# Analysing forest sustainability under various climate change scenarios: a case study in northern Scotland

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One of the major challenges for forestry in the 21st century is how to measure and assess forest sustainability. The Northern ToSIA (Tool for Sustainability Impact Assessment) project is focussed on developing tools for assessing the sustainability of forest based activities in rural areas. The Scottish case study, one of four formed within the project, is based on Inshriach forest within the Cairngorms National Park. This case study examined the current forest management strategies in Inshriach as well as their associated forest operations and assessed their impact on various sustainability indictors. The same process was repeated under three scenarios, each addressing potential pressures arising from climate change. The aggregated indicator results from the completed analysis of each scenario were then compared against the baseline. This allowed for a comprehensive review of how the proposed changes in forest management might affect the sustainability of Inshriach forest.

Keywords: sustainability, forest management, social, environmental, economic indicators

## INTRODUCTION

From providing habitat for the endangered red squirrel (*Sciurus vulgaris*) to acting as carbon reservoirs (Broadmeadow and Matthews 2003), UK forestry provides a range of benefits and products. Yet, the forestry-based sector is being asked to meet a rising number of demands. In addition, environmental policy (e.g. renewable energy targets) and increasing use of technologies (e.g. wood fuel boilers) place further pressure on the sector. Adaptation to these drivers often does not include any thorough methods of sustainability impact analysis.

The techniques to monitor processes within the forestry-wood chain (FWC) are constantly being improved to ensure the activities are both socially and environmentally responsible as well as economically viable (Ahmed and Sanchez-Triana 2008). A wide array of assessment methods has been generated to support the measurement of sustainability (e.g. Walter and Stützel 2009, Weaver and Rotmans 2006). However, current tools such as Environmental Impact Assessment (EIA), Life Cycle Analysis (LCA) and carbon foot printing may only partially address the social, economic and environmental aspects of sustainability.

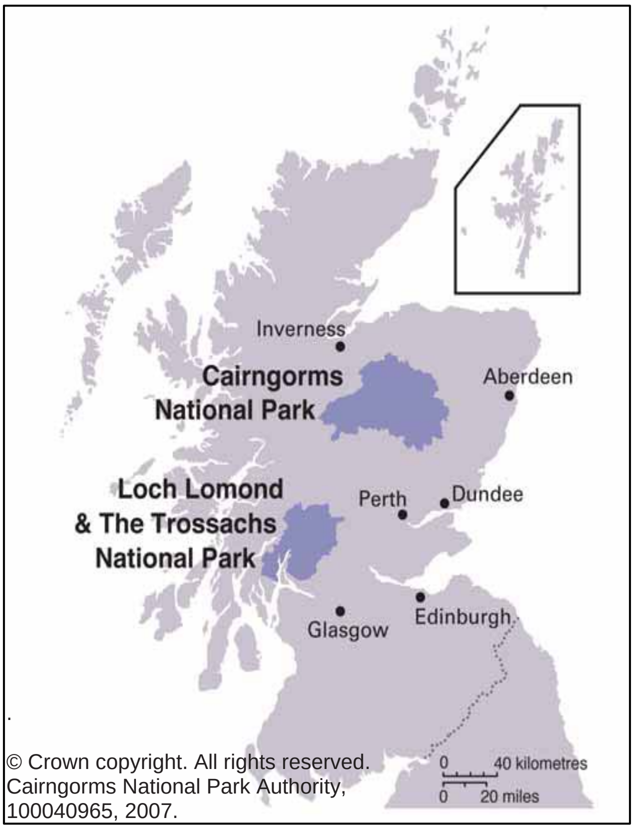
The recently completed EFORWOOD project, funded by the EU Sixth Framework Programme, made great strides in the creation and associated methodology behind a flexible decision support tool called ToSIA (Tool for Sustainability Impact Assessment) (Lindner *et al*. 2009). Päivinen and Lindner (2008) established a concept of how the impacts of various activities on sustainability could be assessed within a FWC. The Northern ToSIA project, a follow-up to Eforwood and which is supported by the EU's Northern Periphery Programme, is focussed on developing tools for assessing the sustainability of forestry-based activities in rural areas of northern Europe. The Scottish case study, one of four formed within the project, is based on Inshriach Forest within the Cairngorms National Park.

