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> The CO_2 Effects of the Swiss Forestry and Timber Industry

Scenarios of future potential for climate-change mitigation

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39 | 07

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Published by the Federal Office for the Environment FOEN
Bern, 2007

Impressum

Issued by
Federal Office for the Environment (FOEN)
FOEN is an office of the Federal Department of Environment, Transport, Energy and Communications (DETEC).

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Suggested form of citation
Taverna R., Hofer P., Werner F., Kaufmann E., Thürig E. 2007: The CO_2 Effects of the Swiss Forestry and Timber Industry. Scenarios of future potential for climate-change mitigation. Environmental studies no. 0739. Federal Office for the Environment, Bern. 102 pp.

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Umdasch Prize
This publication is based on a study which was awarded the prestigious Josef Umdasch research prize for outstanding achievements in the field of forestry and wood science on 17 November 2006 in Vienna.

Orders
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Publications
CH-3003 Bern
Fax +41 (0)31 324 02 16
docu@bafu.admin.ch
www.environment-switzerland.ch/uw-0739-e
Order number and price:
UW-0739-E / CHF 20.– (incl. VAT)
This publication is also available in German (UW-0739-D).

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> Abstracts

The Swiss forestry and timber sector contributes to the reduction of the greenhouse gas effect. This is achieved through the absorption of CO_2 in the forest and through the use of wood in wood products and as an energy source. Model simulations over 100 years show that, depending on the way they are managed, forests absorb (=CO_2 sink) or emit (=CO_2 source) highly varying volumes of CO_2. The harvested wood can also be used for very different purposes. The effects of different wood uses can be demonstrated using simulations of wood flows and wood stocks. Climate-policy-optimized recommendations for action in the forestry and timber sector can be developed on the basis of such models. The following recommendations are made in this study:

1. the maximum possible increment that is also sustainable should be generated in the forest;
2. this increment should be exploited through wood harvesting;
3. the harvested wood should be processed in accordance with the principle of cascade use;
4. waste wood that is not suitable for further use should be used to generate energy.

Keywords:
Forestry sector, timber sector, CO_2 emissions, wood products, models, ecobalances

Die Schweizer Wald- und Holzwirtschaft trägt zur Minderung des Treibhausgaseffektes bei. Dies geschieht durch die Aufnahme von CO_2 im Wald oder durch die Verwendung von Holz für Produkte und als Energieträger. Modellsimulationen über 100 Jahre zeigen, dass Wälder je nach Bewirtschaftung sehr unterschiedliche Mengen an CO_2 aufnehmen (= CO_2-Senke) oder abgeben (= CO_2-Quelle). Die geernteten Holzmengen können dabei für ganz unterschiedliche Zwecke eingesetzt werden. Die Auswirkungen verschiedener Holzverwendungen lassen sich mittels Simulationen der Holzflüsse, der Substitutionseffekte und der Holzlager aufzeigen. Mittels solcher Modelle können klimapolitisch optimierte Handlungsempfehlungen in der Wald- und Holzwirtschaft erarbeitet werden. Aus der vorliegenden Studie ergeben sich folgende Empfehlungen:

1. Erzeugung eines möglichst grossen aber nachhaltigen Zuwachses im Wald.
2. Abschöpfung dieses Zuwachses durch Holzernte.
3. Verarbeitung des geernteten Holzes in einer Kaskadennutzung.
4. Energetische Endnutzung des nicht mehr weiter verwendbaren Abfall- und Altholzes.

Stichwörter:
Waldwirtschaft, Holzwirtschaft, CO_2-Emissionen, Holzprodukte, Modelle, Ökobilanzen

L'économie forestière et l'industrie du bois suisses contribuent à réduire l'impact des gaz à effet de serre. Cet effet est obtenu grâce à l'absorption de CO_2 par la forêt ainsi que grâce à l'utilisation de bois comme matériau de construction ou comme agent énergétique. Les modèles de simulation sur 100 ans montrent que les forêts absorbent ou dégagent des quantités très variables de CO_2 en fonction du mode d'exploitation (elles sont soit des puits soit des sources de CO_2). Les quantités de bois récolté peuvent être utilisées à des fins très diverses. Des simulations tenant compte des flux de bois, des effets de substitution et des stocks de bois montrent quelles sont les conséquences des différentes utilisations. Ces modèles permettent d'élaborer des recommandations pour l'économie forestière et l'industrie du bois afin qu'elles optimisent leurs activités du point de vue de la politique climatique. Sur la base de la présente étude, quatre recommandations sont formulées :

1. Produire un accroissement de la forêt qui soit le plus important possible tout en restant durable.
2. Exploiter cet accroissement en récoltant le bois.
3. Transformer le bois récolté dans le cadre d'une utilisation en cascade.
4. Utiliser comme agent énergétique le bois usagé et les déchets de bois qui ne servent plus à d'autres fins.

Mots-clés :
Économie forestière, industrie du bois, émissions de CO_2, produits ligneux, modèles, écobilans

L'economia forestale e del legno contribuiscono a ridurre l'effetto serra. Ciò avviene con l'assorbimento di CO_2 da parte delle foreste oppure in seguito all'impiego del legno nella fabbricazione di prodotti e come vettore energetico. Modelli di simulazione sull'arco di 100 anni mostrano che, a seconda del tipo di gestione, i boschi assorbono (pozzi di CO_2) o rilasciano (fonte di CO_2) quantità variabili di anidride carbonica. Le quantità di legno raccolte in tal ambito possono essere utilizzate per molti scopi. Gli effetti delle diverse forme di utilizzazione del legno possono essere illustrati mediante la simulazione dei flussi di legno, degli effetti sostitutivi e dei depositi di legname. I modelli permettono di formulare delle raccomandazioni concrete per l'economia forestale e del legno ottimizzate sotto il profilo della politica climatica. Il presente studio raccomanda quanto segue:

1. promozione di un incremento legnoso possibilmente elevato ma anche sostenibile;
2. sfruttamento di tale incremento mediante raccolta del legno;
3. lavorazione del legno raccolto nell'ambito di un utilizzo a cascata;
4. impiego finale a scopi energetici sia dei rifiuti legnosi che del legno usato.

Parole chiave:
Economia forestale, economia del legno, emissioni di CO_2, prodotti di legno, modelli, ecobilanci

> Foreword

The forest has attracted considerable attention in connection with the greenhouse effect in recent years, particularly in relation to its function as a CO_2 sink. Because of this, it featured prominently in the international negotiations surrounding the Kyoto Protocol. Its significance in the climate debate has also been recognized at national level in Switzerland. The National Council and Council of States, i.e. the two chambers of the Swiss parliament, have decided that Switzerland will account for the forest CO_2 sink in the fulfilment of its obligations under the Kyoto Protocol. However, the forest's role in climate protection is not limited to its function as a carbon sink. Its importance as a supplier of the CO_2-neutral raw material wood is at least as significant in this regard. This factor has been largely ignored in the public debate, however awareness of it is now increasing. The aim of this publication is to elevate the importance of the use of wood to its rightful position in relation to climate protection. To this end, it quantifies the CO_2 effects of wood use and compares them with the sink effect of the forest. I clearly interpreted the findings of the study as an incentive for the development of an optimized and sustainable Swiss forestry and timber industry.

The effect of wood harvesting on the CO_2 sink effect and CO_2 emissions is demonstrated using different scenarios. A "stock reduction" scenario was not analysed as this would go against the parliamentary decision to account for CO_2 sinks. The starting point of the study was provided by the wood harvesting figures prior to Storm Lothar, thus parts of the selected scenarios have already become reality today. The scenarios work on the assumption that the situation in relation to foreign trade in wood and wood products will remain unchanged. The effects of a change of this kind are too complex and include the practically incalculable changes in the harvesting of forests in developing countries and the global development of the timber market.

The study's findings show that, from the perspective of CO_2 policy, it would be advisable to increase wood harvesting in the forest and optimize it in the long term. CO_2 emissions from fossil fuels can be avoided through the manufacture of products from wood and its combustion. If wood is harvested sustainably, there is no time limit on this effect. The result of the scenarios also shows that modest sink formation in the Swiss forest is possible for a certain period. However, a one-sided emphasis on the sink effect would lead to a dead end because trees do not grow forever and an over-aged forest eventually becomes a source of carbon. The finding that a moderate increase in growing stock in the forest would also be accompanied by a slight increase in wood increment is somewhat surprising. Thus sink formation and wood harvesting are not entirely incompatible. As opposed to this, however, a reduction in growing stock in the forest would tend to reduce the productivity of the forest and, hence also, the supply of wood available for future generations.

Given that it presents the CO_2 effects of the entire wood chain from the forest to the end use of wood, this study is technically complex. Thus, this publication is primarily aimed at specialists in this area. Nonetheless, accessible responses to frequently asked questions can also be found in the summary, the conclusion and the FAQs.

The publication is intended to make a fundamental contribution to sustainable resource use. We also hope that through this research we can contribute to ensuring that the effects of sustainable wood use are given the consideration they deserve in the international climate negotiations for the post-2012 period.

Bruno Oberle
Director
Federal Office for the Environment (FOEN)

> Summary

Question addressed

The forestry and timber industry contributes to the reduction of the greenhouse effect in different ways, for example through the sink function of the forest, the sequestration of carbon in wood products and through the use of wood as a substitute for fossil raw materials. This report explores the question as to how Switzerland's contribution to the improvement of the CO_2 balance can be optimized through forest management and the use of wood.

Key studies

The study uses models and scenarios to develop a range of options for a future CO_2-optimized policy in the areas of forest harvesting, wood processing and wood use. The effects of different forest management and wood use strategies on CO_2 sinks and CO_2 emissions are examined. Different approaches to forest management produce varying volumes of wood which can be used in either the construction or energy sector. The scenarios presented in this publication differ, first, in respect of the volumes of wood harvested in the forest and, second, in terms of the way the wood is used. The topics explored include the forest, logged wood, wood used in construction and the reduction of CO_2 emissions through the use of wood products.

Modelling elements

The topic was divided into four areas which were analysed with the help of different modelling approaches. The four sub-models work independently.

1. The modelling of the forest and forest management were carried out with the help of data from the Swiss National Forest Inventory (NFI). Different levels of intensity in forest management were examined. The model calculations cover a period of 100 years (1996 to 2096). The C dynamic in the soil was also taken into account.
2. The model of the Swiss timber industry was developed through the adaptation of an existing material flux analysis model using the SIMBOX software program. The model is controlled by the consumption of wood products. The model calculations cover the period from 1900 to 2150.
3. The material substitution calculations are based on the comparison of wood products and non-wood products and the analyses of their life-cycles. To enable the differentiation between the substitution effect in Switzerland and abroad, the greenhouse gas emissions of the individual construction components were coded on the basis of their location of origin.

4. Important issues regarding the delimitation of CO_2 savings in Switzerland and abroad were also examined. The total effects at home and abroad are crucial to climate protection. For political decision-making, it is also important to establish which CO_2 effects arise in Switzerland and which arise abroad.

Scenarios

The scenarios build on the following bases:

- different forest management scenarios and the volumes of wood they generate;
- current consumption figures for wood products and the possible potential for increasing the use of wood in the construction sector.

To begin, four different forest management strategies were defined which give rise to different volumes of wood for harvesting. These volumes of wood were then distributed between areas of application in the construction and energy sectors so as to produce realistic wood use scenarios. In the context of the construction sector, this distribution was implemented to the level of detail of specific building components (ceilings/floors, external walls etc.). It was assumed that foreign trade remained constant.

The following scenarios were studied:

Optimized Increment		
The forest is managed to generate long-term maximum increment. The resulting **9.2 million m³** of industrial roundwood and fuel wood (including brushwood and bark) are fully harvested.		
Focus: building	**Focus: energy**	**Autarky (partial investigations)**
More wood in construction (+80 %) More forest wood for energy (+120 %) Foreign trade constant	No change in construction (+/- 0 %) Significantly more forest wood for energy (+345 %) Foreign trade constant	More wood in construction (+80 %) More forest wood for energy (+60 %) Discontinuation of foreign trade

Kyoto-Optimized	**Baseline**	**Reduced Forest Maintenance**
Forest harvesting so that C sinks arise in the forest simultaneous to a significant increment effect. **8.5 million m³** of industrial roundwood and fuel wood (including brushwood and bark) are removed annually.	Wood harvesting in the **forest** increases by around 20 percent over the coming 30 years to **5.9 million m³** of industrial roundwood and fuel wood (including brushwood and bark).	Annual harvesting in the Swiss **Forest** is reduced by 40 percent to **3.0 million m³** of industrial roundwood and fuel wood (including brushwood and bark).
More wood used in construction (+80 %) More forest wood available for energy (+65 %) Foreign trade constant	Slightly more wood used in construction (+20 %) Slightly more forest wood available for energy (+20 %) Foreign trade constant	Significantly less wood used in construction (-25 %) Far less forest wood available for energy (-80 %) Foreign trade constant

Results

Sum of the CO_2 savings in Switzerland

The results show that the optimized harvesting of the renewable resource wood generates the most sustainable effect for the improvement of the CO_2 balance. From a long-term perspective, the scenarios that include an increase in wood use, in particular in the construction sector *(Optimized Increment, Building* and *Kyoto-Optimized),* are superior to those that focus on the energy use of the wood. Based on these scenarios a total of around 8 million t of CO_2 emissions can be avoided annually in Switzerland around the year 2025. This constitutes an additional effect of around 6.5 million t CO_2 as compared with 1990. This means that a good 12 percent of today's annual greenhouse-gas emissions could be avoided. The advantage of the material use of wood as opposed to its energy use lies in the fact that the savings can be doubled: i.e. through the manufacture and use of the wood products and through their use for energy generation when they are no longer in use and disposed of.

In contrast, in the short to medium term reduced forest maintenance can generate a relatively significant forest sink effect of almost 13 million t CO_2 around the year 2015. However, based on the current Kyoto provisions, this volume cannot be accounted, because the volume that can be accounted by Switzerland is limited to 1.8 million t CO_2. Furthermore, this scenario triggers the emission of CO_2 from the forest from around 2075. In addition, if the increased risk of forest collapse due to the unfavourable age structure and large growing stock are also taken into account, emissions could be produced by the forest at a far earlier stage. It must be taken into account, moreover, that with this scenario the future consumption of wood in the construction and energy sectors must be significantly reduced or supplemented through the import of wood and wood products. If the missing wood is compensated by non-wood products and fossil fuels, the avoidance of CO_2 emissions from the use of wood and, hence also, the net effect of this scenario would be significantly reduced.

Sum of domestic and foreign effects

When the sum of the domestic and foreign effects are taken into account, the building scenarios *(Optimized Increment, Building* and *Kyoto-Optimized)* also produce the best CO_2 balance in the medium to long term. The most significant effects are achieved around the year 2030 when approximately 12–13 million t CO_2 emissions can be avoided. As compared with 1990, this constitutes the avoidance of an additional 8.2 million t of CO_2 emissions. This corresponds to around 15 percent of current greenhouse gas emissions in Switzerland.

Conclusions

Thus, how the Swiss forest is managed and the wood it produces is used play a crucial role in terms of the CO_2 balance. Short-term and long-term CO_2 effects can differ significantly in this context.

The cascade use of wood considered in the building scenarios (i.e. first material use followed by energy use following disposal) produces a far better CO_2 balance than energy use on its own. Accordingly, wood should be used as at as high a level as possible and then be used to generate energy only when it is no longer suitable for use for other purposes.

This study shows that at a constant level of foreign trade, the CO_2-savings achieved through increased wood harvesting and use primarily benefit Switzerland.

The focusing of forest management on the creation of sinks may trigger major reductions in CO_2 emissions in the short term, however in the medium and long term these forests become sources of CO_2. Storms, droughts and bark-beetle infestations represent an ever-increasing threat. Moreover, this scenario provides less wood for the construction and energy sectors and the resulting shortage would have to be compensated by non-wood products, fossil fuels and wood imports.

Thus, from both an ecological and climate-policy perspective, it makes sense, first, to increase the growing stock to the extent that may be accounted under the Kyoto Protocol and, second, to apply the cascade principle to the extra wood produced in addition to this, i.e. start by using it to make long-lived wood products and then for the generation of energy.

> Résumé

Problématique

L’économie forestière et l’industrie du bois contribuent de différentes manières à la réduction de l’effet de serre: par la fixation du carbone en forêt, par le stockage du carbone dans les produits ligneux et en remplaçant des matières premières fossiles par le bois. Le présent rapport traite la question de savoir comment la gestion des forêts et l’utilisation du bois permettent d’optimiser la contribution de la Suisse à l’amélioration du bilan de CO_2.

Recherches centrales

Des modèles et des scénarios permettent de développer les possibilités d’optimiser à l’avenir – du point de vue du CO_2 – la politique d’exploitation de la forêt, de transformation du bois et d’utilisation du bois. On étudie ainsi les effets des diverses stratégies de gestion des forêts et d’utilisation du bois sur les puits et les émissions de carbone. Les différents modes de gestion engendrent des quantités de bois variables susceptibles d’être affectées à la construction ou à la production d’énergie. Les scénarios mis en évidence dans cette publication se distinguent au niveau des quantités de bois récoltées en forêt ainsi qu’en ce qui concerne l’utilisation du bois. Les éléments suivants sont pris en considération: la forêt, le bois récolté et consommé dans la construction, ainsi que la réduction des émissions de CO_2 due à l’utilisation de produits ligneux.

Éléments de la modélisation

La thématique comprend quatre domaines, qui ont été étudiés à l’aide de modèles. Les quatre modèles fonctionnent de manière indépendante :

1. La forêt et la gestion forestière ont été modélisées à l’aide des données de l’Inventaire forestier national (IFN). Différentes intensités d’exploitation ont été étudiées. Les modèles de calcul couvrent une période de 100 ans (de 1996 à 2096). La dynamique du carbone dans le sol a été prise en compte.
2. Le modèle de l’industrie suisse du bois a été développé sur la base du logiciel SIMBOX, par adaptation d’un modèle existant de flux des matériaux. Il varie en fonction de la consommation de produits ligneux. Les modèles de calcul couvrent la période allant de 1900 à 2150.
3. Les calculs concernant la substitution se basent sur la comparaison du bois et des produits non ligneux et de leurs bilans écologiques. Afin de distinguer l’effet de substitution dans le pays et à l’étranger, les émissions de gaz à effet de serre des différents éléments de construction ont été réparties suivant leur lieu d’origine.

4. Les principales questions de délimitation des économies de CO_2 dans le pays et à l'étranger ont également été étudiées. Pour la protection du climat, c'est l'ensemble des effets en Suisse et dans les autres pays qui est déterminant. En vue de décisions politiques, il s'avère cependant aussi important de savoir où se produisent les effets liés au gaz carbonique: en Suisse ou à l'étranger.

Scénarios

Les scénarios se fondent sur les éléments suivants :

> différents scénarios de gestion des forêts et quantités de bois qu'ils impliquent,
> données chiffrées sur la consommation actuelle de produits ligneux et potentiels d'augmentation de l'utilisation du bois dans la construction.

Dans un premier temps, on a défini quatre scénarios différents de gestion des forêts comportant des quantités variables de bois exploitable. Ensuite, la quantité de bois a été répartie entre les domaines d'utilisation de la construction et de la production d'énergie, de sorte à obtenir des scénarios d'utilisation réalistes. La répartition au niveau de la construction a permis d'atteindre le degré de détail de l'élément (planchers, parois extérieures, etc.). On a supposé que le commerce extérieur restait constant.

Les scénarios suivants ont été étudiés:

Zuwachs optimiert		
Der Wald wird auf dauerhaft maximalen Zuwachs hin bewirtschaftet. Die resultierenden **9.2 Mio. m³** Waldnutz- und Waldenergieholz (inkl. Rinde und Reisig) werden vollständig genutzt.		
Schwerpunkt Bau	**Schwerpunkt Energie**	**Autarkie (nur teilweise untersucht)**
Mehr Holz im Bau (+80 %) Viel mehr Waldholz für Energie (+120 %) Aussenhandel konstant	Keine Veränderung im Bau (+/-0 %) Sehr viel mehr Waldholz für Energie (+345 %) Aussenhandel konstant	Mehr Holz im Bau (+80 %) Mehr Waldholz für Energie (+60 %) Einstellung des Aussenhandels

Kyoto optimiert	**Baseline**	**Reduzierte Waldpflege**
Waldnutzung so, dass gleichzeitig mit einer grossen Zuwachsleistung grosse C-Senken im Wald entstehen. Es werden jährlich **8.5 Mio. m³** an Waldnutz- und Waldenergieholz (inkl. Rinde und Reisig) entnommen.	Die Holznutzung im Wald erhöht sich in den kommenden 30 Jahren um rund 20 % auf **5.9 Mio. m³** Waldnutz- und Waldenergieholz (inkl. Rinde und Reisig).	Die Jahresnutzung im Schweizer Wald reduziert sich um 40 % auf **3.0 Mio. m³** Waldnutz- und Waldenergieholz (inkl. Rinde und Reisig).
Mehr Holz im Bau (+80 %) Mehr Waldholz für Energie (+65 %) Aussenhandel konstant	Etwas mehr Holz im Bau (+20 %) Etwas mehr Waldholz für Energie (+20 %) Aussenhandel konstant	Deutlich weniger Holz im Bau (-25 %) Viel weniger Waldholz für Energie (-80 %) Aussenhandel konstant

Résultats

Somme des économies de CO_2 en Suisse

Les résultats montrent qu'une exploitation optimisée de l'accroissement du bois produit l'effet le plus durable sur l'amélioration du bilan de CO_2. À long terme, il faut préférer les scénarios qui prévoient une augmentation de l'utilisation du bois avant tout dans la construction *(optimisation de l'accroissement, priorité à la construction* et *optimisation du point de vue du Protocole de Kyoto)* à ceux qui mettent l'accent sur un emploi du bois à des fins énergétiques. En Suisse, ces scénarios permettent d'éviter annuellement, vers les années 2025, un montant total de quelque 8 millions de tonnes d'émissions de CO_2. Par rapport à 1990, ce résultat représente une économie supplémentaire d'émissions de gaz carbonique de l'ordre de 6,5 millions de tonnes de CO_2. Cela signifie qu'il serait possible d'éviter 12 % des émissions annuelles actuelles de gaz à effet de serre. Par rapport à la production d'énergie, l'utilisation matérielle du bois débouche sur une double économie: les produits ligneux dont on n'a plus besoin, lors de la fabrication et plus tard lors de l'élimination, peuvent encore être valorisés à des fins énergétiques.

Une réduction de l'entretien de la forêt permet certes de fixer à court ou moyen terme une assez grande quantité de carbone en forêt (13 millions de tonnes de CO_2) vers 2015. Cependant, cette quantité ne peut pas être comptabilisée selon les règles de Kyoto, vu que la prise en compte du gaz carbonique est limitée à 1,8 million de tonnes pour la Suisse. Dès 2075 environ, ce scénario cause des émissions de CO_2 d'origine forestière. Compte tenu du risque accrû d'écroulement des peuplements en conséquence de la structure d'âge défavorable et de l'important volume sur pied, la forêt pourrait déjà se muer en source de gaz carbonique bien avant cette date. De plus, il convient de tenir compte, avec ce scénario, du fait que la consommation future de bois dans la construction et dans la production énergétique peut fortement baisser ou être remplacée par l'importation de bois et de produits ligneux. Si le manque de bois est compensé par des produits non ligneux et des énergies fossiles, la diminution des émissions de CO_2 par l'utilisation de bois et, par conséquent, aussi l'effet net de ce scénario sont fortement réduits.

Somme des effets en Suisse et à l'étranger

Pour ce qui est de la somme des effets en Suisse et à l'étranger également, ce sont les scénarios « construction » *(optimisation de l'accroissement, priorité à la construction et optimisation du point de vue du Protocole de Kyoto)* qui présentent à moyen ou long terme le meilleur bilan de CO_2. Les plus grands effets seront obtenus vers 2030. Ils permettront d'éviter l'émission de quelque 12 à 13 millions de tonnes de CO_2. Par rapport à 1990, ce résultat représente une économie supplémentaire d'émissions de gaz carbonique de l'ordre de 8,2 millions de tonnes. Ce qui correspond à près de 15 % des émissions actuelles de la Suisse en matière de gaz à effet de serre.

Conclusions

La manière de gérer la forêt suisse et d'utiliser le bois exploité joue un rôle décisif dans le bilan de gaz carbonique. Les effets sur le CO_2 à court et long terme peuvent par conséquent s'avérer très variables.

L'utilisation en cascade du bois (d'abord sous forme de matériau, puis comme source d'énergie lors de l'élimination) considérée dans les scénarios « construction » présente un bien meilleur bilan de CO_2 qu'une exploitation purement énergétique. C'est pourquoi il faudrait d'abord réserver le bois à un usage hautement valorisant, puis seulement l'employer sous une forme énergétique lorsque toutes les autres possibilités d'utilisation sont épuisées.

Cette étude montre que si le commerce extérieur reste constant, les effets d'économie de CO_2 réalisés par l'accroissement de l'exploitation et de l'utilisation du bois s'avèrent en premier lieu favorables à la Suisse.

Une orientation de la gestion forestière vers la création de puits de carbone entraîne bien à court terme une réduction massive des émissions de gaz carbonique. Cependant, ces forêts se transforment en sources de CO_2 à moyen et long terme. Les tempêtes, les périodes de sécheresse ou les attaques de bostryches constituent un risque en constante augmentation. Par ailleurs, ce scénario concède moins de bois à la construction et à l'énergie. Cette carence devrait alors être compensée par l'utilisation de produits non ligneux et d'énergies fossiles, ou par l'importation de bois.

Tant du point de vue de l'écologie que de la politique climatique, il s'avère judicieux d'accroître le volume de bois sur pied jusqu'au niveau pris en compte par le Protocole de Kyoto et de valoriser le surplus de production de bois dans une utilisation en cascade, d'abord pour des produits ligneux de longue vie, puis comme source d'énergie.

1 > Introduction

1.1 Background and issues

Wood as an important component of active climate policy

By signing and ratifying the Kyoto Protocol, Switzerland committed to the adoption and implementation of an active climate policy. The most important basis for the fulfilment of the CO_2-reduction commitments defined in the Kyoto Protocol is well-founded knowledge of the efficacy of the measures that may be implemented to improve the national CO_2 balance.

In recent years, the political debate in the forestry and timber industry has been strongly focused the fact that the forest can be accounted as a C sink in accordance with Articles 3.3 and 3.4 of the Kyoto Protocol. However, as a renewable CO_2-neutral raw material and energy source, wood can make a far more significant contribution to the reduction of national CO_2 emissions through all of its applications, i.e. through the substitution of fossil fuels by wood, on the one hand, and through the increased use of long-lived wood products in the place of more energy-intensive materials and construction methods, on the other. Moreover, wood products act as carbon stocks during their lifetime. In this way, they extend the residence time of the carbon stored in the wood and thus remove it from the natural CO_2 cycle for extended periods.

As opposed to this, the increase in growing stock in the forest is curbed through the use of wood and the sink effect is reduced. If harvesting exceeds natural increment, the growing stock is actually reduced and the forest becomes a source of CO_2.[1]

The role of foreign trade in wood products

Switzerland's foreign trade causes the transfer of emissions generated by the production and disposal of wood products. In the case of imported goods, the emissions arising from their production arise in the country in which they were produced (abroad), and, conversely, in the case of exported goods, the emissions caused by production are attributed to Switzerland. Furthermore, the import and export of wood products leads to the movement of the carbon stored in these products. Thus, in order to assess the efficacy of climate-policy measures, the effect of cross-border goods traffic on the national greenhouse gas balance must be taken into account. The global effects must not be neglected here either.

All of these climate-relevant aspects of wood are interconnected on various complex temporal and spatial levels. The main aim of this study was to demonstrate these connections with the help of models based on various wood harvesting and use scenarios.

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1 Fischlin, Buchter *et al.* 2003; Fischlin, Buchter *et al.* 2006.

1.2 Aim of the study

Model-based decision bases

The aim of this study is to provide bases for demonstrating the possible utility of the forestry and timber industry in reducing CO_2 emissions in Switzerland. Because the planning horizons in the forestry sector (and timber industry) tend to be long-term, the effects of measures implemented in these sectors must also be examined on a long term and strategic basis for future Kyoto commitment periods.

This study examines political action options for climate-optimized wood harvesting and wood use based on model calculations implemented in the context of different scenarios. Thus, the study examines the effects of different wood harvesting and use strategies on:

> the C stocks in the forest;
> the C stocks in the technosphere;
> the substitution effects arising from the use of wood in place of more energy-intensive materials;
> the substitution effects of the thermal utilization of wood in place of fossil fuels.

The scenarios on the use of wood focus on the building stock (and some additional wood products) as this is where the most significant climate-relevant CO_2 savings can be made.[2]

Working hypothesis

The study is based on the following working hypotheses:

"The contribution to the improvement of the greenhouse gas balance is greatest if:
> *the maximum possible wood increment in the forest is achieved and the wood is fully harvested on an ongoing basis;*
> *as far as possible, long-lived wood products are manufactured using the harvested wood;*
> *if practical, these products are recycled at the end of their lifetime and;*
> *finally, (end-) used to generate energy."*

Based on this study, it is possible to:

> identify decision bases for the definition of an optimal national strategy for forest management and wood use for the alleviation of climate change;
> underpin the significance and potential of the sustainable and ecologically optimized use of wood;
> derive incentives for the promotion of wood use, with particular emphasis on substitution;
> demonstrate the advantage of the cascade use of wood products.

[2] Hofer, Morf *et al.* 2001.

