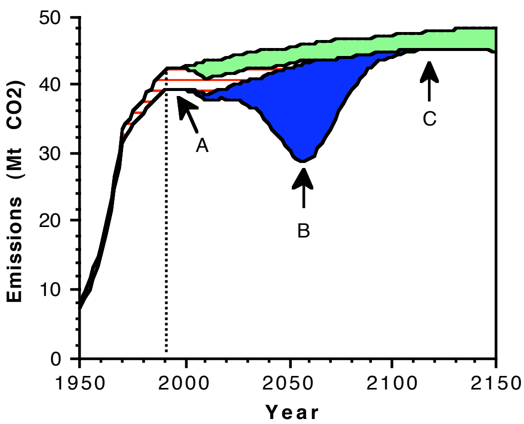
SYSTEMÖKOLOGIE ETHZ

SYSTEMS ECOLOGY ETHZ

Bericht / Report Nr. 13

Think Globally, Act Locally! A Small Country Case Study in Reducing Net CO_2 Emissions by Carbon Fixation Policies

Andreas Fischlin & Harald K.M. Bugmann



Juli / July 1992

Eidgenössische Technische Hochschule Zürich ETHZ
Swiss Federal Institute of Technology Zurich
Departement für Umweltnaturwissenschaften / Department of Environmental Sciences
Institut für Terrestrische Ökologie / Institute of Terrestrial Ecology

The System Ecology Reports consist of preprints and technical reports. Preprints are articles, which have been submitted to scientific journals and are hereby made available to interested readers before actual publication. The technical reports allow for an exhaustive documentation of important research and development results.

Die Berichte der Systemökologie sind entweder Vorabdrucke oder technische Berichte. Die Vorabdrucke sind Artikel, welche bei einer wissenschaftlichen Zeitschrift zur Publikation eingereicht worden sind; zu einem möglichst frühen Zeitpunkt sollen damit diese Arbeiten interessierten LeserInnen besser zugänglich gemacht werden. Die technischen Berichte dokumentieren erschöpfend Forschungs- und Entwicklungsresultate von allgemeinem Interesse.

Paper presented at the IPCC workshop «Carbon balance of the world's forested ecosystems: Towards a global assessment», Joensuu/Finland, May 11-15, 1992.

To appear in: KANNINEN, M. (ed.), *Carbon balance of the world's forested ecosystems: Towards a global assessment*. Publications of the Academy of Finland, VAPK Publishing, Helsinki.

Adresse der Autoren / Address of the authors:

Dr. A. Fischlin & H. Bugmann
Systemökologie ETH Zürich
Institut für Terrestrische Ökologie
Grabenstrasse 3
CH-8952 Schlieren/Zürich
SWITZERLAND

e-mail: fischlin@ito.umnw.ethz.ch
bugmann@ito.umnw.ethz.ch

© 1992 Systemökologie ETH Zürich

Think Globally, Act Locally! A Small Country Case Study in Reducing Net CO_2 Emissions by Carbon Fixation Policies

Andreas Fischlin & Harald K.M. Bugmann

Systems Ecology, Institute of Terrestrial Ecology, Department of Environmental Sciences, Swiss Federal Institute of Technology Zürich (ETHZ), CH-8952 Schlieren/Switzerland

Abstract

28.7% of Switzerland (41'284 km^2) are forested and store 68.1 Mt C. Current annual Swiss net CO_2 emissions totalled to 42.23 Mt CO_2 or 11.51 Mt C in 1988. This corresponds to 6‰ of world's emissions, although the Swiss population is only ca. 1‰ of that of the world. Despite these small emissions, we analyzed the following carbon fixation policies for Switzerland as a case study for a highly industrialized country: 1) Reforestation of uncultivated land, 2) Elevation of standing crops by a forest management optimizing standing wood volume, 3) Maximization of harvested wood for either a) fixation in endurable wood products or b) fossil fuel substitution by firewood. First each policy is analyzed in isolation and its relative contribution to reducing annual net CO_2 emissions is computed by using several simple mathematical forest growth models. The relative reductions expressed in percents of the gross CO_2 emissions from fossil fuel burnings are for policy 1) ca. 11%, 2) 3.9%, 3a) 0.2%, and 3b) 3.5%. The non-conflicting policies (1,2,3b) were combined to project overall reduction in net CO_2 emissions until the year 2150, which averaged ca. 5%. Around 2050 a consequent implementation could not only curb, but even reduce annual net CO_2 emissions. However, this effect must not be misinterpreted, since it depends first on the questionable assumptions of no growth detrimental pollution or climate change and secondly is certainly not sustainable. Particularly the latter might cover up for the increasing long-term trend, which is still dominated by fossil fuel combustion, and might thus put the implementation of a consequent CO_2 emission curbing policy at risk.

