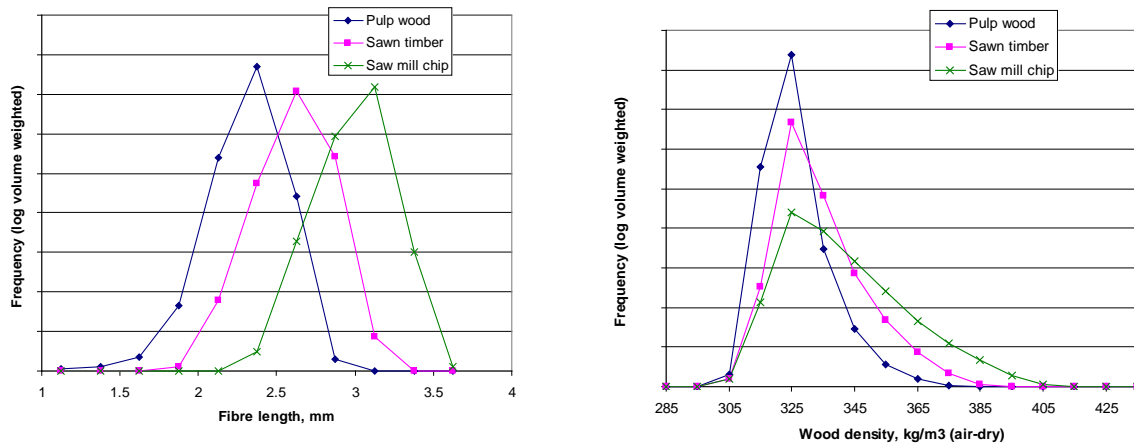
Figure 4. Statistical distributions calculated for fibre length (left) and wood density (right) for pulpwood, sawn goods and sawmill chips available in the Västerbotten region. Timber limit: diameter 14 cm. Data from the high detail Forest Resource Database for Västerbotten (Lundqvist et al 2008). The areas below the graphs represent the relative volumes of the different wood classes, estimated from the simulated trees.

The price of liner is often related to factors like surface weight (which also relates to the sheet thickness), content of recycled fibres and type of top surface, rather than the actual properties of the liner. It has proven difficult to persuade buyers to pay according to function rather than, for example, weight.

3.3 The product chain

The product chain of the case study starts in the Västerbotten forest. The activities involved are illustrated in *figure 5* and listed below.
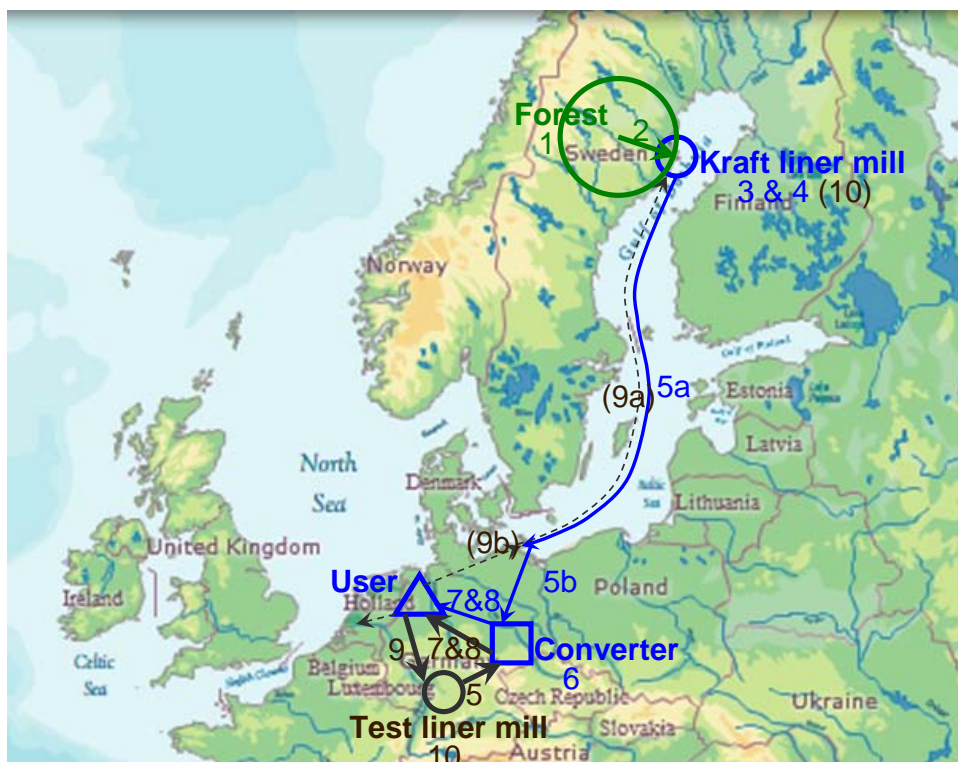
Figure 5. Illustration of the activities included in the product chain of the case study, with the flow and operations of virgin kraftliner and boxes in blue and recycling and testliner in black.

1. Management and harvesting of Norway spruce and Scots pine trees in the forest:

2. Transportation of pulpwood and sawmill chips to a pulp and paper mill

3. Handling of logs and chips in the woodyard and production of kraft pulp

4. Production of kraftliner from kraft pulp, possibly also using some recycled fibres

5. Transportation of rolls of kraftliner to a conversion plant for production of corrugated boxes in Germany, first by ship (a), then by rail (b)

6. Production of flattened corrugated boxes

7. Distribution of boxes by truck, for example to a food supplier

8. Filling of the boxes and transportation of them to a store by truck. Emptying and compaction of the boxes for recycling

9. Transportation of the compacted boxes to a paper mill in Germany, (in some of the alternative scenarios a minor part of this material is returned to the mill in Västerbotten)

10. Defibration and cleaning of the recycled material and production of new liner

The alternatives studies are all compared to the current situation as a reference. To reduce the complexity, only things which change are included in the calculations.

3.4 Calculations

A larger study including most parts of the product chain above but with another scope, the "Scandinavian regional case", has previously been performed within EFORWOOD (Valinger et al 2008). This is a forest-oriented study starting with the Västerbotten forest, including production of sawn products, pellets for heating, kraftliner and fine paper, transport and use of the products in Västerbotten and in other countries as well as collection of used materials, which are partly used for energy generation. The scope of the Scandinavian regional case was, thus, much wider than that of the current case study.

In the current study with more of an industry perspective, parts of the chain has to be described in further detail, especially the parts related to the mills and products. For the current study, ToSIA results from the Scandinavian case were transferred to an Excel sheet. All parts not related to the current chain were removed from the subsequent calculations, as well as all parts identical for the different alternatives. On the other hand, additional calculations related to use of bark and black liquor, generation of electricity and steam, bottle necks in the mills, products, shipping and upgrading of the recycled box materials, etc. were introduced into the calculations.

3.5 Assumptions and comments

The following assumptions and simplifications were made:

Alternatives in allocation

The basis of the study is that it is possible, through improved allocation of wood, to provide the mill, its processes and products with more uniform and suitable wood and fibres. Due to this, better kraft pulp may be produced, which allows re-optimisation of the chain from forest to recycled product.