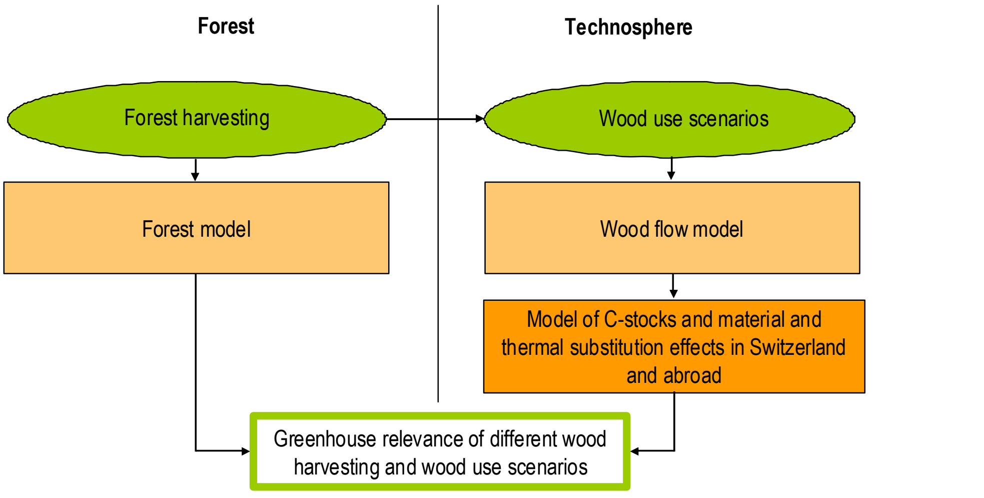
1.3

Methodological approach

In order to assess the greenhouse-gas-relevant effects of the scenarios examined by the study, different computer models were developed, harmonized and their results combined. The models make it possible to comment on the temporal change of the stocks and fluxes and the accompanying substitution effects within the time horizon under consideration, i.e. between 2000 and 2096 (or 2150).

Combination of three separate models

Fig. 1 > Interplay of the models used



The three models developed for the Swiss forest, the timber industry and for the C stocks and substitution effects (cf. Fig. 1) constitute the core of the study; the modelling bases are presented in detail in Chapter 2.

Forest model

The modelling of the forest dynamics is based on the surveys carried out for the Swiss National Forest Inventory[3] (NFI), which is implemented periodically by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL). The most recent research findings on the carbon budget of the Swiss forest were also incorporated into this model and enabled the estimation of the effect of slash and natural losses.[4] The modelling of the forest dynamics is based on the MASSIMO forest model and YASSO soil model (for details, see Chapter 2.1). These approaches enable the modelling of the changes in the carbon stocks in the forest as a result of different forest management strategies. The model calculations cover a period of 100 years (1996 to 2096).

National forest inventories as a basis for the forest model

3 Brassel and Brändli 1999.
4 Thürig 2005.

Wood flux model of the Swiss timber industry

Consumption statistics as basis for the wood flux model

The model for the Swiss timber industry was developed through the adaptation of an existing material flux analysis model using the SIMBOX software program.[5] It incorporates all of the relevant wood stocks in the Swiss technosphere including the wood sector, building stock, the paper cycle and the various forest energy, wood residue and waste wood stocks.

The model is controlled by the consumption of wood products. The model calculations start in the year 1900; the consumption figures from 1900 to 2000 were taken from various statistical sources.[6] The data for future wood consumption used in the scenarios were determined on the basis of potential market considerations[7] and the Swiss forest increment in accordance with the NFI. Thus all of the wood harvesting and use scenarios could constitute the outcome of a conscious strategy adopted for the purposes of climate policy and are "realistic" in this regard. In all scenarios, the consumption changes in terms of the use of wood occur between 2000 and 2030 and remain constant thereafter.

Comprehensive model of the carbon stocks and substitution effects

Wood model and life-cycle analyses as bases for a comprehensive model

The wood fluxes generated by the model of the Swiss timber industry provide the input data for a comprehensive model of the carbon stocks and substitution effects. To enable the presentation of the effect of foreign trade, several stocks of exported and imported wood[8] were added to the stocks of the wood flux model.

The effects of material substitution

The calculation of the emissions effects from the substitution of wood products for non-wood products is based on long-standing experience in the area of life-cycle analyses and on national and international databases. The greenhouse gas emissions generated by a structural wood component were compared over its entire life cycle – i.e. raw material extraction, processing, use and waste disposal including transport – with those of a functionally equivalent substitute component.[9] The substitute product pairs were defined on the basis of a survey of architects and builder's clients[10] and the corresponding substitution effects were classified on the basis of national and foreign shares.

Substitution effects of energy recovery from wood

The effects of the substitution of fossil fuels by fuel wood, wood residues and waste wood were also taken into account. It was also assumed here that oil and gas-based heating systems are being replaced by energy recovery from wood.[11] Furthermore, in the case of the energy substitution effects, the effects in other countries (from the

5 Xyloikos, Müller 1998.
6 Including: ESA 1910; EIF 1912; ESA 1922–1974; ESA 1930; FAO 1953b; FAO 1953a; FAO 1964.
7 Based on BUWAL 1996.
8 As a subtotal of Switzerland's total wood stocks.
9 Werner 2006; Werner, Taverna *et al.* 2006; Hofer, Taverna *et al.* 2002c.
10 Quetting, Wiegand *et al.* 1999; Wiegand and Quetting 1999a; Wiegand and Quetting 1999b.
11 Weighted on the basis of their share of total energy consumption, related to the corresponding energy to be used, for details, see Werner and Richter 2005b.

extraction, refining and transport of crude oil) were distinguished from those in Switzerland (from combustion and partly refining).

Consideration of foreign trade

Greenhouse gas effects arising from foreign trade, e.g. the export of wood stocks, import of foreign wood resources and the transfer of substitution effects, were also taken into account in the study. The following assumptions were made for the purpose of simplification:

> A constant level of foreign trade was assumed for all of the scenarios examined. This meant that sink and source effects in foreign forests could be ignored. The only scenario for which it was necessary to estimate the effect on foreign forests was the "autarky" sub-scenario, in which foreign trade does not take place.
> The imported and exported volumes of wood were reported in accordance with the stock-change approach.[12] This means that exported wood is accounted as a stock by other countries and imported wood is accounted as a stock by Switzerland.
> For the assessment of the substitution effect of exported wood, it was assumed that half of the wood products exported to other countries substitute wood products and the other half substitute non-wood products.

The three models are not directly connected and were operated independently through the exchange of data and through the corresponding interfaces. The scenarios were evaluated through the collation of the results of the forest model and complete model of the C stocks and substitution effects.

1.4 System boundary and reference situation

Comprehensive analysis of greenhouse-relevant processes

The study incorporates the greenhouse-gas dynamics generated by wood harvesting and use scenarios in Switzerland and abroad. The effects considered include:

> carbon sequestration and respiration in the forest;
> carbon stock effects in long-lived wood products;
> production and disposal emissions generated by wood products;
> substitution effects through the avoidance of the production and disposal of (generally more energy-intensive) non-wood products;
> substitution effects of energy recovery from fuel wood, the non-material use of wood residues from wood processing and waste wood through the reduced use of fossil fuels.

Classification in accordance with domestic and foreign effects

The greenhouse-relevant effects from production and disposal can arise both in Switzerland and abroad. For example, the exploration, extraction, refinement and transport of fossil fuels generate greenhouse-relevant effects abroad. Greenhouse gas emissions also arise abroad when auxiliary materials (e.g. paints) and semi-finished products (e.g. steel panels) are produced abroad and then imported.

12 IPCC 2003; UNFCCC/TP 2003.

The influence of foreign trade

In addition to the effects triggered by the Swiss forestry sector and use of wood, the foreign trade for wood products is also taken into consideration. It is taken into account that:

> domestic wood is stored in various products abroad;
> foreign wood is stored in various products in Switzerland;
> wood residues arise from the processing of imported and exported semi-finished wood products both in Switzerland and abroad which can be used to generate energy;
> in the case of the importation of semi-finished wood products, part of the production emissions arise abroad;
> in the case of the export of wood products, part of the production emissions arise in Switzerland;
> exported finished products can replace either wood products manufactured abroad or conventional products manufactured abroad.

Overall effects

As a rule, the presented results specify the actual effects of the scenarios in the year under consideration. This means that:

> for the C stock effects in the forest and in the technosphere, the stock changes are represented as compared with the year 2000;
> in the case of the substitution effects, the effects of the entire wood fluxes are reported.

2 > Computational Bases

2.1 Forest and soil model

Forest modelling

The calculations of the CO_2 effects in the forest for the different scenarios are based on two part-models:

> The MASSIMO[13] forest management model: the target variable calculated by this model is the development of forest structure and the volume of living and dead tree biomass produced. MASSIMO also calculates the annual volumes of forest litter and dead wood produced; these data are required for the soil model.
> The YASSO[14] soil model: this calculates the change in the carbon content of the soil based on the annual volumes of forest litter and dead wood produced and their climate-influenced rates of decomposition.

Both models are based on the country-wide surveys carried out as part of the first and second Swiss National Forest Inventories (NFI) (Tab. 1).

Tab. 1 > Technical data on National Forest Inventories I, II and III

	NFI I	NFI II	NFI III
Inventory cycle	1983–1985	1993–1995	2004–2006
Aerial photo sample points	40'000	160'000	160'000
Terrestrial sample plots	~12'000	~6'000	~6'000
Individual trees measured	~130'000	~70'000	~70'000

The data from the third survey, which was carried out between 2004 and 2006, were not yet available for this study. They will be analysed from spring 2007.

2.1.1 MASSIMO forest management model

MASSIMO forest model

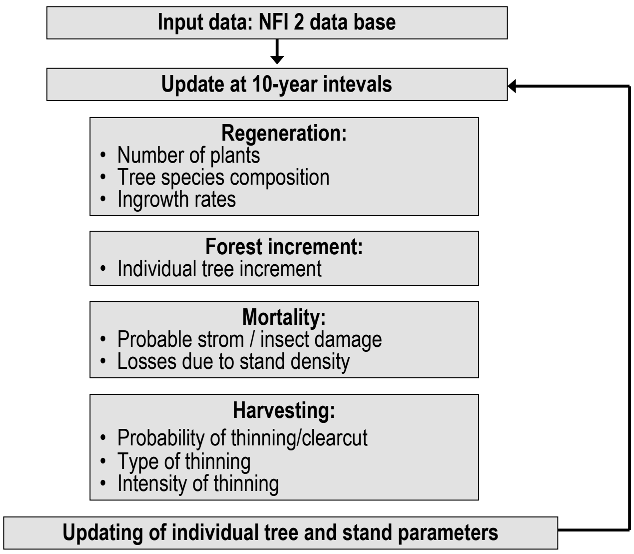
The MASSIMO (Management Scenario Simulation Model) forest model is an empirical stochastic and dynamic forest model based on the individual tree. It comprises four models for regeneration, growth and management scenarios, including wood harvesting, and mortality (cf. Fig. 2). These four processes are depicted on the basis of empirical formulae. The latter were derived from data from NFI I and NFI II, which, in turn, were collected from approximately 6000 sample areas with around 70'000 individual trees.

13 Kaufmann 2000.
14 Liski, Peltoniemi *et al.* 2005.

Growth model

The growth model is the main component of MASSIMO. The growth function was derived from the inventory data from NFI I and NFI II and calculates, at ten-year intervals, the basal area increment of individual trees as a function of location conditions, forest structure and competition conditions.

Fig. 2 > Scenario model flow chart



Wood harvesting

In MASSIMO, wood harvesting is defined as the probability that an individual tree will be logged at a certain point in time. This probability is estimated on the basis of logistical regression models. The explanatory variables here are the stand and location characteristics (i.e. development stage, tree species composition, stand age and location quality), the logging conditions (e.g. accessibility and the logging techniques used), harvesting costs and protective functions. The regression model was derived from data from the Swiss National Forest Inventory. They indicate the harvesting and losses measured in the period between the two NFI surveys of 1985 and 1995.

Natural mortality

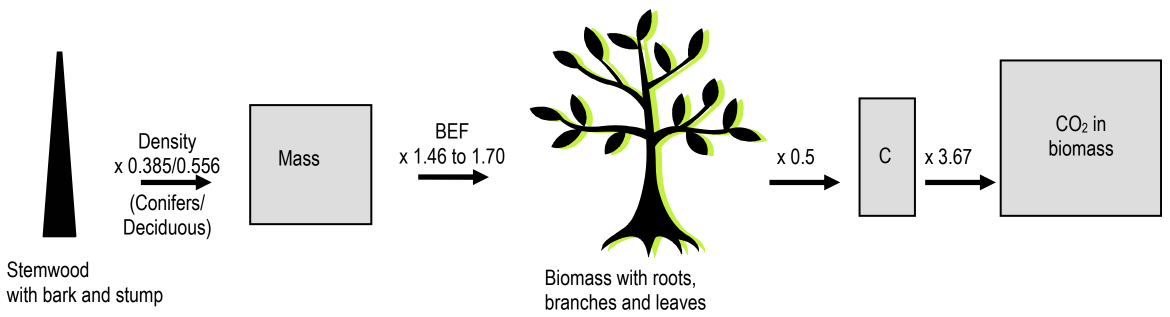
The data for natural mortality were also derived from the empirical data from NFI I and NFI II. However, the simulated stand structures can change considerably in the context of a 100-year simulation. For example, if the harvest volumes are reduced in the model calculation, the stand density increases accordingly. This could lead to increased mortality. A raised mortality level of this kind had to be taken into account in the MASSIMO model. However, corresponding data records for the adaptation of the model are largely unavailable. Thus, an additional density-dependent mortality function was developed. This is based on long-term forest yield studies carried out by WSL on selected NFI samples with extensive growing stock and on expert knowledge. These data were used to define an upper limit for stand density.

The following correlations were extrapolated: if a simulated stand has reached the maximum stand basal area,[15] the rate of mortality increases exponentially with increasing basal area. Mortality also increases exponentially in very old stands, i.e. from an age of 150 years in the Swiss central plateau and from 250 years in the Alps.[16]

Conversion into carbon

The NFI figures are mostly specified in terms of *stemwood with bark and stump*. As opposed to this, this study focused on the carbon content of all of the biomass. The following conversion operations are required to convert *stemwood with bark and stump* into carbon or CO_2. The cubic mass of *wood* [m³] is converted into *solid mass* [t] through multiplication by the wood density. Branches, leaves and roots are added to the mass through multiplication by a specific expansion factor (BEF). The exact conversion figures are described in Thürig, Schmid et al. (2007). Around 50 percent of biomass is carbon. To convert the carbon into the corresponding volume of CO_2, the volume of carbon is multiplied by 3.67.[17] The entire conversion process is presented schematically in Fig. 3.

Fig. 3 > Estimation of the biomass and C content



2.1.2 YASSO soil model

Simulation of the decomposition of forest litter and dead wood

The changes in the carbon stored in the soil were estimated with the help of the YASSO soil model.[18] YASSO is a simple soil model which simulates the decomposition of forest litter and dead wood to humus. This model only requires a few input parameters: i.e. the annual volume of forest litter, its chemical composition and basic climate parameters. No information on soil structure is required. Thus, the decomposition rates in different locations are only differentiated in terms of the quality of the forest litter and basic climate parameters, but not in terms of the soil structure.

[15] 50m²/ha to 75 m²/ha depending on the tree species composition and the stage of development.
[16] Thürig 2005a, p 95.
[17] For the conversion of C into CO_2 see Annex 1.
[18] Liski, Peltoniemi *et al.* 2005.

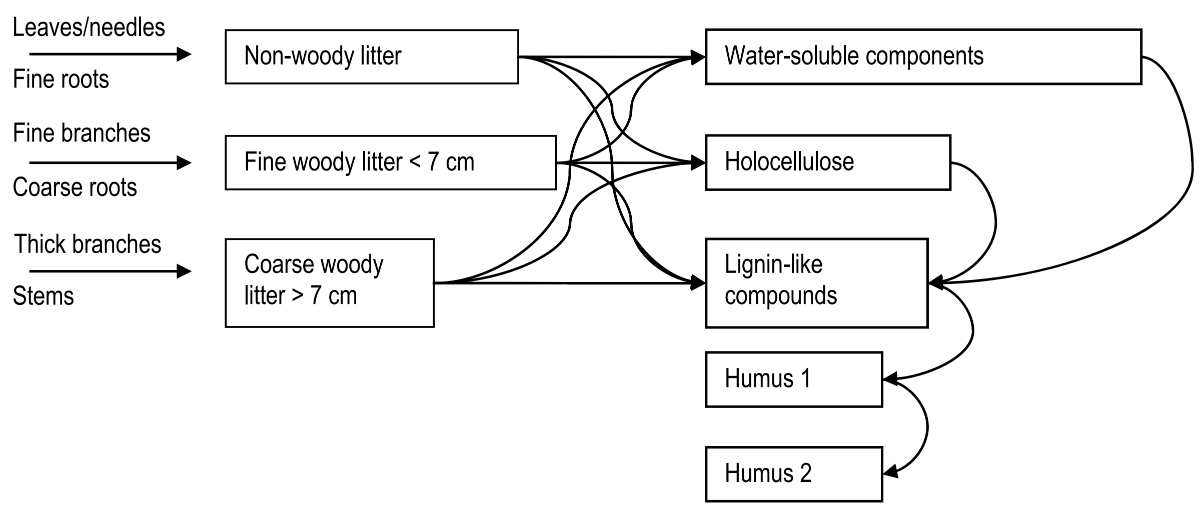
YASSO soil model

Fig. 4 shows the different individual modules taken into account in the model. In terms of litter, a distinction is made between *non-woody litter* (leaves, needles and fine roots), *fine woody litter* (fine branches < 7 cm) and roots) and *coarse woody litter* (branches > 7 cm and stems). Thanks to this differentiation, the mechanically delayed decomposition of woody forest litter can be modelled as compared with that of leaves and needles. The annual volumes of forest litter were estimated using the MASSIMO model. The tree components calculated in MASSIMO, such as needles, branches, roots etc. were assigned specific lifetimes. To calculate the annual litter production of needles, for example, the total volume of needles was divided by the specific lifetime of the needles.

The three groups of litter differentiated in YASSO vary in terms of their chemical composition. They contain different proportions of water-soluble components, cellulose and lignin-type elements. These three chemical groups decompose at different speeds, with the rate of decomposition decelerating from the former to the latter. These components become humus at an advanced stage of decomposition. The YASSO model differentiates between two types of humus which, again, have different rates of decomposition.

All decomposition processes in the model are described by exponential decay. The corresponding decomposition rates reflect the activity of the microorganisms. These are influenced by the climate parameters, temperature and summer drought. The warmer and wetter it is, the more active the microorganisms are and the more material they respire and release into the atmosphere as CO_2.

Fig. 4 > Structure of the YASSO soil model



The initialization and all of the parameters used in this study were taken from Thürig (2005).

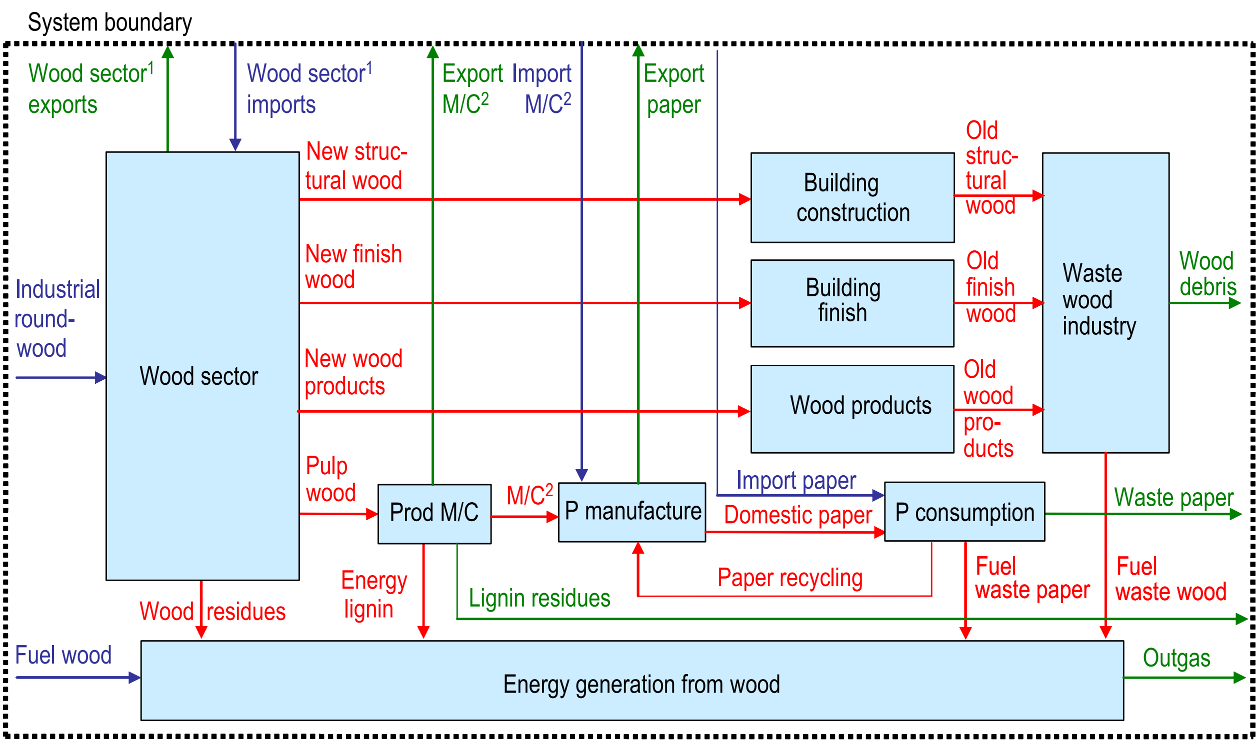
2.2

Model of the Swiss timber industry

A simple material flux analysis model of the timber industry in the technosphere was developed in cooperation with EAWAG for the wood fluxes in Switzerland.[19] An existing model, i.e. Xyloikos,[20] was adapted to accommodate the issues of interest in this study. The calculations were carried out with the help of the SIMBOX software program.

The material flux analysis model consists of nine processes (boxes) and 26 fluxes (arrows) (Fig. 5). Five input fluxes and seven output fluxes exceed the borders of Switzerland as system boundaries while the other fluxes connect the individual processes. A mean residence time of the products (lifetime) is defined for each process. It ranges between 0 years (= no stock formation in paper production) and, for example, 30 ± 15 years in the case of wood used in the finishing of buildings and 80 ± 20 years for wood used in the construction of buildings (cf. also Annex 2).

Fig. 5 > Model system of the Swiss timber industry



[1] Collected from four individual wood fluxes; [2] M/C: mechanical/chemical pulp.

[19] Baccini, Daxbeck *et al.* 1993; Bader and Scheidegger 1995; Baccini and Bader 1996.
[20] Müller 1998; Müller, Bader *et al.* 2004.

System boundaries

The model incorporates all wood uses within Switzerland's technosphere. The C-stock effects of wood products in Switzerland and abroad taking foreign trade into account are calculated in another model (see Chapter 2.3).

Input into the model

The five input fluxes into the model include:

> Industrial roundwood (stemwood and industrial wood) from Switzerland;
> Fuel wood (including hedgerow timber used for energy generation) from Switzerland;
> Imports made by the timber industry: 1) roundwood and wood residues; 2) semi-finished products; 3) three-quarter-finished products; and 4) furniture and prefabricated houses (each calculated individually in the model);
> Imports of mechanical pulp and chemical pulp for paper production;
> Paper imports for final consumption.

Output from the model

The seven output fluxes include:

> *Exports made by the timber industry:* as in the case of the imports, they include 1) roundwood and wood residues; 2) semi-finished products; 3) three-quarter-finished products; and 4) furniture and prefabricated houses;
> *Exports of mechanical pulp and chemical pulp for paper production;*
> *Exports of lignin residues;*
> *Paper exports;*
> *Outgas* from the incineration of wood as the system's main output in terms of volume; solid residues are not taken into account due to their minimal significance (approximately 2 percent);
> *Waste wood* that is not burned in waste wood incinerators or in municipal waste incinerator (MWI). It either leaves Switzerland for use abroad (for example as chipboard) or is deposited in landfill – or, possibly also, illegally burned;
> *Waste paper* which is disposed of in the sewage system, composted or disposed of in another way.

Consumption-controlled model

The system is modelled on a consumption-controlled basis. The remaining wood fluxes and stocks are calculated as a function of time through the specification of the wood uses and foreign trade volumes of the parameters (left-hand column) listed in Tab. 2. In this way, for example, the volume of industrial roundwood is determined through the subsequent uses made of the wood. As opposed to this, the acquisition of fuel wood is specified. The consumption values and selected proportionate values for the year 2000 are indicated in Tab. 2.

Tab. 2 > Defined parameters in the year 2000

Use/Import/Export Parameters	[Mio. m³/y]	kg DM/(I*y)
New structural wood	0.87	62
New finish wood	0.87	62
New wood products	0.76	54
Paper consumption[1, 2]	3.94	245
Fuel wood	1.26	90
Import timber industry	2.70	193
Export timber industry	2.21	158
Import mechanical pulp, chemical pulp	1.99	93
Export mechanical pulp, chemical pulp	0.55	19
Import paper[2]	2.53	157
Export paper[2]	2.56	159

Other parameters	Proportional value in relation to 2000[21]
Proportion of wood residues for industrial roundwood (in energy)	40 % of the new wood
Proportion of wood residues for ½-finished products	30 % of the new wood
Proportion of wood residues for ¾-finished products	20 % of the new wood
Recycling paper	63 % of paper consumption
Additives in paper	13 % of paper volume
Proportion of waste paper	9 % of paper use
Proportion of fuel waste wood	60 % of volume that leaves the waste wood sector
Raw wood → chemical pulp factor	4.5 m³ raw wood for 1 t chemical pulp
Raw wood → mechanical pulp factor	2.8 m³ raw wood for 1 t mechanical pulp
Production ratio of chemical pulp to mechanical pulp	approx 51 % chemical pulp and 49 % mechanical pulp
Proportion of lignin used to generate energy	80 % of total lignin produced

1 Paper consumption is composed of the sum of domestic and imported paper.
2 The conversion factor is assumed as 2.3 m³ wood per tonne of paper.

The consumption volumes used in the different areas of application were derived on the basis of current statistics and studies.[22] The consumption volumes were converted into kilograms of dry matter per inhabitant and year (kg DM/(I*y)). To simplify matters it was assumed that 1 m³ of wood corresponds to 500 kg DM and consists of 50 percent carbon. The population of Switzerland was specified throughout as 7.0 million inhabitants.

Dynamic modelling

The stocks are calculated by means of dynamic modelling using the specified consumption values. The stocks of products with short residence times in the system, such as paper or fuel wood, display a short reaction time whereas the stocks of structural and finish wood are more slow to react. For example, based on the assumed 80-year lifetime of the products, wood consumption in the area of construction from the year 1950 extends up to the year 2030. In order to be able to demonstrate the effects of current or future wood use, the stock developments must be considered over a period of at least 100 years after the last change in consumption. Thus, to obtain an image of the structure of the current wood stocks in the building stock, it was necessary to start the modelling in the year 1900. The figures for wood consumption prior to the year 2000 originate from various archive studies[23] and from the authors' own estimates.

21 Left constant for all calculations.
22 Wüest, Schweizer *et al.* 1994; Arioli, Haag *et al.* 1997; Basler&Hofmann 1997; VHe 1997; Quetting, Mehlisch *et al.* 1998; BfS/BUWAL 2000; Peter and Iten 2001; Hofer, Taverna *et al.* 2004.
23 ESA 1910; EIF 1912; ESA 1922–1974; ESA 1930; FAO 1953b; FAO 1953a; FAO 1964.

2.3 Comprehensive model of carbon stocks

Supplementation of the wood model with wood stocks from foreign trade

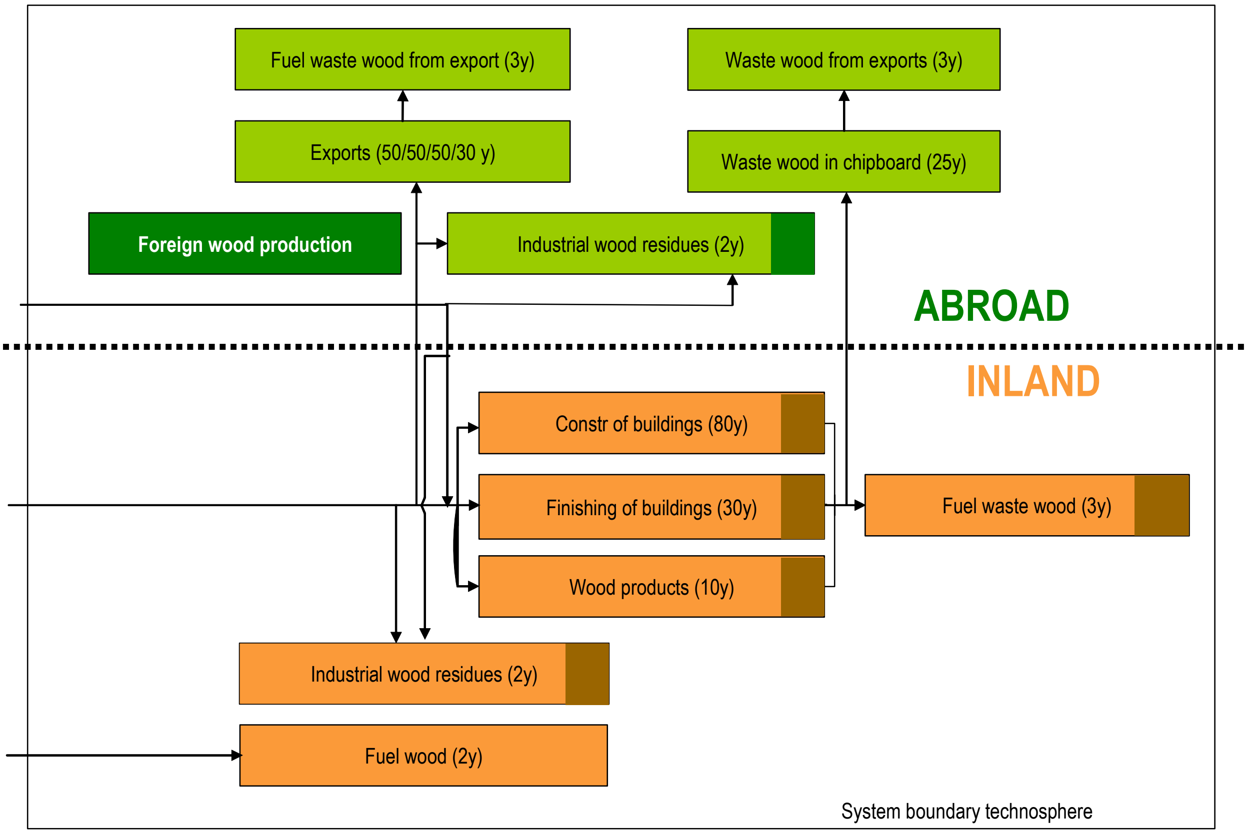
The wood fluxes generated from the model of the Swiss timber industry provided input data for a comprehensive Excel-based model of the carbon stocks and substitution effects.[24] To facilitate the depiction of the effect of the foreign trade, the following stocks were added to the stocks in the wood flux model:

> Stocks of Swiss wood abroad;
> Stocks of foreign wood in the Swiss building stock (as a sub-total of the overall wood stocks in Switzerland).