The case study examined potential management changes in the forests and demand from industry. The impact of these changes on the sustainability of the FWC was then evaluated. The FWC processes included in our analysis were the establishment and growing phases of the trees followed by harvesting and transport to the sawmill gate.

THE CAIRNGORMS NATIONAL PARK CASE STUDY AREA

The Cairngorms National Park (see Figure 1) is Britain's largest National Park. Within the park area (3 800 km$^2$) lies a range of landscapes and habitat which provide a variety of benefits to the local tourism industry, biodiversity including endangered wildlife, and local and regional timber enterprises (CNPA 2007).

FIGURE 1 *The extent of the Cairngorms National Park in northern Scotland.*




The Park has a commitment to investing in its sustainable management. The Cairngorms Forest and Woodland Framework sets out strategic objectives and local priorities which mitigate against climate change, develop a sustainable timber resource, aid forestry business development, foster community development, promote access and health, improve environmental quality and benefit woodland biodiversity (CNPA 2008: 8).

**Inshriach forest**

The Northern ToSIA Scottish case study focuses on Inshriach Forest within the Cairngorms National Park. Inshriach is located on public land managed by the Forestry Commission, and is mainly comprised of Scots pine (*Pinus sylvestris*) and other conifers. Key policies and strategies for the Inshriach Forest Plan include the protection and improvement of biodiversity interests whilst balancing the needs for recreation and timber production to create a diverse, high quality forest (Forestry Commission Scotland 2008: 4).

The area of Inshriach forest is 3 689 ha, and is mainly comprised of even-aged stands with a management history of commercial clear felling. More recently, however, the emphasis has been on restoring areas of native pinewoods through the removal of exotic conifers and adopting more continuous cover silvicultural management. There is also considerable interest in the area for recreational purposes, although timber production will always remain one of the primary objectives. In addition, this forest has high numbers of endangered Red squirrel and Capercaillie (*Tetrao urogallus*) (Forestry Commission Scotland 2008). The total harvested timber volume from the forest in 2008 was 10 832 m$^3$.

FOREST MANAGEMENT ALTERNATIVES

There is a wide variety of choices that can be made in forest management including tree spacing, species composition and level of intensive mechanised operations used. To help monitor and evaluate the impacts of management decisions, a common classification was developed, which is based on the forest objectives and applied processes (Duncker *et al*. 2007).

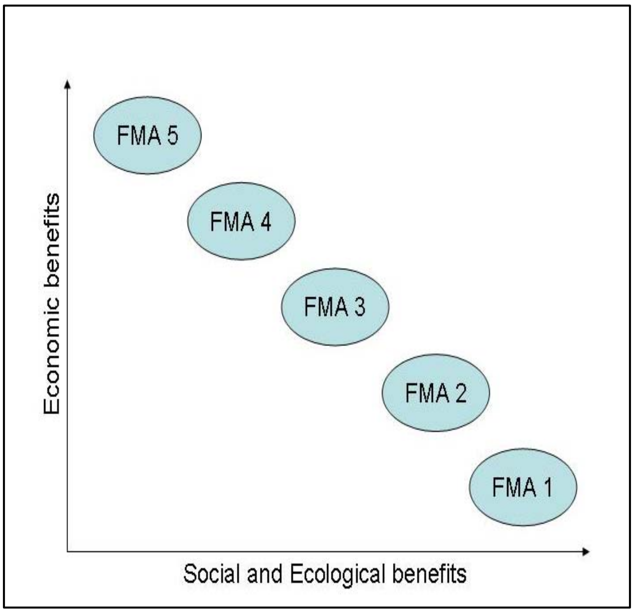
The purpose of the classification into forest management alternatives (FMAs) is to provide a multi-level approach which places all management operations and objectives within five main classes. These classes are placed along a gradient of management intensity:

- FMA 1 is a forest nature reserve
- FMA 2 is continuous cover forestry
- FMA 3 is combined objective forestry
- FMA 4 is intensive even-aged forestry
- FMA 5 is wood biomass production.