The improved allocation would be achieved through a more selective use of wood and fibres. In EFORWOOD, a "Forest Resource Database" has been developed for Västerbotten (Lundqvist et al 2008). In such a database, inventory data are complemented with estimated properties of wood, fibres and knots for stands, trees and parts of trees. Several properties related to quality of pulp and paper are included in the database. *Figure 6* shows an example the statistical distributions of fibre coarseness, mg/m, for different types of wood from Norway spruce and Scots pine delivered to industry, calculated from the Västerbotten database. The distributions are weighted so that the areas under the graphs reflect the volumes of each class available to industry from the Västerbotten resource. Such information on properties is very useful for decisions on wood allocation.

In the current study, following alternatives were considered:

0. Reference: Same procedures as already exist for wood deliveries and woodyard operations
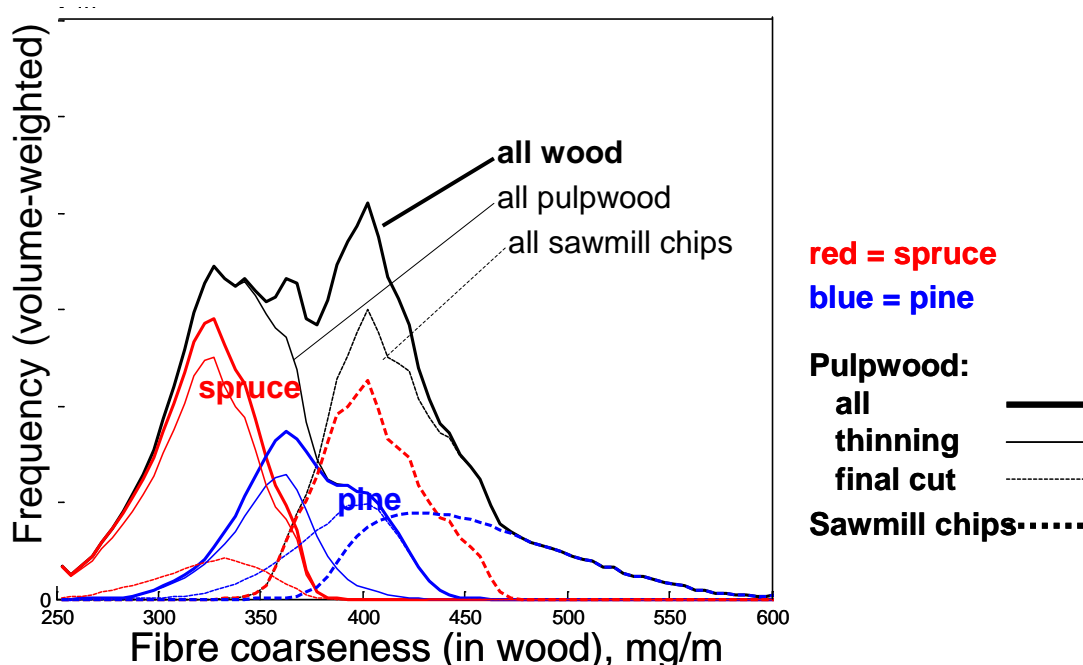

Figure 6. The statistical distributions of fibre coarseness for different wood classes of Norway spruce and Scots pine. The distributions are weighted so that the areas under the graphs reflect the volumes of each class available to industry in the Västerbotten resource.

1. Same deliveries as now, but classification of the loads of logs arriving in trucks or railway wagons to the mill according to their average properties and adaptation of the operations and wood storages on the woodyard, in order to supply the process with more uniform and suitable wood for each product.

2. Classification of the pulpwood delivered from each harvested stand according to average properties, followed by woodyard operations according to alternative 1.

3. Classification of individual logs at harvesting. Aggregation of pulpwood logs with similar properties into a set of separate piles at the forest road representing a number of different wood classes, which are allocated to suitable mills and products.

Alternative 1 involves no changes outside the mill gate, but adaptation of the logistics in the woodyard of the mill and possibly some investment in equipment. Alternative 2 has a potential to provide a better result, especially if the supply area is enlarged, but at additional cost. Alternative 3 would give the best result, but is judged as too expensive for pulpwood at current costs of labour and transportation.

Based on these considerations, two allocation alternatives were defined for the study:

1) *Same wood supply but more selective woodyard operation:*
   The change in cost, impact on environment, employment, etc. are expected to be limited. Therefore, they are not included in this study for illustration, but should be in a more complete project.

2) *Stand-wise selection of supplied pulpwood and more selective woodyard operation:* The operations in the forest and in the woodyard are the same as in alternative 1, but the supply area is increased by 30 % to allow selection of more suitable wood, resulting in an increase of the average transport distance of 14 %.

Alternatives in production of kraftliner

From the more uniform and suitable wood raw material, the mill will be able to produce kraft pulps with more uniform and suitable properties for use in different grades of liner and layers of the paper sheets. The improved pulp could be used to produce better liner, but in the short term, no payback can be expected. However, grades of kraftliner are specified by properties rather than composition, which gives the possibility for optimisation of the sheet if better pulp is available. The aim is always to produce kraftliner with the same properties. The alternatives studied are:

Reference   Kraftliner produced from 100 % kraft pulp in the pulp mill, using wood raw material according to the reference above.

A.   Production of lower grammage kraftliner with the same properties, using 100 % kraft pulp from the mill. The material saving is possible thanks to better kraft pulp produced from improved wood according to alternatives 1 and 2.

B.   Production of kraftliner with the same grammage, thickness and properties, but with replacement of kraft pulp from regional wood with recycled fibre from boxes used in Germany. Different levels of replacement depending on wood allocation.

Detailed assumptions about what re-optimisation could be done for the different alternatives are given in *table 1*. These possibilities are really the foundation of what benefits can be reached for the different alternatives. In a complete project for a mill, much work would be dedicated to understanding the effects on strength, bending stiffness, moisture related properties etc. of the liner, the capacities of various processes in the mill, runnability of the paper machine and on conversion, etc. All this would be quite specific for mills and products. Such analyses are outside the scope of this illustration, and realistic levels have been assumed based on expert opinion.

Table 1. Alternatives compared

Alternative	Wood supply to mill	Woodyard operation	Kraft pulp (in rel to ref)	Recycled materials	Liner weight and thickness
Reference	Ref	Ref	100 %	0 %	Ref
A1	= Ref	Improved	95 %	0 %	95 % of ref
A2	Improved	Improved	90 %	0 %	90 % of ref
B1	= Ref	Improved	90 %	10 %	= Ref
B2	Improved	Improved	80 %	20 %	= Ref

Basis of comparison

The alternatives may be compared in different ways: The comparison could be based on the same use of wood, the same production of pulp or paper or the same supply of utilities to the customers. In this illustrative study, we have selected to compare on the basis of the same supply of boxes to the end users. In "paper terms", we have translated this as supply of the same area of kraftliner with the same properties as the reference situation, regardless of grammage and fibre content. The same number of m^2 of kraftliner is, thus, produced in all alternatives, but the number of tons produced is smaller for the A alternatives, wheres it is the same as for the reference case in the B alternatives.

This basis of comparison is relevant and is the least complex to calculate, as nearly everything in the chain will be the same downstream of the paper machine among the reference and alternatives (more detail is given below). If we had chosen another basis for comparison, we would have had to go into more detail for the specific mill conditions.

In all alternatives, the use of kraft pulp from the pulp mill is reduced. A comprehensive project for a mill would take further factors into account: The recovery boiler of the pulp mill is often the most expensive piece of equipment and the bottle neck limiting the production of the whole mill. If this is the case, the mill would most probably not chose to profit from the option to use less kraft pulp per m^2 of liner by reducing the pulp production and the wood cost. The mill would more likely continue to run the recovery boiler at its maximum, using the same volume of wood to produce the same amount of kraft pulp but increasing the production of kraftliner. This would improve the economics but would not negatively affect employment and other societal aspects. There is, however, then a risk that the paper machine, the most expensive part of the paper mill, will become the bottle neck in the mill. and then often its capacity to dry the paper. Removal of bottle necks often involves large investments.