Fig. 6 shows the wood stocks in Switzerland and abroad that were taken into account, including the lifetimes of the different product categories.

Fig. 6 > Modelled wood stocks in the technosphere in Switzerland and abroad, excluding forest

The assumed mean residence time is noted in brackets;
the dark brown shading indicates the import share of the domestic wood stocks



[24] Werner and Richter 2005a.

Residence times

The following residence times were adopted from the wood flux model of the wood stocks in Switzerland:

> Construction of buildings: 80 years;
> Finishing of buildings: 30 years;
> Wood products: 10 years;
> Fuel waste wood: 3 years;
> Fuel wood and industrial wood residues: 2 years.

On the one hand, cross-border trade generates wood stocks abroad comprising exported Swiss wood. On the other hand, part of the above-specified Swiss wood stocks consist of imported foreign wood. Moreover, the pre-processing of products intended for import results in the formation of stocks of wood residues abroad.

The residence times specified in Tab. 3 are assumed in the calculation of the stock effects abroad, including the substitution effects abroad (on the derivation of the residence times, see also Annex 6).

The same residence times are also used for imported wood in the calculation of the substitution effects; the above-specified residence times are assumed for the calculation of the C-stocks in the imported products (Fig. 6).

Tab. 3 > Assumptions for the modelling of the wood stocks from the foreign trade

Goods	Proportion of wood residues used to generate energy	Residence time [y]
Houses/furniture	0 %	50
Three-quarter-finished products	9 %	50
Semi-finished products	17 %	50
Roundwood[1]	29 %	30
Wood residues as fuel wood	-	2
Exported waste wood	0 %	25
Imported/exported wood residues	0 %	10
Pre-processing of imported houses/furniture	29 %	2
Pre-processing of imported three-quarter-finished products	29 % − 9 % = 20 %	2
Pre-processing of imported semi-finished products	29 % − 17 % = 12 %	2

[1] 40 percent of the entire roundwood flux (including wood residues) is assumed to be imported or exported roundwood. The imported wood residues (60 percent of the total roundwood flux, (including wood residues)) replace the corresponding harvesting of industrial wood in Switzerland.

The paper stocks and all of the fluxes associated with them, including imports and exports, are assumed as constant for all of the scenario perspectives. Given that the main focus of this study is on stock changes, the paper stocks can be omitted for the remaining analyses.

2.4 Substitution effects

Effects of material substitution

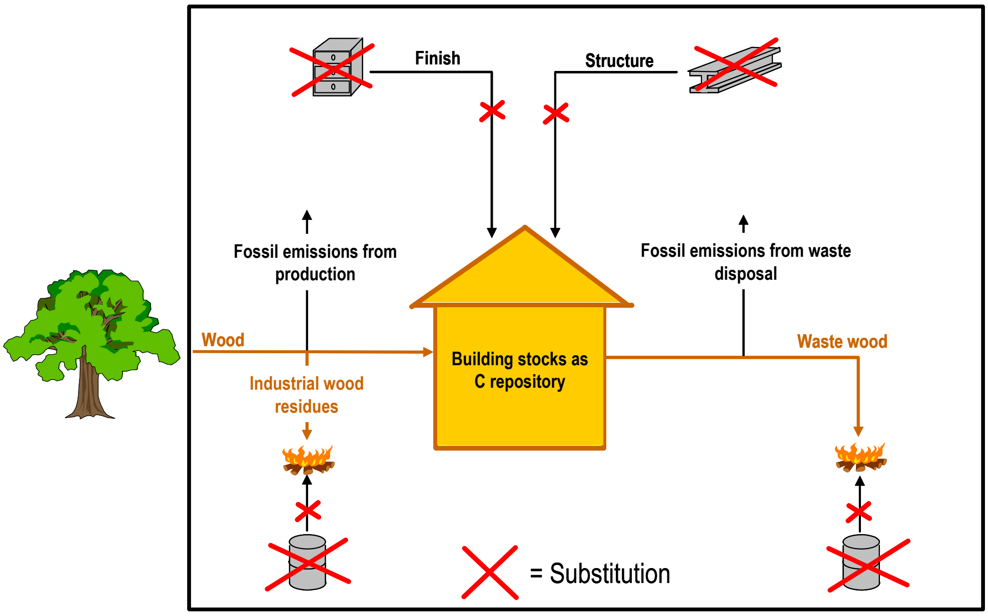
The use of wood products generally enables the substitution of more energy-intensive products, e.g. made of steel or concrete. The use of wood results in a reduction in fossil fuel consumption during production. This effect is known as material substitution.

Energy substitution

However, wood can also be used directly as a CO_2-neutral fuel and reduce the use of fossil fuels in this way. This effect is known as energy substitution. The analysed substitution effects are presented schematically in Fig. 7. In this diagram, wood products replace more energy-intensive structural and finish products and fossil fuels through energy recovery from wood. The other product group examined, i.e. wood products (do-it-yourself products, formwork, packaging), is not presented here.

Fig. 7 > Diagram depicting the analysed substitution effects in Switzerland and abroad

Although greenhouse gas emissions arise during production and waste disposal, when wood products are used they generally substitute more energy-intensive products (material substitution); energy recovery from wood directly replaces fossil fuels (energy substitution).



2.4.1 **The effects of material substitution**

Practice-based definition of functionally equivalent competitive products of structural wood components

The use of wood involves the substitution of products made from competing materials. The results of a comprehensive survey of constructors, architects and engineers were incorporated into the definition of the competitive products of wood products.[25] Foreseeable legislative developments were also taken into account here. Tab. 4 provides an overview of the comparison of competitive products in the building sector.

Tab. 4 > Overview of the analysed structural wood components and their competitive products

Use	Structural wood component	Competitive product
Structure		
(Exterior) walls	Solid wood panel	Brick cavity masonry
Columns	Glulam column	Steel column
Storey ceiling/floor	Wood joist ceiling/floor	Reinforced concrete ceiling/floor
Insulation	Wood fibre insulation board[1]	Rockwool[2]
Roof	Exposed beam structure	Aerated concrete steep roof
Structural engineering	Wood palisade	Concrete palisade
Finish		
Wall and ceiling covering	Spruce panelling	Interior plastering
Stairs	Oak staircase	Precast concrete stairs
Floor coverings	3-layer parquet	Glazed ceramic tiles
Façades	Raw wood siding including lath[1]	Exterior plastering[2]
Fittings	Architrave from derived timber products	Architrave frame
Furniture	Wood furniture	Steel furniture

[1] in solid wood panel construction; [2] in brick cavity masonry

The following functionally equivalent product pairs were analysed for the wood products category (Tab. 5).

Tab. 5 > Overview of the analysed wood components and their competitive products

Use	Wood product	Competitive product
Packaging	Raw wood siding including lath[1]	Same volume of plastic (polypropylene)
Wood products	Raw wood siding including lath[1]	Same volume of plastic (polypropylene)
Auxiliary construction materials	Formwork panels (3-layer spruce panel)	Aluminium formwork
DIY	Spruce panelling	Interior plastering

[1] in solid wood panel construction.

[25] Quetting, Wiegand *et al.* 1999; Wiegand and Quetting 1999a; Wiegand and Quetting 1999b.

Life-cycle assessments as bases for the calculation of substitution effects

The greenhouse gas balance of the analysed products was calculated by means of life cycle assessment (LCA). An LCA takes all of the life phases of a product, from raw material extraction and production to component use and the emissions generated during disposal – including transport – into account. The assessment of the construction components is based on an updated catalogue of components compiled by the Swiss Engineers' and Architects' Association (Schweizerischer Ingenieur- und Architektenverband/SIA)[26] or is based on existing comparative LCAs.[27] The substitution effect is calculated from the difference between the greenhouse gas emissions generated by the wood product and its competitive product.

In terms of the effects arising from material substitution, a distinction is made between two temporally varying substitution effects:

> substitution effects during production in Switzerland and abroad;[28]
> substitution effects during waste disposal.[29]

However, in addition to the temporal dynamic, the location of the emissions is also crucial in terms of the national CO_2 balance. In order to be able to classify the substitution effects in terms of domestic and foreign effects, all processes in a life-cycle assessment were assigned to either Switzerland or abroad.[30]

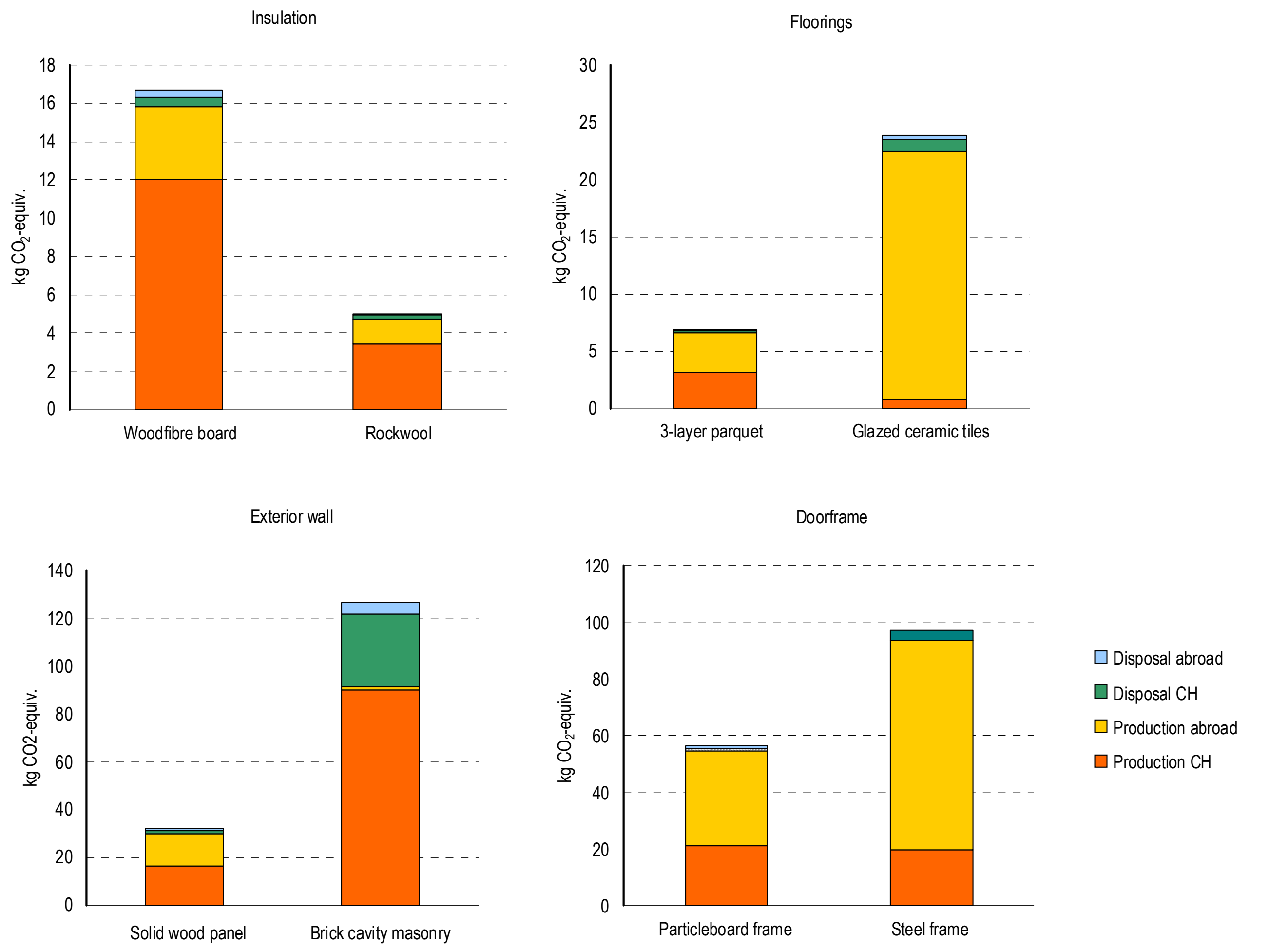
Wood products generally require fewer fossil fuels

The effect of the building component substitution is specified in terms of CO_2 equivalent. This means that all greenhouse-relevant emissions, which are weighted on the basis of their greenhouse gas potential,[31] are added up and specified relative to the CO_2 effect.

As demonstrated by Fig. 8, the substitution effects of wood products prove to be highly varied in reality.

26 SIA 1995, updated on the basis of Biedermann, Carlucci *et al.* 1999.
27 For specific literature, see Werner 2006; Werner, Taverna *et al.* 2006; Hofer, Taverna *et al.* 2002c.
28 The manufacture of wood products generally requires less fossil fuels than that of functionally equivalent products based on other materials.
29 The light wood structures generally require less fossil fuels for transport and waste disposal.
30 The self-imposed target of the clear classification of 90 percent of the emissions was significantly exceeded for most products.
31 IPCC 1996.

Fig. 8 > Greenhouse gas profiles of various functionally equivalent products



Werner, Taverna et al. 2006.

In general, the greenhouse gas emissions from wood products are actually lower than those of functionally equivalent products manufactured using other construction materials.

However, the opposite case, whereby the wood product generates higher emissions also arises, for example, in the case of insulation materials. Moreover, it is possible that the manufacture of a wood product in Switzerland will involve the consumption of more fossil fuels than that of its substitute although, from a global perspective, the wood product releases significantly less greenhouse gases (for example in the case of floor coverings because tiles are not manufactured in Switzerland).

The following orders of magnitude may be specified as a rule of thumb for the effect of material substitution: per m³ of wood, around 700 kg CO_2 may be saved, of which around 300 kg is saved in Switzerland.[32]

The substitution factors per construction component are listed in Annex 7.

2.4.2 The substitution of fossil fuels

Substitution effects of energy recovery from wood

Fossil fuels can be substituted through energy recovered from fuel wood, wood residues and waste wood. In the calculation of this energy substitution effect, it was assumed that oil and gas heating systems are being substituted.[33]

Various substitution effects are identified in the generation of energy from wood:

> fuel wood, wood residues and scrap Swiss wood. In this instance, substitution effects arise both in Switzerland and abroad (e.g. through the avoidance of the emissions generated in the supply of fossil fuels);
> domestic use of wood residues from production which arise in the processing of imported semi-finished products; as in the above case, substitution effects arise both in Switzerland and abroad;
> foreign use of exported Swiss wood whereby the substitution effect only arises abroad;
> foreign use of wood residues abroad arising from the pre-processing of wood products for importation.

A CO_2-saving of 600 kg CO_2 equivalent per m³ of wood was assumed in the estimation of the use of wood for energy generation. Of this, at least 480 kg CO_2 equivalent per m³ of wood is saved in Switzerland.[34] Based on these figures, specific substitution factors were deduced for each type of wood used to generate energy.[35]

2.4.3 The effects of material substitution from the foreign trade

Foreign trade shifts substitution effects

A detailed description of the deduction of substitution factors for the categories modelled as import/export fluxes, i.e. "roundwood/wood residues," "semi-finished products," "three-quarter-finished products" and "houses/furniture" can be found in Annex 6.

In addition, 40 t CO_2 were attributed to Switzerland for 2000 km transport in an HGV;[36] in the case of imports the CO_2 arising from transport is attributed to countries abroad.

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32 These values vary according to the proportion of total wood use represented by wood products; the figures are based on wood use in the *Optimized Growth, Building* scenario.
33 Weighted in terms of their share of Switzerland's total energy consumption on the level of useful energy; for details, see Werner and Richter 2005b.
34 Werner and Richter 2005b.
35 Werner 2006.
36 A sensitivity analysis revealed that transport length is not particularly sensitive.

3 > Current Stocks and Fluxes in the Swiss Forestry and Timber industry

The C stocks and fluxes for the year 2000 are presented in this chapter in terms of an initial or current status. The stock and flux values are always specified in CO_2 equivalent.

3.1 Current C stocks and fluxes in the Swiss forest

3.1.1 Current C stocks in the Swiss forest

Composition of the C stocks in the Swiss forest

The C stocks in the Swiss forest (forest C stocks) are composed of the living tree biomass (biomass above and under the ground), the dead organic matter and the C content of the soil (cf. Tab. 6).

Tab. 6 > Definition of the C stocks in the forest

Stocks		Description
Living biomass	Aboveground biomass	Stem, stump, branches, brushwood, leaves/needles
	Belowground biomass	Roots
Dead organic matter	Dead wood	Standing or fallen dead wood, exceeding 7 cm in diameter
	Slash/litter	All non-living biomass, diameter less than 7 cm
Soil	Organic soil matter	Organic carbon in mineral soils

The living tree biomass is composed as follows (cf. Tab. 7).

Tab. 7 > Composition of the living tree biomass[37]

Stemwood with bark, with stump	100 %	Of which: stemwood without bark, without stump: 85 % bark: 10 %, crown: 2.3 %, stump: 2.7 %
Roots	31 %	
Needles/leaves	4 %	
Branch brushwood	12 %	
Branch compact wood	3 %	
Total living tree biomass	**150 %**	
Potentially utilizable: stemwood in the bark, without stump + branch compact wood + branch brushwood	112 %	

37 For the derivation of this presentation, see Thürig 2005b.

The WSL specifies a stock of living tree biomass of 250 t/ha or 267.5 million t biomass dry matter for all of Switzerland for the year 2000.[38] This corresponds to 490 million t CO_2 for all of Switzerland.

In the year 2000, there were 111 t C/ha or 118 million t C stored in and on the forest soil in all of Switzerland. This corresponds to 435 million t CO_2.

Fig. 9 > C stocks in the Swiss forest in the year 2000

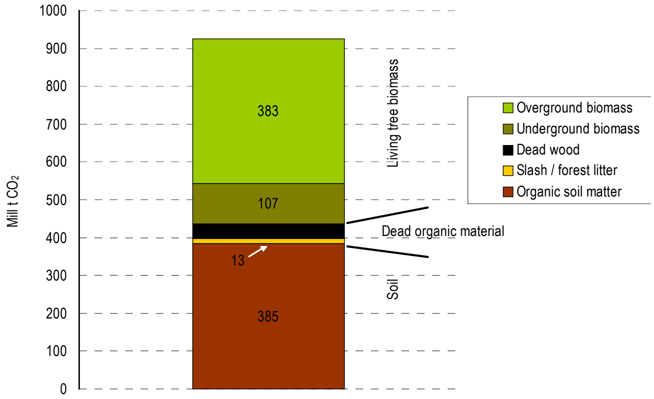
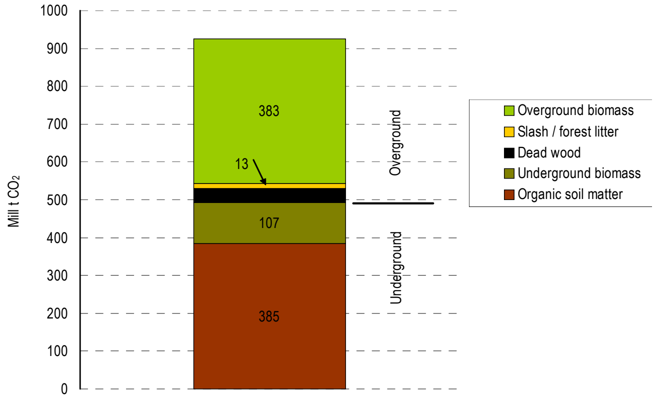


Fig. 10 > C stocks in the Swiss forest in the year 2000 classified on the basis of belowground and aboveground components



A total of around 925 million tonnes of CO_2 are stored in the Swiss forest, including its soil. Therefore, somewhat more C is stored in the living tree biomass than in the dead organic matter and in the soil (cf. Fig. 9). Fig. 10 presents the same figures again, but divided into aboveground and belowground C stocks. This diagram demonstrates that the belowground and aboveground C stocks are more or less equal in size.

[38] Source: unpublished data provided by Edgar Kaufmann, WSL.

3.1.2 Current C fluxes in the Swiss forest

C fluxes in the Swiss forest

The C fluxes in the Swiss forest are composed of both natural (e.g. increment, mortality) and exogenous (e.g. harvesting) fluxes. Tab. 8 shows the figures for the year 2000 adjusted for the effect of Storm Lothar. For purposes of comparability, the C volumes are converted into million t CO_2.

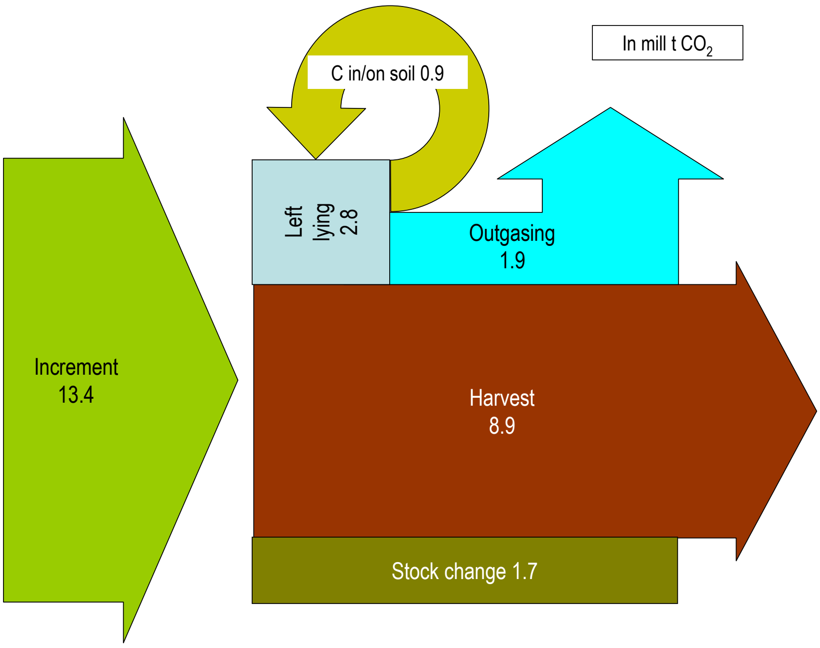
Tab. 8 > C fluxes in the Swiss forest in the year 2000 (adjusted for effect of Storm Lothar)[39]

Flux[1]	Sub-fluxes		Volume [mill t CO_2]
Gross increment			13.4
Total utilization	Harvest		–8.9
	Mortality + trees left lying	in/on soil	–0.9
		Outgasing	–1.9
Stock change			1.7

[1] All fluxes and the stock change in living tree biomass are specified.

The gross increment includes all of the living biomass here. "Harvest" refers to the wood that is taken from the forest. "Outgasing" refers to the volume of CO_2 that escapes into the atmosphere through decomposition processes in the wood left lying on the ground and the forest soil. The C fluxes in the forest are represented schematically in Fig. 11.

Fig. 11 > Schematic representation of the C fluxes in the forest



[39] Kaufmann and Taverna 2007.

3.2 ## Current wood stocks and fluxes in the Swiss technosphere

3.2.1 ### Current C stocks in the Swiss technosphere

C stocks in the Swiss technosphere

To enable the estimation of the wood stocks in the technosphere, reference is made to Fig. 5. The wood stocks are named and quantified in Tab. 9.

Tab. 9 > C stocks in the Swiss technosphere in the year 2000

Stock	Sub-stock	Volume [mill t CO_2]
Timber industry	Sawmills, wood panelling works etc.	6.7[1]
Building stock incl. construction sector	Structure	48
	Finish	22
	Wood products	6.8
Waste wood sector	Waste wood stocks	1.7
Paper sector	Paper consumption (stocks)	8.0
Energy sector	Fuel wood	7.8
TOTAL		101

[1] Authors' assumption: the volume of stored wood in the sawmills, wood panelling works etc. corresponds to a double year's production
Source: Hofer, Morf et al. 2001; Hofer, Taverna et al. 2002a.

Construction sector the most important C repository

Converted to CO_2, there are a total of approximately 100 million tonnes of CO_2 in the Swiss technosphere. This corresponds to a good tenth of the current C stocks in the forest. The building stock, which accounts for over 75 percent of the stored C volume, represents the largest C repository. Equal volumes, i.e. around 8 percent each, are stored in the timber, paper and energy sectors.[40]

Formative role of the past

The current C stocks in the construction centre are largely dictated by the past. Due to the long lifetime of construction products, wood that was used in construction in the early years of the last century is only leaving the technosphere today.

3.2.2 ### Current C fluxes in the Swiss technosphere

C fluxes in the Swiss technosphere

Reference is also made to Fig. 5 regarding the specification of the C fluxes in the Swiss technosphere. The most important C fluxes in the technosphere are presented in Tab. 10.

Stock structure in the construction sector

The largest C fluxes are converted in the timber sector followed by the energy sector. Wherever the input volumes do not correspond to the output volumes, a process fails to establish a balance of flux and a stock change occurs (in all cases here stock increases). This phenomenon mainly involves the construction sector and, to a significantly lesser extent, the energy sector.[41] Thus, the stocks in the year 2000 are not balanced because consumption increased steadily from 1900 and the maximum lifetime is 100 years.

[40] Hofer, Morf *et al.* 2001; Hofer, Taverna *et al.* 2002a.
[41] Cf. lifetimes in Chapter 2.2 and in Annex 2.

Tab. 10 > C fluxes in the Swiss technosphere in the year 2000 and the resulting stock changes

Economic sector		Wood flux	[mill m³]	Volume [mill m³]	Stock change per economic sector [mill t CO_2]
Timber sector	Input	from harvesting	3.6	3.3	± 0
		imports	2.7	2.4	
	Output	exports	2.2	2.0	
		to paper industry	0.93	0.86	
		to construction sector	2.5	2.2	
		to energy sector	0.74	0.68	
Construction sector	Input	structural wood	0.85	0.78	+ 0.56
		finish wood	0.85	0.78	
		new wood products	0.74	0.68	
	Output	waste wood from construction	0.38	0.35	
		waste wood from finishing	0.72	0.66	
		waste wood from products	0.73	0.67	
Waste wood sector	Input	waste wood from construction	0.38	0.35	+ 0.01
		waste wood from finishing	0.72	0.66	
		waste wood from products	0.73	0.67	
	Output	waste wood to energy sector	1.1	1.0	
		waste wood exports	0.73	0.67	
Energy sector	Input	fuel wood from harvesting	1.3	1.2	+ 0.14
		fuel wood from timber sector	0.74	0.68	
		fuel wood from waste wood	1.1	1.0	
		energy from waste paper[42]	0.96	0.88	
		lignin from pulpwood[43]	0.33	0.31	
	Output	incineration	4.2	3.9	

Hofer, Morf et al. 2001; Hofer, Taverna et al. 2002a.

[42] 2.3 m³ of wood is assumed per tonne of waste paper.
[43] 4.5 m³ of raw wood is assumed per tonne of chemical pulp and 2.8 m³ of raw wood is assumed per tonne of mechanical pulp.

4 > Scenarios for Future Harvesting, Use and Processing Policies

4.1 General introduction/brief description

Realistic scenarios in support of climate policy

The purpose of this study is to suggest realistic options for the Swiss forestry and timber industry and demonstrate their effects on the national and global CO_2 budget. The scenarios differ on the basis of forest yields and the use made of the harvested wood. Thus, the yields selected were always smaller than or equal to increment.

Recent demands to increase yield in excess of increment would result in the reduction of the growing stock which, in turn, would give rise to a carbon source in the forest.[44] In terms of the improvement of Switzerland's CO_2 balance this scenario was viewed as incompatible with the defined objectives. Moreover, a new study has shown that the reduction of stocks in the Swiss forest would have negative effects on productivity.[45] For these reasons a scenario involving the reduction of forest stock was not developed.

Constant foreign trade

In order to be able to ignore the effects in forests abroad as far as possible, a constant level of foreign trade based on the year 2000 is assumed. The following scenarios were defined and compared with the corresponding status in the year 2000:

Tab. 11 > Summary of the scenarios

	Initial Value 2000 [million m^3]	Optimized Increment [million m^3]		Kyoto-Optimized [million m^3]	Baseline [million m^3]	Reduced Forest Maintenance [million m^3]
Harvesting[5] Wood harvesting Switzerland	5.0[1]	9.2[2] + 90 %		8.5[2] + 75 %	5.9[2] + 20 %	3.0[2] –40 %
		Construction	Energy			
Consumption Construction, finishing, wood products	2.5[3]	4.5 + 80 %	2.5 ± 0 %	4.5 + 80 %	3.0 + 20 %	1.9 –25 %
fuel wood	1.3[4]	2.8 + 120 %	4.9 + 340 %	2.1 + 65 %	1.5 + 20 %	0.2 –80 %
Foreign trade[6]		Constant		Constant	Constant	Constant
Export	1.4	1.4		1.4	1.4	1.4
Import	2.2	2.2		2.2	2.2	2.2

1 Based on forest statistics for the year 2000.
2 Harvestable volumes of wood: compact wood, bark, branches, see Annex 4.
3 Hofer 2004.
4 BfS/BUWAL 2000.
5 Due to wood residues, the amount of wood consumption and foreign trade can not be summed up to the harvesting amount
6 OZD 2001; minus mechanical and chemical pulp, paper and paperboard.