The more intense the management regime, the more the economic gain, but at the expense of social and ecological services (see Figure 2). The main benefit of adhering to the FMA structure is that it presents the possibility to classify and compare any forest area regardless of location.

For the purposes of this case study, a range of management processes were assumed for each FMA (see Table 1).

FIGURE 2 *A diagram of Forest Management Alternatives (FMAs) along a gradient of management intensity.*




### Forest management alternative 1

The Forest Nature Reserve approach (FMA 1) occurs on sites where there is little forest management intervention. For this case study, however, it was assumed that there was no management such as stand thinning nor was there any timber production. FMA 1 completely relies on natural regeneration which is likely to be associated with higher biodiversity and recreational values.

### Forest management alternative 2

The Continuous Cover Forestry (CCF) approach (FMA 2) occurs on sites with suitable soils and low risk from wind. It was assumed that only 40% of each hectare is planted while leaving the remainder to be established through natural regeneration. The stand rotations are, in this case study, 80-90 years with 5 thinnings and a partial (selective log) felling. Tree stems in this FMA are more likely to reach a large diameter at breast height (dbh) and possibly a high timber quality due to these long growth periods and multiple thinnings. Other priorities for FMA 2 include providing areas for recreational activities, habitat for wildlife, carbon uptake and landscape connectivity.

### Forest management alternative 3

The Combined Objective approach (FMA 3) occurs on sites which are less sheltered from wind and therefore needs to be thinned less frequently than FMA 2. Since timber production is one of the key purposes, natural regeneration is no longer used but social and ecological needs are still taken into consideration during forest management operations. Such sites rely on intensive forest establishment and maintenance practices such as mounding and drainage and may be planted with genetically improved material. The stand rotations are, in this case study, 75 years (for conifers) and 50 years (for broadleaves) with 3 thinnings and a final clear felling.

### Forest management alternative 4

The Intensive Even-aged approach (FMA 4) occurs on sites where timber production is the major objective though there may be associated social and ecological benefits. Forest growth periods are decreased but are still long enough to produce large quantities of timber, some of which may be of high quality. As in FMA 3, intensive forest establishment and maintenance practices are used and sites are planted with genetically improved material. The stand rotations are, in this case study, 60-75 years with 2 thinnings and a final clear felling.

**Forest management alternative 5**

The wood biomass production (FMA 5) occurs on sites where timber production for the woodfuel industry is the primary aim, but timber quality is not. For this case study, a broadleaf mixture of Sycamore, Ash and Birch was planted which did not require intensive establishment and maintenance practices. There is only one pre-commercial thinning and a final clearfell at 40 years where the whole stem (including harvest residues) are chipped and transported in a container truck.

SCENARIOS

The impact of forest management decisions on sustainability indicators was measured in four separate scenarios. The scenarios were not modeled into the future but instead directly replaced the Baseline Business as Usual regime. Each scenario was developed under the guidance of forest planners, incorporated the different primary objectives of the area, and was designed to reflect actual or potential changes to Inshriach's forest design plan. The proportion of FMAs fluctuated between scenarios to represent these changes (see Table 2). The four scenarios are:

- Baseline: Business as Usual, *i.e.* the current management system.
- Scenario 1: Due to climate change, there is an increasing intensity of biotic threats (e.g. Red Band Needle Blight *Dothistroma septosporum*) which primarily attacks pines. In addition, there is a corporate target that forested land be restored to broadleaves where possible. The combined effect leads to the widespread conversion of Scots pine to another suitable species such as Birch (*Betula* spp.).
- Scenario 2: There is a general desire to restore intensive forested areas to a more natural system. The objective is to increase both biodiversity and the stands' attractiveness for tourism. Areas designated for intensive even-aged forestry decrease leading to a rise in the area managed using continuous cover forestry.
- Scenario 3: Responding to climate change mitigation policies, woodfuel industries increase their demand for wood chips and pellets. Areas of intensive even-aged forestry and wood biomass production increase dramatically.

