Recalculation of emission factors in Swiss forests for the Swiss GHGI

Internal documentation of technical adjustments of data delivery and more recent data

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Summary

For the Swiss Greenhouse Gas Inventory 1990-2011 (FOEN 2013), we revised the way the emission factors for the forest sector are calculated in response to technical improvements and more recent data. This report describes, documents and analyzes all changes in the recalculation of the time series 1990-2011, and compares them with the Austrian inventory. The recalculated sink between National Forest Inventory (NFI) 1 and 2 is +3.65 million t CO_2 per year and between NFI 2 and 3 +1.53 million t CO_2 per year. The estimated sink between NFI 1 and 2 is therefore much larger than that between NFI 2 and 3.

For the recalculation, the original data of the single tree measurements of the NFIs were used as input data. Changes in the estimated sink effect, therefore, are the result of technical improvements. The sink estimation for 1986-1995 (NFI 1-2) increased by +4%, and for 1996-2006 (NFI 2-3) by +21% with improved data derivation. The sink effect between NFI 2 and 3 decreased by 6.2% as a result of a new parameterization of the root function for conifers. The sink effect between NFI 1 and 2 decreased by -0.11 Mio t CO_2 per year or -3%, and increased between NFI 2 and 3 by +0.37 Mio t CO_2 per year or +32% because of a change from applying biomass expansion- and conversion factors to aggregated stand-level volume estimates to applying biomass functions to tree-wise data decreased the sink effect.

For the first time, estimates for the time period 2007 - 2011 are no longer based on extrapolation of NFI 2 and 3 data but on real measurements of NFI 4a. The use of real data increases the sink effect, because harvesting amounts since 2008 have decreased.

1 Introduction

For the Swiss Greenhouse Gas Inventory (GHGI) in 2013 (FOEN 2013), we revised the calculation of the emission factors for the forest sector taking into account technical improvements and more recent data. To ensure temporal consistency the revised methodology was used to recalculate emission factors for all years since 1990. This report documents the resulting differences between the old and the new, revised emission factors for *forest land remaining forest land*. For transparency, the technical improvements and their effect on the emission factors are reported in detail for 1) the further development of the formulation of National Forest Inventory (NFI) data derivations, 2) the use of a more accurate allometric function for calculating the volume of coniferous roots, and 3) the more precise approach to calculating gains and losses. For the first time, most recent NFI 4a data for the years 2009-2011 have been included in the report.

2 Derivations of NFI data

In each NFI, single tree variables such as stem diameter at breast height (DBH, 1.3 m above the anticipated germination point), tree height or diameter at 7 m tree height have been collected in the field. Those data are called basic data. Combining different basic data and applying functions to those data, derivations of basic data can be derived. Those derived variables strongly vary in complexity. They can be simple combinations of basic data such as mean basal area or complex combinations of several dependent variables and functions such as stem volume, growth and cut & mortality.

In former Swiss GHGIs (FOEN 2012 and before), emission factors of growing stock, gains and losses in the forest sector were based on the NFI derivations dating from October 2008. These derivations were used for the analysis of stocks and stock changes resting on basic data of NFI 1 and 2 (cf. Brassel and Brändli 1999) and NFI 2 and 3 (cf. LFI3-Ergebnisbericht, V1, Annex). The results of the stock change analysis between two consecutive NFIs with the derivations dating from 2008 are shown in Table 1.

In the course of quality assurance and control, the formulations of the NFI data derivations were revised for plausibility and realism. The largest inconsistency that was identified related to the negative growth that was observed in the results of the first version of NFI 3 results publication. Negative growth can occur when random measurement errors of repeated measurements such as DBH are larger than the real change of DBH over time. However, the analysis indicated that negative growth was often correlated with the application of NFI specific functions to derive stem volume. The coefficients for these functions were estimated independently for all NFIs. The random variations of the model coefficients could therefore cause shifts in tree volume between NFIs. These shifts caused a high variability in the estimated growth of single trees. To estimate gains and losses of single trees more consistently, a function (*Tarif 123*) that has been modified with respect to consistency of parameter estimation was applied in the second version of the NFI 3 results publication (Brändli 2010). Compared with the first version, the effect of the improvement of the data derivations was:

- a 0.2% increase in growing stock,
- a 0.6% increase in losses, and
- a 1.6% increase in gains.