44 Fischlin, Buchter *et al.* 2003; Fischlin, Buchter *et al.* 2006.
45 Kaufmann 2006.

It was assumed that the relevant changes in consumption and production take place between 2000 and 2030 and therefore follow a logistical curve. Consumption figures were left constant from 2030. Due to the lengthy duration of stock formation for long-lived wood products in the technosphere and the long-term processes in the forest, the development of the different stocks was observed over 150 years in the technosphere and over 100 years in the forest.[46]

Change in consumption from 2000 to 2030

4.1.1 Wood harvesting scenarios

Definition of forest area and increment

The effects of different forest management approaches are examined in the development of the forest scenarios. The changes from the previous approaches to new forms of intervention and management intensities are implemented for the period 2000 to 2030. The defined harvesting level is continued from 2030 to the end of the 21st century. The perimeter adopted was accessible forest in Switzerland, not including shrub forest. The 1.07 million hectares under forest in both 1984 and 1994 were taken into consideration. The resulting increment was expressed in terms of harvestable yield, i.e. bole wood, branch compact wood, bark and brushwood (see also Annex 4).

The defined and evaluated scenarios were based on the following forest maintenance strategies:

Optimized Increment

Maximum increment, equal age-class distribution

The aim of this scenario is to maximize increment performance in the forest in the long term through appropriate management. This is achieved through the selection of suitable turnover periods (cf. Tab. 12) and consistent regeneration in the uniform (even-aged) high forest. This created equal age-class distribution after one turnover period. Only half as many trees are removed during thinning (intervention up to final harvest) as in the Baseline scenario. The non-uniform high forest is managed in the same way as it is in the Baseline scenario. Considerably larger volumes of brushwood and bark are removed from the forest for energy use than in the Baseline scenario. As a result, smaller volumes of logging slash and bark remain in the forest.

Tab. 12 > Optimized turnover periods

Low/moderate location quality (up to 2250 kg/(ha*year))	Jura and Central Plateau Pre-Alps Alps	120 years 140 years 170 years
Low/moderate location quality (2250–4500 kg/(ha*year))	Jura and Central Plateau Pre-Alps Alps	100 years 120 years 150 years
Very good location quality (over 4'500 kg/(ha*year))	Jura and Central Plateau Pre-Alps Alps	80 years 100 years 130 years

46 Hence, the extrapolation of the results of NFI I and II for 100 years resulted in the culmination of the combined consideration of forest and wood in 2096.

Kyoto-Optimized

Higher increment and increased stock

The aim of this scenario is to combine the two forest functions of wood production and carbon sinks. In addition to optimum increment, the growing stock would be increased annually by the volume that may be accounted under the Kyoto protocol. Thus, a stock increase of 65 m^3/ha or 1.5 m^3/(ha*year) would mean that forest sink effects of 1.8 million t CO_2 could be accounted by Switzerland up to the year 2012 (and over 40 years beyond this). The additional aim here is to achieve equal age-class distribution in the uniform high forest over the course of one turnover period. Approximately 6 percent of the productive forest is classified as protected forest area and islands of old growth. The targeted stock increase of 1.5 million m^3 of stemwood with bark per year is achieved through a gradual reduction of thinning. Considerably larger volumes of brushwood and bark are removed from the forest for energy use than in the Baseline scenario. As a result, smaller volumes of slash and bark remain in the forest. Despite (or because of) reduced thinning interventions, there is an increase in (final) harvest volumes because there is more wood in the cleared areas due to the reduced thinning.

Baseline

Continuation of previous management approach

The forest is managed in the years to come in the way observed on the basis of the two national forest inventories, i.e. NFI I (1983–85) and NFI II (1993–95). This conclusion relates, in particular, to the probability with which the individual tree in a specific stand with its structure and age will be harvested in the follow-up periods. The probability of storm activity and damage are adapted to the post-Lothar situation. The outcome involves a moderate increase in harvesting.

Reduced Forest Maintenance

Maximum carbon sinks in the forest

The aim of this scenario is to maximize the effect of forests as carbon sinks for the purpose of optimizing the contribution of the forests to the alleviation of climate change and the reduction of CO_2 emissions. Forest management in protective mountain forests is reduced to a minimum level to conserve their protection capacity. The high level of increment and low level of harvesting gives rise to a significant increase in growing stock. The increase in growing stock is finally halted through increased mortality. With time, the growing stock is reduced naturally. Finally, the increased decomposition of forest litter and dead wood in the stands gives rise to high CO_2 emissions.

4.1.2 Wood use scenarios

Incorporation of market analyses and construction activity

The volumes of wood made available by the wood harvesting scenarios provide the basis for the different wood use scenarios. To facilitate the development of realistic scenarios for wood use, market analyses on the potential of wood in the building sector[47] and in the area of wood energy[48] were consulted and predictions on construc-

[47] Quetting, Wiegand *et al.* 1999; Wiegand and Quetting 1999a; Wiegand and Quetting 1999b.
[48] BFE 2006.

tion activity[49,50] were also incorporated. The changes in wood consumption arising from the scenarios occur from 2000 to the year 2030 and are kept constant thereafter. The changes in consumption follow a logistical curve. The allocation of the quantities of building components was undertaken on the basis of the sub-categories specified in Chapter 2.4.1 The current and future market shares are listed in Annex 3. An effort was made to ensure that wood consumption per building component remains realistic.[51]

Omission of the effects of the paper cycle

The foreign trade in paper and paperboard, which is already almost equally balanced today, becomes fully balanced by the year 2030 and, like other forms of consumption, is kept constant thereafter. As opposed to this, foreign trade in mechanical pulp and chemical pulp are far from balanced as a clear import surplus exists in this case.[52] However, like the other categories of foreign trade, this one was also kept constant in the scenarios. The procedure for the paper and cardboard industry was applied in the same way in all scenarios. Therefore, the effects of the paper cycle can be factored out.

Constant foreign trade

To be able to disregard the influences on foreign forests, it was generally assumed that the level of foreign trade remains constant as compared with current levels (year 2000).

4.2 The scenarios in detail

The scenarios (and other sub-scenarios) are described in detail in Annexes 3 and 4.

[49] Wüest, Schweizer *et al.* 1994; Arioli, Haag *et al.* 1997 and oral statements from the construction sector, 2001.
[50] SBV 1997.
[51] Hofer, Morf *et al.* 2001; Hofer, Taverna *et al.* 2002a; Hofer, Taverna *et al.* 2002b.
[52] ZPK 2003.

4.2.1 Optimized Increment scenario

Hypothesis for optimum CO_2 effect

This scenario is based on the working hypothesis specified at the outset of the study, i.e. that the increment in the Swiss forest should be as extensive as possible and should be used entirely for the production of long-lived wood products with subsequent end-utilization for energy generation.

Variant a) Optimized Increment BUILDING

Consumption:	Strong increase in the consumption of structural wood, finish wood and wood products of 80 percent as compared to today's levels, i.e. 4.5 million m³/year.
	Strong increase in the consumption of fuel wood, i.e. a good 120 percent to 2.8 million m³/Jahr.
Wood harvest:	84 percent increase in harvest to 9.2 million m³/year.
	Of which, 8.0 million m³/year from logged compact wood (wood with a diameter in excess of 7 cm) + 1.2 million m³/year of bark and brushwood, mainly used in energy generation. Together with natural losses, around 20 percent of a tree remain in the forest.
Domestic production:	Strong development of domestic timber industry.
Foreign trade:	Foreign trade constant based on current levels.

Variant b) Optimized Increment ENERGY

Consumption:	Constant consumption of structural wood, finish wood and wood products as compared with today.
	Very significant increase in the consumption of fuel wood, i.e. over 340 percent to 5.6 million m³/year.
Wood harvest:	84 percent increase in harvest to 9.2 million m³/year.
	Of which, 8.0 million m³/year from logged compact wood + 1.2 million m³/year bark and brush-wood, mainly used in energy generation. Together with natural losses, around 20 percent of a tree remain in the forest.
Domestic production:	No development of the domestic timber industry.
Foreign trade:	Foreign trade constant based on current levels.

Optimized Increment	
The forest is permanently managed to produce maximum increment. The resulting **9.2 million m³/year** of industrial roundwood and fuel wood are harvested in full.	
Development: Building	**Development: Energy**
More wood used in construction (including furniture etc.) (+80 %) More forest wood for energy generation (+122 %) No change in foreign trade	No change in construction (including furniture etc.) (+/- 0 %) Significantly more forest wood for energy generation (+345 %) No change in foreign trade

Autarky scenario

An additional scenario, *Optimized Increment, Autarky,* was developed to facilitate the estimation of the effects of self-sufficiency in wood supply in Switzerland. Given that far-reaching assumptions concerning foreign forests had to be made in the case of this scenario, which were difficult to estimate in part, and in view of the fact that the closure of Swiss borders to trade is viewed as an unlikely event, the results of this scenario are dealt with separately in a special sub-chapter (Chapter 5.5.3) (cf. also Annexes 3 and 4).

4.2.2 Kyoto-Optimized scenario

Sink/harvest compromise

The *Kyoto-Optimized* scenario is intended to present a compromise between the need for forest sinks based on the Kyoto Protocol and the need for the optimum use of wood by the forestry and timber industry. In order to provide the forest sink services that may be accounted in the first Kyoto commitment period (2008–2012), mean growing stock must increase by around 1.5 m^3 per hectare and year. Under the following preconditions, forest increment and harvesting can be optimized and the Kyoto sink policy fully exploited for the next 40 years:

1. The sink potential of 1.8 million t CO_2/year that may be accounted in the first commitment period remains the same for the subsequent commitment periods;
2. The wood stocks in the forest are increased each year by the volume that may be accounted in accordance with the Kyoto Protocol.

As in the case of the *Optimized Increment* scenario, priority regarding the use of the additional volumes of wood was given to the construction sector and direct energy use. The effects of the energy scenario run parallel to the results of the *Optimized Increment, Energy* scenario but on a slightly lower level. For reasons of clarity, therefore, these results are not presented below (cf., however, Annex 3 and 4).

Consumption:	Very significant increase of 80 percent in the consumption of structural wood, finish wood and wood products as compared with today's levels to 4.5 million m^3/year.
	Increase of a good 65 percent in the consumption of fuel wood to 2.1 million m^3/year.
Wood harvest:	70 percent increase in harvest to 8.5 million m^3/year.
	Of this, 7.4 million m^3/year from logged compact wood + 1.1 million m^3/year bark and brushwood, mainly used in energy generation. Together with natural losses, around 20 percent of a tree remain in the forest.
Domestic production:	Clear development of the domestic timber industry.
Foreign trade:	Foreign trade constant based on today's levels.

Kyoto-Optimized
Wood harvested in a way that creates large C sinks while simultaneously generating significant increment. **8.5 million m^3/year** of industrial roundwood and fuel wood are removed from the forest annually.
More wood used in construction (including furniture etc.) (+80 %) More forest wood for energy generation (+67 %) No change in foreign trade

4.2.3 Baseline scenario

Continuation of existing trends

This scenario describes the perpetuation of the *status quo* through the retention of current trends:

Consumption:	20 percent increase in the domestic production of structural wood, finish wood and wood products as compared with today corresponds to 3.0 million m³/year.
	20 percent increase in the use of fuel wood to 1.5 million m³/year.
Wood harvest:	18 percent increase in wood harvest to 5.9 million m³/year.
	Of this, 5.4 million m³/year from logged compact wood + 0.5 million m³/year bark and brushwood, mainly used in energy generation. Together with natural losses, around 40 percent of a tree remain in the forest.
Domestic production:	Development of the domestic timber industry.
Foreign trade:	Foreign trade constant based on today's levels.

Baseline
Wood harvesting in the **forest** increases in the following 30 years by around 20 % to **5.9 million m³/year** of industrial roundwood and fuel wood.
Slightly more wood used in construction (+21 %) Slightly more forest wood available for energy generation (+22 %) No change in foreign trade

4.2.4 Reduced Forest Maintenance scenario

Sink forest

This scenario demonstrates the effect of a significant reduction in wood harvesting as compared with today's volumes and a pared-back domestic timber industry.

Because current consumption levels cannot be sustained with foreign trade remaining constant and a significant reduction in domestic harvesting, consumption must be adapted to the volumes of wood available. This means that significantly less wood is available to the construction and energy sectors.

Consumption:	As compared with today, 24 percent reduction, i.e. 1.9 million m³/year, in the consumption of structural wood, finish wood and wood products.
	Very significant reduction in the consumption of fuel wood by a good 80 percent to 0.24 million m³/year.
Wood harvest:	40 percent reduction in harvest, i.e. 3.0 million m³/year.
	Of this, 2.8 million m³/year from logged compact wood and 0.2 million m³/year of bark and brushwood, mainly used in energy generation. Due to the high level of natural losses, a good 60 percent of a tree remain in the forest.
Domestic production:	Considerable weakening of the domestic timber industry.
Foreign trade:	Foreign trade constant based on today's levels.

Reduced forest maintenance
Annual harvest in the Swiss **forest** is reduced by 40 % to **3.0 million m³/year** of industrial roundwood and fuel wood.
Significantly less wood used in construction (-24 %) Far less forest wood available for energy generation (-81 %) No change in foreign trade

5 > The CO_2 Effects of the Scenarios in Switzerland

The more negative, the better

Because the graphics presented below demonstrate the greenhouse-gas reduction effects, the following principle applies: the more negative the values the greater the reductions, and the more positive the values the greater the additional emissions. The changes per year and the total (cumulative) values over the years are demonstrated.

Climate-relevant effects

Four climate-relevant effects can be identified in the area of forest and wood harvesting:

> the formation of C stocks in the forest;
> the formation of C stocks in wood products;
> the material-related substitution effects from the use of wood in place of other materials;
> energy substitution from the use of wood in place of fossil fuels.

The individual CO_2 effects, how they relate to Switzerland and some economic issues are explored in detail in the following sections.

5.1 The Swiss forestry sector

5.1.1 Change in growing stock

Different harvesting strategies

The results of the changes in growing stock in the forest reflect the different approaches to harvesting in the scenarios. Thus, the *Reduced Forest Maintenance* scenario produces the best values by a clear margin, because in this case the main focus is on the development of C stocks in the forest. The lowest stock changes are found in the *Optimized Increment* scenario as in this case the increment is fully exhausted or used for energy generation where possible. It is interesting to note, however, that even with this harvesting strategy, the growing stock in the forest still increase by up to 4 million t CO_2 or 4 m³/ha and year and the best annual stock changes arise at the end of the period under consideration (cf. Fig. 12[53]).

[53] The significant fluctuations in the graph are due to the shift from the extremely imbalanced age classes in the regions and location quality categories to a balanced age class distribution in the year 2000. Thus it is possible, for example, that in the *Optimized Increment* scenario a large volume of wood is also logged in the years 2050 to 2070.

Fig. 12 > Annual stock change in the standing Swiss forest (living biomass minus effects from slash and natural losses)

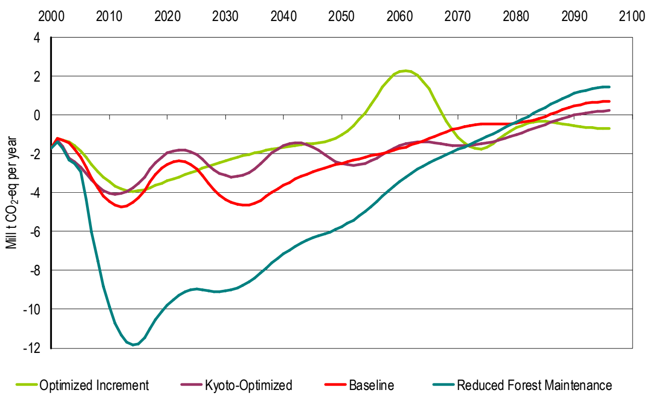
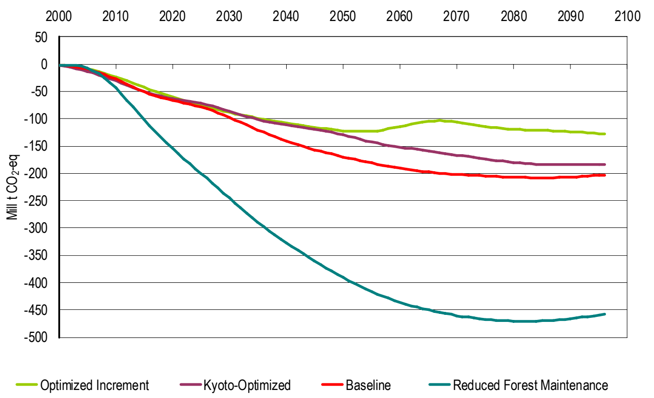


Fig. 13 > Cumulative stock change in the standing Swiss forest (living biomass minus effects from slash and natural losses)



The above graphics present the changes in the C stocks of the entire living tree biomass, i.e. stemwood with bark and stump + roots + needles/leaves + branch brushwood + branch compact wood, converted into CO_2 equivalent.

Bad long-term prognosis and significant risk for sink forest

From around 2080, the *Reduced Forest Maintenance* scenario leads to declining growing stock in the Swiss forest due to the increase in natural losses. Thus, the forest becomes a source of CO_2 emissions. This is also true to a lesser extent of the *Baseline* and *Kyoto-Optimized* scenarios. Moreover, due to the less favourable age structure and extensive growing stock, with the *Reduced Forest Maintenance* scenario, there is a clear increase in the risk of forest collapse in the event of storms or other natural disasters. Indeed, in a comparison of the scenarios, this scenario displays the greatest vulnerability to such risks. Thus, the point at which the forest becomes a source of carbon could also arise significantly earlier with the *Reduced Forest Maintenance* scenario.

5.1.2 Effects on the dead wood balance

Effect of lying wood

Wood consisting of slash and natural losses which is left lying on the forest floor leads to an increase in the C stocks in and on the soil (Fig. 14, elongated curves), on the one hand, and to CO_2 emissions due to the emission of C from rotting wood, on the other (Fig. 14, dashed line). Fig. 15 shows the sum of these two annual effects.

C outgassing exceeds C stocks

Outgassing exceeds the increase in the C stocks in and on the soil almost at all times. Thus, despite C stocks, in all of the scenarios, wood left lying on the ground leads to a net increase in CO_2 emissions.

Fig. 14 > Comparison of the annual C effects of dead wood in and on the soil (–) and in the atmosphere (--) in the Swiss forest

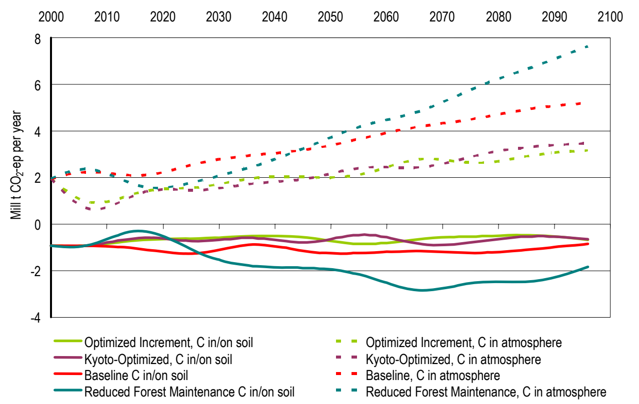
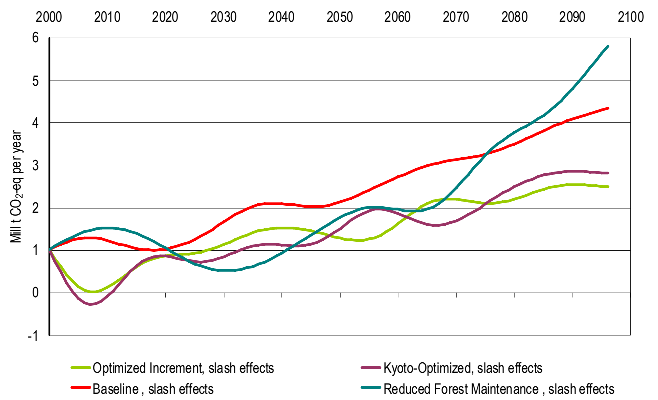


Fig. 15 > Sum of annual C effects of dead wood in the Swiss forest



The *Reduced Forest Maintenance* and *Baseline* scenarios display the poorest results in terms of the sum of the effects of slash and natural losses — this is due to the high proportion of wood left lying on the ground *(Baseline)* and the high mortality towards the end of the century *(Reduced Forest Maintenance)*.

5.1.3 Sum of the effects in the Swiss forest

The actual CO_2 effect of the Swiss forest is demonstrated through the combination of the effects arising from tree growth, harvesting, the natural degradation of slash, natural losses and development of the C stocks in the soil (Fig. 16 and Fig. 17).

Fig. 16 > Annual sum of the effects in the Swiss forest

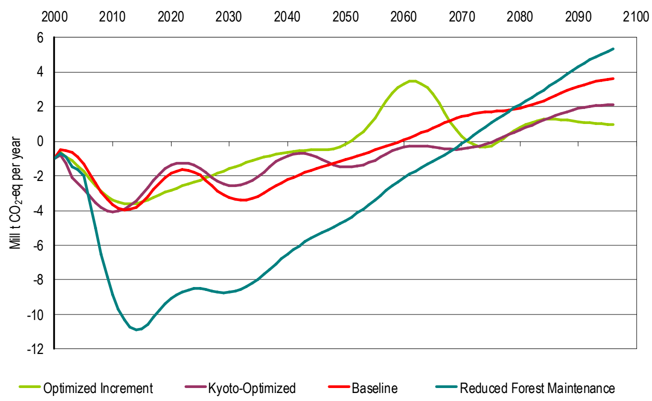
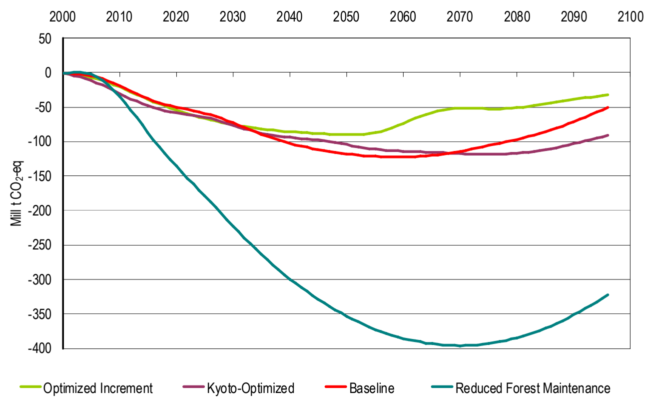


Fig. 17 > Cumulative sum of the effects in the Swiss forest



As shown in the previous section 5.1.2, CO_2 emissions arising from slash and natural losses increase over the course of time. Thus, with all scenarios, the forest in its entirety will become a C source: i.e. from 2050 in the case of the *Optimized increment* scenario, later in the case of the other scenarios. The worst trends in this regard are displayed by the *Reduced Forest Maintenance* and *Baseline* scenarios (cf. Fig. 16).

All forest becomes a C source

When the annual effects are accumulated until the end of the period under consideration (2096), all of the management scenarios have a positive effect, i.e. overall, a CO_2 sink results in the forest as compared with the year 2000 (cf. Fig. 17).

5.2 The Swiss timber industry

To facilitate the optimum demonstration of the mechanisms involved in stock and flux changes in the technosphere, the effects are presented here up to the year 2150.

5.2.1 Stock change in the technosphere

Stock balance

Due to the long residence times of wood used in construction, changes in wood use in the technosphere take effect until around 2130. After this, the wood fluxes in and out of the stocks are balanced, i.e. the same amount of wood fluxes in and out of a stock. The stock changes then aim towards zero (cf. Fig. 18).

Fig. 18 > Annual C stock changes in the domestic technosphere

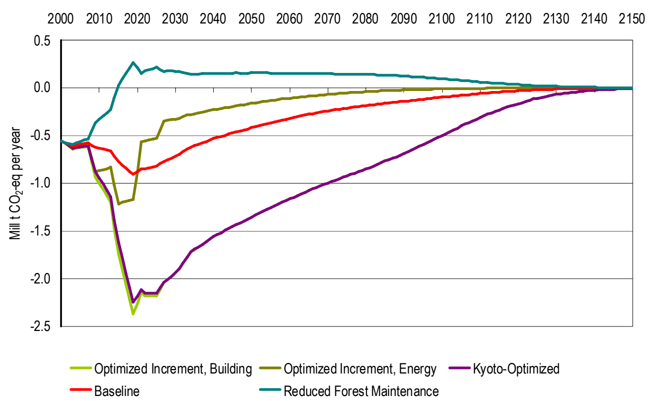
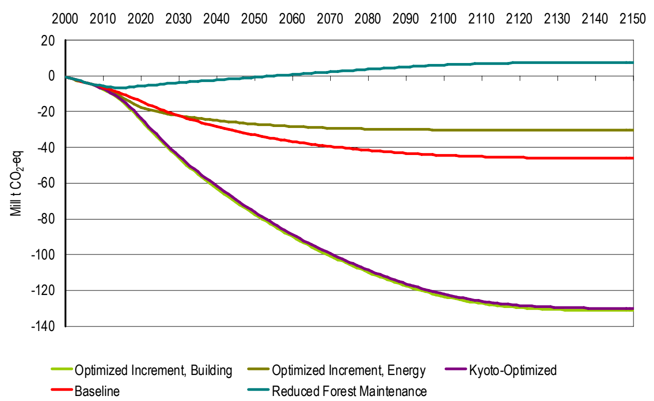


Fig. 19 > Cumulative C stock changes in the domestic technosphere



Large stock effect of building scenarios

In line with expectations, the building scenarios prompt the most significant stock changes in the technosphere. Due to the reduced wood consumption, the *Reduced Forest Maintenance* scenario performs by far the worst here: as compared with the year 2000, the wood stocks in the technosphere actually decrease and a CO_2 source arises. Due to the constant level of wood consumption in the building sector, the Energy scenario also shows a considerably worse CO_2 effect as compared with the Building scenarios.

The comparison of the annual graphs for the Energy scenario with the *Baseline* scenario proves interesting (Fig. 18). Up to 2020, the Energy scenario performs better than the *Baseline* scenario – despite the fact that the level of wood consumption in the building sector in the *Baseline* scenario is significantly higher. The very significant increase in the consumption of fuel wood initially prompts a clear increase in stocks. Fig. 19 demonstrates, however, that as a result of the increased use of construction and other wood products in the *Baseline* scenario, overall there is a greater CO_2 reduction effect from 2030.

The maximum CO_2-saving potential through the formation of C stocks in the building stock cumulates in the building scenarios up to the year 2150 at around 130 million t CO_2. The most significant effects arise around the year 2020 with a maximum of 2.5 million t CO_2 sequestration per year. This corresponds to around 4.5 percent of today's annual greenhouse gas emissions in Switzerland.

5.2.2 Material substitution effects

The domestic material substitution effects are composed of four sub-effects:

1. *the substitution effects of domestic production and waste disposal,* i.e. when domestic non-wood products are replaced with wood products;
2. *the substitution effects from the further processing and use of imported wood products,* i.e. the effects that arise when imported roundwood, partly processed and finished wood products are used in place of domestic non-wood products;
3. *the substitution effects of exports in Switzerland,* i.e. the emissions that arise in the production of products for export;
4. *the transport emissions generated by exports to other countries,* which are assigned to Switzerland as a model assumption (as opposed to the transport emissions caused by imports).

The first two sub-effects cause a reduction in CO_2 while the last two generate additional CO_2 emissions. Because the scope of the CO_2 effects the first two sub-effects is more significant, overall CO_2 savings arise for all scenarios (Fig. 20 and Fig. 21).

Fig. 20 > Annual domestic material substitution effects from domestic wood use

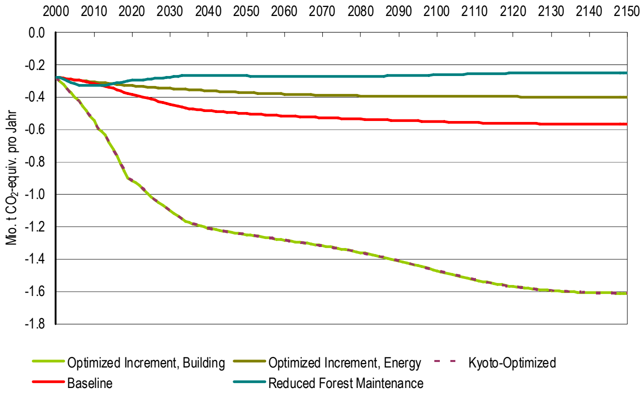
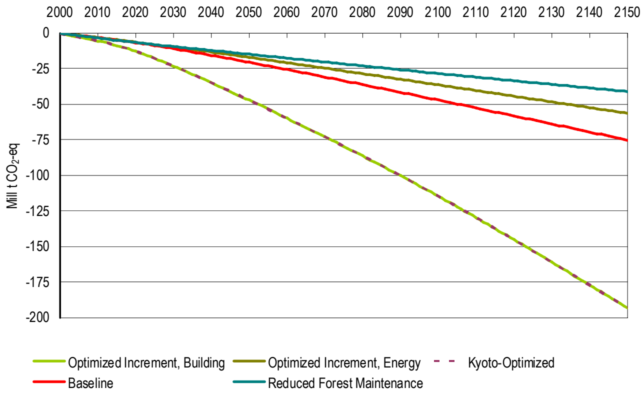


Fig. 21 > Cumulative domestic material substitution effects from domestic wood use



Advantage of the building scenarios

The building scenarios perform best for material substitution because it is here that the greatest proportion of non-wood products are replaced by wood products. Due to the identical levels of wood consumption in the construction sector, the *Optimized Increment, Building and Kyoto-Optimized* scenarios produce the same results. The smallest CO_2 savings in the building sector arise in the *Reduced Forest Maintenance* scenario due to the low level of wood consumption.