INDICATORS AND ASSUMPTIONS

The impact of these scenarios was measured against various sustainability indicators. The sustainability values for all the indicators followed the ToSIA protocol developed under the EFORWOOD project (Linder et al., 2007). Values are calculated per hectare within the forest during the growth phase, and per cubic metre once the trees are harvested and transported to the sawmill. The assumed management regime within each FMA allows for a prediction of volume of timber produced per hectare. Indicators were measured for every process from establishment through the growing period, to harvesting and transport to the sawmill gate. At the end of each scenario all indicators and their associated values were aggregated to provide the absolute value per hectare and the total value for Inshriach forest. All costs and values were measured in pounds sterling (£) for a reference year of 2005.

**Gross Value Added**

Gross Value Added (GVA) is calculated from the costs and the value of products and 0% inflation is assumed.

*Log diameter and quality designations*

There are many methods of material allocation (e.g. Lundqvist *et al.* 2009) and quality assessment (Macdonald *et al.,* 2009). For the purposes of this case study, log quality to determine Green sawlogs (high grade timber) and Red sawlogs (lower grade timber) was based on the Forestry Commission classification system (Anonymous, 1993) and expert knowledge of actual timber production in Inshriach. Other log designations were based on log top diameters:

- Sawlog: Top diameter over bark normally greater than 18cm. The sawlog material is further designated into Green and Red logs.
- Pallet: Top diameters over bark normally between 14 and 18cm.
- Pulp: Log top diameter normally less than 14cm.
- Biomass: For the biomass scenario, the entire stem (including harvest residues) is used and processed as chips.

*Timber value*

The stumpage values were calculated using the following assumptions based on actual prices paid from a major UK sawmilling company (Mochan, S. *pers. comm.*):

- £37/$m^3$ for Green sawlogs
- £34/$m^3$ for Red sawlogs
- £27/$m^3$ for pallet logs
- £22/tonne for pulp
- £22/tonne for biomass

*Costs and value added*

The costs breakdown was taken as follows:

- Cost of growing the stand is given by *Cost* = ∑operational costs + (94**Age*) where operational costs were specific to each FMA (see Table 1) and £94 is an aggregation of fixed costs that occur every year during stand growth.
- The value added of harvesting is £4/$m^3$
- The value added of forwarding is £5/$m^3$
- The value added of chipping is £5/$m^3$
- The value added of transport is £10/$m^3$ for all products regardless of distance.

**Greenhouse gas emission**

Each FMA has a different mixture of management techniques used (see Table 1). The more intensive the management (particularly with regards to machinery used), the more fuel is consumed which consequently leads to higher greenhouse gas emissions. The emissions considered were only from direct sources and not indirect sources from, for example, the emissions created during the manufacturing of the machinery itself. The fuel usage for a selection of operations is as follows:

- Mounding: 250 litres/ha
- Drainage (maintenance): 250 litres/ha
- Harvesting (clearfell): 1.2 litres/$m^3$
- Forwarding: 0.9 litres/$m^3$
- Transport (of logs): 0.035 litres/$m^3$/mile

The total fuel consumption for a given scenario was then converted to $CO_2$ emitted (kg) using the conversion (DEFRA, 2009) $CO_2(emitted) = 2.661 * litres$.

*Transport distance*

Transport for sawlogs, pallet and pulp was all carried out by 44-tonne truck (25.9-tonne timber capacity). Transport for biomass was carried out by container truck (assumed 20.83-tonne capacity). Conversion from $m^3$ to tonne was assumed to be a one-to-one ratio. The transport (miles/$m^3$) was calculated by using the following equation: total trips needed*total miles to sawmill. The trucks were assumed to have a 40mph average travelling speed with two hours added per trip to account for time spent loading and unloading. The transport includes empty backhauling, which effectively doubled all distances:

- Inshriach to Gordon's sawmill in Nairn (pallet) = 88 miles
- Inshriach to BSW sawmill in Boat of Garten (red sawlogs) = 26 miles
- Inshriach to BSW sawmill in Fort William (green sawlogs) = 136 miles
- Inshriach to Norboard in Inverness (pulp) = 80 miles
- Inshriach to Balcas biomass plant in Invergordon (wood chips) = 110 miles

**Carbon stock**

The carbon stocks for each FMA were calculated by extrapolating existing estimations from Morrison *et al.* (2009: Table 3.1). The figures are based on whole tree carbon stocks.