Another important aspect which would be considered in a complete case is whether the customers in the A alternatives could be expected to accept paying by performance but with a lower grammage when they are used to paying by weight.

Consequences in forest and wood supply

All alternatives studied make use of less wood raw materials from the forest. In this illustrative study, emphasising the products, we have made the straight forward simplification to use the average sustainability impacts for forestry, harvesting and transportation for all types of wood as valid for all pulped materials. The ToSIA calculations for Västerbotten provide aggregated values of sustainability indicators, lumping together data for pulpwood and timber; for pine, spruce and birch (small part); for thinning and final cut, etc. From these values, averages per ton have been calculated and used to describe effects per ton of raw materials used for pulp production. This means that harvesting, employment, emissions, etc. related to the use of wood in the kraft liner chain will decrease in proportion to the reduction in use of kraft pulp.

For the transportation of raw materials from the forest to the mill, the indicators are related to the average distance of transportation. This is assumed to be proportional to the production of pulp but also affected by the selectivity in wood supply, adding 14 % for the B alternatives. These average distances for the different alternatives may be calculated from table 1 as A1: 97 %; A2: 108 %; B1: 95 %; B2: 102 % compared to the reference.

The integrated pulp and paper mill

To estimate the consequences of these assumptions in the pulp and paper mill, material and energy balances have been calculated, using a detailed model for a kraft pulp and liner mill from the model library of Innventia (Lundström et al 2007). To illustrate the complexity and the need for specific details in a more complete study, the energy balance of the mill will be briefly described.

In a kraft pulp mill, a large part of the wood substance is dissolved on pulping, for kraftliner typically 43 %. Apart from pulp, an energy-rich "black liquor" is obtained. This is concentrated in an evaporation plant and burnt in the recovery boiler to regain chemicals for pulping and to generate steam and hot water. The bark attached to the wood is also burnt in a bark boiler or sold to outside users. There is a large need for steam in the mill. The largest consumers are the paper machine and the evaporation plant, followed by the turbine for generation of electricity and heat for the digester.

The models used in the calculations describe a mill with the best available technique of 2003. It is more energy efficient than the typical Scandinavian mill but less than new mills. This model mill was designed so that in the reference case all bark from the woodyard is sold and the steam from the recovery boiler is enough to feed all processes and to generate about 60 % of the electricity needed at the mill. The rest of the electricity required is bought from the public grid. This was a wise thing to do in 2003. Today, with the strong political and economical support for production of electricity, such a mill would probably make investments to re-optimise the energy balance. It would burn all bark from the woodyard in the bark boiler, plus possibly some extra bio-fuel purchased from outside, and produce as much electricity as possible, benefiting from not only the low price of electricity produced but also from power certificates.

Consequences in the pulp and paper mill

For the A alternatives, all flows are assumed to be reduced proportionally as compared to the reference and also the need for energy, chemicals, etc. in the processes. (This is a simplification, as there are in reality non-linearities.) The steam and electricity needed is then still available without the burning of bark. For the B alternatives, however, the same tons of kraftliner are dried, while less steam and electricity would be supplied, if no action was taken. The deficit is assumed to be covered by burning part of the bark from the woodyard in the bark-boiler, and less bark is sold to the market. Some more electricity also has to be bought, corresponding approximately to what is needed to prepare the recycled fibres for the kraft liner production.

Consequences in product logistics and recycling

The alternatives are compared for the same supply to the end users: This equates to the same area of kraftliner with the same properties as the reference converted to the same number of boxes with the same properties. In the A alternatives, more m^2 of kraftliner may be transported on each ship and railway wagon from the liner mill in Sweden to the converting plant in Germany. In the B alternatives, recycled material will be brought to Sweden on the returning ships. Otherwise everything is assumed to be so similar among the alternatives, from the production of the corrugated material to the storage of collected and compacted used boxes, that this part can be excluded from the relative comparison.

For the B alternatives, the mill will become an integrated part of the recycling system. For the A alternatives, there will be a slightly smaller influx of new fibres to the system. In both cases it is assumed that there will be only insignificant effects on the recycling system and the steady state of the properties of test liner.

3.6 Results

In *table 2*, some deliverables from the product chain are shown for the different alternatives, as well as the consumption of some important materials. It also presents examples of indicators related to transportation, emissions, economy and society for the different alternatives. Keep in mind that all data are shown in relation to the reference.

Supply to user, see lowest part of the table: The delivered m^2 of kraftliner, proportional to the number of boxes produced, equals that of the reference for all alternatives. This is, however, achieved with use of less tons of kraftliner in the A alternatives. For all alternatives, less bark is sold to outside users, but the reduction is much larger for the B alternatives, where bark is used for steam generation.

Consumption: For all alternatives, less wood (with attached bark) is used. In the B alternatives, recycled fibres are added. Less water is used for all alternatives. For the B alternatives, electricity has to be bought from the public grid.

Transportation: When the production of kraft pulp is reduced, also the need for transportation decreases. The average distance of wood transportation decreases, too, except for case A2, where the effect of a larger supply area to improve the basis for selection of more suitable wood supersedes the effect from reduced wood consumption. The B alternatives involve the transportation of recycled materials on the ships going back from Germany to Västerbotten.

Emissions: All emissions are reduced due to reduced production of kraft pulp, which means reduced burning in boilers and less transportation of wood. The shipping of recycled materials on returning ships has only a limited effect, as the ship has to return to bring more liner to the continent and the extra load of the recycled material corresponds to only 5 and 10 % of the freight capacity.

Economy: The relative change in production cost decreases when the grammage of the paper is reduced. Reduction in pulp production has also a clear effect, not least in the purchase of wood. On the income side (not shown) is not only the revenue from selling the paper but also the value of electricity certificates.

Society: Both employment and occupational accidents are related to the production of pulp. This is a reasonable simplification at least in forestry and wood supply. In the mill. The number of employees in the mill, which is smaller, is not as strongly related to production.

Overall result

This limited analysis for illustration indicates that among the alternatives defined:

- Most indicators are strongly influenced by the kraft pulp needed to make comparable products. All alternatives involve decreased production of kraft pulp, which also brings use of less wood from the forest, less transportation, etc.

- Production cost is, however, even more influenced by the grammage of the kraftliner.