INTRODUCTION

Out of fear that the economic activities of mankind are leading to an uncontrolled increase in greenhouse gas concentrations, global climate change has attracted much scientific and public attention in recent years (SCHNEIDER, 1989; HOUGHTON *et al.*, 1990). Due to the radiative properties of these gases, a global rise in temperature is likely to ocurr (SIEGENTHALER & OESCHGER, 1978). There is now a general consensus in the scientific community concerning the reality of accelerated warming of the atmosphere, based essentially on the predictions by atmospheric General Circulation Models (GCMs), and also on paleo-climatic evidence linking atmospheric CO_2 concentrations and mean temperatures (NEFTEL *et al.*, 1982; SIEGENTHALER, 1988; WANNER & SIEGENTHALER, 1988; SIEGENTHALER *et al.*, 1988; SCHNEIDER, 1989; HOUGHTON *et al.*, 1990). Moreover, the necessity to stabilize CO_2 emissions, which contribute about 50% of global warming, arises clearly. Local actions on a number of levels and of various kinds are called for in order to curb current global CO_2 emissions.

According to the dictum «Think globally, act locally!» we attempted to assess the contribution and role of a small country like Switzerland in the context of a globally changing carbon cycle. Hereby we focussed on the potential of locally altered sylvicultural practices, forest management and wood consumption strategies. We attempted to assess quantitatively the reduction in net CO_2 emissions by the fixation of atmospheric CO_2 into woody biomass or wood products in function of a small set of policies.

In Switzerland live about $6.62 \cdot 10^6$ inhabitants (ANONYMOUS, 1990), which amounts only to about 1‰ of the world population, however its CO_2 emissions amount to roughly 6‰ of the world's emissions (ANONYMOUS, 1990; HOUGHTON *et al.*, 1990). Although these emissions are globally of neglectable importance, we feel that Switzerland is worth studying as a case study for a highly developed country. The methodology to assess the potential effectiveness of particular policies in increasing carbon fixation by forests and thus reducing CO_2 emissions should be in principle transferable to any other highly industrialized country within the latitudes of the temperate or boreal zone.

Several studies have dealt with the problem of reducing global CO_2 emissions. Most of them (e.g. DYSON, 1977, MARLAND, 1989, SEDJO, 1989) have calculated the area of forest plantations required to offset annual global CO_2 emissions, whereas the work by SCHROEDER & LADD (1991) has assessed what area would have to be reforested to offset the United States' CO_2 emissions. However, we are not aware of a study investigating how much of the emissions could realistically be offset within a single country under current economic, sylvicultural and ecological conditions, and in particular not within a time-horizon of two centuries. HARMON *et al.* (1990) have examined the effect of converting old-growth to young forests, coupled with maximizing forest yield and fixation of the timber e.g. in the form of wooden buildings and other long-lasting wooden products. Their findings suggest that unless the lifespan of lumber and wooden buildings is greatly increased, a net loss of carbon to the atmosphere is to be expected. In order to examine similar policies and to assess their effectiveness under Swiss conditions, we constructed new, simple models which allow to track the biomass development of a country's forests under different policy regimes.

The following policies were considered in our study: 1) Reforestation on uncultivated, mostly agriculturally abandoned land; 2) Elevation of the total wood volume in all Swiss forests; 3) Maximization of the harvested wood on behalf of some C-balance reducing measures. The third policy can be subdivided into the following two alternatives: Either it is assumed 3a) that the carbon in the harvested wood is subsequently temporally fixed in form of endurable wood products. The other alternative 3b) is to substitute fossil fuel combustion with firewood. Note that under Swiss conditions deforestation is unlikely, since neither forest diebacks are epidemic nor does the Swiss forest law allow for any clearcutting.

The first policy is supported by the fact that at present, mainly due to migration into urban areas, relatively large agricultural land areas are neglected and no longer cultivated; they are subject to secondary succession, ultimately leading to a natural reforestation. Unattended natural reforestation is rather slow, but this process can be greatly accelerated under average Swiss conditions, e.g. by planting and other growth furthering measures. A combination of all three policies is likely to be most effective for increasing total Swiss carbon fixation. However, in order to implement optimal policies, their relative importance and their overall net effect remains to be assessed quantitatively and in particular also for its sustainability. Our analysis showed that C-sequestrations via forestry can contribute to curbing net CO_2 emissions but that there is also a danger of misinterpreting the role of forests within industrialized countries in the context of the anthropogenically enhanced green-house effect and global change.

MATERIAL AND METHODS

In 1988 Swiss CO_2 emissions totalled to 42.23 Mt CO_2, corresponding to 11.51 Mt carbon. This is equivalent to an energy amount of 577.01 PJ, i.e. the fraction of fossil fuel combustion (coal, oil, gas) is 75.3% of the total energy consumption of 765.84 PJ (ANONYMOUS, 1990).