These changes are within the standard error of the estimate of 2%. Results of the second version of the NFI 3 results publication are summarized in Table 1. They correspond to the results published in Brändli (2010) and the Swiss GHGI submission in 2013 (FOEN 2013).

2.1 Estimation of sink effect

The sink effect is estimated as gains minus losses. The uncertainty of this sink effect can be approximated by combining the absolute error of gains and losses. In case of NFI 1-2 and NFI 2-3, this amounts to ±0.3 $m^3ha^{-1}year^{-1}$ (68% confidence interval, see Table 1). This uncertainty is the same for the former and the new data delivery. In case of NFI 1-2, the recalculated sink effect is 2.6 $m^3ha^{-1}year^{-1}$ with the uncertainty of ±0.3 $m^3ha^{-1}year^{-1}$ or ±12% of the estimated sink. For NFI 2-3, the recalculated sink effect is 0.51 $m^3ha^{-1}year^{-1}$, but the uncertainty remains ±0.3 $m^3ha^{-1}year^{-1}$. This results in an uncertainty of ±60% expressed in percent of the estimated sink effect. This example shows that the smaller the sink effect is, the larger percentage uncertainty becomes. In addition, changes of the recalculation are much more apparent in case of small sink effects. Between NFI 1-2, the recalculated sink increased by 0.1 $m^3ha^{-1}year^{-1}$ corresponding to 4% of the absolute sink. Between NFI 2-3, the same effect of recalculation accounted for 21% of the absolute sink.

Table 1 Summary of NFI data delivery 2008 for GHG reporting under the UNFCCC and under the Kyoto Protocol and comparable data in 2012. 2008 data has been used in former GHGI submissions (FOEN 2012 and before), recalculated data in 2012 build the basis for data delivery for the GHGI 1990-2011 (FOEN 2013).

	Data delivery October 2008	Comparable data 2012	Absolute diff.	Diff. in percentage
Gains NFI 1-2	9.2* ±0.1 $m^3ha^{-1}year^{-1}$	9.3*** ±0.2 $m^3ha^{-1}year^{-1}$	+0.1 $m^3ha^{-1}year^{-1}$	+1%
Losses NFI 1-2	6.7* ±0.2 $m^3ha^{-1}year^{-1}$	6.7*** ±0.2 $m^3ha^{-1}year^{-1}$	+0	0%
Sink NFI 1-2	2.5 ±0.3! $m^3ha^{-1}year^{-1}$	2.6 ±0.3! $m^3ha^{-1}year^{-1}$	**+0.1 $m^3ha^{-1}year^{-1}$**	**+4%**
Gains NFI 2-3	8.61+ ±0.2 $m^3ha^{-1}year^{-1}$	8.75** ±0.2 $m^3ha^{-1}year^{-1}$	+0.14 $m^3ha^{-1}year^{-1}$	+1.6%
Losses NFI 2-3	8.19+ ±0.25 $m^3ha^{-1}year^{-1}$	8.24** ±0.2 $m^3ha^{-1}year^{-1}$	+0.05 $m^3ha^{-1}year^{-1}$	+0.6%
Sink NFI 2-3	0.42 ±0.3! $m^3ha^{-1}year^{-1}$	0.51 ±0.3! $m^3ha^{-1}year^{-1}$	**+0.09 $m^3ha^{-1}year^{-1}$**	**+21%**

* From Brassel and Brändli (1999)
** From Brändli (2010)
*** Publication of revised form of NFI 1-2 results in WEB tables (2012) (http://www.lfi.ch/resultate/)
+ First version of NFI 3 publication of results (LFI3-Ergebnisbericht, V1), 20.08.2008, for tables see Annex (later on replaced by Brändli (2010), see main text)
! Calculation of error: accumulated standard error: sqrt($std1^2$ + $std2^2$)

3 New root function for conifers

The biomass of all tree compartments (stem-wood over bark including stump, coarse and small branches, needles/leaves, and roots) were estimated based on established allometries for tree compartments (Table 2). Estimates for branches, foliage and roots were derived from tree diameter at breast height (DBH) only; for stem-wood over bark including stump also diameter at tree height 7 m (D7) and total tree height were required. Except for roots, the biomass functions were empirically derived from a large number of single tree data from Swiss forest sites (cf. references in Table 2).

Table 2 Applied allometric biomass functions, dependencies and literature.

