Scientific arguments for net carbon increase in soil organic matter in Dutch forests

Alterra Report 2324
ISSN 1566-7197

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Dit onderzoek is uitgevoerd binnen het kader van Beleidsondersteunend onderzoek: Project code BO-11-017-019.
Alterra rapport is uitgebracht op basis van EU project Eclaire: Project code KB-14-001-036

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Alterra Report 2324

Alterra, part of Wageningen UR
Wageningen, 2012

Abstract

J.P. Mol-Dijkstra, I.J.J. van den Wyngaert en W. de Vries, 2012. *Scientific arguments for net carbon increase in soil organic matter in Dutch forests*. Wageningen, Alterra, Alterra Report 2324. 32 pp.; .1. fig.; .1. tab.; .32. ref.

If reporting of emissions associated with Forest Management becomes obligatory in the next commitment period, the Netherlands will try to apply the 'not-a-source' principle to carbon emissions from litter and soil in land under Forest Management. To give a scientific basis for the principle of carbon stock change being 'not-a-source', a review is first made of the methods and arguments of other countries and the acceptance or disapproval by UNFCCC experts. Second, we investigated whether available Dutch datasets and literature information confirm the claim that Dutch forest soils are not a carbon source. This review indeed showed convincing arguments for soil being a carbon sink in the Netherlands under forest management, based on a combination of (i) measurements in Loobos, (ii) literature on soil carbon increases based on repeated measurement in comparable areas, (iii) N retention assessments, assuming that the soil C/N ratio stays constant, (iv) European scale modelling approaches on soil carbon changes including the Netherlands and (v) argumentation from expected changes in climate and N deposition in the Netherlands, combined with the results from meta-analysis and modelling.

Keywords: Kyoto protocol, carbon sequestration, forest soil.

ISSN 1566-7197

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Alterra Report 2324
Wageningen, May 2012

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Summary

If reporting of emissions associated with Forest Management becomes obligatory in the next commitment period, the Netherlands will try to apply the 'not-a-source' principle to carbon emissions from litter and soil in land under Forest Management. To give a scientific basis for the principle of carbon stock change being 'not-a-source' we first have made a review of methods how to report this and what is accepted. Second, we have investigated what sources are available in the Netherlands to argument that the Dutch forest soils are not a carbon source. These sources were searched in Dutch datasets with measurements and literature. Finally, we argued that changes in air quality and climate are most likely leading to increased soil carbon pools.

Review methods
To report a pool as 'not-a-source', a country is expected to show that the respective pool, usually in a non-aggregated way, is not-a-source for the specific situation in this country and in the years of the commitment period. Very few countries have been able to justify their reporting of soil carbon stock change under forest management as 'not-a-source' in a way that was totally acceptable to the review team in 2010. It is currently not clear how the experience gained by countries and reviewers has influenced the 2011 review process. In general, countries that are able to justify (more or less) satisfactorily that the carbon stock change is not-a-source have measured data or estimated quantities or extensive modelling (or a combination of those). 'Simple' reasoning is accepted only for Spain.

Carbon stock changes
Although there are no datasets on soil C pool changes at an adequate time scale, there are enough arguments to indicate net soil carbon increase in the Netherlands:
- First of all, at the Dutch intensively monitored research location Loobos, with a tree species that is representative for one third of the Dutch forests, a net carbon sink was found, during the past ten years. This is a strong indication that Dutch forest soils still sequester carbon, since the Loobos site is a relative old forest.
- Secondly, N retention data and dynamic modelling at the European scale, including the Netherlands, indicate the occurrence of soil C retention.
- Thirdly, C changes in chronosequences also indicate C sequestration in humus layers and the same holds for literature information on repeated soil C pools in areas comparable to the Netherlands.
- Finally, different dynamic modelling studies show carbon stock increases in the Netherlands.

All the methods of these studies are described and ranges of the measurements or model results are given. Except for the Loobos location, all results are documented in peer reviewed articles.

Carbon stock changes under expected environmental circumstances
The expected changes in climate and N deposition in the Netherlands, combined with the results from meta-analysis and modelling make it likely that soil carbon sequestration will continue in the future in the Netherlands. Literature data, including meta-analysis of experimental data and model calculations show that an increase in CO_2, temperature and nitrogen deposition in temperate climates leads to an increased C sequestration in the soil caused by increased forest growth and thus increased carbon supply through leaf fall and decreased decomposition. Temperature rise also increases forest growth and litterfall, but on the other hand, higher temperatures lead to higher decomposition rates. In temperate climates, temperature rise however seems to lead to an increase of C sequestration.

Available methods in the Netherlands to report 'not-a-source'

The arguments for soil being a carbon sink in the Netherlands are a combination of (i) measurements in Loobos, (ii) literature on soil carbon increases based on repeated measurement in comparable areas, (iii) N retention assessments, assuming that the soil C/N ratio stays constant, (iv) European scale modelling approaches on soil carbon changes including the Netherlands and (v) argumentation from expected changes in climate and N deposition in the Netherlands, combined with the results from meta-analysis and modelling. These are strong arguments to make the plea of 'not-a-source' for Dutch forest soils.