Table 2. Supply to users, consumptions and other sustainability indicators, in relation to the reference
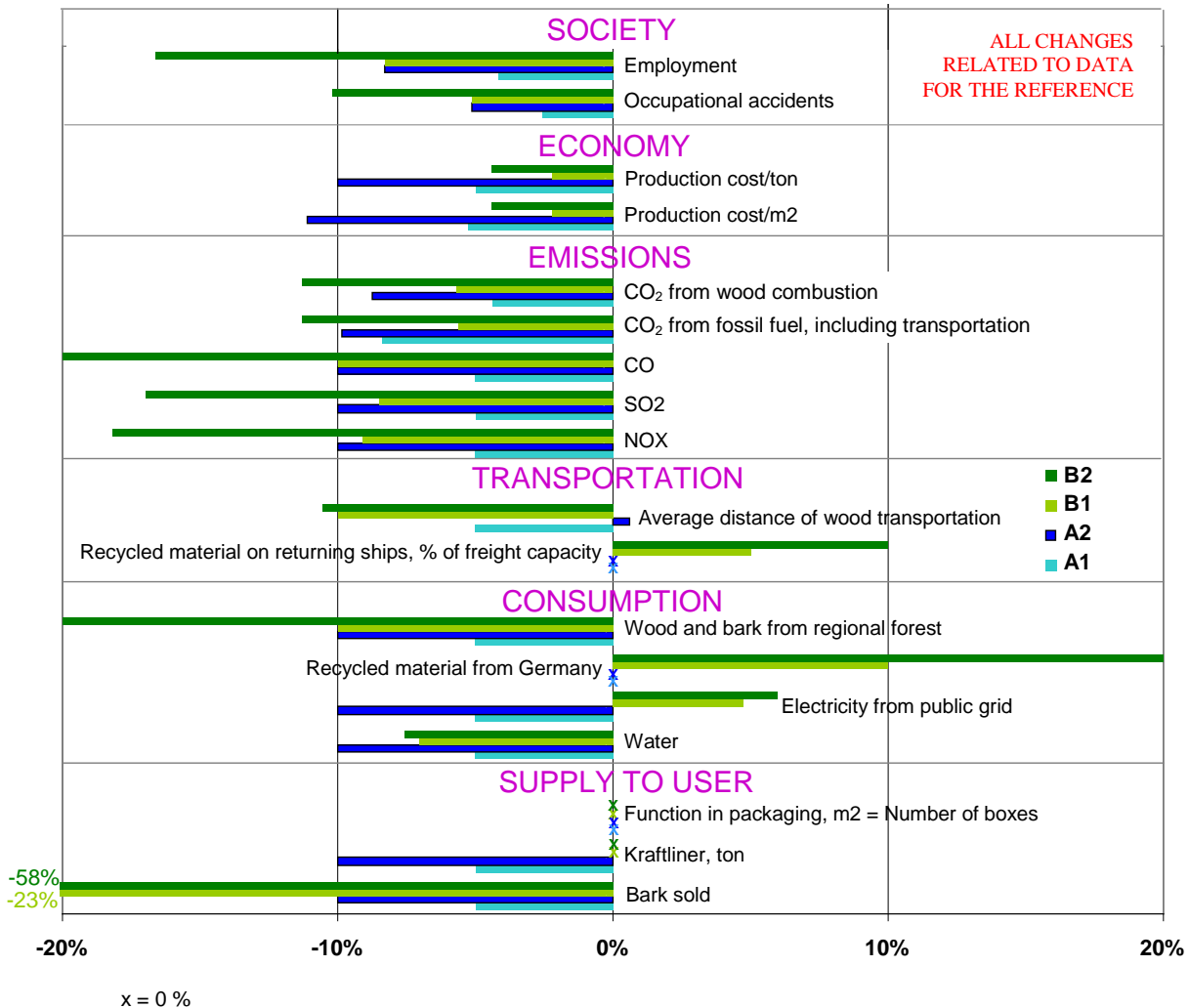
3.7 Widening of the perspective

All alternatives are favourable regarding most sustainability indicators illustrated, including cost. From a cost point of view, it would be best to decrease the grammage as much as the properties allow and the market accepts, without cutting prices. An expert can easily feel the difference between kraftliner of different grammages, but the differences are smaller when comparing boxes. Therefore, it should be easiest to apply this approach for a company integrating production of liner and boxes, selling boxes rather than liner. However, to produce kraftliner with the same grammage but with and increased content of recycled fibres seems to involve lower risks on the market. It also offers a potential to cut back more on the use and production of kraft pulp than reduced grammage. This is the strategy most mills have prioritised so far. In reality, it would be interesting for the mill to combine the two alternatives.

If the use of wood in the kraftliner mill could be reduced, this can offer opportunities to other companies in the region and to the society. The most probable scenario from today's perspective is that the wood would be used by other industries or for bio-energy. Other scenarios could be to create forest reserves for biodiversity benefits or for recreation, which could offer new employment opportunities.

However, the mill would most probably not choose to decrease the production of pulp to make the same tonnes of kraftliner. If the capacity of the paper machine could be increased with limited investments, it would normally be more beneficial for the mill to use the full capacity of the recovery boiler, produce more liner while using the same volume of wood. Alternative B2 offers the largest increase in production and is probably very attractive from this perspective.

It should be stressed that such changes do not come without costs. Large investments are normally needed. When instruments are introduced to stimulate the industry to change for the fulfilment of new policies, it is very important that these are sound and long-term decisions, so that these large investments are not made in vain.

3.8 Comments on and conclusions from the case

This discussion about the interpretation of the results and how conclusions may change when different perspectives are applied shows that there is a need for tools to support assessment sustainability. These tools need to be able to incorporate the full chains,in order to describe how single changes propagate along the chain and to deal with interactions. But the discussion also shows that it is difficult to produce generic results because the conditions vary so much. It may be possible to work with generalized models for effects from dominant isolated factors. But when several counteracting effects are involved resulting in a balance, then the need for detailed models and precision in data increases. If the intention is to use the results as a basis for decision-making, it is necessary to be very specific in the set-up of the analysis.

In the current case study we have mimicked and compared the different options available to a mill. One experience is that many of the process models in ToSIA are too

simplistic and aggregated to deal with this. More detailed models and data are needed. Another experience is that when making studies which may be applicable a lot of specific expertise on processes, products, logistics and markets is needed to reach realistic results in order to define the case, specify interactions and limitations, add detail and implement modifications. Otherwise, there is a large risk that the results will be misleading.

When approaching specific applications, even for an illustrative study like this, many additions are needed and more dedicated tools would be useful. But ToSIA has provided models and data used as an important starting point and served as a roadmap for the application of the holistic approach necessary in the assessment of sustainability.

4   Case solid wood product and bio energy: South Scotland

4.1   Brief on the South Scotland regional case study

This case study is focussed on Craik Forest in the Scottish Borders District of the Forestry Commission. Craik Forest is approximately 5000 ha and is predominately spruce. It produces significant amounts of high value timber, and is located within 300 km of 11 sawmills. The purpose of the case study is to examine the current management plans including the timber products created from Craik Forest stands, and then to make modifications to the allocation system. The modifications include altering how the timber is cut, which sawmill material is sent to and increasing the harvesting of material for biomass. The simulations only currently include processes within the M2 (Forest Resource Management) and M3 (Forest to Industry Interactions) areas of EFORWOOD.