Switzerland covers an area of 41'284 km^2. Depending mainly on the altitude, its forested area belongs to the temperate and boreal zone and amounts to 11'863 km^2 (28.7%). For the purpose of our study we have subdivided Swiss forests into three major forest classes (Tab. 1, for more details see also Tab. 3):

Forest type	Area [km^2], %	Dominating phytosociological units	Dominating species	Site index [m]
A - Temperate mixed deciduous	4230 (35.7%)	sub-alliances *Luzulo-Fagion, Eu-Fagion* and *Cephalanthero-Fagion*	European beech (*Fagus silvatica* L.)	18–20
B - Montane, mixed soft-hardwood	3815 (32.2%)	sub-alliances *Abieti-Fagion* and *Piceo Abietion*	Silver fir (*Abies alba* Mill.), Norway spruce (*Picea abies* L.)	16–18
C - Subalpine softwood	3816 (32.2%)	class *Vaccinio-Piceetea*	Norway spruce (*Picea abies* L.)	14

Tab. 1: Classification and quantitative attributes of the three types of Swiss forests as used in this study. For the phytosociological units see ELLENBERG & KLÖTZLI (1972). The site index ("Bonität") is the height of 50 years old dominant trees (BADOUX, 1967). For further data s.a. Tab. 3.

The first type is a temperate, mixed deciduous forest typically found at lower altitudes, the second is a montane, mixed soft-hardwood forest, and the third a coniferous, in particular Norway spruce dominated subalpine softwood forest (ELLENBERG & KLÖTZLI, 1972). All biomass estimates in the present study are given in metric tons of dry matter. As a whole, Swiss forests store approximately 68.1 Mt C (Tab. 1 and 3).

REFORESTATION ON UNCULTIVATED LAND

In Switzerland, for economical reasons plantations of *Picea abies* L. are still wide-spread. Hence we assumed that this species would be planted on all uncultivated areas. Expected annual biomass increase and total standing crop were calculated from yield tables (BADOUX,

1967) by using an average site index for each forest type (Tab. 1). We further assumed that tree growth would always come to a halt at a stand age of 60 years.

ELEVATING STANDING CROPS

The current standing crop of Swiss forests was calculated using a model by BACHMANN (1968). In order to assess the growth for each of the three studied forest types, yield tables for each of the dominating species were used. Analyzed were the following sylvicultural measures: 1) increased rotation length, 2) natural regeneration, i.e. two overlapping tree generations, and 3) no thinning beyond stand age of 100 years.

MAXIMIZING YIELD AND FIXATION IN WOOD PRODUCTS

Based on the logistic equation for total above-ground biomass B, forest dynamics are modelled as follows:

$$\frac{dB}{dt} = G(B) - H(B,t) = \frac{r\cdot(K-B)}{K\cdot B - H(B,t)} \qquad (1)$$

where

G(B)	Growth depending on currently present Biomass	[t dW/a]
H(B,t)	Harvest depending on currently present Biomass and time t	[t dW/a]
B	Tree biomass	[t dW]
r	The intrinsic growth rate of B	[/a]
K	Carrying capacity	[t dW]

The harvest H(B,t) was modelled algorithmically to reflect the following harvesting practices: According to conventional forest management, harvesting occurs when biomass reaches 90% of the ecosystem carrying capacity K. Trees are then harvested three times within 16 years. Hereby 30, 50 respectively 70% of total biomass are harvested (Fig. 1 Left).

The maximum sustainable yield can be harvested at B* satisfying the criteria dG(B)/dB = 0, i.e. B* = K/2, i.e. harvest should occur on a continuous basis at a standing crop with the biomass B* equal to half of the carrying capacity. However, due to infrastructural and economical constraints, continuous harvesting of forests is not possible. Therefore we assumed first that harvesting occurs in a semi-quantitative fashion, i.e. whenever the woody biomass B is larger than some difference ε (Tab. 2) to the half of the carrying capacity K, and second that the harvest amounts to 2·ε (Fig. 1 Right).

Parameter	Unit	*A* - Beech forests	*B* - Fir-spruce forests	*C* - Spruce forests
r	$year^{-1}$	0.04	0.05	0.05
K	t dry weight/ha	550	600	170
d	$year^{-1}$	0.025	0.037	0.037
ε	t dry weight/ha	40	80	25

Tab. 2: Model parameters used for simulating biomass development for three types of forests in Switzerland.