Tree parts	Input parameter	Nr. of trees	Literature
Stem-wood over bark incl. stump	DBH, D7, height	12’000	Kaufmann et al. 2001
Coarse branches (>= 7 cm)	DBH	40’000	Kaufmann et al. 2001
Small branches (< 7 cm)	DBH	40’000	Kaufmann et al. 2001
Needles, Leaves	DBH	400	Perruchoud et al. 1999
Broadleaved Roots	DBH	443	Wutzler et al. 2008
Coniferous Roots	DBH	80	Zell and Thürig 2012

To ensure international compatibility of our results, we regularly evaluate our methods and analyses with reporting systems of other countries. The reporting system of Switzerland and Austria are quite similar and both countries report gains and losses of biomass in the forest sector based on repeated single tree measurements of the NFI (see NIR from Austria, Umweltbundesamt 2012). Up to now, Austria and Switzerland used the same root function for conifers from Wirth et al. (2004). In its NIR 2012, Austria indicated that the application of this root function can lead to an overestimation of the root mass of large conifers. Austria therefore decided to apply a different function from Wirth et al. (2004) with tree age as a predictor variable, stabilizing the overestimation of larger trees. This solution cannot be implemented in Switzerland because tree age is not measured for all trees and the uncertainty of modeled tree age is unknown. We therefore had to develop a more conservative parameterization of the initial Wirth-function for large trees based on the single tree data from Wirth et al. (2004). The parameter development and new values were described and discussed in the internal report from Zell and Thürig (2012).

The effect of the more conservative parameterization of the coniferous root function was:

- a 2.3% decrease in biomass in growing stock,
- a 2.5% decrease in losses, and
- a 3.9% decrease in gains.

These changes lead to a decrease of the national sink in the forest sector of 6.2%.

4 Calculation of gains and losses in biomass

Until the Swiss GHGI 2012, the calculation of gains and losses in biomass was done in two steps. First, all gains and losses were calculated as aggregated stand-level estimates in stem-wood over bark including stump (in m^3 ha^{-1}) corresponding to the generally applied reporting unit of growing stock, increment and losses in the Swiss NFI (Brassel and Brändli 1999). The exact method is described in Kaufmann (2001). Second, the aggregated stand-level estimates of stem-wood were converted and expanded to above- and below-ground biomass by applying biomass expansion and conversion factors (BCEF).

For Switzerland, country specific BCEFs were calculated as the ratio between the total above- and below-ground biomass (t ha^{-1}) and stem-wood over bark including stump (m^3 ha^{-1}) for all living trees. BCEFs (t m^{-3}) were calculated following Equation 1:

Equation 1

$$BCEF_j = \frac{\sum_{i=1}^{n} biomass_{ij}}{\sum_{i=1}^{n} stem\ wood_{ij}}$$

where i is the population of all living trees and *j* represents 30 strata (conifers/broadleaves x 3 elevation classes x 5 geographic regions). Prior to FOEN (2013), those BCEFs were use to transform growing stock, net annual increment (gains) and wood removals (losses) in m^3 stem-wood over bark including stump into total living biomass, total biomass growth and total biomass removals (t) following Equations 2 to 4:

Equation 2

$$Biomass\ in\ Growing\ stock_{\mathrm{j}} = \left(\sum_{i=1}^{n} Stem\ wood_{Growing\ stock\ i}\right)_j * BCEF_j$$

Equation 3

$$Biomass\ in\ Gains_{\mathrm{j}} = \left(\sum_{y=1}^{n} Stem\ wood_{gains\ y}\right)_j * BCEF_j$$

Equation 4

$$Biomass\ in\ Losses_{\mathrm{j}} = \left(\sum_{z=1}^{n} Stem\ wood_{Losses\ z}\right)_j * BCEF_j$$

Where i is the population of all living trees, y the population of all trees contributing to gains and z all trees contributing to losses. J indicates and the 30 strata mentioned above. However, BCEFs applied to increment and removals were derived from the population of living trees (growing stock). During the UNFCCC in-country review 2007, it was requested that Switzerland revises its calculation of gains and losses in biomass, and specifically adjusts the expansion and conversion of stem-wood for the different populations of growing stock, gains and losses (UNFCCC 2007: §92).