All stands designated for harvesting between 2005 and 2030 were included in the simulation and all were assumed to be managed under Forest Management Alternative 4 (Dunker et al., 2008). A product allocation model has been developed and is utilised when comparing different log breakout scenarios. Predictions have also been made of the average stem form within the stand and the wood stiffness of the trees. These predictions are based on empirical models of tree growth and wood properties based on extensive surveys of growth, straightness and wood stiffness across the UK (see Lundqvist et al., 2009). Within the different scenarios, log product proportions are adjusted based on the stem straightness and stiffness of the timber. The final result is a prediction of the volumes of logs that will become available for different end uses (structural timber, pallet wood, and biomass) using different allocation strategies. The impacts of the alternative allocation scenarios have been measured using four key indicators: Gross Value Added (GVA), transport distance, greenhouse gas emissions, and employment.
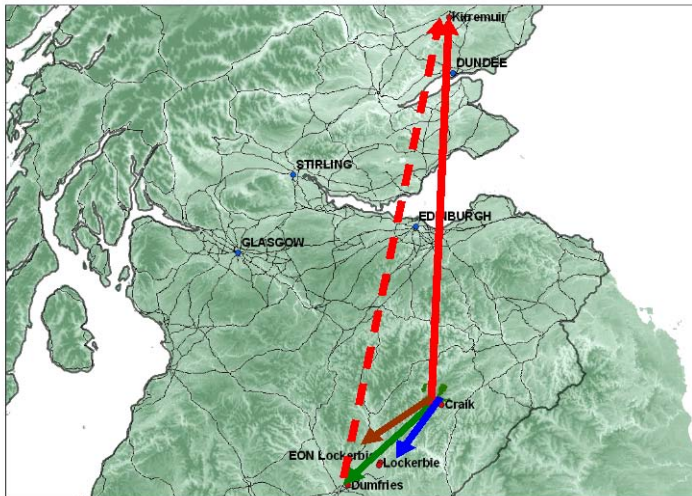
Figure 7: Location of Craik Forest showing transport routes for different products. Brown arrow = Biomass, Blue arrow = pallet logs, green arrow = green sawlogs, red arrows = red sawlogs.

4.2   Quality designation

Full details of the methods for predicting from site and stand conditions the quality measures used in material allocation are given in Lundqvist et al. (2009). The key factors are:

1. Diameter overbark. The diameter at the top of a log (smaller end) is measured overbark and is used in determining log type (see below).

2. The mean stand straightness (Macdonald et al., 2009) is used to assess the percentage of sawlogs making the "green" or millable log grade. This is based on the curvature of the log with "green" logs having less than 1cm bow in any metre and "red" logs having a greater than 1cm bow in a metre (Anonymous 1993).

3. The mean wood stiffness (Moore et al., 2009) is used to designate those logs suitable for construction grade timber and for the purposes of these simulations is set at 95% of 8 GPa in order for the timber to meet the C16 structural grade (CEN, 2003).

4.3   Product designation

There are 3 primary designations of logs from the Craik Forest used in these simulations:

1. Biomass: Log top diameter normally less than 14cm. In the simulations all biomass is sent to EON Lockerbie.

2. Pallet log: Top diameters over bark normally between 14 and 18cm. In these simulations all pallet logs are sent to James Jones and Sons Ltd. at Lockerbie.

3. Sawlog: Top diameter over bark normally greater than 18cm. The sawlog material is further designated into "green" and "red" logs. In these simulations all "green" logs are processed at James Jones and Sons Ltd. at Dumfries and all "red" logs at James Jones and Sons Ltd. in Kirriemuir.

4.4   Primary processors

Within the simulation we considered processing at 4 different primary processing facilities:

1. EON Lockerbie. EON Lockerbie is a 44MW biomass power station which started operations in 2008. It is fuelled entirely by biomass material. Over 480,000 tonnes of fuel is needed to power the station every year. The fuel is a blend of:

   a. 60% sawmill co-products and small round wood

   b. 20% short rotation coppice (willow)

   c. 20% recycled fibre (from wood product manufacture)

   All biomass products are sent to EON Lockerbie.

2. James Jones and Sons Ltd. pallet mill at Lockerbie. The plant was built in 2000 with an annual capacity of 100,000 m^3 and produces pallet, timber and fencing. All pallet logs are processed here.

3. James Jones and Sons Ltd sawmill at Dumfries. The Dumfries sawmill was built in 1984. It has an annual capacity of 65,000 m^3 and produces kiln dried graded sawn wood, unseasoned and ungraded wood, economy wood, and boarding. In this simulation all "green" sawlogs are processed here. Any logs designated as not meeting specification for construction grade timber (set for simulations at 20%, which is normal rejection rate for sawn timber) are retransported to Kirriemuir (see below).

4. James Jones and Sons Ltd. sawmill at Kirriemuir. Originally built in 1950 it had major investment in 2006 to install a line capable of handling logs of up to 8 m length and 80 cm diameter. Production is 15,000 m^3 annually and is mainly fencing with the emphasis on heavy sections and purlins (heavy rafters). This sawmill is able to deal with large logs and "red" sawlogs and in the simulations all "red logs" are processed here.

4.5   Alternatives investigated

There were 3 basic allocation options investigated but there are also 3 alternatives within the Forest Level Allocation (FLA):

1. Business as Usual (BAU). This is the method of allocation currently in operational use and only uses the top diameter of logs to allocate material.

However, 20% of sawlog material arriving at James Jones in Dumfries is regarded as not suitable for processing because it does not meet "green" log specifications and it is retransported on to James Jones and Sons Ltd. at Kirremuir (dashed red arrow in *figure 7*)

2. Forest Level Allocation (FLA). All the material to be harvested from the forest was allocated to 1 of 3 possible alternatives

   a. Biomass (FLA B): All material in the forest was cut as fuel for the bio-energy plant (EON) at Lockerbie.

   b. Pallet (FLA P): All material in the forest with top diameter greater than 14cm is designated as pallet and sent to Lockerbie pallet mill. All remaining material is sent to EON Lockerbie. There are no sawlogs.

   c. Sawlog (FLA S): All material within the forest with top diameter greater than 18cm is designated as sawlogs and sent to Dumfries sawmill. All remaining material is sent to EON Lockerbie. Again 20% of sawlogs transported to Dumfries are designated as "red" logs and transported on to Kirriemuir. There are no pallet logs.

3. Stand Level Allocation (SLA): Based on the predicted properties of the trees and timber the logs from each stand are allocated to primary processors from within the forest.

   a. Biomass: If the mean stem diameter at 6 m above the ground is less than 14 cm overbark then all the material in the stand is designated as biomass (similar to 2a above but at stand level).

   b. Pallet: If the mean stem diameter at 6 m above the ground is between 14 and 18 cm **OR** the average stem straightness is less than 3 **OR** the mean wood stiffness is less than 0.95*8 GPa then the whole stand is cut for pallet wood and biomass as in 2b above.

   c. Sawlogs: If the mean stem diameter at 6 m above the ground is greater than 18 cm **AND** the average stem straightness is greater than or equal to 3 **AND** the mean wood stiffness is greater than or equal to 0.95*8 GPa then the whole stand is cut for sawlogs and biomass as in 2c above. However, the assumption is made in this simulation that all "green" logs transported to Dumfries are suitable for construction grade timber and there is no retransportation of logs from Dumfries to Kirriemuir.

The different allocations are illustrated schematically in *figure 8*.

Scenario: BAU

Scenario: FLA B

Scenario: FLA P

Scenario: FLA S

Scenario: SLA

Figure 8. Allocation of products for the different scenarios.