- FMA 1 457 $tCO_2eq\ ha^{-1}$
- FMA 2 286 $tCO_2eq\ ha^{-1}$
- FMA 3 257 $tCO_2eq\ ha^{-1}$
- FMA 4 229 $tCO_2eq\ ha^{-1}$
- FMA 5 86 $tCO_2eq\ ha^{-1}$

**Employment**

Employment figures were measured in hours but converted to Full-Time Equivalent (FTE) using a conversion rate of 1 584 hours per working year (Spencer, S., *pers. comm.*). The employment from direct forest operations was calculated for each scenario using figures derived from expert opinion and actual experience. Furthermore, a fixed amount of labour was assumed per hectare for indirect forest operations such as administration, management and research.

**Recreation**

Recreation scores were derived through a Delphi survey method involving experts in landscape preference research who provided scores for the recreational value of 180 forest stand types in upland areas of Great Britain (Edwards *et al*. 2009). It was inferred that recreational value and associated aesthetic impressions are to some extent dependent upon silvicultural attributes, in particular stand structure, age class and tree species composition (Edwards. *et al*. 2009).

For each FMA, the forest stands were divided into four phases of development: establishment (0-5 years), young (5-15 years), medium (15-50 years), and adult (>50 years) (Duncker *et al*., 2007). The resulting recreation scores (on a relative scale of 1 – 10) were then attributed to each phase in each FMA.

**Forest biodiversity**

Forest biodiversity scores were derived based on expert opinion and analysis of various biodiversity sub-indicators including vertical and horizontal structure, associated habitats, dead wood, ground flora, faunal diversity, tree and shrub composition, epiphytes, naturalness and continuity (Smith, M. and Mason, B. *pers. comm.*). The forest stands within Inshriach were divided into four phases of development (see Recreation indicator above), and the biodiversity scores (on a relative scale of 1 – 10) were attributed to each phase in each FMA.

RESULTS

The case study generated a large amount of results which were analyzed to determine the impacts each scenario had on the sustainability indicators.

In Figure 3 the relative values of all the calculated indicators are shown against the baseline (business as usual). Displaying the results in this way allows for a comparative analysis of the scenarios.