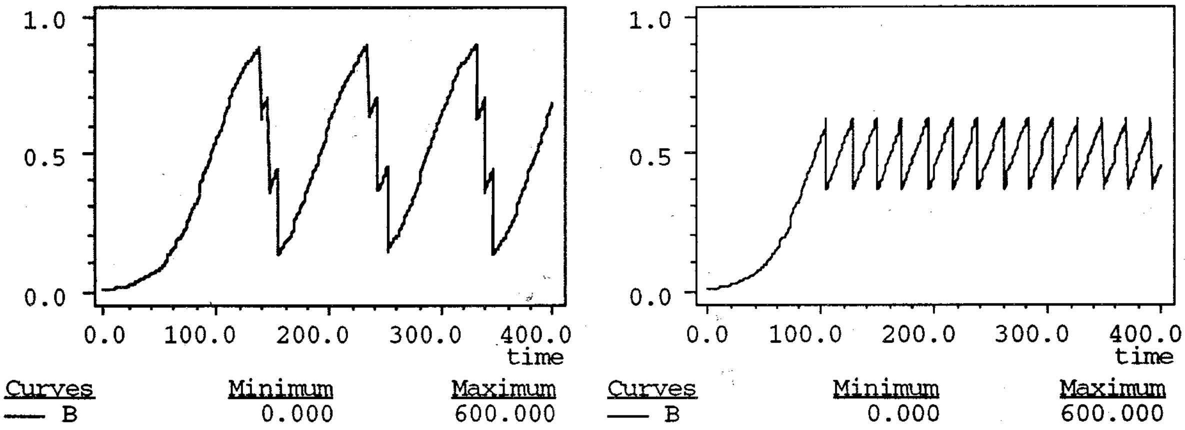


Fig. 1: Total biomass (t dry weight/ha) under two different harvesting regimes: Left: Conventional management where harvesting takes place roughly every 90 years. Right: Maximum stustainable yield strategy (with a much more frequent harvesting around $B^* = K/2$) within infrastructural constraints of Switzerland.

Wood biomass harvested from the forest is assumed to be converted with a 40% efficiency to durable wood products (HARMON *et al.*, 1990). The model assumes that 95% of hard- and softwood products will be replaced after 120 and 80 years, respectively. This leads to an exponential decay model (see decay parameters d, Tab. 2). Tab. 2 lists all other parameter values used to model the three forest types.

RESULTS AND DISCUSSION

REFORESTATION OF UNCULTIVATED LAND

At present about 2'600 km^2 (6%) of the area of Switzerland falls into the class of land which is no longer cultivated (ANONYMOUS, 1973). Assuming an average net production of spruce plantations of 5 t C/ha during about 60 years, an average net fixation (mean annual increment) of $1.3 \cdot 10^6$ t C/a can be reached. Based on data from the year 1988, this corresponds to ca. 11% of the Swiss anthropogenic annual CO_2 emissions (ANONYMOUS, 1990). Furthermore total standing crop of these forests would amount to some 16.6 Mt C, which could be harvested sustainably for firewood. These calculations overestimate carbon fixation for the first years of plant growth and towards the end of the sixty year period (SCHROEDER & LADD 1991); yet for an estimation of an overall balance, which covers several decades, this method appears useful.

Although the assumed planting of spruce trees only and immediately everywhere is simplicistic, the associated error affects mainly the timing of the estimated balance, not its value. Therefore this simplification appears to be justifiable for a rough assessment of the effects of reforestation measures. Hence, apart from the costs of large-scale reforestations we may conclude that this policy may contribute considerably in temporarily reducing CO_2 emissions.

ELEVATING STANDING CROPS

The results from calculations by BACHMANN (pers. comm.) using the model by BACHMANN (1968) are given in Tab. 3. According to the model, current total standing crop in Swiss forests amounts to 152 Mt wood. This is in good agreement with estimates of the Swiss Forest Inventory (1988), which lists 183 Mt. The 20% difference stems from the fact that the model assumes rather intensive forest management; however, only about half of the annual biomass increase in Swiss forests is currently being harvested (VOLZ, 1990). If rotation length is increased by 30 up to 50 years (Tab. 3), model calculations indicate a total standing crop of 187 Mt. The absolute difference between model estimates (35 Mt) most probably overestimates the effect of this measure. Assuming that the current standing crop is given by the arithmetic mean between model estimate and Swiss Forest Inventory, increased rotation length would lead to a biomass increase of about 19 Mt. Since an annual biomass increase of 1 Mt dry weight corresponds to 0.45 Mt C, this measure would reduce annual Swiss CO_2 emissions by 0.8% only.

If natural regeneration and no thinning are added to previous policies, the model yields an estimate of total standing crop of 240 Mt with a difference of 72 Mt to current conditions. This increase of total standing crop lasts 50 to 100 years. Therefore this policy might reduce annual emissions by up to 3.9% within this limited period. In general, elevating standing crops in order to reduce Swiss net CO_2 emissions appears to be much less effective than reforestation measures.

			current		future	
region	**site index**	**area**	**rotation length**	**standing crop**	**rotation length**	**standing crop**
	[m]	**[km²]**	**[years]**	**[t/ha]**	**[years]**	**[t/ha]**
A - Jura	Beech 18	1365	150	114.5	180	270
	Fir 14	585	150	162.5	180	380
A - Lower main land	Beech 18	1141	150	114.5	180	270
	Spruce 22	228	120	172.0	160	420
	Fir 16	913	130	166.5	160	400
B - Northern Alps	Spruce 18	1302	130	133.0	180	340
	Fir 12	868	160	146.0	180	325
C - Alps	Spruce 16	3816	140	118.5	200	310
B - Southern Alps	Beech 16	823	160	96.5	180	215
	Spruce 18	823	130	133.0	180	340

Tab. 3: Geographical regions (s.a. Tab. 1) and major tree species distinguished for calculation of total standing crop in Swiss forests and its elevation via increasing rotation length. The data for future conditions consider only increased rotation length, although our analysis included also other sylvicultural practices (see Text). Site index ("Bonität") is the height of dominant trees at age 50 (BADOUX, 1967). Units for standing crop are dry weight (data and computations by BACHMANN, pers. comm.).