4.6   Indicator calculation

There were 4 indicators used to test the impact of the different scenarios on sustainability. These were:

1. Gross Value Added (GVA). This is calculated from the costs and the value of products and 0% inflation is assumed. The costs breakdown was taken as follows:

    a. Cost in pounds sterling (£) of growing the stand is given by
        $Cost = 1139 + 119 * Age$

    b. The cost of harvesting is £4/m^3

    c. The cost of forwarding is £5/m^3

    d. The cost of transport is £10/m^3 for all products regardless of distance.

    e. The cost of retransport is £5/m^3

        The values of products were calculated using the following assumptions:

    a. £35/m^3 for "green" sawlogs

    b. £30/m^3 for "red" sawlogs

    c. £25/m^3 for pallet logs

    d. £20/tonne for biomass

2. Transport distance. These were calculated in miles/m^3 and the following distances used in the simulation. This includes empty backhauling, which doubles all distances:

    a. Craik to Eon Lockerbie = 54 miles

    b. Craik to James Jones and Sons Ltd. Lockerbie = 54 miles

    c. Craik to James Jones and Sons Ltd. Dumfries = 63 miles

    d. Craik to James Jones and Sons Ltd. Kirremuir = 135 miles

    e. Dumfries to Kirremuir (retransport) = 231 miles

3. Greenhouse gas emissions. All the stands were assumed to be mounded and drained. All harvesting (thinning and clearfelling) was carried out with a medium harvester (12-20 tonnes) and the forwarding with a medium forwarder (14-15 tonnes). Transport was all by 40 tonne truck. The fuel usage for these operations was taken as:

    a. Mounding: 250 litres/ha

    b. Drainage: 250 litres/ha

    c. Harvesting: 1.55 litres/m^3

    d. Forwarding: 0.9 litres/m^3

    e. Transport: 0.035 litres/m^3/mile

The total fuel usage for a particular scenario was then converted to CO_2 emitted (kg) using the conversion $CO_{2\,emitted} = 2.661 * litres$.

4. Employment. The employment calculated for each scenario used the following figures:

    a. Establishment (0-5 years): 0.0008 people years/ha

    b. Young Stage (5-15 years): 0.0008 people years/ha

    c. Medium Stage (15-50 years): 0.0019 people years/ha

    d. Adult Stage (> 50 years): 0.0004 people years/ha

    e. Harvesting: 0.0004 people years/m^3

    f. Forwarding: 0.0004 people years/m^3

    g. Transport: 0.0002 people years/m^3

The sustainability values for all the indicators followed the ToSIA protocol (Linder et al., 2007). Values are calculated per hectare within the forest and per cubic metre outside the forest. The conversion from hectares to cubic metres is given by the volume of timber produced per hectare from the forest. At the end of the scenario all indicators are summed to give the absolute value and the value per cubic metre.

4.7 Calculation of sustainability Indicators

As discussed earlier the ToSIA tool is currently set up to deal with the wood-chain at a European or national level and not at a regional or individual forest level. Therefore, an Excel$^®$ model was developed with exactly the same structure and methodology as ToSIA in order to calculate the required accumulated indicators. The values of indicators for each process in the chain were identical to those used for the UK values in the European wood-chain. In the forest (M2) all values are calculated per ha and from harvesting to the mill (M3) all values are calculated per m^3. At each process it is necessary to ensure that 100% of material is accounted for both on the input and outputs sides in order to ensure that no leakage occurs.

4.8 Examples of results

The absolute values for each sustainability indicator calculated over the 25 year period (2005-2030) are given in *figures 9* and *10*. They show that for all the alternative scenarios chosen the GVA is reduced comparative to the BAU scenario with the greatest reduction in the FLA B scenario when all the material is treated as biomass. However, GHG production and miles travelled are also reduced in most of the other scenarios except for the FLA S scenario in which they are slightly increased. The impact on employment is much smaller with little difference between the scenarios. Relative values are given in *figure 11*.

It is possible to determine which parts of the process are most responsible for a particular indicator value. This is demonstrated in the pie chart diagrams in *figure 12*. These show that the GVA is shared approximately equally between the growing stage, harvesting, forwarding and transport. In contrast employment is concentrated in the harvesting, forwarding and transport and there is little employment engaged in managing the forest. Not surprisingly transport dominates the production of GHG and miles travelled although there are still sizeable contributions from the mounding, drainage, harvesting and forwarding in the production of GHG.
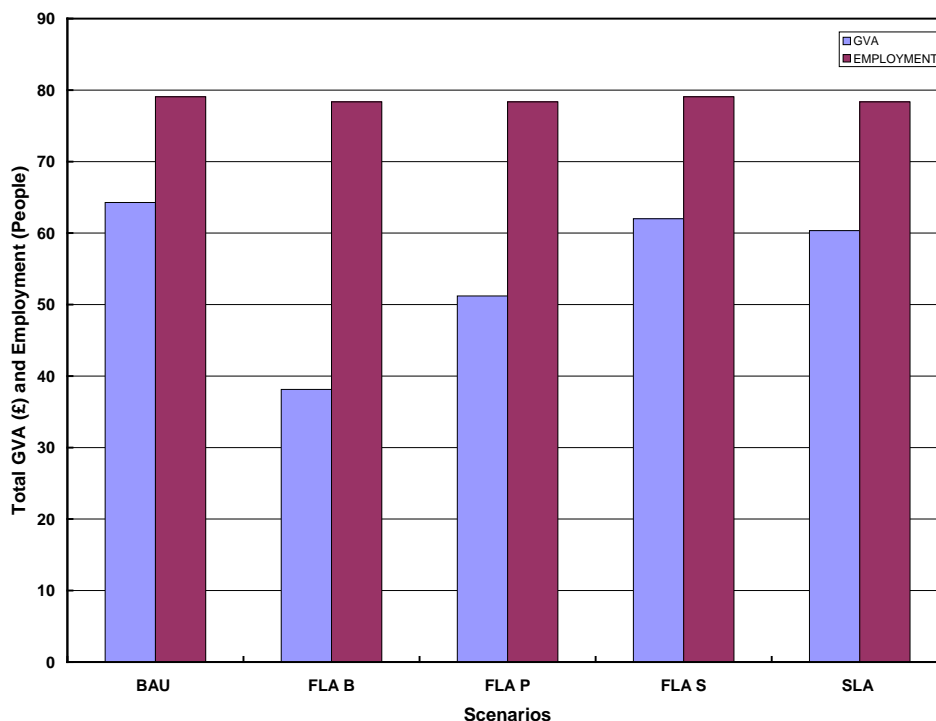

Figure 9: Forecast GVA and employment between 2005 and 2030 associated with Craik Forest for different allocation strategies.
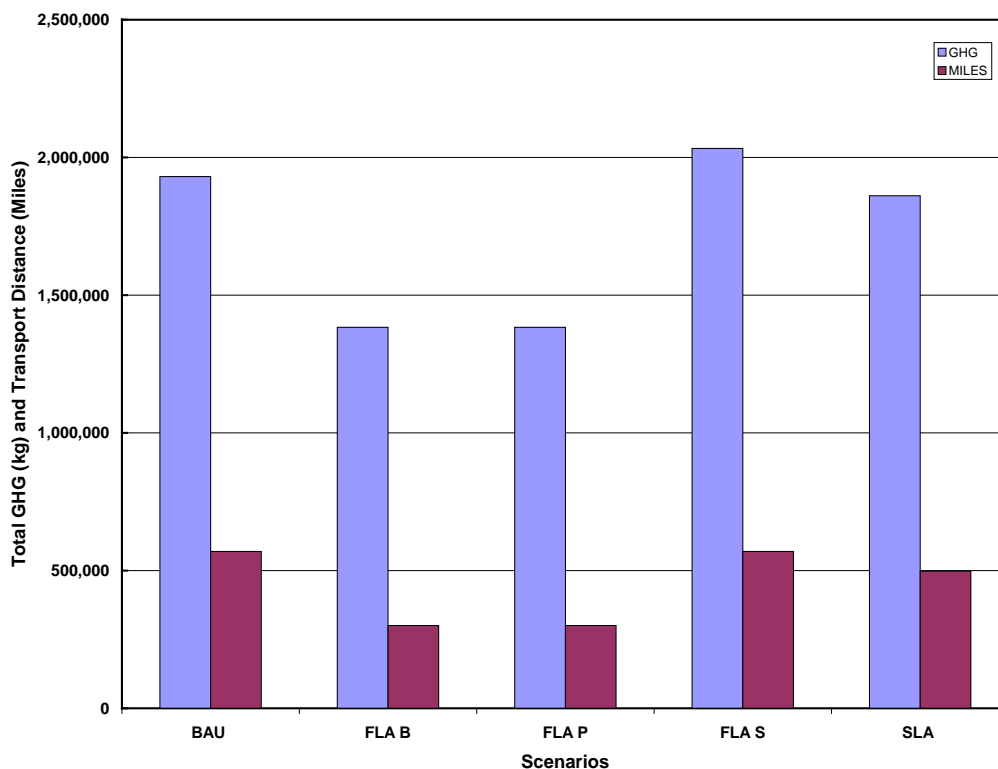
Figure 10: Forecast GHG production and miles travelled between 2005 and 2030 associated with Craik Forest for different allocation strategies