The maximum possible savings in terms of CO_2 equivalent totals around 110 million t up to the year 2096 (end of forest modelling) and around 200 million t up to 2150 (cf. Fig. 21)[54]. At around 1.6 million t CO_2 equivalent (i.e. around 3 percent of current CO_2 equivalent emissions), the most significant annual saving effect occurs towards the end of the period under consideration with the increase in the annual substitution effects clearly declining from 2030. This occurs because consumption is treated as constant from 2030. After that only the emission values from waste disposal change. With the attainment of the stock balance around the year 2130, the sum for the annual material substitution is also constant (cf. Fig. 20).

5.2.3 Energy substitution effects

Slight advantage of the energy scenario, astonishing effect of the building scenarios

The temporal course of the CO_2 effects from energy substitution are the same as those of material substitution, however the savings are significantly larger. The comparison of the building scenarios with the energy scenario prove particularly interesting. Initially, and in line with expectation, the energy scenario performs best as the use of forest wood for energy generation is significantly increased from the beginning.

[54] These values relate to the total volumes of harvested wood and not to the additionally harvested volumes as compared with the year 2000.

From around 2100, the *Optimized Increment, Building* scenario provides the best results (cf. Fig. 22). Overall, the *Optimized Increment, Energy* scenario performs best due to the high CO_2 reduction effects at the beginning of the period under consideration (cf. Fig. 23). In the long term, however, the building scenarios perform more or less as well as the energy scenario because the volume of waste wood used to generate energy that becomes available increases over time.

Because increasing volumes of wood residues from production are also utilized for energy purposes on a continuous basis, the differences between the building and energy scenario are less significant than initially expected. In line with expectation, due to the low volumes of fuel wood and wood residues produced, the *Reduced Forest maintenance* scenario performs worst.

Fig. 22 > Annual domestic energy substitution effects from domestic wood use

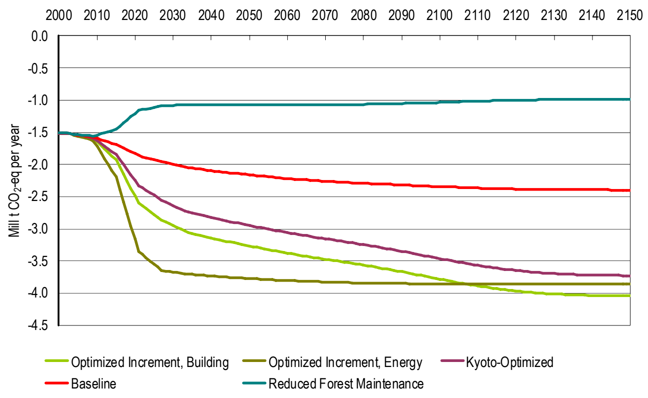
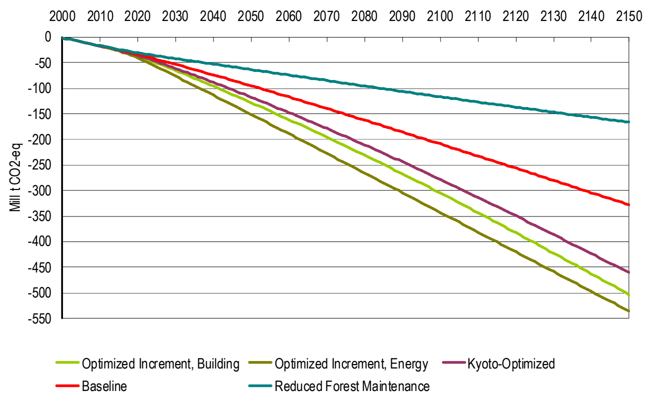


Fig. 23 > Cumulative domestic energy substitution effects from domestic wood use



Given that the stock changes in the case of fuel wood endure beyond the year 2130 (waste wood flux), due to the extensive lifetimes of structural wood, the energy substitution effects also attain constant values at a very late stage (cf. Fig. 22).

The maximum possible effects are attained towards the end of the period under consideration with annual savings of around 4 million t CO_2 savings achieved. This corresponds to a good seven percent of current annual CO_2 equivalent emissions. A maximum of just under 550 million t CO_2 equivalent can be saved with the *Optimized Increment, Energy* scenario.[55]

55 These values relate to the total volumes of harvested wood and not to the additionally harvested volumes as compared with the year 2000.

5.2.4 Sum of the effects of the technosphere

The sum of the effects of the technosphere is composed of the individual effects of the wood stock changes and of material and energy substitution.

Ranking of the scenarios

When the scenarios are compared, the building scenarios clearly emerge as the strongest performers. As a result of the decline in wood consumption in the *Reduced Forest Maintenance* scenario, the CO_2 balance actually deteriorates as compared with today's status.

Fig. 24 > Sum of the annual CO_2 effects in the technosphere in Switzerland

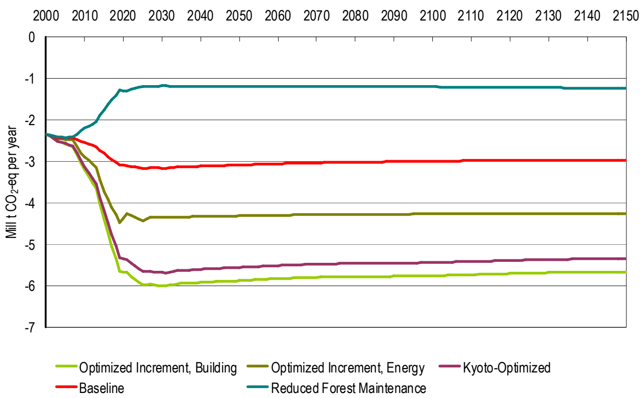
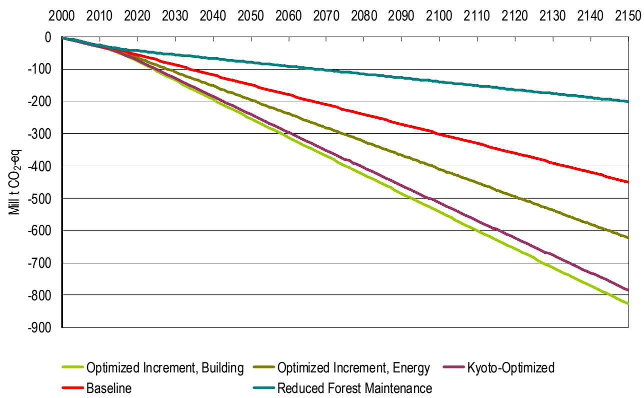


Fig. 25 > Sum of the cumulative CO_2 effects in the technosphere in Switzerland



The effects of the technosphere give rise to maximum savings of six million t CO_2 equivalent in total, which corresponds to 12 percent of current CO_2 equivalent emissions. This saving is attained from around 2025 and largely sustained throughout the entire period under consideration (cf. Fig. 24).

Thus, in this way, a good 500 million t CO_2 equivalent can be saved up to 2096 and 800 million t CO_2 equivalent up to the end of the period under consideration, i.e. in the year 2150.[56]

[56] These values relate to the total volumes of harvested wood and not to the additionally harvested volumes as compared with the year 2000.

5.3 Contribution and temporal dynamic of the individual CO_2 effects in Switzerland

As a next step it is interesting to compare the areas of forestry (living biomass + dead wood/brushwood and soil carbon) and the technosphere (wood stocks + material substitution + energy substitution) with respect to their sink effects.

5.3.1 Comparison of the forest and technosphere

Because the effects of the forest were only modelled up to 2096, in this chapter, the effects of the technosphere are only demonstrated up to this point in time.

Varying importance of the forest

The varying effects of the individual management and use strategies emerge clearly when the effects of the individual scenarios in forestry and in the technosphere are compared. While in the *Reduced Forest Maintenance* scenario the CO_2 effects are considerably more significant in the forest than in the timber industry, in the other scenarios the forest effects are subordinate in their significance (cf. Fig. 26 and Fig. 27).

Fig. 26 > Comparison of the total annual CO_2 effects in the forest (–) and in the technosphere (--) in Switzerland

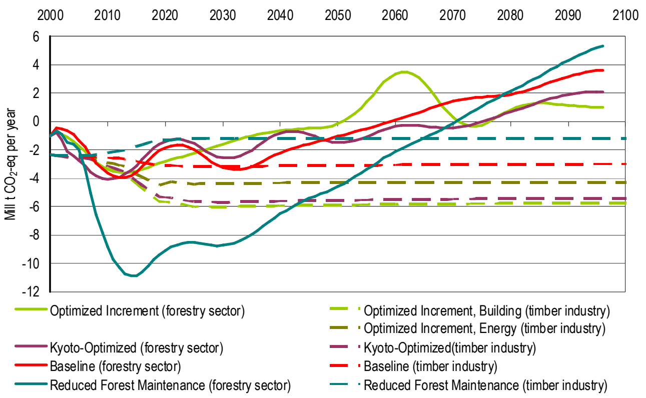
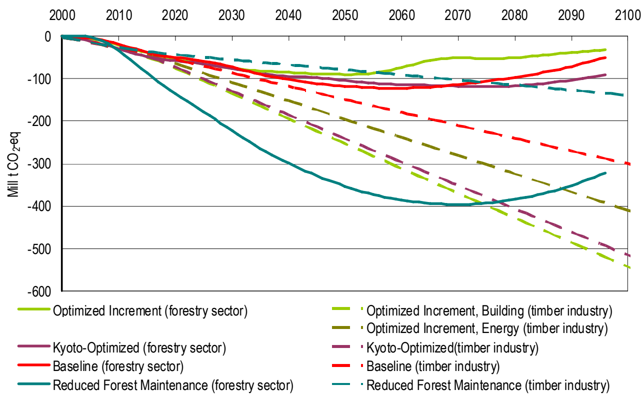


Fig. 27 > Comparison of the total cumulative CO_2 effects in the forest (–) and in the technosphere (--) in Switzerland



Sustainable substitution effect

It is also very clear that the effects in the technosphere (in particular material and energy substitution) trigger a constant and sustainable reduction in CO_2 levels. As opposed to this, the stock effects in the forest decline and lead to a clear dismantling of the stocks and increasing CO_2 emissions towards the end of the period under consideration (cf. Fig. 26).

5.3.2 Comparisons within the technosphere

The comparison of the effects within the technosphere reveals in part equally significant differences in terms of both quantities and time.

Comparison of wood stocks/material substitution

In the case of the wood stocks, the maximum annual CO_2 effects arise significantly earlier than they do with material substitution (i.e. around 2020) and move towards zero around the end of the period under consideration (cf. Fig. 28 and Fig. 29). As opposed to this, in the case of material substitution, the effects increase constantly but never attain the annual effect of the wood stocks. However, when considered over a period of 150 years, greater CO_2 savings can be achieved through material substitution than by increasing the size of the wood stocks (cf. Fig. 30 and Fig. 31).

Fig. 28 > Annual C stock changes in the domestic technosphere as compared with the year 2000

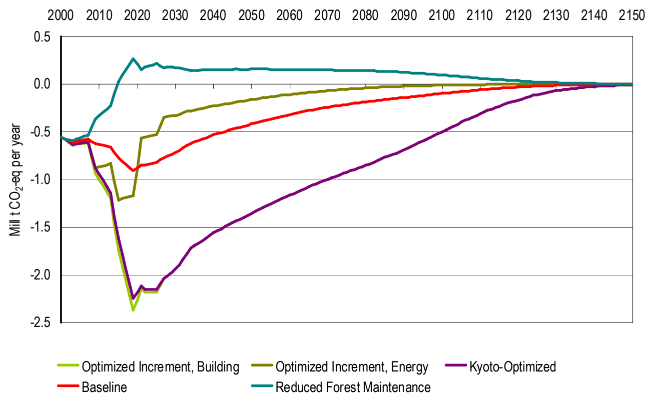


Fig. 29 > Annual domestic material substitution effects from domestic wood use

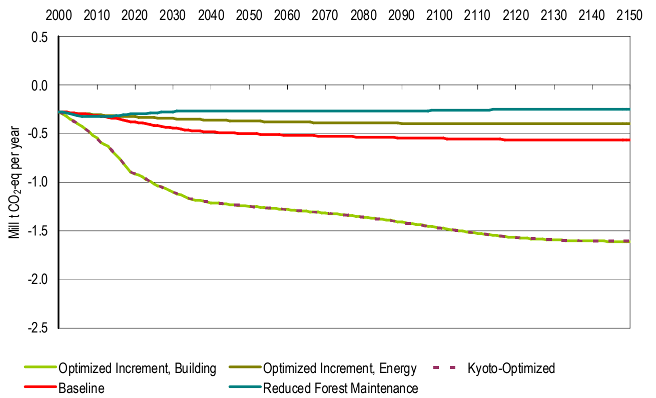


Fig. 30 > Cumulative domestic C stock change in the technosphere as compared with the year 2000

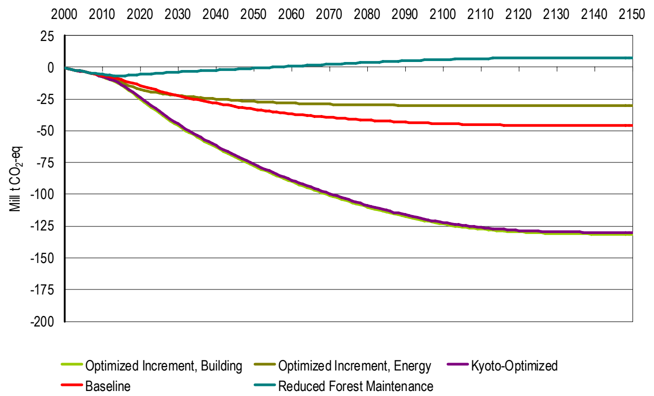
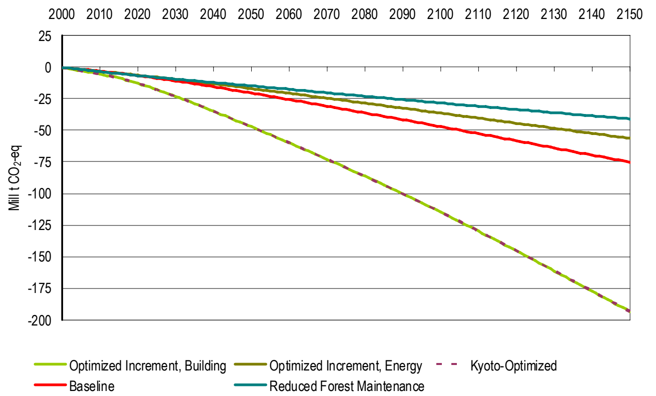


Fig. 31 > Cumulative domestic material-substitution effects from domestic wood use



A comparison of the effects of energy substitution with those of material substitution reveals that the annual domestic energy effects exceed those arising from material substitution by a factor of two (Fig. 32 and Fig. 33).

Energy substitution far more effective than material substitution

Fig. 32 > Annual domestic energy substitution effects from domestic wood use

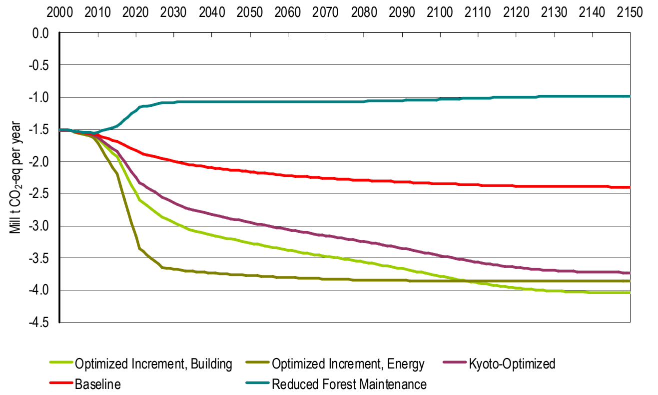


Fig. 33 > Annual domestic material substitution effects from domestic wood use

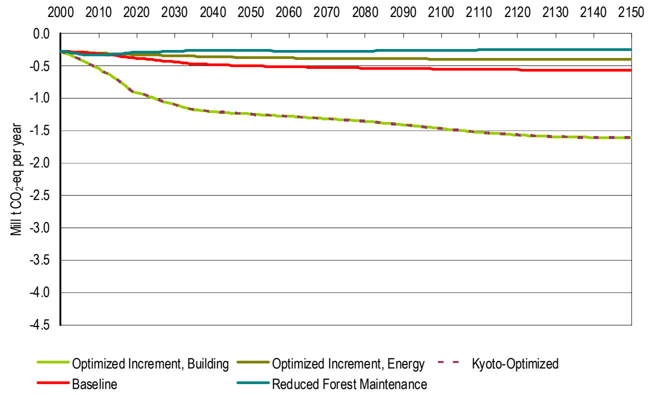


Fig. 34 > Cumulative domestic energy substitution effects from domestic wood use

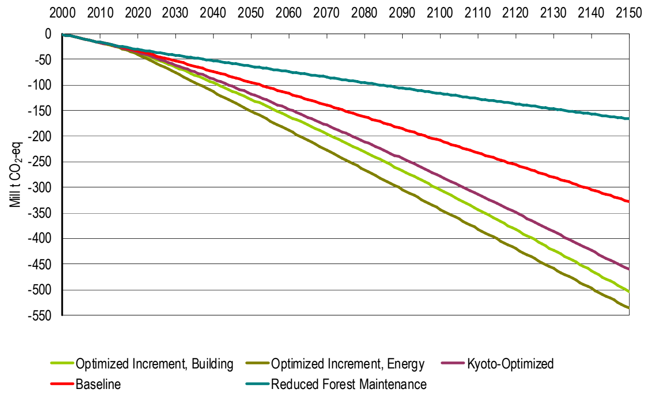
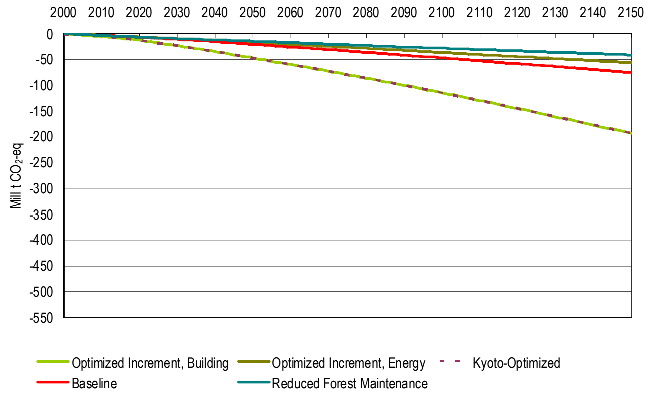


Fig. 35 > Cumulative domestic material substitution effects from domestic wood use



Cumulatively, the effects of material substitution in the year 2150 only amount to around one third of those of energy substitution (cf. Fig. 34 and Fig. 35).

Energy substitution can be combined with building scenario

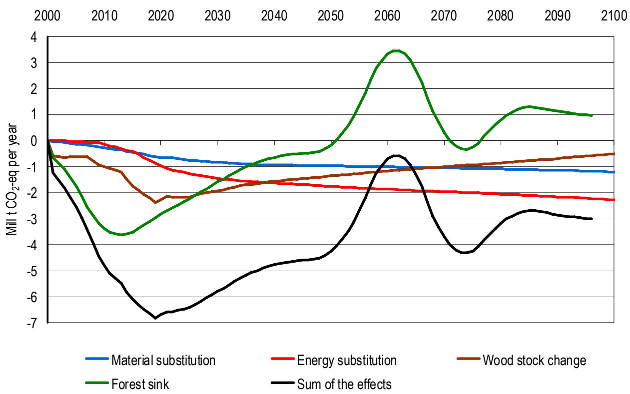
The material substitution effect is far greater in the building scenarios than in the energy scenario. However, the energy substitution effect is almost identical for both scenarios. This is the case because when wood is used for material purposes, its energy use is only temporarily delayed (energy recovery from waste wood) and wood residues are generated in the manufacture of wood products which are used immediately for the generation of energy (on this point cf. also 5.2.3). As opposed to this, the direct use of wood for energy purposes does not have any material substitution effects. Thus, the energy scenario gives clearly poorer results here.

5.3.3 Temporal sequence of the CO_2 effects based on a scenario

Effects from the year 2000

It is possible to demonstrate the temporal sequence of the CO_2 effect clearly by comparing the annual CO_2 effects from a single scenario (cf. Fig. 36). The effects up to the year 2000 are ignored here. Thus, the only effects demonstrated are those that result from the scenario under consideration *Optimized Increment, Building,* i.e. the additional stock effects and the substitution effects from the additional harvested wood as compared with the year 2000. Therefore, in contrast to the previous diagrams, the effects here start at zero in the year 2000.

Fig. 36 > Temporal sequence of individual annual stock and material effects based on the *Optimized Increment, Building* scenario, related to the year 2000



Clear sequence of the effects

The stock changes in the forest (green line) and in the technosphere (brown line) initially give rise to the most significant CO_2 savings. The joint maximum is attained here between 2015 and 2020. From around 2035, the substitution effects overtake (blue line "Material"; red line "Energy) the stock effects; the stock and substitution effects change places here. The effects peak around the year 2020.

The conspicuous hump for the forest sink originates from the forest model and reflects a temporary decline in growing stock (cf. footnote no. 53). From around 2080, the wood stocks in the forest remain constant; the decomposition of logging slash has a negative effect.

5.4 The sum of the CO_2 effects in Switzerland

Building scenarios the most sustainable; sink scenarios most risky

In terms of the sum of all effects, thanks to the significant long-term forest sink effect (to 2045), the *Reduced Forest Maintenance* scenario provides the most significant CO_2 saving effect in the context of Switzerland, (cf. Fig. 37). However, this does not take into account the fact that under the currently applicable Kyoto provisions only a small part of this increase in the forest sink may be officially accounted for. Furthermore, from around 2075, this scenario generates increasing emissions. This is mainly due to the source-effect of the forest. Because the risk of forest collapse is most significant with this scenario, this effect could also arise far earlier. In addition, it must also be taken into account that in this scenario the future consumption of wood in the construction and energy sectors is significantly scaled back. This means that either future building activity and energy use must be reduced (as assumed in this study) or that the missing wood is provided by non-wood products and fossil fuels. This involves an additional and very significant deterioration in the balance for the *Reduced Forest Maintenance* scenario. Against this background, the building scenarios emerge as more sustainable variants for Switzerland.

Fig. 37 > Total effects for Switzerland per year

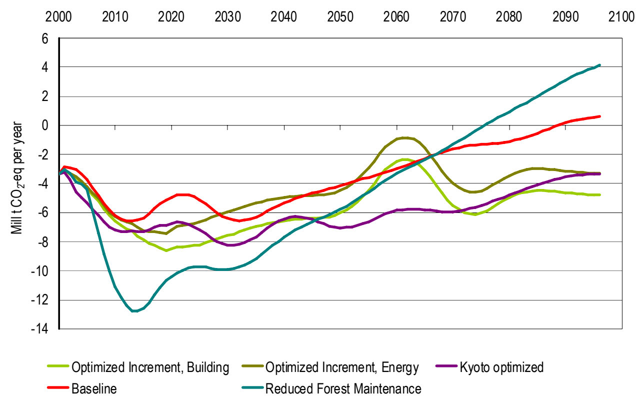
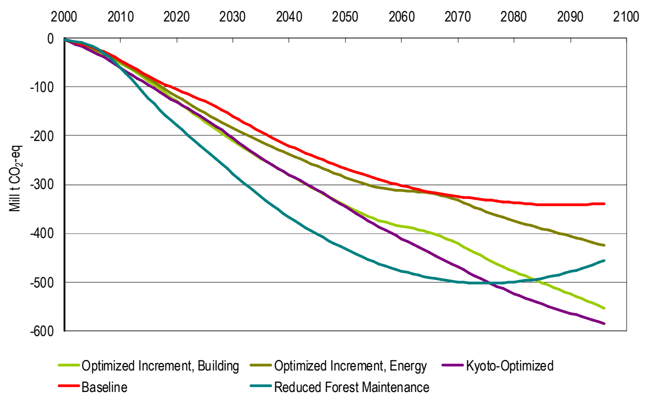


Fig. 38 > Total cumulative effects for Switzerland



Relevant CO_2 effect

With the building scenarios it is possible to save a good 8 million t CO_2 emissions annually around the year 2025 (cf. Fig. 37). This corresponds to around 15 percent of current annual CO_2 equivalent emissions of 52 million t. Thus, it would be possible to make cumulative savings of around 550 million t CO_2 up to the end of this century (cf. Fig. 38)[57] Therefore, the effects discussed here are entirely significant.

Conversion and application of the results in the context of the Kyoto commitments

The results presented in the above graphics and in all of the preceding chapters show the total effects of wood use, including the amount used before the year 2000. In order to determine the *additional* effect as compared with the year 2000, the substitution

[57] These values relate to the total volumes of utilized wood and not to the additionally utilized volumes as compared with the year 2000.

effect of wood use, which was already effective in the year 2000, must be discounted from the demonstrated effects (approximately 1.8 million t CO_2 equivalent).

In terms of the Kyoto Protocol, the additional substitution effects can be accounted from 1990. Moreover, during the first Kyoto commitment period, only the substitution effects from wood use are accounted and increases in the wood stocks in the techno-sphere are not. In addition, under the Kyoto Protocol, Switzerland can only account for the sink effect of the forest up to a maximum of 1.8 million t CO_2 per year. From this perspective, the *Reduced Forest Maintenance* scenario does not represent an expedient option.

Even if it is taken into account that only the additional effect leads to a reduction in CO_2 emissions, with the *Optimized Increment, Building* scenario around three million t CO_2 are still saved. This corresponds to a good five percent of today's CO_2 equivalent emissions. In the short term, over six million t CO_2 can even be avoided which corresponds to around twelve percent of today's CO_2 equivalent emissions.

5.5 The socio-economic effects of the scenarios

The sustainability of forest management and the employment effect are adopted here as indicators of the socio-economic effects.

5.5.1 Estimation of the sustainability of forest management

Sustainable harvesting

All of the scenarios are based on the assumption of a harvest volume that does not exceed the increment potential of the forest in the long term. The management practices implemented during wood harvesting, on which the model calculations in the forest are based, remain unchanged as compared with the current status.

The risks associated with elevated growing stock

It may be expected that in the *Reduced Forest Maintenance* scenario, in particular, the elevated and potentially over-aged stands could quickly become actual sources of carbon in the event of storms and other disasters. The study does not reflect this risk but it must be taken into account. The same also applies to the *Baseline* scenario which also involves a clear increase in growing stock.

Stable forests

The *Optimized Increment* scenario creates a permanent state of stability in the woodlands with acceptable growing stock and permanently elevated increment. The same applies for the *Kyoto-Optimized* scenario. Slash is largely used for energy purposes. However a certain level of dead wood remains in the forest. This means that the needs of biodiversity are not neglected. On the other hand, it remains unclear as to the extent to which the increased removal of micro wood together with material effects from the air would result in the nutrient deprivation of the soils.

5.5.2 **Estimation of the employment effect**

The following table estimates the effects of altered processing volumes on the domestic employment market in Switzerland in the year 2030 based on the scenarios.

Tab. 13 > Estimation of the employment effects of changes in the volumes of wood harvested, processed and used in Switzerland in accordance with the scenarios

Employment effect	Status 2000		Reduced Maintenance		Optimized Increment			
					Build		Energy	
Production sector[1]	Production	Employees	Extra Production	Extra Employees	Extra Production	Extra Employees	Extra Production	Extra Employees
	in 1000 m³	amount	in 1000 m³	amount[3]	in 1000 m³	amount[2]	in 1000 m³	amount[2]
Forestry sector	5000	7250	-2000	-2900	4200	2030	4200	2030
1st process level	3070	5030	-822	-1350	2779	1520	-	-
2nd process level	400	8770	-156	-3430	529	3860	-	-
3rd process level	2160	65'700	-590	-17'950	1994	20'220	-	-
Total (rounded)		86'800		-25'600		27'600		2000

Employment effect	Status 2000		Kyoto-optimized		Baseline	
Production sector[1]	Production	Employees	Extra Production	Extra Employees	Extra Production	Extra Employees
	in1000 m³	amount	in 1000 m³	amount[2]	in 1000 m³	amount[2]
Forestry sector	5'000	7'250	3'500	1'690	900	650
1st process level	3'070	5'030	2'779	1'520	925	760
2nd process level	400	8'770	529	3'860	178	1'950
3rd process level	2'160	65'700	1'994	20'220	530	8'060
Total (rounded)		86'800		27'300		11'400

[1] Each excluding mechanical pulp, chemical pulp, paper, paperboard production, except in forestry sector
[2] It is assumed that the new jobs feature in the scenarios with increased domestic processing as compared with the previous triple productivity.
[3] The loss of jobs in the Reduced Forest Maintenance scenario is proportional to the volumes produced.
Source: Calculations based on Hofer, Taverna et al. (2004)

27'000 new jobs

Based on the above calculations, thanks to the building scenarios, a good 27'000 permanent new jobs could be created up to the year 2030 as compared employment levels in the year 2000. The *Reduced Forest Maintenance* would give rise to a loss of over 25'000 jobs by 2030. By way of qualification, it should be noted here that these job losses are mainly a consequence of the reduced consumption of wood by the third processing level. It would also be conceivable, however, that in the case of reduced wood harvesting, consumption would be sustained at today's level through imports. In this case, the third processing level would only be marginally affected by the reduced wood harvesting. The *Baseline* scenario gives rise to a good 11'000 new jobs. This calculation does not include possible new jobs that may be created in the environment of extended utilization of fuel-wood, be they jobs in the mechanical engineering sector or the incineration sector. The relatively modest increase in the numbers employed in the Energy scenario could be greater for this reason also. However, this still does not alter the clearly stronger employment effect of the building scenarios as compared with the energy scenarios.