1 Introduction

Under the Kyoto Protocol, the carbon stock change in all carbon pools should either be reported (quantified) or it should be adequately demonstrated that the carbon pool is not-a-source of emissions: **16/CMP.1 art 21**: 'Each Party included in Annex I shall account for all changes in the following C pools: above- and below-ground biomass, litter, dead wood, and soil organic carbon. A Party may choose not to account for a given pool in a commitment period if transparent and verifiable information is provided that the pool is not-a-source'. This is called the 'not-a-source' principle.

Currently, the Netherlands applies the 'not-a-source'; principle to the carbon emissions from dead wood, litter and soil carbon in re/afforested units of land, based on land use changes, which was accepted by the 2011 review team (ARR NL 2011, comment 147). If reporting of emissions associated with Forest Management becomes obligatory in the next commitment period, the Netherlands will try to apply the 'not-a-source' principle also to litter and soil in land under Forest Management. Reporting 'not-a-source' under forest management requires other methods, which are described in this note.

In review reports of both EU member states and of the EU, the application of the 'not-a-source' principle proved a recurring issue. This prompted JRC (responsible for the EU submission for LULUCF) to develop a decision tree as guidance, as shown in Figure 1.

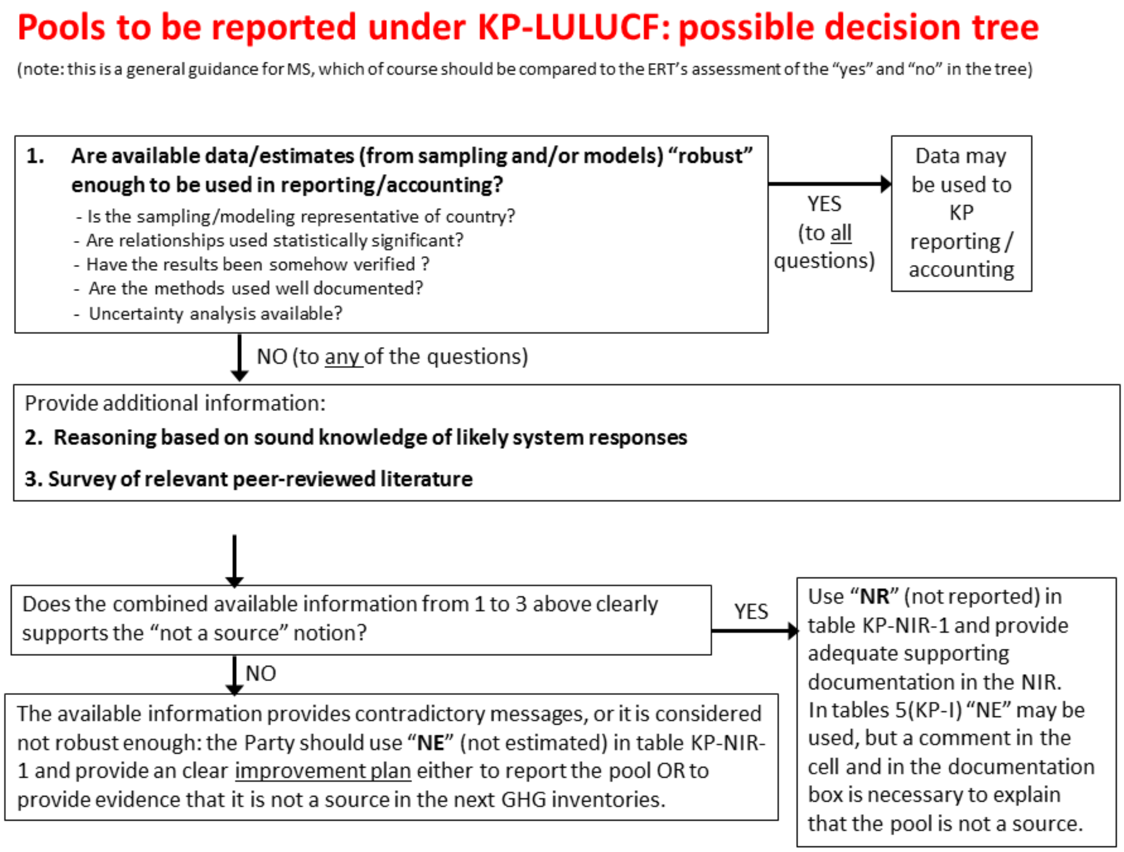

Figure 1
Decision tree to using the 'not-a-source' principle based on reviews of country submissions.

They took the starting position that the 'not-a-source' principle was developed to facilitate countries submissions. Thus, requirements to demonstrate that a pool is not-a-source of carbon should be less strict than requirements applied to data used for quantified reporting. The 'not-a-source' principle especially provides the opportunity to use multiple sources of information, none of which are entirely decisive on their own, but making a much stronger case when combined.