MAXIMIZING YIELD AND FIXATION IN WOOD PRODUCTS

The simulations showed that total carbon fixed in wood and wood products decreases for spruce forests by 0.9 and spruce/fir forests by 3.4 t C/ha when yield is maximized. This is mainly due to the rather low efficiency of converting wood to wood products and the faster decay rate of wood products made of softwood as compared to hardwood products. Yield maximization has positive effects only in deciduous forests, where total cabon storage would increase by 2.9 t C/ha. Therefore, assuming that this measure is implemented only in the mixed deciduous forest type, which is representative for 35.7% of all Swiss forests, the total carbon storage could be augmented by 1.2 Mt. Furthermore, assuming that the implementation of this measure would last 50 years, a marginal annual reduction of only 0.2% of current Swiss CO_2 emissions could be reached. Since this measure would be very costly to implement given its effectiveness, we conclude that this policy is to be dropped in favor of fossil fuel substitution by firewood.

SUBSTITUTING FOSSIL FUELS BY REPLACEMENT YIELD FIREWOOD

Given that forest management optimizes maximum carbon sequestration only by reforestation and maximizing standing crops, the resulting forest can still produce harvestable wood. The then possible replacement yield could be fully used for firewood as an energy equivalent substitute for fossil fuel combustion. Neglecting within our time constraints the long-term humus dynamics, this policy is unlikely to affect the net carbon balance of our forests, since if the growth would not be harvested it would be subject to natural decomposition. At present Swiss wood volume increases annually by about 4 Mt, of which 50% are actually harvested (VOLZ, 1990). If this growth was harvested fully and was partly used to substitute fossil fuel combustion, e.g. for heating purposes, this could offset 3.5% of the 1988 CO_2 emissions.

COMBINING POLICIES AND SCENARIO BASED PROJECTIONS IN THE FUTURE

Assuming a particular scenario for future Swiss CO_2 emissions from fossil fuel combustion, it is possible to project with our model future net CO_2 emissions by subtracting from the gross CO_2 emissions the C-sequestrations according to all forestry policies described above. Excepted from these calculations were the maximum yield and C-fixation in endurable wood product policy in favor of the elevating standing crop policy. This is because the first policy has an objective which keeps the forest storage rather low. This result is in conflict with the obective of the second policy of elevating standing crops.

The first «Business as usual» scenario I in accordance with IPCC scenarios for developed countries (HOUGHTON *et al.*, 1990) assumes an increase in gross CO_2 emissions by an annual rate of 1% (Fig. 2 left). A second scenario II results if we optimistically assume that by the year 2150 anthropogenic emissions of CO_2 in Switzerland will eventually be stabilized around 50 Mt CO_2/year (Fig. 2 right).

CONCLUSIONS

An integrated long-term strategy combining reforestation and a moderate increase of the standing crop followed by a consequent harvesting of the annual production could reduce annual Swiss gross carbon dioxide emissions in the average by approximately 5% (Fig. 2). Such a combined policy has in both scenarios roughly the same potential to curb the annual net CO_2 emissions.

From all the policies analyzed the results suggest that reforestation is the most effective. This is mainly due to the fact that forests store an order of magnitude more carbon than agricultural land and that any forestry policy falls short in modifying this ratio at the same magnitude. Therefore most forestry policies obviously have a marginal, yet economically relatively easily achievable effect on carbon sequestration (Fig. 2). However, it is important to consider that the carbon sink effect resulting from reforestation is a temporal phenomenon and can't be sustained. Therefore the relative contribution of the policies changes considerably with time and must be carefully evaluated on this background.