2.2 billion Swiss francs extra value added

Value added may be estimated on the basis of the publication "Branchenprofil der Wald- und Holzwirtschaft 2001"[58] (Profile of the Forestry and timber industry in 2001). The value added per employee in the forest is assumed at CHF 79'800, and CHF 81'400 for those in the timer sector. The rounded up/down values presented in Tab. 14 arise for the different scenarios. According to these values, it would be possible to yield around 2.2 billion francs more in the forestry and timber industry with the building scenarios. Regarding the CHF 2.1 billion sales losses associated with the *Reduced Forest Maintenance* scenario, the comments made in relation to jobs also apply here. The *Baseline* scenario produces an increase in value added of CHF 900 million per year from the year 2030 as compared with today's figures.

Tab. 14 > Estimation of the value added effects of changes in the volumes of wood harvested, processed and used in Switzerland based on the scenarios

Value added	Status 2000		Reduced Maintenance	Optimized Increment	
				Build	Energy
Production sector[1]	per employee in CHF	Total in million CHF	extra in million CHF	extra in million CHF	extra in million CHF
Forestry sector	79'800	580	-230	160	160
1st process level	81'400	410	-110	120	-
2nd process level	81'400	710	-280	310	-
3rd process level	81'400	5'350	-1'460	1'650	-
Total (rounded)		7'100	-2'100	2'200	160

Value added	Status 2000		Kyoto-Optimized	Baseline
Production sector[1]	per employee in CHF	Total in million CHF	extra in million CHF	extra in million CHF
Forestry sector	79'800	580	130	50
1st process level	81'400	410	120	60
2nd process level	81'400	710	310	160
3rd process level	81'400	5'350	1'650	660
Total (rounded)		7'100	2'200	930

[1] Each excluding mechanical pulp, chemical pulp, paper, paperboard production, except in forestry sector.
Source: Calculations based on Hofer, Taverna et al. (2004)

[58] Hofer, Taverna *et al.* 2004.

The consideration of both employment and value added is limited to the Swiss forestry and timber industry. It may be assumed that jobs would disappear as a result of the substitution of other products in these sectors. However, it is not possible to supplement the consideration of the forestry and timber industry with figures for the entire Swiss economy. It is also impossible to quantify the effect abroad of Swiss harvesting, production and use policy based on one of the scenarios. A few qualitative considerations will have to suffice here:

Limitation to the Swiss forestry and timber industry

> If imported products in Switzerland are replaced by domestic wood products, a gain in employment in the forestry and timber industry in Switzerland would be accompanied by losses in the same sector abroad. The same would also apply if Swiss wood exports replace foreign wood products abroad.
> If Swiss wood products replace products made of other materials in Switzerland or abroad, the employment effect in the corresponding manufacturing sector is negative and added value declines accordingly.
> If the additional Swiss wood products are covered by market expansion, the development of the Swiss forestry and timber industry does not have any negative effects on either foreign wood producers or the producers of the substitute products.

5.5.3 Estimation for an autarky scenario in Switzerland

In order to estimate the effects of wood scarcity which could limit or even prevent the import of wood and wood products, the *Optimized Increment, Building* scenario was also calculated in conjunction with the discontinuation of foreign trade. Given that an import surplus exists in the construction sector today, more wood would have to be channelled into energy as compared with the initial *Optimized Increment, Building* scenario. The volume of wood available still made it possible for the volume of fuel wood to increase by 60 percent as compared with today's levels (cf. Annex 3). The import surplus also results in the foreign forests being "conserved" in this sub-scenario. Thus, less wood is harvested abroad. When this effect was taken into account, it was assumed that the state of the foreign forests and the harvesting situation correspond to those in Switzerland. Significant uncertainties must, however, be reckoned with here.

Effects of global wood scarcity

Surprisingly, the calculations indicate at first glance that this scenario performs best, both for the wood stock and material substitution effects and second best for the energy substitution effects. Autarky also performs very well in terms of the totality of the effects in Switzerland (cf. Fig. 39 to Fig. 42); this is not "thanks" to the closed borders but because most of the wood is channelled into the building industry and processed there (large wood stocks and extensive material and energy substitution). A sensitivity study revealed that the reduction in transport distances is of far less significance.

Good results thanks to extensive wood use by the construction sector

Fig. 39 > Annual domestic energy substitution effects from domestic wood use, including autarky

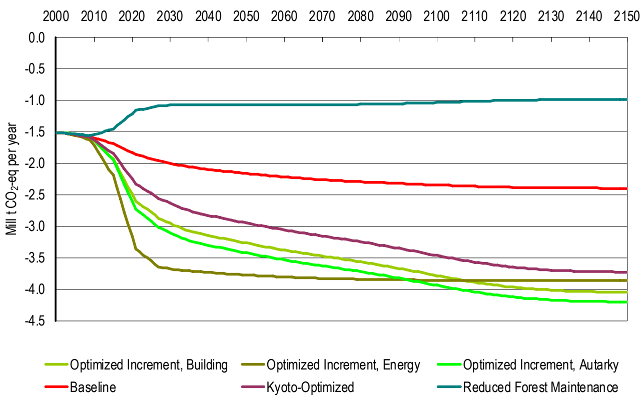


Fig. 40 > Annual domestic material substitution effects from domestic wood use, including autarky

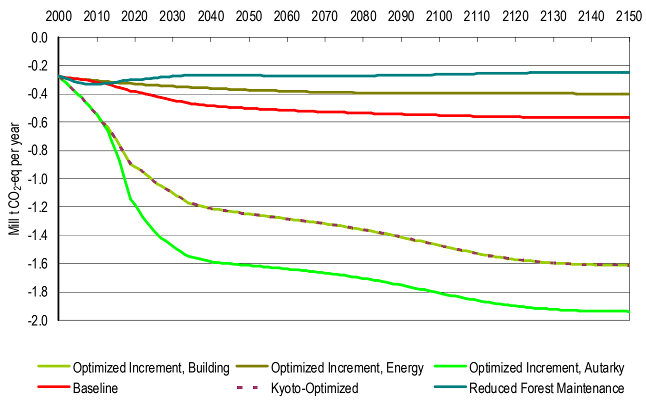


Fig. 41 > Annual C stock changes in the domestic technosphere, including autarky

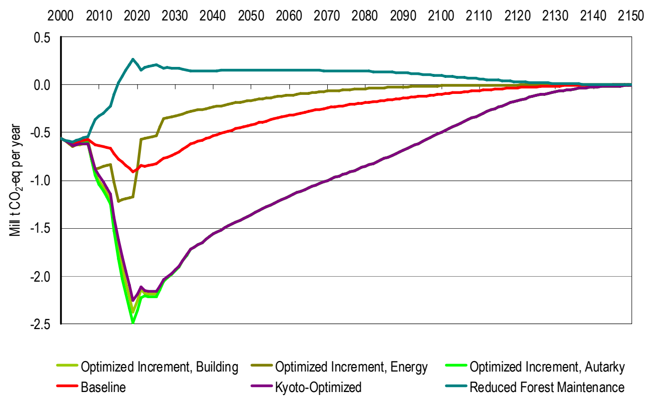
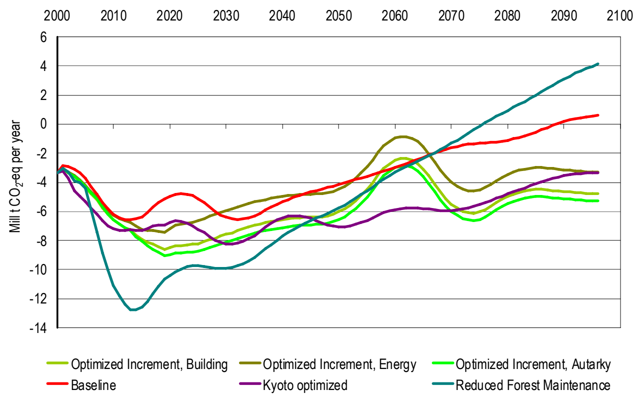


Fig. 42 > Total annual effects for Switzerland, including autarky



Because the discontinuation of foreign trade is not realistic, however, and the observations made in relation to the assumptions regarding the foreign forests are associated with major uncertainties, the results of this sub-scenario were not incorporated into the other comparisons. Two important substantiated conclusions may, however, be drawn from the findings:

5. Switzerland could meet the demand arising from significantly increased domestic wood consumption (both in the material and energy sectors) itself.
6. The more wood that is channelled into the building sector, the greater the desired CO_2 effects. The development of the domestic timber industry and, in association with this, the export of wood products is therefore to be welcomed from a global perspective.[59]

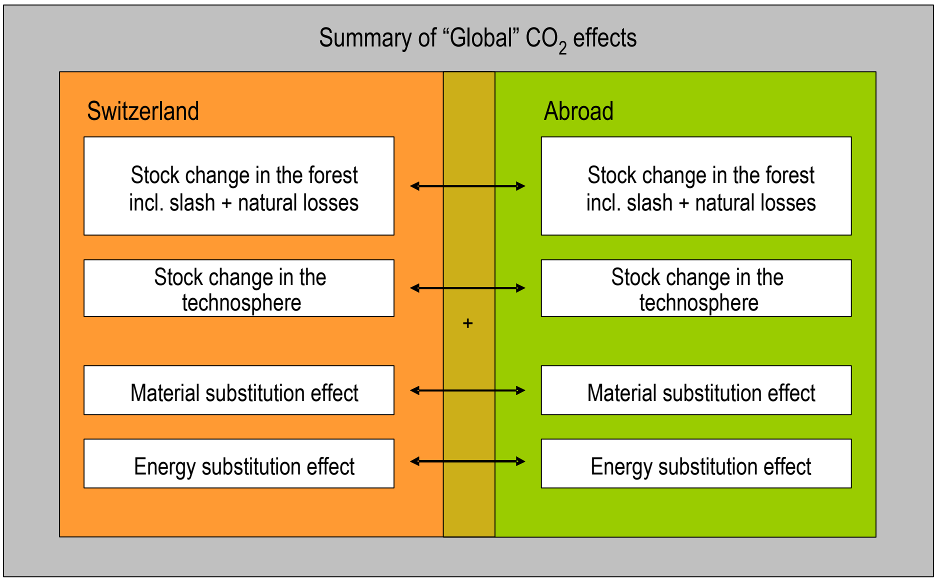
[59] Assuming that Swiss wood products replace non-wood products abroad.

To be able to estimate the climate-relevant effects of increased exports more accurately, the effects in the foreign forests would have to be studied in greater detail. The increased export of Swiss wood products would partly replace wood products and non-wood products abroad. As a result, as in the case of a ban on imports, less foreign wood would be harvested. It is not certain, however, whether this "conservation" would have positive effects. The stability of the under-harvested foreign forest would possibly even be enhanced through increased harvesting. In order to be able to answer these questions, the current foreign trade wood fluxes would have to be examined in greater detail. It was not possible to do this in the context of this study.

6 > The Sum of the CO_2 Effects in Switzerland and Abroad based on the Scenarios

The CO_2 effects in Switzerland and abroad are composed of the combined totals of greenhouse gas emissions in Switzerland and abroad. The same effects must, however, be taken into account in Switzerland and abroad (cf. Fig. 43).

Fig. 43 > Sum of the CO_2 effects in Switzerland and abroad



6.1 Overall effects abroad

Swiss activities also trigger effects abroad

Measures implemented in the area of the forestry and timber industry in Switzerland also trigger effects in other countries. The import of fossil fuels and semi-finished products for the manufacture of wood products give rise to CO_2 emissions abroad. On the other hand, production emissions are avoided through the export of Swiss goods abroad.

As is the case in Switzerland, the total effects abroad are composed of the effects in the forest and in the technosphere.

Fig. 44 > Total effects abroad, per year

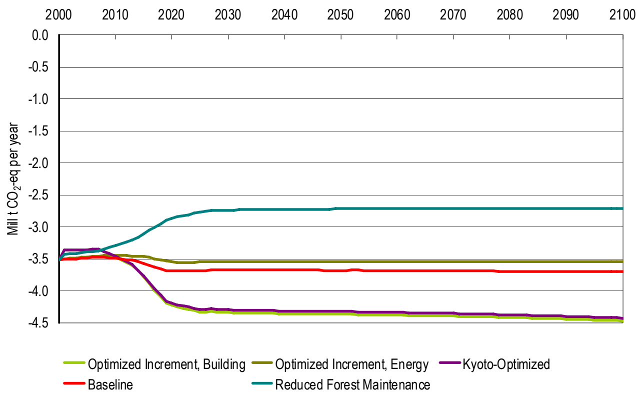
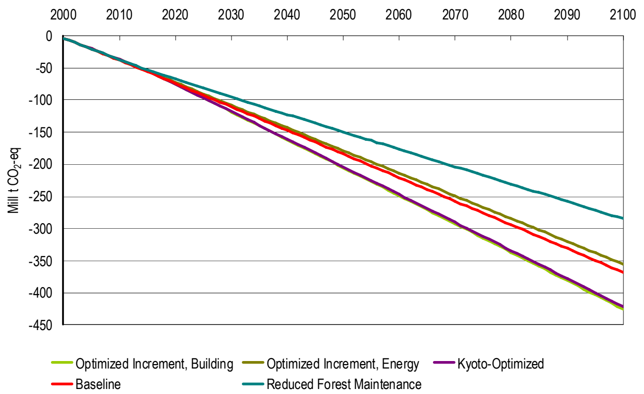


Fig. 45 > Total effects abroad, cumulative



Main effect of the building scenarios

The effects abroad mainly arise during the change in domestic consumption from 2000 to 2030. Because only marginal stock changes also arise abroad from 2030, the annual result graphs are virtually horizontal from this point in time onwards (Fig. 44). The order of the graphs reflects the increase or decrease in domestic consumption. The more domestic wood products used, the greater the CO_2 savings abroad.

Overall, the maximum savings that could be made in CO_2 emissions abroad is a good 4.5 million t annually, or around 420 million t up to the end of this century (cf. Fig. 45)[60].

[60] These values relate to the total volumes of harvested wood and not to the additionally harvested volumes as compared with the year 2000.

6.2

Comparison with Switzerland

Greater effects in Switzerland

The comparison of the annual effects in Switzerland and abroad shows that CO_2 reduction effects in Switzerland clearly predominate at the beginning of the period under consideration (cf. Fig. 46) – assuming that foreign trade is kept at a constant level and the effects in foreign forests can, therefore, be ignored.

Fig. 46 > Comparison of the annual CO_2 effects abroad and in Switzerland

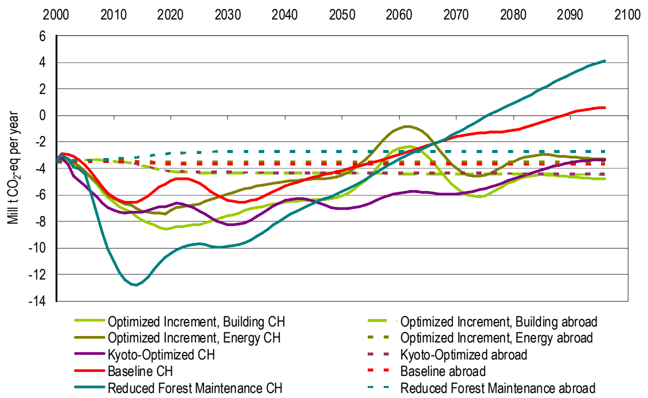
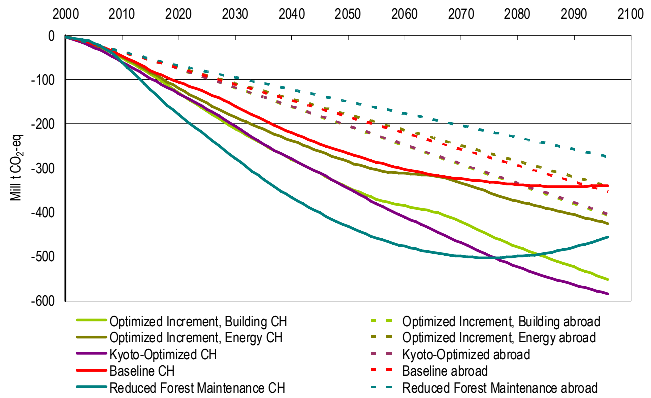


Fig. 47 > Comparison of the cumulative CO_2 effects abroad and in Switzerland



Due to the initially extensive effects, the cumulative domestic CO_2 savings exceed those abroad up to the end of the century (cf. Fig. 47). Because the Swiss forest was only modelled up to 2096, it is not possible to extend the comparison further. The course of the graph would prompt the expectation, however, that beyond the year 2100 the building scenarios would achieve at least the same CO_2 saving effects in Switzerland as they do abroad.

6.3 Total domestic and foreign effects

Building scenarios perform best

The sum of all of the effects in the analysed scenarios, i.e. the sum of the effects in Switzerland and abroad ("global effects") are presented in Fig. 48 and Fig. 49. From a long-term perspective, the scenarios *Kyoto-Optimized* and *Optimized Increment, Building* clearly present the best carbon balance and display the most sustainable curve progression. At savings of approximately 12–13 million t CO_2 equivalent, which corresponds to around 25 percent of today's CO_2 equivalent emissions in Switzerland, they achieve the most significant effects around the year 2030 (Fig. 48). With these scenarios, a total of around 1000 million t CO_2 equivalent emissions can be saved by the end of this century as compared to today's emission levels (Fig. 49)[61].

Sink promotion unsustainable

Thanks to the sink effect, in the short term, the most significant CO_2 savings (16 million t CO_2 per year around the year 2015) arise from the *Reduced Forest Maintenance* scenario. From a long-term perspective, however, this is the worst scenario and even leads to an increase in CO_2 emissions towards the end of the period under consideration — because the very extensive growing stock in the forest result in a marked increase in natural mortality. Moreover, the risk of forest collapse is significantly higher with this scenario than with the others (cf. Chapter 2.1.1 and Chapter 5.1.1). Furthermore, in this case the renunciation of use or compensation with non-wood products and fossil fuels must be accepted (see Chapter 5.4). Hence, this scenario must be classified as unsustainable.

Fig. 48 > Total effects in Switzerland and abroad per year

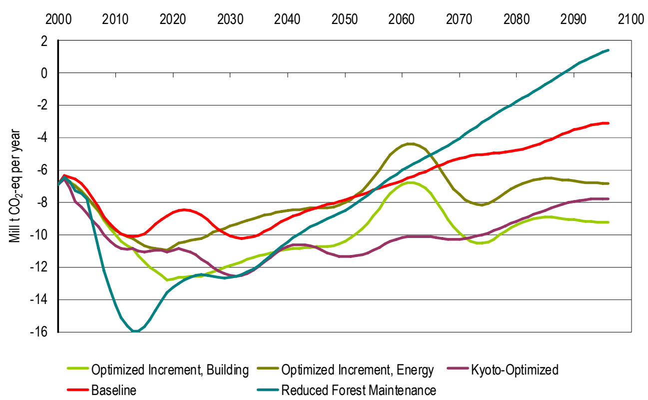
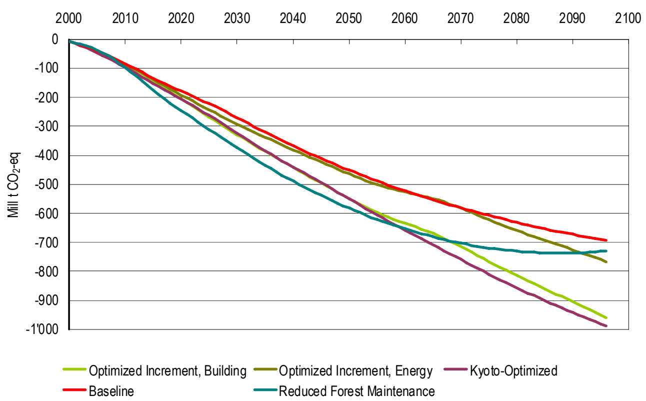


Fig. 49 > Total cumulative effects in Switzerland and abroad



[61] These values relate to the total volumes of harvested wood and not to the additionally harvested volumes as compared with the year 2000.

Less extensive effect of the energy scenario

As compared with the building scenarios (*Optimized Increment, Building and Kyoto-Optimized),* which aim to achieve an increase in the use of wood in the construction sector, the energy scenario *(Optimized Increment, Energy)* with its focus on energy recovery from wood produces clearly poorer results at all times (cf. Fig. 48). In total, the difference up to the end of the century is approximately 200 million t CO_2 equivalent in favour of the building scenarios (cf. Fig. 49).

Strategy change required

The comparison of the *Energy* and *Baseline* scenarios shows that both scenarios perform more or less equally up to 2065. After this, the *Baseline* trend is clearly worse and this scenario performs worse in the long term. This shows that a change in strategy involving increased harvesting in the forest and forestry sector is definitely required.

Effects similar to those in Switzerland

As already mentioned in Chapter 5.4, the results presented display the overall effect of wood use, including the amount used before the year 2000. To determine the additional effect as compared with the year 2000, the substitution effect of the use of wood which was already effective in the year 2000 must be subtracted (approximately 4.7 million t CO_2 equivalent). The resulting effects take a similar form to those relating to Switzerland. This is because foreign trade was left constant. In the long term, from a global perspective, around 5 million t CO_2 emissions per year may be saved with the *Optimized Increment, Building* scenario. In the short term, it is even possible to achieve savings of a good 8 million t per year as compared with the year 2000. This corresponds to a good 9 percent or even 15 percent of current CO_2-equivalent emissions.

Unsustainable sink scenario

In net terms, the *Reduced Forest Maintenance* scenario gives rise to additional CO_2 emissions from as early as 2065. As indicated in Fig. 48 , the unfavourable trend begins as early as 2015 and lasts until the end of the period under consideration. Moreover, the same restrictions apply as already discussed in Chapter 5.4 (renunciation of use or use of non-wood products and fossil fuels). As opposed to this, the substitution scenarios give rise to a constant improvement in CO_2 emissions.

7 > Conclusions

Global perspective – domestic perspective

Necessary national and global perspective

In a country whose economy is as extensively integrated at international level as that of Switzerland, consideration of both domestic and foreign CO_2 effects is fitting and useful. Otherwise we risk producing a distorted image of reality and of making incorrect judgements (e.g. increased emissions through the processing of domestic raw material in Switzerland – reduced emissions due to the absence of substitute product production abroad). Because CO_2 balancing is being implemented on the basis of individual countries for the time being, consideration of the effects in our own country cannot be omitted. The clarifications have shown that for the case of Switzerland the domestic effects of the forestry and timber industry significantly exceed those abroad.

Forest and technosphere – stock effects and substitution

Utilization of increment and cascade use

In the long term, the best improvement in the CO_2 balance can be achieved through the maximum possible utilization of high increment, the processing of the resulting wood in long-lived products in cascade use and end utilization for energy generation.

Uncertainty regarding the increase in growing stock

The effect of improvements in the CO_2 balance through C-stock formation is temporally limited. All stocks reach the limits of their capacity in the short or long term. Despite the presence of extensive growing stock, considerable increases are still possible in the forest. Whether well-stocked forests are also stable is questionable and it was not the object of this study to establish this. Human beings have no influence on the most significant risk factor in this context, i.e. storms. They can at best ensure a high level of stability for forests. Storm events like those that occurred in 1990 and 1999 not only cause large-scale destruction of material assets, they also alter the CO_2 balance drastically from one minute to the next. Climate change also influences forest development (growth, distribution of tree species, disturbances). This was only taken into account to a limited extent in this study but should be examined in more detail in future studies.

Stable wood stocks in the technosphere

The stocks in the technosphere may be less significant, however they are not at risk from disasters, e.g. fires, to the same extent as those in the forest. If a particular use of wood products is maintained, the stocks do not change again significantly over time.

Important substitution effect

As long as the consumption of wood products is maintained, the effect of substitution through the material and energy use of wood is more significant and sustained as compared with the stock effects. Given that a wood stock would not be created in the technosphere for the purpose of CO_2 sequestration alone, the stock effect here is a welcome side-effect.

Stock, increment and harvesting policy

Is higher increment possible in conjunction with stable forests?

The modelling results point to a sustainably harvestable increment of 9.2[62] million m³/year *(Optimized Increment* scenario). However, the situation in which constant increment of this magnitude can actually be utilized will only be reached in around 70 years. This increment will be achieved with slightly higher growing stock than today's levels. This means that from the perspective of attaining the highest possible increment, a reduction of growing stock would not appear to be opportune. For reasons of raw material policy, the attainment of maximum possible mass increment makes sense and is worth aiming for. It should, however, also be ensured that the forest maintains a high level of stability. The determination of the optimum level in this context needs to be explored in detailed by experts.

High demand for wood

The demand situation and increasing wood prices in late 2006 and early 2007 clearly demonstrated that the development of Kyoto forests is not a matter of course. The under- harvesting of the Swiss forest, which has been observed for many years, can be reversed extremely quickly and develop into a situation of over-harvesting.

Complete clearing of logged wood if possible?

Logging slash left lying on the forest floor which could be used for energy generation constitutes a potential that is not currently being exploited. Increasing wood prices are providing an incentive to make greater use of this kind of wood. Suitable technologies still need to be developed in part to enable the better utilization of biomass. However, to a certain extent, the complete utilization of biomass runs contrary to the need for biodiversity which necessitates an adequate volume of dead wood in the forest. Moreover, the sustainability of soil quality and growth performance must be guaranteed. There is a need for additional information in this area.

Wood use policy

Use wood in the construction sector

In the context of climate policy, the greatest effect can be achieved through a maximum possible wood-use quota in the construction sector and, moreover, in applications with the most favourable greenhouse gas balances. This mainly concerns structural components, for example storey ceilings/floors, columns, floor coverings and façades as well as finish components such as furniture, architraves and packaging.

Material use before energy use

From a global perspective, the effect of material substitution exceeds that of energy recovery from wood. In the Swiss context, however, the energy recovery from wood generates a greater substitution effect than material substitution.

The cascade use of wood enables the realization of both substitution effects. This highlights the importance of this concept. Thus, the primacy of material substitution over energy recover is also clearly applicable from the Swiss perspective (cf. Tab. 15 below).

[62] 8 million compact wood, 1.2 million bark and brushwood.

The substitution effects are greatest in Switzerland where domestically manufactured energy-intensive products made of materials other than wood are replaced by domestic wood products. These include, in particular, structural components for buildings, in particular storey ceilings/floors, external walls and façades, but also packaging. As opposed to this, significantly more of the substitution effects generated by finishing components arise abroad as these substitution products or their semi-finished components are mostly manufactured in other countries.

Structural wood before finish wood

It is known from the analysis of paper recycling that the proportion of "fresh wood" required can be significantly reduced through recycling. In terms of material use, apart from its use in chipboard, the re-use of waste wood has hitherto remained an exception with small volumes at most being used in wood structures (for example the re-use of old barns for new holiday houses in mountain regions). Because it has not been possible hitherto to determine the (chemical) contamination of waste wood using simple methods – and the dissipation of contaminants cannot be recommended for environmental reasons – the priority with waste wood lies in its use for energy recovery. Thus, based on the extensive substitution effects, the efficient use of wood residues from production and waste wood for energy recovery is one of the key strategies for the reduction of domestic greenhouse gas emissions.

Use of waste wood for energy generation

Wood processing policy

The increased utilization and use of wood in Switzerland is accompanied by the expansion of the forestry and timber industry. This means gains for the sector of a total of around 27'000 jobs and two billion Swiss francs in value added. It is not possible to ascertain here how many jobs would be lost in other sectors in Switzerland and abroad.

New jobs and greater value added

The processing of wood from Swiss forests in its country of origin makes sense not only for reasons of adding value. The replacement of previously imported wood products by domestically manufactured products increases the positive global climate effect. The fact that wood residues that arise during processing can be used domestically to generate energy and thus eliminate transport also makes a difference.

Process Swiss wood in Switzerland

Foreign trade policy

At an initial glance, the results of the *Autarky* scenario would suggest that the walling-off of the Swiss market would be a successful strategy. In reality, however, with this scenario, the proportion of domestic wood used for material purposes and, in particular, construction would be increased by the previous import volume. Due to the wood residues generated, the energy proportion would remain high despite this and a lot of transport could be eliminated.

Autarky only appears to be a good solution

However, as the market for wood products in Switzerland is limited, the only way to channel a higher proportion of wood production into construction is through increased exports. Because a change in foreign trade necessarily leads to a change in wood harvesting abroad, comprehensive studies on the topic of foreign forests would have to be undertaken to provide a reliable account of these effects.

Rule of thumb for the determination of CO_2 savings

The following figures (cf. Tab. 15) indicate the scale of the substitution effects per volume of wood used:

Tab. 15 > Rounded figures for CO_2 emissions saved per volume of wood used

CO_2 emissions saved per volume of wood used [kg CO_2/m^3 wood]	Switzerland	Abroad	Total
Material substitution	-300	-400	-700
Energy substitution	-500	-100	-600
Total	-800	-500	-1'300

8 > FAQs

Based on this study, it is possible to provide clear and simple answers to the following questions

Does it really matter how forests are managed and how wood is used?

Yes The comparison of the results of the scenarios clearly shows that different strategies produce very different effects. Moreover, the short-term effects can differ significantly from the long-term effects.

Should as much CO_2 as possible be sequestered in forests?

No The *Reduced Forest Maintenance* scenario shows that large volumes of CO_2 can be sequestered initially. In the medium to long term, the effect is reversed, however, as the forest's carbon pool becomes full and decomposition gradually commences. Furthermore, this scenario poses the greatest risks to forest stability. The high sink effect of this scenario is, moreover, of little use for carbon accounting in accordance with the Kyoto Protocol as the sequestered volume that may be accounted by Switzerland (Cap) in the first commitment period is 1.8 million t CO_2 per year. Moreover, this scenario means that less domestic wood is available for construction and energy production. If consumption remained the same, the missing volumes of wood would have to be replaced by non-wood products or fossil fuels which would further degrade CO_2 balance provided by this scenario.