To comply with this request, Switzerland changed the calculation of gains and losses to a single tree basis corresponding to the method applied in Austria (Umweltbundesamt 2012). In the Swiss GHGI to be submitted in April 2013 (FOEN 2013), the revised method will be applied: first, the biomass of all individual trees was calculated and, second, gains and losses were calculated for each tree as the difference in its biomass between NFIs (equations 5 to 7):

Equation 5

$$Biomass\ in\ Growing\ stock_{\mathrm{j}} = \left(\sum_{i=1}^{n} Biomass_{Growing\ stock\ i}\right)_j$$

Equation 6

$$Biomass\ in\ Gains_{\mathrm{j}} = \left(\sum_{y=1}^{n} \Delta\ Biomass_{Gains\ y}\right)_j$$

Equation 7

$$Biomass\ in\ Losses_{\mathrm{j}} = \left(\sum_{z=1}^{n} \Delta\ Biomass_{Losses\ z}\right)_j$$

where i is the population of all living trees, y the population of all trees contributing to gains and z all trees contributing to losses. J indicates the 30 strata mentioned above used for the spatial aggregation of emission factors and application to the areal data (see FOEN 2012).

For illustration and transparency, BCEFs were calculated from the revised single tree calculation system (Table 3). Please note: these expansion factors are not used for calculation of gains and losses in FOEN (2013).

Table 3 Comparison of Biomass Conversion and Expansioni Factors (BCEFs) used in GHG reporting 2012 (FOEN 2012 and before) and updated BCEFs 2013 (weighted averages, not used for calculation). BCEFs 2013 are only shown for transparency reasons and for better interpretation of recalculated sink effects.

		BCEF 2012 Growing stock	BCEF 2013 Growing stock	BCEF 2013 Gains	BCEF 2013 Losses	Difference (BCEF 2013 Gains – Losses)
Conifers	NFI 1		0.62			
	NFI 1-2			0.59	0.60	-0.01
	NFI 2		0.61			
	NFI 2-3			0.61	0.59	0.02
	NFI 3*	0.64	0.62			
	NFI 3-4			0.62	0.60	0.02
	NFI 4		0.63			
	Austria**			0.62	0.61	0.01
Broadleaves	NFI 1		0.81			
	NFI 1-2			0.82	0.79	0.03
	NFI 2		0.82			
	NFI 2-3			0.85	0.81	0.04
	NFI 3	0.83	0.83			
	NFI 3-4			0.86	0.83	0.03
	NFI 4		0.83			
	Austria**			0.88	0.86	0.02

* For conifers, BCEFs 2013 for growing stock is smaller than BCEF 2012 because of the new parameters for coniferous roots (see Section 3).
** In Umweltbundesamt 2012, only BEFs are published. For comparison in this report, BEFs are converted to BCEFs by multiplication with wood densities (0.38 for conifers, 0.54 for broadleaves as given in Umweltbundesamt 2012, Table 215).

BCEFs for gains and losses vary between the four inventories (Table 3). The values for gains range from 0.59 to 0.61 for conifers and from 0.82 to 0.86 for broadleaves. The values for losses show a similar range; 0.59 to 0.60 for conifers and 0.79 to 0.83 for broadleaves (Table 3). The BCEFs and difference between gains and losses, respectively, are in the same range as those reported in the Austrian NIR 2012 (Umweltbundesamt 2012).

5 Resulting sink estimates

Between NFI 1 and 2, the improved method led to a decrease of the reported sink of 0.11 Mio t CO_2 per year or 3% relative to the previously reported sink. The new sink estimation is 3.65 Mio t CO_2 per year.

Between NFI 2 and 3, the improved method resulted in:

- a 0.5% increase in gains in biomass, and
- a 2.7% decrease in losses.

These changes led to an increase in the sink between NFI 2 and 3 of approx. 0.37 Mio t CO_2 per year or 32% relative to the previously reported sink. The new sink estimation is 1.53 Mio t CO_2 per year.

6 New data for the years 2009-2011

In former Swiss GHGIs (FOEN 2012 and before), gains and losses after 2006 were based on extrapolating NFI 2 and 3 data. The first data from NFI 4a (2009-2011) were available for reporting in FOEN (2013). Therefore, extrapolation for the Swiss GHGI 1990-2011 (FOEN 2013) is only needed for the inventory year 2012. Gains remained at almost the same level. However, losses for 2008 to 2011, were lower than in the previous decade (for decrease of harvesting see FOEN (2012a, p. 31). Therefore, the updated estimate of the sink for the years 2007 to 2010 will be larger than estimated in the Swiss GHGI 1990-2010 (FOEN 2012).