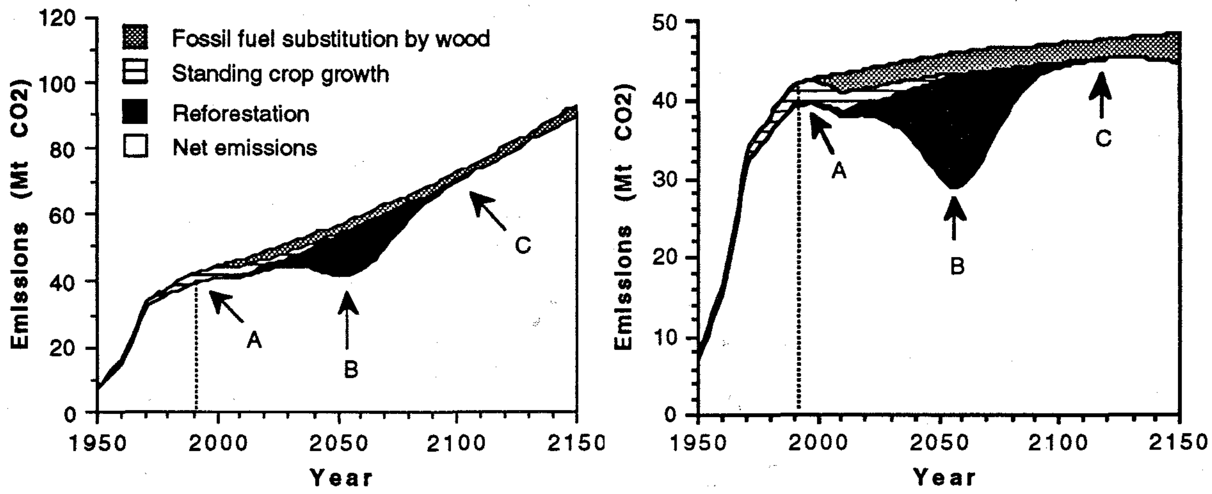


Fig. 2: Two scenarios for total anthropogenic CO_2 emissions in Switzerland until the year 2150 showing the effects of a combined policy integrating various measures for emission reduction. Left: Scenario I – Annual, exponential increase of total anthropogenic CO_2 emissions by 1%. Right: Scenario II – Stabilization of total emissions around 50 Mt CO_2 by the year 2150. **A**: Start of the measures 1) reforestation in no longer cultivated land areas, 2) elevated standing crop, 3) substitution of fossil fuel combustion by wood burning. **B**: Biomass increase in reforested areas peaks and maximizes the decrease in the CO_2 balance. **C**: In mature forests the biomass carbon fixation reaches saturation and is out-balanced by total ecosystem respiration; all wood production is used for fossil fuel substitution.

Fig. 2 (**B**) shows that around the year 2050 even a decrease of net CO_2 emissions could be obtained. However we would like to warn from misinterpretations of these projections:

First note that this large carbon sink is due to the reforestation and depends strongly on the assumption that all planted trees will still be able to grow normally. Hereby any detrimental effects of environmental pollution or climate change on tree growth were completely ignored. However, since at that time climate is likely to start changing (HOUGHTON *et al.*, 1990), this assumption is presumably wrong and might have strong effects on the distribution and abundance of tree species (BOLIN *et al.*, 1986; FISCHLIN *et al.*, 1992). Hence, the advocated spruce plantations could suffer large-scale diebacks, which would require to modify the contribution by reforestations drastically (Fig. 2). Moreover, any substantial forest dieback is likely to produce relatively tremendous CO_2 emissions, when considering that the Swiss forests currently store about 68.1 Mt C, which is almost an order of magnitude, i.e. 5.9 times, larger than the current annual net emissions of 11.51 Mt C/a.

Second, even if assumed that the forests will prosper and remain healthy within the next 200 years, the fact that the reforestation contribution to emission reduction is not sustainable, may tend to cover-up the overall trend.Shortly after the years of actual emission reduction follow years with a steep increase in net emissions. Hence, depending on the awareness of the general public to these effects, the willingness to curb fossil fuel combustion may relax, and decision makers could have difficulties to persuade people to maintain and support a restrictive fossil fuel combustion policy as currently envisaged by the Swiss federal government. Thus, the combined forestry measures outlined above may first delay an eventual increase of Swiss CO_2 emissions, but it should not be taken as a remedy against and excuse for exhaustive fossil fuel combustion. Additionally, even if a temporary decrease in emission rates could be achieved, one should keep in mind that the *net carbon balance* of Switzerland would still remain positive, thus continuously contributing to the enhancement of the greenhouse effect. Our projections also clearly indicate that the only true Swiss counter-measure to the enhanced greenhouse effect lies in the reduction of CO_2 emissions from fossil fuel burning, which is probably not just the case for Switzerland alone.

Acknowledgements. This work had its origin in a contribution of a group of students and staff of ETHZ to the Day of the Environment (Umwelttag) organized by ETH Zürich in 1990. We would like to thank M. Brunner, O. Bürgi, T. Etter, S. Guidese and Prof. P. Bachmann for their invaluable help in preparing the basis for this article.

REFERENCES

ANONYMOUS, 1973. *Brachflächen der Schweiz.* Swiss Federal Institute of Forest, Snow and Landscape Research, 8903 Birmensdorf.

ANONYMOUS, 1980. *Jahrbuch der schweizerischen Wald- und Holzwirtschaft.* Swiss Federal Statistical Office, Bern.

ANONYMOUS, 1990. *Statistisches Jahrbuch der Schweiz.* Swiss Federal Statistical Office, Bern, ed: Verlag NZZ, Zürich, 371 pp.

BACHMANN, P., 1968. *Untersuchungen zur Wahl des Verjüngungszeitpunktes im Waldbau.* Ph.D. Thesis, Beih. Z. Schweiz. Forstver., **42**: 112 pp..

BADOUX, 1967a,b,c. *Etragstafel Buche, Fichte, Tanne (Yield tables for beech, spruce and fir).* Swiss Federal Institute of Forest, Snow and Landscape Research, 8903 Birmensdorf.