Should as much wood as possible be used directly for energy generation in Switzerland?

No The *Optimised Increment, Energy* scenario performs consistently and significantly worse than the *Building* scenarios. The material use of wood followed by its use in energy generation represents a far better option than its exclusive use for energy recovery. To provide the same volume of construction products, in the energy scenario additional non-wood products would have to be manufactured which, in turn, would result in greater CO_2-emissions.

Should the Swiss forestry and timber industry continue to operate as previously?

No The *Baseline* scenario performs worst in the short and medium term and second worst in the long term. Increased wood use should definitely be adopted as an objective.

Should Switzerland use the Kyoto forest sinks that can be accounted for?

Yes The *Kyoto-Optimized* scenario performs well in the medium and long term. However, as compared with the *Optimized Increment* strategy the forest structure would lose stability in the long term due to reduced thinning activity. Due to the expected high demand for wood in the future, the Kyoto forest sinks will not emerge "automatically." Suitable economic framework conditions are necessary.

Will measures adopted in Switzerland also benefit Switzerland?

Yes The comparison of the effects in Switzerland and abroad shows that at constant levels of foreign trade, the CO_2 savings in Switzerland clearly predominate over those achieved abroad.[63]

[63] However, the sink effect from the increased wood stocks in the technosphere may not be accounted during the first Kyoto Protocol commitment period. The possibility of the accounting of wood products in other commitment periods is currently being discussed at international level.

> Annexes

A1 Base Data

Dry weight of wood	Weight kg/m³	Stock in %
Spruce	430	48
Fir	410	15
Other conifers	460	9
Beech	680	17
Other deciduous species	580	11
Simplified assumpion	500 kg/m³	Average weight of Swiss wood

Source: Schweizer 2006

Wood consists of the following components (weight)

Carbon (C)	50 %
Oxygen (O_2)	43 %
Hydrogen	6 %
Nitrogen	< 1 %
Minerals	< 1 %

Source: Pöhler Rotach, Seubert Hunziker 2002

Conversion factor from C to CO_2

Atomic weight C	12.0
Atomic weight O	16.0
Atomic weight O_2	32.0
Total CO_2	44.0

1 kg C is produced from the photosynthesis of 3.67 kg CO_2

3.67 kg CO_2 is produced from the combustion of 1 kg C

1 kg C = 3.67 kg CO_2 or 1 t C = 3.67 t CO_2

CO_2 reduction in the atmosphere through the production of 1 m³ of wood

Source: application of above-specified data

1 m³ wood weights 500 kg

of which = 50 % C

Thus 1 m³ wood contains 250 kg C

These 250 kg C were produced from 250 kg x 3.67 = 917 kg CO_2

Rounded up: the production of 1 m³ wood removes 920 kg CO_2 from the atmosphere

Conversely: the combustion of 1 m³ wood releases 920 kg CO_2 into the atmosphere

Productive forest area was assumed as 1.07 million ha

Source: application of above-specified data

A2 Elements of the timber industry model

The timber industry model incorporates a total of 9 processes and 26 (+6) fluxes. They are cross-linked by mathematical equations. The processes and fluxes are described in Table 16 below.

Tab. 16 > Processes and fluxes in the wood flux model

Process/stocks

1	Timber industry	Involves the transformation of forest wood into the various wood products and into wood residues used in energy generation. For modelling reasons, the duration of time spent by wood in this stock had to be defined as 0 years. The annual wood flux was doubled for the estimation of the wood stocks in the timber industry.
2	Energy generation	This activity is supplied from a range of sources, i.e. fuel wood, wood residues, lignin, fuel waste paper and fuel waste wood. This activity involves the conversion of wood into energy and the C in wood into CO_2 in the outgas. The average sojourn time was assumed as 2.0 years ±0.5 years.
3	Construction of buildings	This stock contains all structural components made of wood that remain in buildings for a long time. These include all structural building components with an estimated residence time of 80 ±20 years.
4	Finishing of buildings	The finishing of buildings includes all elements of buildings that have a shorter lifetime than the structural components and also includes furniture. The average sojourn time was assumed as 30 years ±15 years.
5	Wood products	A stock comprising a wide variety of wood products such as indirect building materials, do-it-yourself articles, wood products and packaging. The sojourn time was assumed as 10 years ±3 years.
6	Mechanical/chemical pulp production	It was necessary to introduce a separate process to represent foreign trade in mechanical/chemical pulp and the use of lignin for energy recovery correctly. A residence time of 0 years was assumed.
7	Paper production	Also conceived as a flux process to facilitate the presentation of paper recycling. The sojourn time is assumed as 0 years.
8	Paper consumption	In the case of paper consumption, the widely varying residence times of paper, which range from a few days to many years, were presented on the basis of an assumed average residence time of 2.5 years ±2 years. A recycling loop goes back to paper production from the area of paper consumption: one part becomes fuel waste paper and one part leaves the system as waste paper.
9	Waste wood sector	The waste wood sector takes all wood withdrawn from the use of buildings and wood products. The waste wood sector – wood remains here for an average of only 1 year ± 0.2 years – supplies fuel waste wood and waste wood. The latter also leaves the system.

Input fluxes

1a	Import roundwood/wood residues	Volume of imported roundwood and wood residues. This is a default variable.
1b	Import semi-finished products	Imported volume of semi-finished products. Semi-finished products in this context are sawnwood products and wood derivatives. This is a default variable.
1c	Import ¾-finished products	Imported volume of ¾-finished products. Examples of ¾-finished products include doors, windows, glued-laminated timber etc. This is a default variable.
1d	Import furniture/houses	Imported volume of prefabricated houses and furniture. This is a default variable.
2	Industrial roundwood	Industrial roundwood is one of the input parameters into the system. It includes all stemwood and industrial wood from Switzerland that is fed into the system. Industrial roundwood is a derived variable as the total volume required is dictated by the system requirement in the model.
3	Fuel wood	Fuel wood is the second input parameter into the system and includes all energy or fuel wood which is supplied to the system by the Swiss forest. Wood from field shrubs is also included. This is a default variable.
4	Import mechanical/ chemical pulp	Imported volume of mechanical and chemical pulp for paper production. This is a default variable.
5	Import paper	Volume of imported paper for domestic use. Total domestic consumption and the import share are specified.

Output fluxes

1a	Export roundwood/wood residues	Volume of exported roundwood and wood residues. This is a default variable.
1b	Export semi-finished products	Volume of semi-finished products exported. Semi-finished products in this context are sawnwood products and wood derivatives. This is a default variable.
1c	Export ¾-finished products	Volume of ¾-finished products exported. Examples of ¾-finished products include doors, windows, glued-laminated timber etc. This is a default variable.
1d	Export furniture/houses	Volume of prefabricated houses and furniture exported. This is a default variable.
2	Export mechanical/ chemical pulp	Volume of mechanical/chemical pulp exported from production. This is a default variable.
3	Lignin residues	Refers to the goods volume of lignin (and hemicellulose) that arises annually during wood pulping and is not suitable for energy generation. This is a defined default ratio.
4	Export paper	Volume of paper exported from paper production. This is a default variable.
5	Waste paper	The volume of paper that leaves the system through sewage or compost. Calculated as a percentage of paper consumption. Used at most for energy generation in the form of sewage sludge.
6	Waste wood	Volume of old wood that leaves the system through export or (illegal) deposition in landfills. This is a residual variable (waste wood output minus fuel waste wood).
7	Outgas	Volume of “wood” that leaves the system in gaseous form following energy generation.

Internal fluxes

1	New structural wood	The volume of wood products which is incorporated annually into the construction of buildings from the timber industry system in the form of long-lived and mainly structural components. This is a default variable.
2	New finish wood	The volume of wood products which is incorporated annually into buildings from the timber industry system in the form of long-lived and mainly non-structural components. This goods flows also includes furniture. This is a default variable.
3	New wood products	The volume of wood products which is incorporated annually from the timber industry into the consumption of relatively short-lived wood products. This is a default variable.
4	Wood residues	The volume of wood supplied by the timer industry for energy generation. The volume of wood residues is a derived variable. It is calculated as a percentage of the sum of deliveries to building construction and finishing and wood products.
5	Pulpwood	The volume of wood supplied to the paper industry as roundwood from the forest or industrial wood from the timber industry. For simplification purposes, it is assumed that forest wood for mechanical pulp and cellulose is also supplied via the wood sector. This is a derived variable.
6	Energy lignin	Refers to the lignin (and hemicellulose) goods volume that arises every year from wood-pulping and is used for energy generation. This is a defined default ratio.
7	Mechanical/chemical pulp	The volume of mechanical/chemical pulp produced domestically for domestic use.
8	Domestic paper	Volume of paper produced domestically for domestic use. The totals for domestic consumption and import share are specified.
9	Recycling paper	The volume of used paper collected annually and re-used as fibre for paper production. It is calculated as a percentage share of paper consumption.
10	Fuel waste paper	Volume of paper burned in furnaces or in waste incineration plants and used (at least in part) to generate energy. A residual variable from: paper (eliminated from consumption) – recycling paper – waste paper.
11	Waste structural wood	The volume of wood eliminated from the building stock in the form of built structures. With the delay in the defined residence time it roughly corresponds to the input into the construction of buildings.
12	Waste finish wood	The volume of wood eliminated from the building stock in the form of finish wood. With the delay in the defined residence time it roughly corresponds to the input into the finishing of buildings
13	Waste wood products	The volume of wood products eliminated from use. With the delay in the defined residence time it roughly corresponds to the input into the consumer area buildings and wood products.
14	Fuel waste wood	Volume of waste wood burned in waste wood furnaces and in waste incineration plants and used (at least in part) to generate energy. Calculated as a percentage share of the volume eliminated from the waste wood industry.

Definied parameters

	New structural wood	Volume of new structural wood used annually
	New finish wood	Volume of new finish wood used annually
	New wood products	Volume of new wood products used annually
	Hedgerow timber	Volume defined as 180’000 m³
	Other wood fuels	Volume defined as 60’000 m³
	Chemical/mechanical pulp	Production ratio of chemical pulp to mechanical pulp: 1.1
	Paper (consumption)	Volume of annual domestic paper consumption
	Fuel wood	Volume of fuel wood used annually
	Proportion of wood residues	Percentage of the total of new structural wood + new finish wood + new wood products, calculated as 40 %
	Proportion of import wood residues	Defined for roundwood: 29 %, for semi-finished products: 17 %, for ¾-finished products: 9 %
	Proportion of export wood residues	Defined for roundwood: 0 %, for semi-finished products: 20 %, for ¾-finished products: 30 %
	Chemical pulp yield	Ratio of raw wood to chemical pulp: 4.5
	Mechanical pulp yield	Ratio of raw wood to mechanical pulp: 2.8
	Ratio of energy lignin to lignin residues	Ratio of energy lignin to lignin residue from pulp production: 0.8 Ratio of energy lignin to lignin residue from pulp production: 1.0
	Proportion of recycling paper	Percentage of paper consumed annually, defined as 63 %
	Recycling paper wastage	Defined as 13 %
	Paper additives	Defined as 13 %
	Proportion of waste paper	Percentage of annual paper consumption, calculated as 9 %
	Proportion of fuel waste wood	Percentage of old wood output from waste timer industry, calculated as 60 %

A3 Szenario details

Tab. 17 > Details of the *Optimized Increment* scenarios

	Situation 1900			Optimized Increment, Building		Change as compared with situation 2000	Optimized Increment, Energy		Change as compared with situation 2000	Optimized Increment, Autarky		Change as compared with situation 2000
				Optimized Increment								
	Annahmen aufgrund von Recherchen			Consumption (C+F+W)		+80%	Consumption (C+F+W)		0%	Consumption (C+F+W)		+80%
				Fuel wood		+122%	Fuel wood		+344%	Fuel wood		+61%
				Foreign trade		0%	Foreign trade		0%	Foreign trade		-100%
Consumption data Switzerland			kg/l*y			kg/l*y			kg/l*y			kg/l*y
Construction	350	1000 m^3	25	1'894	1000 m^3	135	868	1000 m^3	62	1'894	1000 m^3	135
Finishing	280	1000 m^3	20	1'400	1000 m^3	100	868	1000 m^3	62	1'400	1000 m^3	100
Wood products	252	1000 m^3	18	1'190	1000 m^3	85	756	1000 m^3	54	1'190	1000 m^3	85
Paper and paperboard			10			245			245			245
Fuel wood (inc hedgerow timber)	2100	1000 m^3	150	2'800	1000 m^3	200	5'600	1000 m^3	400	2'030	1000 m^3	145
			223			*765*			*823*			*710*
Export			kg/l*y			kg/l*y			kg/l*y			kg/l*y
Export roundwood, wood residues	600	1000 m^3	42.9	1'390	1000 m^3	99.3	1'390	1000 m^3	99.3	-	1000 m^3	-
Export semi-finisched products (minus chemical pulp)	140	1000 m^3	10.0	670	1000 m^3	47.9	670	1000 m^3	47.9	-	1000 m^3	-
Export 3/4: packaging, building mat, wood products	7	1000 t	1.0	30	1000 t	4.3	30	1000 t	4.3	-	1000 t	-
Export furniture/houses	7	1000 t	1.0	45	1000 t	6.4	45	1000 t	6.4	-	1000 t	-
Export chemical pulp	14	1000 t	2.0	110	1000 t	15.7	110	1000 t	15.7	110	1000 t	15.7
Export mechanical pulp	14	1000 t	2.0	20	1000 t	2.9	20	1000 t	2.9	20	1000 t	2.9
Export Paper and paperboard	14	1000 t	2.0	1'100	1000 t	157.1	1'100	1000 t	157.1	1'100	1000 t	157.1
Wood residues in CH arising from exports (C+F+W)	*408*	*1000 m^3*	*12.0*	*1'376*	*1000 m^3*	*58.6*	*1'376*	*1000 m^3*	*58.6*	-	*1000 m^3*	-
Wood residues in CH arising from exports (C+F+W)			2.64			13.4			13.4			-
Import			kg/l*y			kg/l*y			kg/l*y			kg/l*y
Import roundwood, wood residues	400	1000 m^3	28.6	890	1000 m^3	63.6	890	1000 m^3	63.6	-	1000 m^3	-
Import wood residues	80	1000 m^3	5.7	534	1000 m^3	38.1	534	1000 m^3	38.1	-	1000 m^3	-
Import roundwood	320	1000 m^3	22.9	356	1000 m^3	25.4	356	1000 m^3	25.4	-	1000 m^3	-
Import semi-finished products (minus chemical pulp)	210	1000 m^3	15.0	1'070	1000 m^3	76.4	1'070		76.4	-		-
Import 3/4: packaging, building mat, wood products	14	1000 t	2.0	160	1000 t	22.9	160	1000 t	22.9	-	1000 t	-
Import furniture/houses	14	1000 t	2.0	210	1000 t	30.0	210	1000 t	30.0	-	1000 t	-
Import chemical pulp	7	1000 t	1.0	440	1000 t	62.9	440	1000 t	62.9	440	1000 t	62.9
Import mechanical pulp	7	1000 t	1.0	5	1000 t	0.7	5	1000 t	0.7	5	1000 t	0.7
Import Paper and paperboard	21	1000 t	3.0	1'100	1000 t	157.1	1'100	1000 t	157.1	1'100	1000 t	157.1
As product (K+A+H) in CH utilizable	*586*		*41.9*	*2'166*	*1000 m^3*	*154.7*	*2'166*	*1000 m^3*	*154.7*	-	*1000 m^3*	-
As product (K+A+H) in CH utilizable			33.6			132.6			132.6			-
Wood residues in CH arising from imports (C+F+W)			8.3			22.1			22.1			-

Wood consumption from CH forest	kg/l*y	1000 m^3	kg/l*y	1000 m^3	kg/l*y	1000 m^3	kg/l*y	1000 m^3
Production (K+A+H)	41	580	246	3'447	104	1'455	320	4'484
Wood residues produced			88	1'239	32	442	128	1'794
Production of mechanical/chemical pulp	19	273	24	341	24	341	62	875
Fuel wood	150	2'100	200	2'800	400	5'600	145	2'030
Export roundwood and wood residues	43	600	99	1'390	99	1'390	0	-
Total	**267**	**3'737**	**658**	**9'217**	**659**	**9'228**	**656**	**9'183**

Tab. 18 > Details of the *Kyoto-Optimized* scenarios

				Kyoto-Optimized					
	Situation in 2000 (minus Lothar effects)			**Kyoto-Optimized Building**		Change as compared with situation 2000	**Kyoto-Optimized Energy**		Change as compared with situation 2000
	The mean values for 1996-99 are used for foreign trade (Jahrbuch Wald und Holz) The consumption figures correspond to final consumption in 2001 (Branchenprofil)			Consumption (C+F+W) Fuel wood Foreign trade		+80% +67% 0%	Consumption (C+F+W) Fuel wood Foreign trade		+0% +289% 0%
Consumption data Switzerland			kg/I*y			kg/I*y			kg/I*y
Construction	868	1000 m^3	62	1'894	1000 m^3	135	868	1000 m^3	62
Finishing	868	1000 m^3	62	1'400	1000 m^3	100	868	1000 m^3	62
Wood products	756	1000 m^3	54	1'190	1000 m^3	85	756	1000 m^3	54
Paper and paperboard			245			245			245
Fuel wood (inc hedgerow timber)	1'260	1000 m^3	90	2'100	1000 m^3	150	4'900	1000 m^3	350
			513			*715*			*773*
Export			kg/I*y			kg/I*y			kg/I*y
Export roundwood, wood residues	1'390	1000 m^3	99.3	1'390	1000 m^3	99.3	1'390	1000 m^3	99.3
Export semi-finisched products (minus chemical pulp)	670	1000 m^3	47.9	670	1000 m^3	47.9	670	1000 m^3	47.9
Export 3/4: packaging, building mat, wood products	30	1000 t	4.3	30	1000 t	4.3	30	1000 t	4.3
Export furniture/houses	45	1000 t	6.4	45	1000 t	6.4	45	1000 t	6.4
Export chemical pulp	110	1000 t	15.7	110	1000 t	15.7	110	1000 t	15.7
Export mechanical pulp	20	1000 t	2.9	20	1000 t	2.9	20	1000 t	2.9
Export Paper and paperboard	1'110	1000 t	158.6	1'100	1000 t	157.1	1'100	1000 t	157.1
Wood residues in CH arising from exports (C+F+W)	*1'376*	*1000 m^3*	*58.6*	*1'376*	*1000 m^3*	*58.6*	*1'376*	*1000 m^3*	*58.6*
Wood residues in CH arising from exports (C+F+W)			13.4			13.4			13.4
Import			kg/I*y			kg/I*y			kg/I*y
Import roundwood, wood residues	890	1000 m^3	63.6	890	1000 m^3	63.6	890	1000 m^3	63.6
Import wood residues	534	1000 m^3	38.1	534	1000 m^3	38.1	534	1000 m^3	38.1
Import roundwood	356	1000 m^3	25.4	356	1000 m^3	25.4	356	1000 m^3	25.4
Import semi-finished products (minus chemical pulp)	1'070	1000 m^3	76.4	1'070		76.4	1'070		76.4
Import 3/4: packaging, building mat, wood products	160	1000 t	22.9	160	1000 t	22.9	160	1000 t	22.9
Import furniture/houses	210	1000 t	30.0	210	1000 t	30.0	210	1000 t	30.0
Import chemical pulp	440	1000 t	62.9	440	1000 t	62.9	440	1000 t	62.9
Import mechanical pulp	5	1000 t	0.7	5	1000 t	0.7	5	1000 t	0.7
Import Paper and paperboard	1'100	1000 t	157.1	1'100	1000 t	157.1	1'100	1000 t	157.1
As product (K+A+H) in CH utilizable	*2'166*	*1000 m^3*	*154.7*	*2'166*	*1000 m^3*	*154.7*	*2'166*	*1000 m^3*	*154.7*
As product (K+A+H) in CH utilizable			132.6			132.6			132.6
Wood residues in CH arising from imports (C+F+W)			22.1			22.1			22.1

Wood consumption from CH forest	kg/I*y	1000 m^3	kg/I*y	1000 m^3	kg/I*y	1000 m^3
Production (K+A+H)	104	1'455	246	3'447	104	1'455
Wood residues produced	32	442	88	1'239	32	442
Production of mechanical/chemical pulp	32	445	24	341	24	341
Fuel wood	90	1'260	150	2'100	350	4'900
Export roundwood and wood residues	99	1'390	99	1'390	99	1'390
Total	**357**	**4'992**	**608**	**8'517**	**609**	**8'528**

Tab. 19 > Details of the *Baseline* and *Reduced Forest Maintenance* scenarios

				Baseline			Reduced Forest Maintenance		
	Situation in 2000 minus Lothar effects)			**Trend as before**		Change as compared with situation 2000	**Reduced Forest Maintenance, Energy**		Change as compared with situation 2000
	The mean values for 1996-99 are used for foreign trade (Jahrbuch Wald und Holz) The consumption figures correspond to final consumption in 2001 (Branchenprofil)			Consumption (C+F+W) Fuel wood Foreign trade		21% 22% 0%	Consumption (C+F+W) Fuel wood Foreign trade		-24% -81% 0%
Consumption data Switzerland			kg/l*y			kg/l*y			kg/l*y
Construction	868	1000 m³	62	1'050	1000 m³	75	650	1000 m³	46
Finishing	868	1000 m³	62	1'050	1000 m³	75	634	1000 m³	45
Wood products	756	1000 m³	54	910	1000 m³	65	616	1000 m³	44
Paper and paperboard			245			245			245
Fuel wood (inc hedgerow timber)	1'260	1000 m³	90	1'540	1000 m³	110	238	1000 m³	17
			513			*570*			*398*
Export			kg/l*y			kg/l*y			kg/l*y
Export roundwood, wood residues	1'390	1000 m³	99.3	1'390	1000 m³	99.3	1'390	1000 m³	99.3
Export semi-finisched products (minus chemical pulp)	670	1000 m³	47.9	670	1000 m³	47.9	670	1000 m³	47.9
Export 3/4: packaging, building mat, wood products	30	1000 t	4.3	30	1000 t	4.3	30	1000 t	4.3
Export furniture/houses	45	1000 t	6.4	45	1000 t	6.4	45	1000 t	6.4
Export chemical pulp	110	1000 t	15.7	110	1000 t	15.7	110	1000 t	15.7
Export mechanical pulp	20	1000 t	2.9	20	1000 t	2.9	20	1000 t	2.9
Export Paper and paperboard	1'110	1000 t	158.6	1'100	1000 t	157.1	1'100	1000 t	157.1
Wood residues in CH arising from exports (C+F+W)	*1'376*	*1000 m³*	*58.6*	*1'376*	*1000 m³*	*58.6*	*1'376*	*1000 m³*	*58.6*
Wood residues in CH arising from exports (C+F+W)			13.4			13.4			13.4
Import			kg/l*y			kg/l*y			kg/l*y
Import roundwood, wood residues	890	1000 m³	63.6	890	1000 m³	63.6	890	1000 m³	63.6
Import wood residues	534	1000 m³	38.1	534	1000 m³	38.1	534	1000 m³	38.1
Import roundwood	356	1000 m³	25.4	356	1000 m³	25.4	356	1000 m³	25.4
Import semi-finished products (minus chemical pulp)	1'070	1000 m³	76.4	1'070		76.4	1'070		76.4
Import 3/4: packaging, building mat, wood products	160	1000 t	22.9	160	1000 t	22.9	160	1000 t	22.9
Import furniture/houses	210	1000 t	30.0	210	1000 t	30.0	210	1000 t	30.0
Import chemical pulp	440	1000 t	62.9	440	1000 t	62.9	440	1000 t	62.9
Import mechanical pulp	5	1000 t	0.7	5	1000 t	0.7	5	1000 t	0.7
Import Paper and paperboard	1'100	1000 t	157.1	1'100	1000 t	157.1	1'100	1000 t	157.1
As product (K+A+H) in CH utilizable	*2'166*	*1000 m³*	*154.7*	*2'166*	*1000 m³*	*154.7*	*2'166*	*1000 m³*	*154.7*
As product (K+A+H) in CH utilizable			132.6			132.6			132.6
Wood residues in CH arising from imports (C+F+W)			22.1			22.1			22.1

Wood consumption from CH forest	kg/l*y	1000 m³	kg/l*y	1000 m³	kg/l*y	1000 m³
Production (K+A+H)	104	1'455	141	1'973	62	863
Wood residues produced	32	442	46	649	15	205
Production of mechanical/chemical pulp	32	445	24	341	24	341
Fuel wood	90	1'260	110	1'540	17	238
Export roundwood and wood residues	99	1'390	99	1'390	99	1'390
Total	**357**	**4'992**	**421**	**5'893**	**217**	**3'037**

Market shares and consumption volumes

Tab. 20 > Volumes and changes in market shares for the individual scenarios as compared with current status

	Situation 2000		Baseline 2030		Optimized Increment 2030						Kyoto-Optimized 2030				Reduced Forest Maintenance 2030	
					Building		Energy		Autarky		Building		Energy			
		1000 m^3		1000 m^3		1000 m^3		1000 m^3		1000 m^3		1000 m^3		1000 m^3		1000 m^3
Construction	Market share	861	Market share	1050	Market share	1'893	Market share	861	Market share	1893	Market share	1'893	Market share	861	Market share	649
Walls	8%	55	9%	80	25%	220	6%	55	25%	220	25%	220	6%	55	5%	48
Columns	39%	4.0	38%	5.0	45%	5.9	31%	4.0	45%	6	45%	6	31%	4.0	26%	3.4
Storey ceilings/floors	9%	137	10%	200	40%	770	7%	137	40%	770	40%	770	7%	137	5%	100
Insulation	11%	12	13%	17	20%	27	9%	12	20%	27	20%	27	9%	12	6%	8
Roofs	74%	480	85%	570	84%	560	72%	480	84%	560	84%	560	72%	480	54%	360
Structural engineering		136		130		220		136		220		220		136		115
Maintenance		37		48		90		37		90		90		37		15
Finishing	Market share	872	Market share	1050	Market share	1'399	Market share	872	Market share	1399	Market share	1'399	Market share	872	Market share	634
Wall and ceiling coverings	15%	82	17%	100	25%	150	14%	82	25%	150	25%	150	14%	82	11%	66
Stairs	15%	5.7	19%	8.0	25%	11	13%	5.7	25%	11	25%	11	13%	5.7	10%	4.2
Floor coverings	23%	89	28%	120	35%	150	21%	89	35%	150	35%	150	21%	89	16%	70
Façades	14%	45	15%	55	25%	93	12%	45	25%	93	25%	93	12%	45	10%	38
Fittings	71%	163	85%	220	75%	195	63%	163	75%	195	75%	195	63%	163	54%	139
Maintenance		86		97		240		86		240		240		86		35
Furniture		400		450		560		400		560		560		400		282
Wood products		757		910		1190		757		1190		1190		757		616
Total Consumption (C+F+W)		2'490		3'010		4'481		2'490		4'481		4'481		2'490		1'900
Fuel wood (incl. hedgerow timber)		1'260		1'540		2'800		5'600		2'030		2'100		4'900		392

As compared with today, wood storey ceilings/floors undergo the most significant increase in the building scenarios (by a factor of 4). The wood market share for walls is tripled. The wood market share for roofs, which is already high, only increases slightly.

In the *Baseline* scenario all of the construction components examined show a small increase in wood market share.

The market share of wood in the energy scenarios does not undergo any change.

The market share of wood in the *Reduced Forest Maintenance* scenario is reduced throughout.

Tab. 21 > Share of the individual construction components within construction and finishing

	Situation 2000		Baseline 2030		Optimized Increment 2030						Kyoto-Optimized 2030				Reduced Forest Maintenance 2030	
					Building		Energy		Autarky		Building		Energy			
		1000 m^3		1000 m^3		1000 m^3		1000 m^3		1000 m^3		1000 m^3		1000 m^3		1000 m^3
Construction	Part of Construction	861	Part of Construction	1050	Part of Construction	1'893	Part of Construction	861	Part of Construction	1893	Part of Construction	1'893	Part of Construction	861	Part of Construction	649
Walls	6%	55	8%	80	12%	220	6%	55	12%	220	12%	220	6%	55	7%	48
Columns	0%	4.0	0%	5.0	0%	5.9	0%	4.0	0%	6	0%	6	0%	4.0	1%	3.4
Storey ceilings/floors	16%	137	19%	200	41%	770	16%	137	41%	770	41%	770	16%	137	15%	100
Insulation	1%	12	2%	17	1%	27	1%	12	1%	27	1%	27	1%	12	1%	8
Roofs	56%	480	54%	570	30%	560	56%	480	30%	560	30%	560	56%	480	55%	360
Structural engineering	16%	136	12%	130	12%	220	16%	136	12%	220	12%	220	16%	136	18%	115
Maintenance	4%	37	5%	48	5%	90	4%	37	5%	90	5%	90	4%	37	2%	15
Finishing	Part of Finishings	872	Part of Finishings	1050	Part of Finishings	1'399	Part of Finishings	872	Part of Finishings	1399	Part of Finishings	1'399	Part of Finishings	872	Part of Finishings	634
Wall and ceiling coverings	9%	82	10%	100	11%	150	9%	82	11%	150	11%	150	9%	82	10%	66
Stairs	1%	5.7	1%	8.0	1%	11	1%	5.7	1%	11	1%	11	1%	5.7	1%	4.2
Floor coverings	10%	89	11%	120	11%	150	10%	89	11%	150	11%	150	10%	89	11%	70
Façades	5%	45	5%	55	7%	93	5%	45	7%	93	7%	93	5%	45	6%	38
Fittings	19%	163	21%	220	14%	195	19%	163	14%	195	14%	195	19%	163	22%	139
Maintenance	10%	86	9%	97	17%	240	10%	86	17%	240	17%	240	10%	86	6%	35
Furniture	46%	400	43%	450	40%	560	46%	400	40%	560	40%	560	46%	400	44%	282
Wood products		757		910		1190		757		1190		1190		757		616
Total Consumption (C+F+W)		2'490		3'010		4'481		2'490		4'481		4'481		2'490		1'900
Fuel wood (incl. hedgerow timber)		1'260		1'540		2'800		5'600		2'030		2'100		4'900		392

In terms of the use of wood in construction, roofs currently account for over 50 percent of the wood used. In the building scenarios, the share for storey floors/ceilings will increase to 40 percent in future and the share for roofs will be correspondingly reduced to 30 percent. In terms of finishing, furniture accounts for the largest share of wood use in all scenarios.