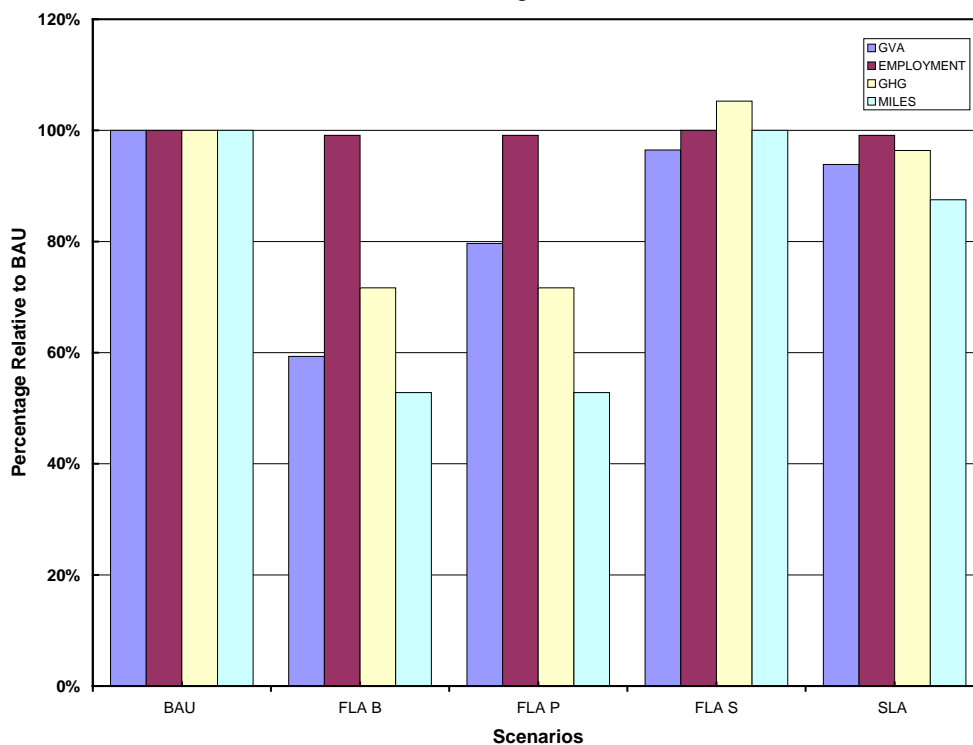Figure 11: Relative values of GVA, employment, GHG production and miles travelled compared to the BAU (Business As Usual) scenario.
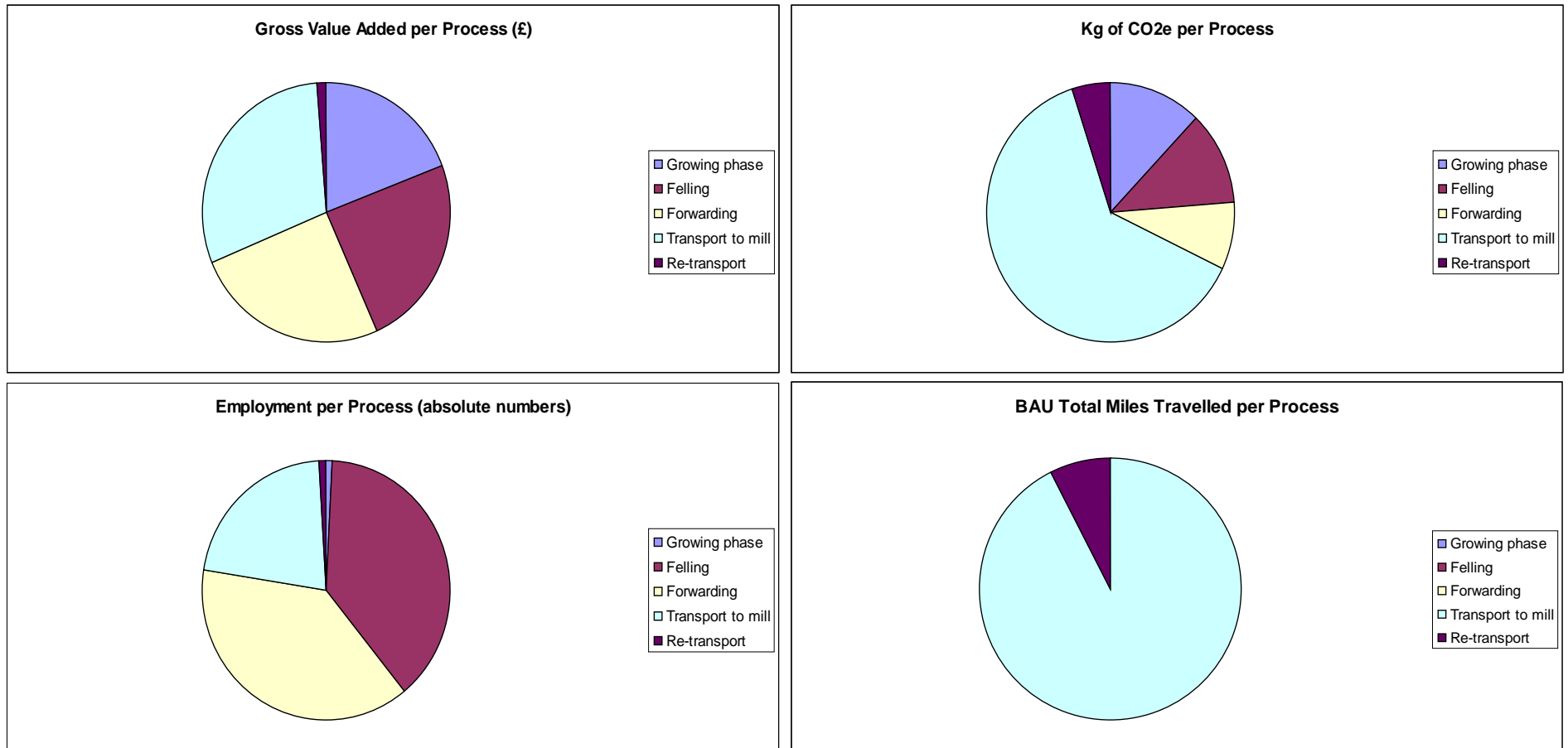
Figure 12: Proportion of contribution to indicators from the different processes within the forest-wood chain in Craik Forest

4.9   Comments on and conclusions from the case

The scenarios illustrated in the examples above are for illustrative purpose only and are simplified relative to actual operations and actual values. However, they demonstrate that it is possible to calculate sustainability indicators of value and importance for the forest based industries for a range of allocation options if the data are available.