BEER, J., SIEGENTHALER, U. & BLINOV, A., 1988. *Temporal 10Be variations in ice: information on solar activity and geomagnetic field intensity.* In: Stephenson, F.R. & Wolfendale, A.W. (eds.), Secular solar and geomagnetic variations in the last 10'000 years. Kluwer Academic Publishers, 297-313pp.

BOLIN, B., DÖÖS, B.R., JÄGER, J. & WARRICK, R.A., 1986. *The greenhouse effect, climatic change and ecosystems.* Wiley, Chichester a.o. (SCOPE Vol. 29), 541 pp.

DYSON, F.J., 1977. *Can we control the carbon dioxide in the atmosphere?.* Energy, **2**: 287-291.

ELLENBERG, H. & KLÖTZLI, F., 1972. *Waldgesellschaften und Waldstandorte der Schweiz.* Eidg. Anst. Forstl. Versuchswes., Mitt., **48**: 587-930.

FISCHLIN, A., BUGMANN, H. & GYALISTRAS, D., 1992. *Sensitivity of a forest ecosystem model to climate parametrization schemes.* In: Proc. of the International Symposium «Impact of Global Change on Terrestrial Ecosystems», June 1992, Bad Dürkheim, BRD, Elsevier (in prep.)

HARMON, M.E., FERRELL, W.K. & FRANKLIN, J.F., 1990. *Effects on carbon storage of conversion of old-growth forests to young forests.* Science, **247**: 699-702.

HOUGHTON, J.T., JENKINS, G.J. & EPHRAUMS, J.J. (EDS.), 1990. *Climate change - the IPCC scientific assessment.* Report prepared for IPCC by Working Group 1. Cambridge Univ. Press, Cambridge a.o., 365 pp.

MARLAND, G., 1989. *The role of forests in addressing the CO_2 greenhouse.* In: White, J.C. (ed.), Global climate change linkages: Acid rain, air quality and stratospheric ozone. Elsevier, New York.

NEFTEL, A., OESCHGER, H., SCHWANDER, J., STAUFFER, B. & ZUMBRUNN, R., 1982. *Ice core sample measurements give atmospheric CO_2 content during the past 40000 yr.* Nature, **295**: 220-223.

SCHNEIDER, S.H., 1989. *The greenhouse effect: science and policy.* Science, **243**: 771-81.

SCHROEDER, P. & LADD, L., 1991. *Slowing the increase of atmospheric carbon dioxide: A biological approach.* Climatic change, **19**: 283-290.

SEDJO, R., 1989. *Forests to offset the greenhouse effect.* J. For., **87**: 12-15.

SIEGENTHALER, U. & OESCHGER, H., 1978. *Predicting future atmospheric CO_2 levels.* Science, **199**: 388-395.

SIEGENTHALER, U. & OESCHGER, H., 1987. *Biospheric CO_2 emissions during the past 200 years reconstructed by deconvolution of ice core data.* Tellus, **39B**: 140-154.

SIEGENTHALER, U., 1988. *Causes and effects of natural CO_2 variations during the glacial-interglacial cycles.* In: Wanner, H. & Siegenthaler, U. (eds.), Long and short term variability of climate. Springer lecture notes in earth sciences, **16**: 153-171.

SIEGENTHALER, U., FRIEDLI, H., LOETSCHER, H., MOOR, E., NEFTEL, A., OESCHGER, H. & STAUFFER, B., 1988. *Stable-isotope ratios and concentration of CO_2 in air from polar ice cores.* Ann. Glaciol., **10**: 1-6.

VOLZ, R., 1990. *Zur CO_2-Bilanz des Schweizer Waldes und seiner Nutzung.* BUWAL-Bulletin, Bern, Switzerland, 1/1990, pp. 15-18

WANNER, H. & SIEGENTHALER, U. (EDS.), 1988. *Long and short term variability of climate.* Springer, Lecture Notes in Earth Sciences, **16**.

ZINGG, A. & BACHOFEN, H., 1988. *Schweizerisches Landesforstinventar: Anleitung für die Erstaufnahme 1982-1986.* Eidg. Anst. Forstl. Versuchswes., Ber., **304**: 134 pp.

BERICHTE DER FACHGRUPPE SYSTEMÖKOLOGIE
SYSTEMS ECOLOGY REPORTS
ETH ZÜRICH

Nr./No.

1 FISCHLIN, A., BLANKE, T., GYALISTRAS, D., BALTENSWEILER, M., NEMECEK, T., ROTH, O. & ULRICH, M. (1991, erw. und korr. Aufl. 1993): Unterrichtsprogramm "Weltmodell2"

2 FISCHLIN, A. & ULRICH, M. (1990): Unterrichtsprogramm "Stabilität"

3 FISCHLIN, A. & ULRICH, M. (1990): Unterrichtsprogramm "Drosophila"

4 ROTH, O. (1990): Maisreife - das Konzept der physiologischen Zeit

5 FISCHLIN, A., ROTH, O., BLANKE, T., BUGMANN, H., GYALISTRAS, D. & THOMMEN, F. (1990): Fallstudie interdisziplinäre Modellierung eines terrestrischen Ökosystems unter Einfluss des Treibhauseffektes