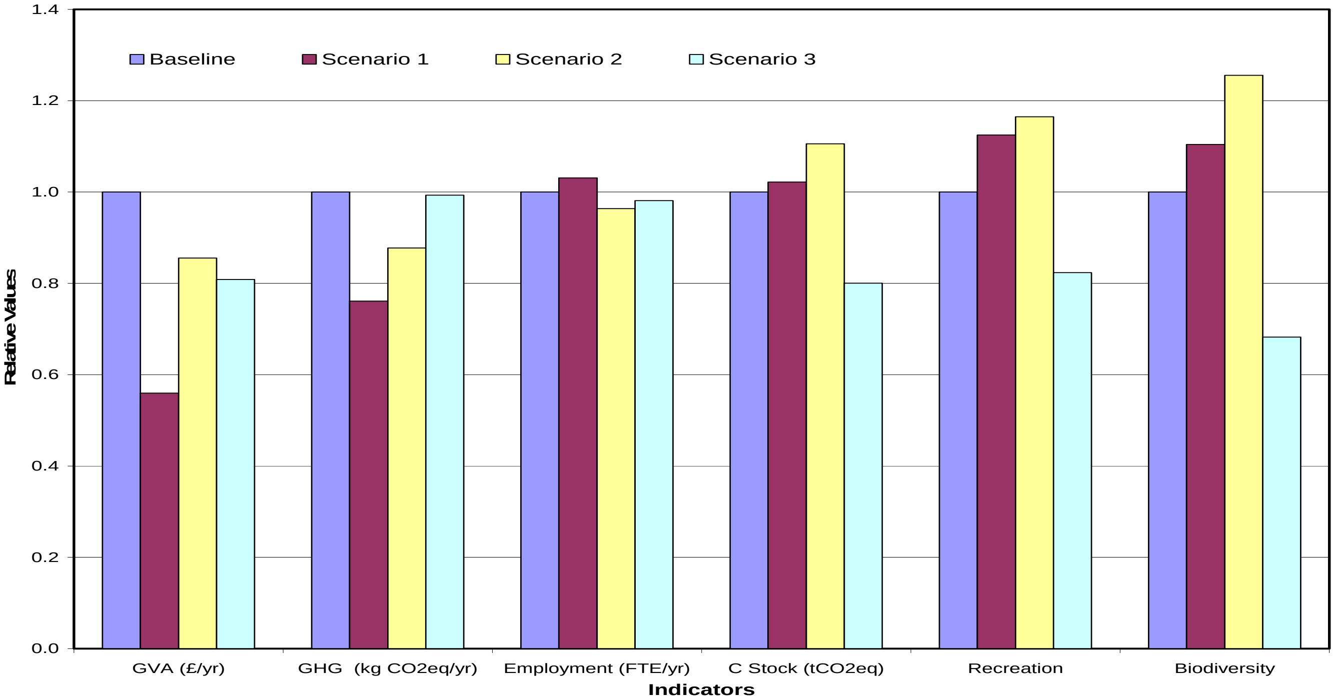
Choice of scenario can have a big impact on the sustainable indicator results. In particular, GVA was greatly affected in Scenario 1 with an approximate 50% reduction in value when compared to the baseline. This is mainly attributed to the decrease in intensely forested land and the increase in planting Birch (*Betula* spp.).

Greenhouse gas emissions are also lowest in Scenario 1 as planting broadleaves (non-intensive forestry) requires very few machine-based operations during establishment, such as mounding and drainage, thus producing less $CO_2$ emitted (kg). Scenarios 2 and 3 both primarily plant conifers which do require intensive establishment, however, Scenario 3 focuses far more on intensive wood production as well which led to further greenhouse gas emissions.

Employment does remain fairly constant throughout the scenarios but does not include additional employment outside the wood chain such as tourism. However, even a small variation in assumptions such as rotation length, survival of seedlings, and rate of natural regeneration may affect employment figures, and this will be assessed in future refinements of the data.

Carbon stock, recreation and biodiversity all show the same trend when compared to the baseline scenario. Scenario 2 demonstrated the highest potential for increasing the carbon stock,

FIGURE 3 *Relative values of key indicators for 3 scenarios in comparison to the Baseline (current management).*




recreation value, and biodiversity value. This is due to the decrease in short-rotation intensive forestry and the significant increase in long-rotation continuous cover forestry where there is no clear felling, only tree group selection (0.1–0.4 hectare). The characteristics of minimal disturbance from heavy machinery and mixed-age stands both contribute to a forests' capacity to sequester carbon, provide habitat for various wildlife, and create a visually pleasing environment for recreational activities.

It is also possible to assess the results in greater detail, for example, at a hectare level instead of forest stand level. In Figure 4, Figure 5, and Figure 6 the accumulated values of GVA, greenhouse gas emissions and employment are shown as the proportion contributed from each stage of the wood chain for FMA 4 (baseline scenario). GVA and employment are relatively evenly distributed between operations although clearly the time scales involved vary widely. However, transport dominates greenhouse gas emissions contributing over 50% of the total for all operations to the mill.