Some of the results might seem slightly unexpected but make sense on closer inspection. The reduction in GVA with the SLA scenario is due to the fact that a large number of stands are being designated as pallet only when they would have provided some sawlogs in the BAU scenario. The penalty of having to retransport 20% of logs in the BAU scenario is compensated for by the increased value of the sawlogs that one obtains. It would be desirable to run sensitivity analyses to see what levels should be set for stem straightness and wood stiffness for designating a stand as a sawlog stand in order to determine the optimum levels for maintaining GVA but reducing GHG production and transport mileage.

Further work is now required to refine the allocation models and to make the allocations closer to operational practice and possibilities. In particular we would like to include the following in the next stage of modelling:

1.   Sensitivity analysis needs to be conducted on the existing scenarios to determine the impact of changing the assumptions in the model. These include the values, costs and fuel usage used and the levels set for the determination of stand allocation in the SLA scenario.

2.   The scenarios need to be made more realistic. In particular the SLA scenario needs to cut pallet logs from the stands designated as sawlog stands and not just sawlogs and biomass.

3.   Other scenarios need to be tested. For example:

   a.   Transporting all "red" logs to Lockerbie for pallet wood rather than to Kirriemuir.

   b.   Include a proper costing of the rejection of material at the Dumfries sawmill. Currently the assumption is that 20% of the material is retransported to Kirriemuir but in reality all material would be sawn, kiln dried and then approximately 20% of the sawn material downgraded to economy grade sawn timber.

4.   Conducting a Tree Level Allocation (TLA) in which decisions are made on each tree within a stand as to whether it is suitable for sawlogs or should be used as pallet logs. This is possible because there are models available for predicting the variation in stem form and wood stiffness within a stand (see Lundqvist et al., 2009, Gardiner et al., 2009).

5.   Including M4 (Processing and Manufacturing) processes in the scenarios. The overall costs and value are not fully realised in the current scenarios because much of the allocation at present takes place within the primary processing. Including the costs of processing and the value added following processing would make the scenarios much more realistic. At the end of M4 there are then finished products

that are sent to customers in M5 (Industry to Consumer Interactions) and this would be an ideal point at which to identify the different levels of sustainability indicators for a range of management and allocation scenarios. It is planned to add M4 processes in future work.

6. Run regional (South Scotland) and national (Scotland) level scenarios. Models of volume availability and timber quality have been run for the whole Forestry Commission estate in Scotland and produced in GIS map layers. Together with knowledge of the location of primary processors it would be possible to run, within the GIS, scenarios for the forests in both South Scotland and the whole of Scotland in order to try and identify the best strategies for utilising the Scottish forest resource.

7. Add additional sustainability indicators to the scenarios. The current indicators are only a small number of the possible indicators that could be analysed Rametsteiner et al. (2006).

8. Run Cost/benefit analysis with the results of the scenarios to determine which scenario offers the best balance between different measures of sustainability.

4.10 Widening of the perspective

It needs to be remembered that the work is only a first stage and a number of improvements need to be made before such a system could be developed for operational use and a fully "tailor made" supply chain introduced. Specifically the following areas of development are required:

1. The mapping of wood and tree properties is currently dependent on model predictions. These need to be supplemented and enhanced by measurements either before or during harvesting. This could include satellite and airborne LiDAR, terrestrial laser scanners, acoustic tools and the measurements made by harvesting machines (taper, volume, etc.). By linking model predictions with measurements a more precise description of the properties of the trees and wood within a stand is possible by confining the model predictions by the measured characteristics. Such a technique is known as data assimilation.

2. The importance of tree to tree variability is not fully accounted for in the simulations run. Generally around 50% of all variability in wood properties is due to tree to tree variation. A probabilistic approach that provide users with a measure of the likelihood of material (wood fibres or solid wood) meeting a desired specification would be more useful and a better representation of reality.

3. The material property prediction models are limited in their geographic range and applicability. A fundamental requirement for the wider applicability of the methods outlined in this report is the continued development of models able to predict the key wood and fibre properties for the major European timber species over the range of growing conditions in which they are found.

4. The processes and chains analysed were of necessity simplistic. However, in order to be of practical use the detailed cutting patterns, price variations and costs in real wood-chains will need incorporating. A particular weakness is the absence of

primary processing (M4) in the wood-chain. Currently forest material allocation occurs as a collective exercise involving the dimensions and location of material available within the forest and the demands of the customer for products from the primary processors. Inclusion of M4 processes would allow proper account to be made of the costs of unsuitable material being sent from the forest and processed. Minimising the allocation of unsuitable material from the forest to a processor is where the largest gains can be made in the efficient use of forest raw materials.

5   General conclusions

As world demand for raw material resources increases and pressure develops to manage manufacturing in as sustainable manner as possible it will become increasingly necessary to be "smart" about how we utilise European forests and to measure how sustainably we are managing this resource.

The sustainability of the production and use of products can not be judged from a narrow perspective. Effects on environment, economy and society all along the chain of activities related to the products have to be included in the evaluation. A true analysis of sustainability will thus by nature become quite complex. Therefore, tools and databases designed for this purpose are needed to perform realistic evaluations of sustainability.

The allocation of suitable materials to mills, processes and products is crucial for the sustainability of the forestry wood chains, affecting the economics, the environment and society. If unsuitable material is allocated to a process, this will normally lead to use of more material, energy, etc. than necessary and the quality, product functionality and customer satisfaction may be compromised. Changes in allocation of wood raw materials may thus influence the sustainability all along the chain from the forest to the recycled product.

Sustainability effects from raw material allocation have been illustrated in two case studies, one related to fibre-based products performed by Innventia and one addressing wood-based products performed by Forest Research. These exercises illustrate the complexity involved in this kind of studies. They also showed that methods and models now exist to enable a first attempt at allocation of material from the forest based on material properties and to also calculate the impact of different allocation strategies on key sustainability indicators.

The two cases show that the results change markedly when different perspectives, constrains, etc. are applied. The work also illustrates that it is not possible to give generic answers to material allocation and the ideal management options. Several of the process models in ToSIA have been shown to be too simplistic and would need to be made more realistic to give useable results at the regional or local level. If the work is to be applied, much specific expertise on processes, products, logistics and markets is needed to provide realistic results. In addition more detail is required to define each case, specify interactions and limitations, add detail and implement modifications. More dedicated tools would be useful but ToSIA provides models and data which are an important starting point and serve as a roadmap for the holistic perspective needed in the assessment of sustainability.

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Innventia Database information

Title

Illustration of sustainability effects from allocation - Results from EFORWOOD case studies on corrugated boxes from Västerbotten fibres and sawn products from South Scotland

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Abstract

The allocation of suitable materials to mills, processes and products is crucial for the sustainability of the forestry wood chains. In the report, sustainability effects from raw material allocation are illustrated in two case studies related to: a) fibre-based products, deals with the production, use and recycling of boxes from corrugated materials, performed by Innventia, b) wood-based products, examining the current management plans and potential modifications to the allocation system applied for a forest area, performed by Forest Research, Scotland. The two cases show that the results will change very much when different perspectives, constrains, etc. are applied. It is not possible to give general answers. More dedicated tools would be useful. Models and data from the EFORWOOD project have provided an important starting point and a roadmap for the holistic perspective needed in the assessment of sustainability.

Keywords

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