6 FISCHLIN, A. (1990): On Daisyworlds: The Reconstruction of a Model on the Gaia Hypothesis

7 * GYALISTRAS, D. (1990): Implementing a One-Dimensional Energy Balance Climatic Model on a Microcomputer *(out of print)*

8 * FISCHLIN, A., & ROTH, O., GYALISTRAS, D., ULRICH, M. UND NEMECEK, T. (1990): ModelWorks - An Interactive Simulation Environment for Personal Computers and Workstations *(out of print→ for new edition see title 14)*

9 FISCHLIN, A. (1990): Interactive Modeling and Simulation of Environmental Systems on Workstations

10 ROTH, O., DERRON, J., FISCHLIN, A., NEMECEK, T. & ULRICH, M. (1992): Implementation and Parameter Adaptation of a Potato Crop Simulation Model Combined with a Soil Water Subsystem

11 * NEMECEK, T., FISCHLIN, A., ROTH, O. & DERRON, J. (1993): Quantifying Behaviour Sequences of Winged Aphids on Potato Plants for Virus Epidemic Models

12 FISCHLIN, A. (1991): Modellierung und Computersimulationen in den Umweltnaturwissenschaften

13 FISCHLIN, A. & BUGMANN, H. (1992): Think Globally, Act Locally! A Small Country Case Study in Reducing Net CO_2 Emissions by Carbon Fixation Policies

14 FISCHLIN, A., GYALISTRAS, D., ROTH, O., ULRICH, M., THÖNY, J., NEMECEK, T., BUGMANN, H. & THOMMEN, F. (1994): ModelWorks 2.2 – An Interactive Simulation Environment for Personal Computers and Workstations

15 FISCHLIN, A., BUGMANN, H. & GYALISTRAS, D. (1992): Sensitivity of a Forest Ecosystem Model to Climate Parametrization Schemes

16 FISCHLIN, A. & BUGMANN, H. (1993): Comparing the Behaviour of Mountainous Forest Succession Models in a Changing Climate

17 GYALISTRAS, D., STORCH, H. v., FISCHLIN, A., BENISTON, M. (1994): Linking GCM-Simulated Climatic Changes to Ecosystem Models: Case Studies of Statistical Downscaling in the Alps

18 NEMECEK, T., FISCHLIN, A., DERRON, J. & ROTH, O. (1993): Distance and Direction of Trivial Flights of Aphids in a Potato Field

19 PERRUCHOUD, D. & FISCHLIN, A. (1994): The Response of the Carbon Cycle in Undisturbed Forest Ecosystems to Climate Change: A Review of Plant–Soil Models

---

* Out of print

20 THÖNY, J. (1994): Practical considerations on portable Modula 2 code

21 THÖNY, J., FISCHLIN, A. & GYALISTRAS, D. (1994): Introducing RASS - The RAMSES Simulation Server

22 GYALISTRAS, D. & FISCHLIN, A. (1996): Derivation of climate change scenarios for mountainous ecosystems: A GCM-based method and the case study of Valais, Switzerland

23 LÖFFLER, T.J. (1996): How To Write Fast Programs

24 LÖFFLER, T.J., FISCHLIN, A., LISCHKE, H. & ULRICH, M. (1996): Benchmark Experiments on Workstations

25 FISCHLIN, A., LISCHKE, H. & BUGMANN, H. (1995): The Fate of Forests In a Changing Climate: Model Validation and Simulation Results From the Alps

26 LISCHKE, H., LÖFFLER, T.J., FISCHLIN, A. (1996): Calculating temperature dependence over long time periods: Derivation of methods

27 LISCHKE, H., LÖFFLER, T.J., FISCHLIN, A. (1996): Calculating temperature dependence over long time periods: A comparison of methods

28 LISCHKE, H., LÖFFLER, T.J., FISCHLIN, A. (1996): Aggregation of Individual Trees and Patches in Forest Succession Models: Capturing Variability with Height Structured Random Dispersions

29 FISCHLIN, A., BUCHTER, B., MATILE, L., AMMON, K., HEPPERLE, E., LEIFELD, J. & FUHRER, J. (2003): Bestandesaufnahme zum Thema Senken in der Schweiz. Verfasst im Auftrag des BUWAL

30 KELLER, D. (2003): *Introduction to the Dialog Machine, 2nd ed*. Price,B (editor of 2nd ed)

31 FISCHLIN, A. (2008): *IPCC estimates for emissions from land-use change, notably deforestation*

Erhältlich bei / Download from

http://www.ito.umnw.ethz.ch/SysEcol/Reports.html

Diese Berichte können in gedruckter Form auch bei folgender Adresse zum Selbstkostenpreis bezogen werden / Order any of the listed reports against printing costs and minimal handling charge from the following address:

SYSTEMS ECOLOGY ETHZ, INSTITUTE OF TERRESTRIAL ECOLOGY
UNIVERSITÄTSTR. 16, CH-8092 ZURICH, SWITZERLAND