FIGURE 4 *GVA values by process for Baseline FMA 4.*

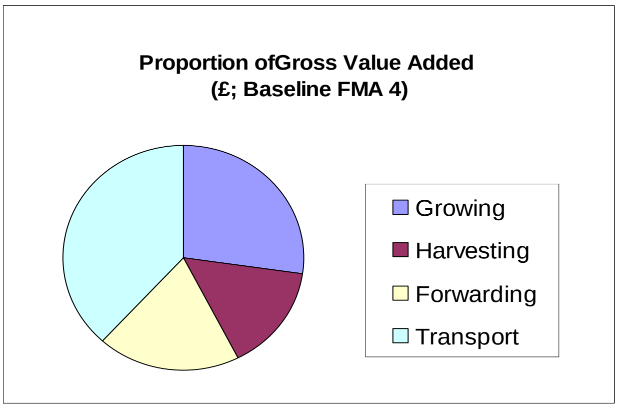



FIGURE 5 *GHG values by process for Baseline FMA 4.*

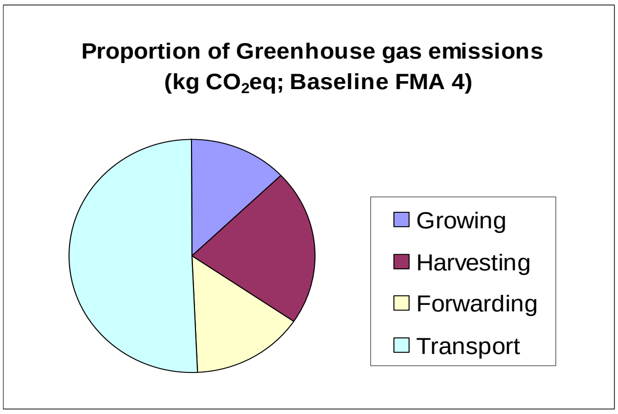
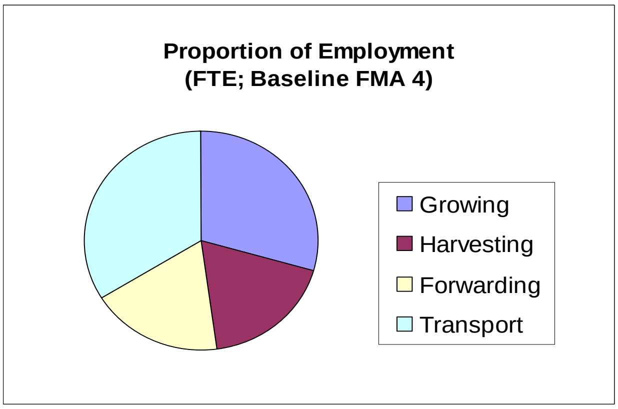


FIGURE 6 *Employment values by process for Baseline FMA 4.*




DISCUSSION

The results illustrate the ToSIA methodology and its use to evaluate different forest management scenarios against a number of key indicators. Overall, Scenario 2 seems to offer the best alternative with increased carbon stocks, biodiversity and recreation values and reduced greenhouse gas emissions but with little impact on employment and only a relatively slight reduction in GVA (26%).

However, the analysis can only be as good as the data available. Every attempt was made to collect accurate and realistic data to support the various indicators used. Sometimes data was not readily available or, on occasion, did not even exist in the format required. Expert opinion and knowledge became an invaluable resource during this case study but there still remains a need for data refinement to provide more rigorous and defendable results.

A key driver in ToSIA is the volume of timber generated and its division into wood products. The allocation of timber into sawlog, pallet or pulp products is a critical step in assessing the value of the forest stand. At the time of this case study, a Scots pine allocation model was still in its final stages of development and was not able to be utilised. Therefore, the allocation figures used in this case study were derived from data from harvested material from Inshriach forest.

The results to do not detail jobs created from road or forest track construction. Additional data acquisition would be required to complete this area of research. Furthermore, the results do not specify possible jobs created from associated forest industries (e.g.—eco-tourism) as this sector is considered to be outside the forest wood chain for our study.

The recreation indicator is currently not spatially explicit, and would be improved through further work using view shed analysis weight the contribution of each stand to the overall recreational value of the forest by its visibility or accessibility to the public. Other design-related features of the forest landscape could be incorporated into the analysis through participatory modelling approaches. Similar landscape-level refinements to the approach may be possible with other indicators including biodiversity.