Foreign trade per construction component

Tab. 22 > Foreign trade and production in the *Optimized Increment* scenarios

	Situation 2000			Optimized Increment 2030 Building			Optimized Increment 2030 Energy			Optimized Increment 2030 Autarky		
	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³
Construction	Production	Import	Export	Production	Import	Export	Production	Import	Export	Production	Import	Export
Walls	39	48	32	204	48	32	39	48	32	220	-	-
Columns	3.0	3.4	2.4	4.9	3.4	2.4	3.0	3.4	2.4	5.9	-	-
Storey ceilings/floors	122	100	85	755	100	85	122	100	85	770	-	-
Insulation	12	8	8	27	8	8	12	8	8	27	-	-
Roofs	397	375	255	530	375	255	397	375	255	650	-	-
Structural engineering (fences)	104	115	83	188	115	83	104	115	83	220	-	-
Total Construction	678	649	465	1'709	649	465	678	649	465	1'893	-	-
Finishing	Production	Import	Export	Production	Import	Export	Production	Import	Export	Production	Import	Export
Wall and ceiling coverings	72	71	49	161	71	49	72	71	49	183	-	-
Stairs	5.1	4.2	3.6	9.9	4.2	3.6	5.1	4.2	3.6	11	-	-
Floor coverings	89	80	55	200	80	55	89	80	55	225	-	-
Façades	35	38	28	83	38	28	35	38	28	93	-	-
Fittings	154	159	100	268	159	100	154	159	100	327	-	-
Furniture	177	282	59	337	282	59	177	282	59	560	-	-
Total Finishing	533	634	295	1'059	634	295	532	634	295	1'399	-	-
Wood products	Production	Import	Export	Production	Import	Export	Production	Import	Export	Production	Import	Export
Packaging	355	135	14	627	135	14	355	135	14	747	-	-
Wood products	16	75	10	62	75	10	16	75	10	127	-	-
Auxiliary constr. materials (formwork)	109	35	25	177	35	25	109	35	25	187	-	-
DIY	18	75	11	64	75	11	18	75	11	129	-	-
Total Wood products	497	320	60	930	320	60	497	320	60	1'190	-	-

Tab. 23 > Foreign trade and production for the *Kyoto-Optimized* scenarios

	Situation 2000			Kyoto-Optimized 2030 Building			Kyoto-Optimized 2030 Energy		
	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³
Construction	Production	Import	Export	Production	Import	Export	Production	Import	Export
Walls	39	48	32	204	48	32	39	48	32
Columns	3.0	3.4	2.4	4.9	3.4	2.4	3.0	3.4	2.4
Storey ceilings/floors	122	100	85	755	100	85	122	100	85
Insulation	12	8	8	27	8	8	12	8	8
Roofs	397	375	255	530	375	255	397	375	255
Structural engineering (fences)	104	115	83	188	115	83	104	115	83
Total Construction	678	649	465	1'709	649	465	678	649	465
Finishing	Production	Import	Export	Production	Import	Export	Production	Import	Export
Wall and ceiling coverings	72	71	49	161	71	49	72	71	49
Stairs	5.1	4.2	3.6	9.9	4.2	3.6	5.1	4.2	3.6
Floor coverings	89	80	55	200	80	55	89	80	55
Façades	35	38	28	83	38	28	35	38	28
Fittings	154	159	100	268	159	100	154	159	100
Furniture	177	282	59	337	282	59	177	282	59
Total Finishing	533	634	295	1'059	634	295	532	634	295
Wood products	Production	Import	Export	Production	Import	Export	Production	Import	Export
Packaging	355	135	14	627	135	14	355	135	14
Wood products	16	75	10	62	75	10	16	75	10
Auxiliary constr. materials (formwork)	109	35	25	177	35	25	109	35	25
DIY	18	75	11	64	75	11	18	75	11
Total Wood products	497	320	60	930	320	60	497	320	60

Tab. 24 > Foreign trade and production in the *Baseline* and Reduced *Forest Maintenance* scenarios

	Situation 2000			Baseline 2030			Reduced Forest Maintenance		
	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³	1000 m³
Construction	Production	Import	Export	Production	Import	Export	Production	Import	Export
Walls	39	48	32	64	48	32	32	48	32
Columns	3.0	3.4	2.4	4.0	3.4	2.4	2.4	3.4	2.4
Storey ceilings/floors	122	100	85	185	100	85	85	100	85
Insulation	12	8	8	17	8	8	8	8	8
Roofs	397	375	255	498	375	255	255	375	255
Structural engineering (fences)	104	115	83	98	115	83	83	115	83
Total Construction	678	649	465	866	649	465	466	649	465
Finishing	Production	Import	Export	Production	Import	Export	Production	Import	Export
Wall and ceiling coverings	72	71	49	93	71	49	49	71	49
Stairs	5.1	4.2	3.6	7.4	4.2	3.6	3.6	4.2	3.6
Floor coverings	89	80	55	120	80	55	55	80	55
Façades	35	38	28	45	38	28	28	38	28
Fittings	154	159	100	219	159	100	100	159	100
Furniture	177	282	59	227	282	59	59	282	59
Total Finishing	533	634	295	711	634	295	295	634	295
Wood products	Production	Import	Export	Production	Import	Export	Production	Import	Export
Packaging	355	135	14	380	135	14	218	135	14
Wood products	16	75	10	53.3	75	10	15.1	75	10
Auxiliary constr. materials (formwork)	109	35	25	133	35	25	87	35	25
DIY	18	75	11	81	75	11	34	75	11
Total Wood products	497	320	60	647	320	60	354	320	60

A4 Wood harvesting in the individual scenarios

Fig. 50 > Harvesting in the *Optimized Increment* scenario

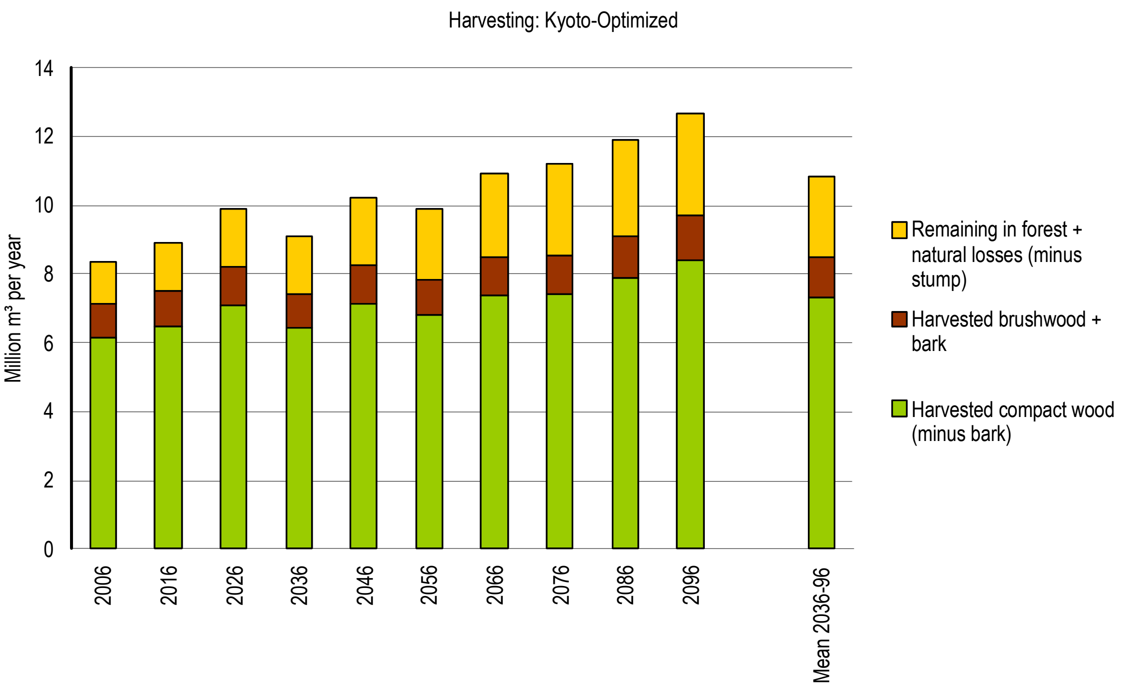


Fig. 51 > Harvesting in the *Kyoto-Optimized* scenario

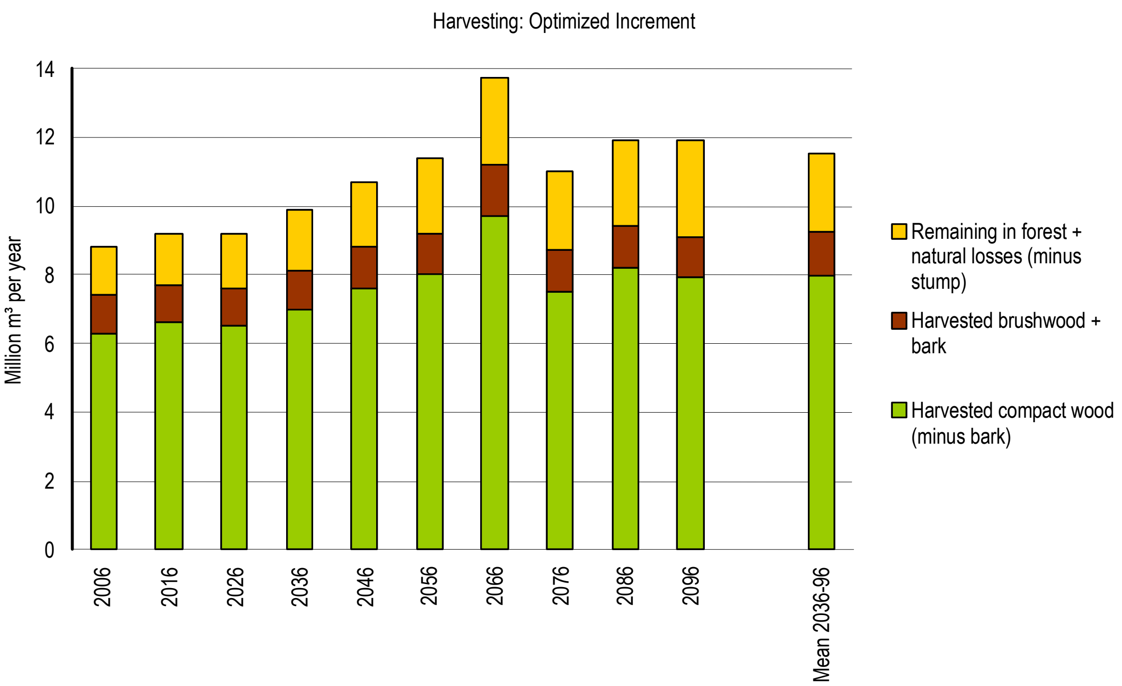


Fig. 52 > Harvesting in the *Baseline* scenario

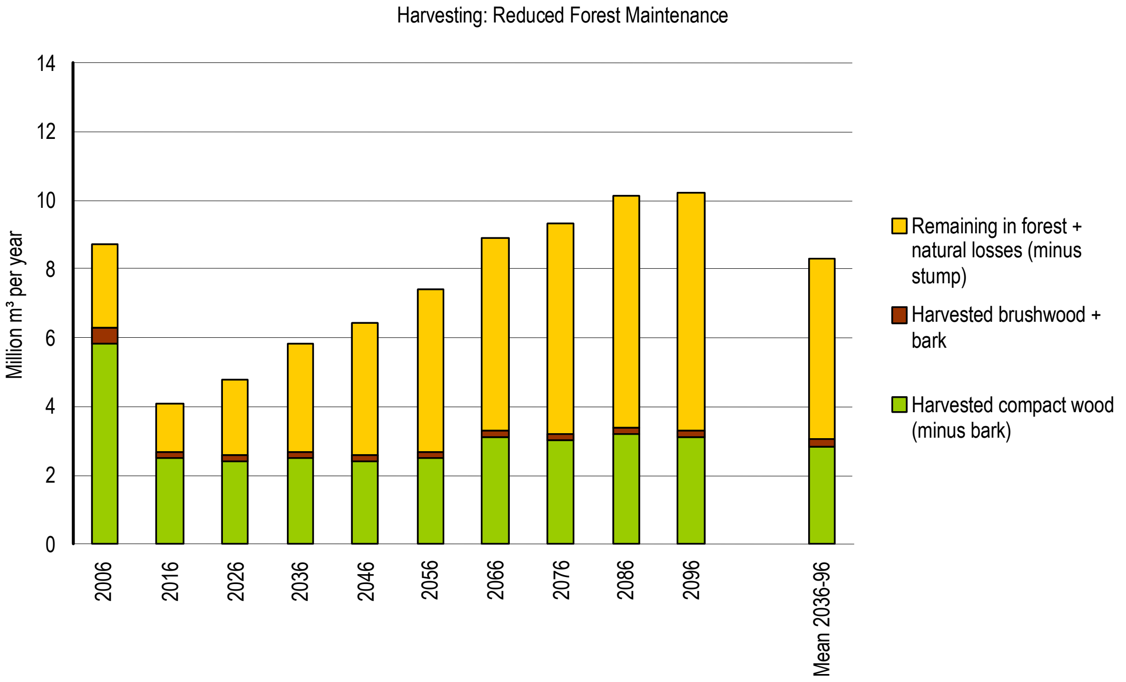
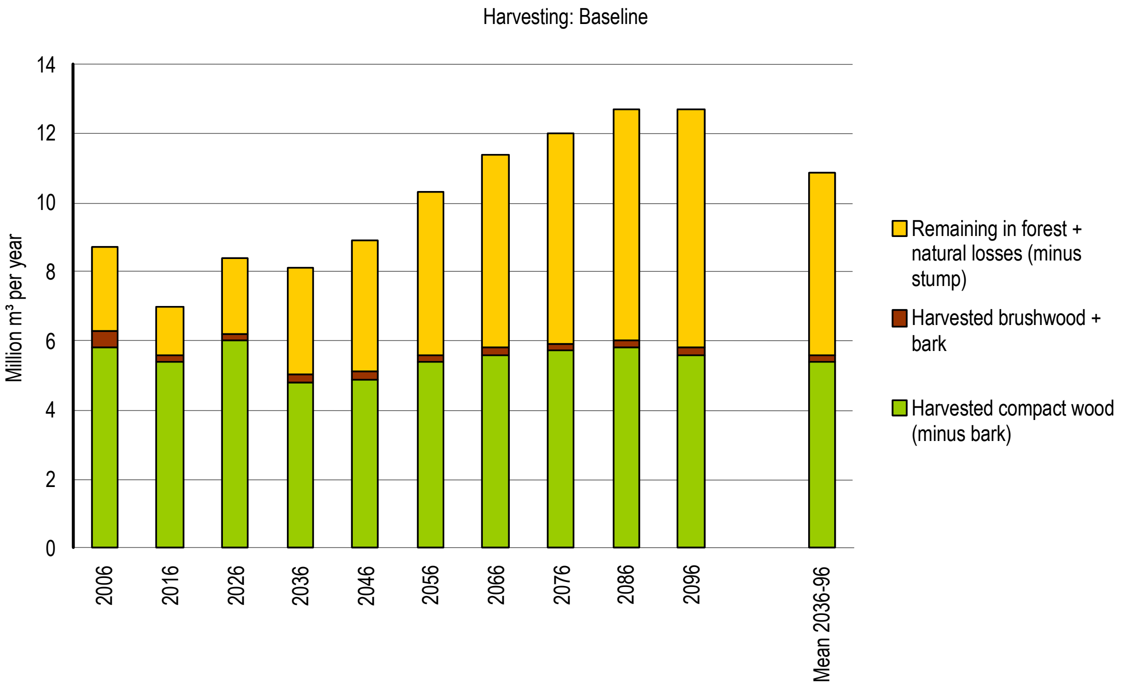


Fig. 53 > Harvesting in the *Reduced Forest Maintenance* scenario



A5 Material substitution factors

The following tables, Tab. 25 and Tab. 26 summarize the material substitution factors used. They are expressed in kg CO_2 per kg wood and can, therefore, be multiplied by the corresponding wood fluxes in or out of the building stock.

Tab. 25 > Substitution factors for material substitution: finish and wood products (authors' own calculations)

			per kg wood		Substitution effect	
			Fossil fuel emissions CH [kg CO_2 eq]	Fossil fuel emissions abroad [kg CO_2 eq]	Fossil fuel emissions CH [kg CO_2 eq]	Fossil fuel emissions abroad [kg CO_2 eq]
Construction						
Exterior wall	Solid wood panel	Production	0.246	0.208	-1.116	-0.252
		Disposal	0.017	0.015	-0.172	-0.057
		Total	0.264	0.222		
	Brick cavity masonry	Production	1.362	0.460		
		Disposal	0.189	0.071		
		Total	1.551	0.531		
Columns	Glulam column	Production	0.110	1.139	0.081	-2.378
		Disposal	0.017	0.013	0.017	0.013
		Total	0.127	1.152		
	Steel column	Production	0.029	3.517		
		Disposal	0.000	0.000		
		Total	0.029	3.517		
Storey ceiling/floor	Wood joist ceiling/floor	Production	0.468	0.520	-1.057	-0.088
		Disposal	0.081	0.037	-1.255	-0.336
		Total	0.548	0.558		
	Reinforced concrete ceiling/floor	Production	1.525	0.608		
		Disposal	1.335	0.374		
		Total	2.860	0.982		
Insulation	Wood fibre insulation board	Production	0.420	0.133	0.301	0.086
		Disposal	0.016	0.013	0.009	0.010
		Total	0.436	0.146		
	Rockwool	Production	0.119	0.046		
		Disposal	0.007	0.002		
		Total	0.126	0.049		
Roof	Exposed beam structures	Production	0.886	0.255	-0.038	-1.218
		Disposal	0.070	0.029	-0.034	-0.013
		Total	0.957	0.283		
	Aerated concrete steep roof	Production	0.924	1.473		
		Disposal	0.104	0.041		
		Total	1.028	1.514		
Structural engineering	Wood palisade	Production	0.049	0.268	-0.696	0.020
		Disposal	0.011	0.001	-0.044	-0.009
		Total	0.060	0.269		
	Concrete palisade	Production	0.746	0.248		
		Disposal	0.055	0.010		
		Total	0.801	0.258		

Tab. 26 > Substitution factors of material substitution: finish and wood products (authors' own calculations)

			per kg wood		Substitution effect	
			Fossil fuel emissions CH [kg CO_2 eq]	Fossil fuel emissions abroad [kg CO_2 eq]	Fossil fuel emissions CH [kg CO_2 eq]	Fossil fuel emissions abroad [kg CO_2 eq]
Finish						
Wall and ceiling coverings	Spruce panelling	Production	0.034	0.052	-0.603	-1.086
		Disposal	0.017	0.017	-0.172	-0.052
		Total	0.052	0.069		
	Interior plaster	Production	0.638	1.138		
		Disposal	0.190	0.069		
		Total	0.828	1.207		
Stairs	Oak staircase	Production	0.024	0.093	-0.486	-0.780
		Disposal	0.015	0.011	-0.360	-0.094
		Total	0.038	0.105		
	Precast concrete stairs	Production	0.509	0.873		
		Disposal	0.375	0.106		
		Total	0.884	0.979		
Floor coverings	3-layer parquet	Production	0.384	0.421	0.284	-2.228
		Disposal	0.027	0.018	-0.091	-0.027
		Total	0.412	0.438		
	Glazed ceramic tiles	Production	0.100	2.649		
		Disposal	0.118	0.045		
		Total	0.218	2.694		
Façades	Raw wood siding incl. lath	Production	0.043	-0.032	-0.730	-1.398
		Disposal	0.019	0.021	-0.213	-0.072
		Total	0.062	-0.011		
	Exterior plastering	Production	0.773	1.366		
		Disposal	0.232	0.093		
		Total	1.005	1.459		
Fittings	Door frame from particleboard	Production	1.444	2.271	0.106	-2.765
		Disposal	0.067	0.058	-0.165	0.058
		Total	1.510	2.329		
	Steel door frame	Production	1.337	5.035		
		Disposal	0.231	0.000		
		Total	1.569	5.035		
Furniture	Wood furniture	Production	1.105	1.696	0.593	-2.620
		Disposal	0.067	0.058	0.067	0.058
		Total	1.172	1.754		
	Steel furniture	Production	0.513	4.316		
		Disposal	0.000	0.000		
		Total	0.513	4.316		

			per kg wood		Substitution effect	
			Fossil fuel emissions CH [kg CO_2 eq]	Fossil fuel emissions abroad [kg CO_2 eq]	Fossil fuel emissions CH [kg CO_2 eq]	Fossil fuel emissions abroad [kg CO_2 eq]
Packaging / wood components						
Packaging/wood components	Raw wood siding incl. lath	Production	0.043	-0.032	-0.618	-1.131
		Disposal	0.019	0.021	-1.373	0.021
		Total	0.062	-0.011		
	Polypropylen	Production	0.661	1.099		
		Disposal	1.392	0.000		
		Total	2.053	1.099		
Formwork	3-layer spruce panel	Production	0.357	0.285	0.357	0.108
		Disposal	0.016	0.014	-0.011	0.014
		Total	0.373	0.299		
	Aluminium formwork	Production	0.000	0.178		
		Disposal	0.027	0.000		
		Total	0.027	0.178		
Wall covering	Spruce panelling	Production	0.034	0.052	-0.603	-1.086
		Disposal	0.017	0.017	-0.172	-0.052
		Total	0.052	0.069		
	Interior plaster	Production	0.638	1.138		
		Disposal	0.190	0.069		
		Total	0.828	1.207		

A6 Substitution factors for the product categories in the balance of foreign trade

The fact that the SIMBOX model does not model the foreign trade statistics for wood products in the domestic production product categories represented a technical problem. For this reason, it made sense to allocate the emissions and substitution factors for domestic production to the following product categories:

> furniture/houses;
> three-quarter-finished products;
> semi-finished products;
> roundwood/wood residues.

In addition, the emissions and substitution factors from production and disposal for wood products and their substitutes had to be adapted locally for both the import and export situations.

The determination of the emission and substitution factors for the imports of wood products under the assumption of the substitution of domestic wood products was based on the following considerations:

> The composition of the houses/furniture product category consists of the weighted mean from the weighted product categories construction and finishing in accordance with import and export statistics.
> The composition of the roundwood/wood residues, semi-finished products and three-quarter-finished products consists of the weighted mean from the weighted product categories construction, finishing and wood products in accordance with the import or export statistics.
> In the case of the product category roundwood/wood residues, the production emissions for roundwood generation are assigned on the basis of the assumption of 28 percent hardwood and 82 percent softwood to countries abroad for imports and to Switzerland for exports.
> In the case of the product category houses/furniture, the assumption of complete production in Switzerland is assumed for exports and abroad for imports. With production abroad all emissions arise abroad; with domestic production the emissions are divided between Switzerland and abroad in accordance with the production emissions factors for domestic production.
> The product categories semi-finished products and three-quarters-finished products are modelled analogously to the product category roundwood/wood residues with the additional production emissions from manufacture, i.e. all of the production emissions minus roundwood manufacture in the case of semi-finished products being divided half and half between Switzerland and abroad. In the case of the three-quarter-finished products, for imports three quarters of the further processing emissions are allocated to countries abroad and one quarter of the further processing emissions to Switzerland (whereby domestic further processing again involves emissions from the provision abroad of fossil fuels and auxiliary products such as glues). In the case of exports, three quarters of the further processing emissions are allocated to Switzerland (whereby domestic further processing again involves supply emissions abroad) and one quarter of the further processing emissions are allocated to countries abroad.

> Index

Acronyms

BEF
Biomass expansion factor

BFE
Bundesamt für Energie (Swiss Federal Office of Energy)

C
Chemical symbol for the element carbon

CO_2 eq
Carbon dioxide equivalent

CO_2
Chemical formula for carbon dioxide

DM
Dry matter

EAWAG
Swiss Federal Institute of Aquatic Science and Technology – the aquatic research institute of the ETH domain

EMPA
Swiss Materials Science and Technology Research Institute

FOEN
Swiss Federal Office for the Environment (formerly SAEFL)

H
Chemical symbol for hydrogen

HGV
Heavy goods vehicle

IPCC
Intergovernmental Panel on Climate Change

kg DM/I*y
Kilogram of dry matter per inhabitant per year

LCA
Life cycle assessment

MWI
Municipal Waste Incinerator

NFI
Swiss National Forest Inventory

O
Chemical symbol for oxygen

SAEFL
Swiss Agency for the Environment, Forest and Landscape (now FOEN)

WSL
Swiss Federal Institute for Forest, Snow and Landscape Research

ZPK
Verband der Schweizerischen Zellstoff-, Papier- und Kartonindustrie (Association of the Swiss Pulp, Paper and Paperboard Industry)

Glossar

Allometry
In this context, the difference in size between different tree parts (e.g. stemwood/branch brushwood and roots).

Basal area increment
The basal area refers to the total cross-section area of the trees in a stand at a height of 1.30 m (= breast height). The increment of this basal area is calculated on the basis of the difference in the measurements taken for two surveys.

Building scenarios
Scenarios in which priority is given to the use of wood in the construction sector: i.e. *Optimized Increment, Building, Kyoto-Optimized*

Building stock
All buildings

Technosphere
The anthroposphere or human habitat in which the biological and technical processes developed and operated by man are located and where human activity takes place.

Turnover period
Turnover period refers to the period between the emergence of a tree stand as a result of planting or natural wind dispersion to the end-use or regeneration of the stand.

CO_2 equivalent
CO_2 equivalent is a parameter that expresses the greenhouse gas potential of substances in the earth's atmosphere such as, for example, methane (CH_4) and nitrous oxide or "laughing gas" (N_2O). The greenhouse effect of carbon dioxide is used as a reference value. CO_2 equivalent is important as a reference indicator *inter alia* for the Kyoto Protocol, as all of the greenhouse gases regulated by the Protocol are specified using this value.

Cumulative values
Total values for the entire period under consideration (2000 to 2096, or 2150).

Effects
Used in the context of this study, generally refers to CO_2-relevant effects (apart from economic effects).

Empirical
Based on experience or observation; the data from the Swiss National Forest Inventories I and II were used as empirical values in this study.

Employment effect
Effect of the number of people employed in a given sector

Energy substitution
Replacement of fossil fuels with wood (i.e. fuel wood, wood residues and waste wood)

Finish wood
Floors/ceilings, wall and ceiling coverings, windows and doors, fixtures and furniture are classified as finish components. Their lifetime is considerably shorter and presumably far more scattered than in the case of structural components. Their average lifetime is assumed as 30 years.

Foreign trade
Import and export of goods

Forest C stocks
Sum of the CO_2 effects in the forest (change in the living tree biomass + change in the C stocks in and on the soil and emission into the atmosphere).

Heterotroph
An organism that depends on the metabolic products of other organisms for growth and development

Input
Inputs are third-party goods and services consumed in the production process. These include supplied materials and related services but not the labour factor.

Kyoto Protocol
The Kyoto Protocol (named after the location where the conference leading to the compilation of the Kyoto Protocol was held, i.e. Ky to in Japan) is an additional protocol to the United Nations Framework Convention on Climate Change which was passed in 1997. The agreement, which came into force in 2005 and is valid until 2012, prescribes binding target values for greenhouse gas emissions which are the main cause of global warming.

Logistical curve
The graph of the function takes the form of an s-shaped curve. Initially the growth is small. The curve rises most steeply in the centre until it becomes horizontal again towards the end.

Logistical regression
Logistical regression refers to a procedure for the (usually multivariate) analysis of binary dependent variables.

MASSIMO
Empirical dynamic forest model which enables the simulation of forest development.

Material substitution
Here: the replacement of non-wood construction materials (concrete, steel etc.) with wood components.

Mortality
In the context of forests, the proportion of trees in a stand that die due to age, external factors or excessive stand density.

Process
Expression from material flux analysis: a process refers to a balance volume, in which materials or goods are transported, transformed or stored or change their value.

Regression model
Regression analysis measures the connection between two or more values.

Slash
Waste wood generated during logging

Socio-economic effects
Effects on employment figures and value added.

Stochastic
Related to or characterized by randomness

Stock balance
State whereby the fluxes into and out of a stock are equal (i.e. no stock change).

Structural wood
The structure of a building comprises all of the structural components, i.e. the roof structure, storey ceilings/floors, structural external and internal walls and stairs. It also includes all of the exterior structures, such as bridges and jetties. Structural components share a long lifetime which is defined as 80 years in the context of this study.

Substitution scenarios
Scenarios in which the main focus is on energy or material substitution: i.e. *Optimized Increment, Building; Kyoto-Optimized; Optimized Increment, Energy*

Substitution
Replacement of a particular thing by another

Thinning
Silvicultural (maintenance) measures carried out up to logging.

Total effects
Sum of the individual effects (e.g. domestic and foreign effects)

Value added
Value added measures the return on economic activity as the difference between the output of an economic entity and the input used in the generation of this output.

Waste wood
Wood withdrawn from use (construction, finishing, wood products) which is used for energy production in Switzerland. Exported waste wood is put to both energy and material use (e.g. in chipboard).

Wood products
These include packaging, indirect construction materials and do-it-yourself products. They are assigned to the construction sector in this study.

Wood residues
All wood originating from wood processing which is used for energy generation.

Wood stocks
All of the wood stored in the technosphere

YASSO
Model for the determination of the change in the carbon stocked in the soil

Figures

Tables

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