7 Literature

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8 Annex

First version of NFI 3 publication of results (LFI3-Ergebnisbericht, V1), 20.08.2008

LFI2 - LFI3

Jährlicher Bruttozuwachs nach Eigentum

pro Produktionsregion
Auswertungseinheit: gem. zugänglicher Wald ohne Gebüschwald der Inventuren 2 und 3
Netz: gemeinsam terrestrisch LFI2-LFI3
Veränderung 1993/95 - 2004/06

		Aussageeinheit Produktionsregion											
		Jura		Mittelland		Voralpen		Alpen		Alpensüdseite		Schweiz	
Jährlicher Zuwachs	Eigentumskategorie	$m^3 \cdot y^{-1} \cdot ha^{-1}$	± %	$m^3 \cdot y^{-1} \cdot ha^{-1}$	± %	$m^3 \cdot y^{-1} \cdot ha^{-1}$	± %	$m^3 \cdot y^{-1} \cdot ha^{-1}$	± %	$m^3 \cdot y^{-1} \cdot ha^{-1}$	± %	$m^3 \cdot y^{-1} \cdot ha^{-1}$	± %
mit Einwuchs	öffentlich	7.9	4	11.6	5	9.7	6	5.7	4	4.8	8	7.6	2
	privat	9.1	9	13.7	6	12.2	5	7.2	8	5.7	12	10.5	4
	Total	**8.2**	**4**	**12.4**	**3**	**10.9**	**3**	**6.0**	**3**	**5.0**	**7**	**8.6**	**2**
ohne Einwuchs	öffentlich	7.2	5	10.1	5	9.0	6	5.0	5	4.1	10	6.8	3
	privat	8.6	9	12.8	6	11.6	6	6.4	8	4.7	13	9.7	4
	Total	**7.5**	**4**	**11.2**	**3**	**10.3**	**3**	**5.4**	**4**	**4.3**	**8**	**7.8**	**2**

LFI2 - LFI3

Jährliche Nutzung und Mortalität nach Eigentum

berechnet pro Produktionsregion
Auswertungseinheit: gem. zugänglicher Wald ohne Gebüschwald der Inventuren 2 und 3
Netz: gemeinsam terrestrisch LFI2-LFI3
Veränderung 1993/95 - 2004/06

		Aussageeinheit Produktionsregion											
		Jura		Mittelland		Voralpen		Alpen		Alpensüdseite		Schweiz	
Jährliche Nutzung und Mortalität	Eigentumskategorie	$m^3 \cdot y^{-1} \cdot ha^{-1}$	± %	$m^3 \cdot y^{-1} \cdot ha^{-1}$	± %	$m^3 \cdot y^{-1} \cdot ha^{-1}$	± %	$m^3 \cdot y^{-1} \cdot ha^{-1}$	± %	$m^3 \cdot y^{-1} \cdot ha^{-1}$	± %	$m^3 \cdot y^{-1} \cdot ha^{-1}$	± %
Nutzung	öffentlich	7.2	7	14.1	6	8.4	10	2.6	9	0.5	26	6.1	4
	privat	5.3	15	12.8	9	7.8	10	2.9	19	0.7	39	7.0	6
	Total	**6.7**	**6**	**13.5**	**5**	**8.1**	**7**	**2.7**	**8**	**0.5**	**22**	**6.4**	**3**
verbleibende und ungenutzte Mortalität	öffentlich	1.0	11	1.4	11	2.6	15	1.2	8	0.9	15	1.4	6
	privat	0.7	21	1.7	14	2.8	14	1.7	16	1.7	19	1.9	8
	Total	**0.9**	**9**	**1.6**	**9**	**2.7**	**10**	**1.3**	**7**	**1.1**	**11**	**1.5**	**4**
Abgänge unbekannter Ursache	öffentlich	0.2	57	0.5	27	0.2	38	0.1	23	0.0	52	0.2	19
	privat	0.1	51	0.2	28	0.4	51	0.2	59	0.3	48	0.2	28
	Total	**0.2**	**51**	**0.4**	**21**	**0.3**	**35**	**0.1**	**32**	**0.1**	**36**	**0.2**	**16**
Nutzung und Mortalität (inkl. verbleibende Mortalität)	öffentlich	8.4	7	16.0	6	11.2	9	3.8	7	1.4	15	7.7	4
	privat	6.1	14	14.7	8	11.0	9	4.8	14	2.6	18	9.2	5
	Total	**7.8**	**6**	**15.5**	**4**	**11.1**	**6**	**4.1**	**6**	**1.7**	**11**	**8.2**	**3**