CONCLUSIONS

This case study was an illustration of how ToSIA principles may be applied at forest stand level. A major advantage of the ToSIA methodology is that it allows the user to analyze not only current sustainability impacts but also impacts from potential future scenarios as well. Such analysis allows managers and policy makers to evaluate the advantages and disadvantages of different management options and to compare this against the planned objectives for a forest. This information can be valuable in planning and in consultation with stakeholders in order to aid decision making and to ensure local engagement with management plans.

The scenarios detailed in the examples above are for illustrative purpose only although effort was made to reflect actual operations and values. Considerations must be given to the assumptions made and the possible inaccuracies due to unavailability of data. However, the scenarios demonstrate that it is possible to calculate sustainability indicators of value and importance for the forest based industries.

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Research. Thank you as well to Steve Smith and Peter Walling in Inverness Forest District who were a major foundational support throughout this case study.

TABLE 1. *A list of the management processes used in Inshriach forest for each forest management alternative (FMA). Some proportions changed between scenarios. FMA 1 is a Forest nature reserve, FMA 2 is Continuous cover forestry, FMA 3 is Combined objective forestry, FMA 4 is Intensive even-aged forestry, and FMA 5 is Wood biomass production forestry.*

| Management operations | FMA 1 Proportion/ha | FMA 2 Proportion/ha | FMA 3 Proportion/ha | FMA 4 Proportion/ha | FMA 5 Proportion/ha |
|---|---|---|---|---|---|
| Scots pine (SP) | Unmanaged nature reserve | | 95% | 95% | |
| Broadleaves containerised | | 40% | 5% | 5% | 100% |
| Replace SP failures | | | 15% | 20% | |
| Fencing to protect against deer | | | 100% (of FMA site) | 100% (of FMA site) | 100% (of FMA site) |
| Electrodyn | | | 100% | 100% | 25% |
| Top up spray | | | 100% | 100% | 25% |
| Hand weed labour | | | 100% | | |
| Pesticide spot weed | | | 100% | 100% | 100% |
| Excavator ground preparation | | | 100% | 100% | |
| Drains maintenance | | | 25% | 25% | |
| Respacing - chainsaw | | 10% | | | |
| Cleaning | | 20% | 20% | | |
| Thinning - medium harvester | | 80% | 85% | 100% | 100% |
| Thinning - chainsaw | | 20% | 15% | | |
| Clearcut - medium harvester | | | 95% | 100% | |
| Clearcut - biomass harvester | | | | | 100% |
| Selective logging - medium harvester | | 40% | | | |
| Selective logging - chainsaw | | 60% | 5% | | |
| Medium forwarder | | 60% | 95% | 100% | 100% |
| Cable crane extraction | | | | | |
| Large skidder | | 40% | 5% | | |
| Chipping | | | | | 100% |
| Transport with 44-tonne truck | | 100% | 100% | 100% | |
| Transport by truck with container | | | | | 100% |

TABLE 2 *The proportions of FMAs vary between scenarios. Ten percent of Inshriach is open space (e.g. unsuitable land for forestry) and this ratio was kept constant throughout the scenarios.*

| | Baseline (% forest cover and hectares) | | Scenario 1 (% forest cover and hectares) | | Scenario 2 (% forest cover and hectares) | | Scenario 3 (% forest cover and hectares) | |
|---|---|---|---|---|---|---|---|---|
| FMA 1 | 3% | 111 | 5% | 184 | 10% | 368 | 3% | 111 |
| FMA 2 | 44% | 1621 | 30% | 1105 | 55% | 2026 | 5% | 184 |
| FMA 3 | 0% | 0 | 30% | 1105 | 10% | 368 | 12% | 442 |
| FMA 4 | 43% | 1584 | 25% | 921 | 15% | 553 | 50% | 1842 |
| FMA 5 | 0% | 0 | 0% | 0 | 0% | 0 | 20% | 737 |

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