This report aims to report arguments for the 'not-a-source' principle as mentioned in the decision tree. Chapter 1 first reviews the experience of reporting litter and soil as 'not-a-source' by countries that have already decided to report Forest Management in the current commitment period. Results are evaluated to gain insight which methods are considered acceptable. Chapter 2 present an overview of arguments for soil 'not being a-source' in the Netherlands, based on measurements, modelling and literature data. It tries to answer point 1 in the decision tree: are data/estimates from sampling and models robust enough to be used in reporting, also providing additional literature information (point 3). At the end of this chapter, literature information on effects of changes in climate, air quality and forest management is presented as an argument that soil carbon sequestration is likely in the Netherlands. This relates to the 'reasoning based on sound knowledge of likely system responses' mentioned in the decision tree (point 2). Chapter 3 summarizes the conclusions. An overview of the characteristics of Dutch forest is given in Appendix 1.

2 Review of methods how to report 'not-a-source' principle

2.1 Introduction

Each year, all Annex I countries submit a report on the annual emissions of greenhouse gases to the UNFCCC. Each year, the information in all submissions is put together by the UNFCCC in a so-called Synthesis & Assessment report, which provides an overview of the current state of reporting. From this information, countries were selected that had indicated not to report litter and soil carbon under the Kyoto protocol. This chapter reviews their experience with reporting litter and soil as 'not-a-source' from the countries that have decided to report impacts of article 3.4 Forest Management in the current commitment period. It also takes into account the guidance the EU has based on experiences with reviews in previous years. On the basis of the National Inventory Reports and background reports from these countries for the year 2010, an overview is made of the methods used by those countries. The respective Annual Review Reports, i.e. the reports of the annual review by UNFCCC experts of countries submissions, were studied to assess the acceptance of methods as foundation of the 'not-a-source' principle, based on the decision tree shown in Figure 1.

The eight countries that indicated not report 'NR' for at least soil carbon under article 3.4 Forest Management in 2010 (UNFCCC, 2010; UNFCCC, 2011) as shown in Table 1. For each of these countries, the NIR 2010, the Annual Review Report 2010 and the following NIR 2011 were screened. Information was collected from paragraph 11.3.2.1 (Justification when omitting any carbon pool or GHG emissions/removals from activities under Article 3.3 and elected activities under Article 3.4), and other paragraphs if referred to. One should keep in mind that in the NIR 2010 this information was presented for the first time, and also reviewed only once and for the first time. None of the ARR 2010 was available in time to be used by countries for their NIR 2011, i.e. before 1st January 2011 (the earliest was from Denmark, which was available 3th March).

Table 1
Countries that submitted NR ('not reported') according to Table 7.2(b) of the UNFCCC synthesis and assessment reports 2010 (and 2011). NO ('Not occurring') is assumed to be equivalent to NR.

Country	2010			2011		
	Litter	Deadwood	Soil	Litter	Deadwood	Soil
Czech Republic	NR		NR			NR
Greece	NR	NR	NR	NR	NR	NR
Hungary	NR	NR	NR	NR	NR	NR
Portugal	NR	NR	NR			
Slovenia	NR		NR	NR		
Spain	NR	NR	NR	NR	NR	NR
Switzerland	NR		NR	NR		NR
Ukraine	NR	NR	NR			NO
Denmark						NR,R
Germany	NO			NO		
Romania				NR	NR	

In the following chapter, abbreviations are used as explained below:
- ARR-XXX: Annual Review Report of country abbreviated with XXX, drawn up by the UNFCCC review team to evaluate the annual submission of greenhouse gas emissions.
- NIR: National Inventory Report drawn up by a country to support and explain the values submitted for greenhouse gas emissions.
- AR: land subject to afforestation or reforestation under article 3.3 of the Kyoto Protocol.
- D: land subject to deforestation under article 3.3 of the Kyoto Protocol.

2.2 Czech Republic

Soil

Paragraph 11.3.1.2 (NIR-CZE 2010) refers the reader to Cienciala et al. (2008). This is a modelling study (EFISCEN + YASSO) that simulates the development of forest carbon stock in the Czech Republic until 2060 under three management scenario's and three climate scenario's, that were not necessarily realistic scenario's. All results indicated an increase in biomass and soil carbon (Cienciala et al., 2008). The review committee did not agree that this study was sufficient to definitively justify that the litter and soil carbon pools were no net sources (ARR-CZE, 2010). However, the review committee was prepared to accept that simulations with the YASSO model using the most recent data on forest biomass, growth performance and growing conditions, as well as the sustainable (realistic) forest management regimes implemented in the Czech Republic (instead of the scenario's used in the former study), showed that the forest carbon pool was not-a-source, for the current submission. It requested more detailed information in following submissions, especially on the INDIVIDUAL pools litter and soil carbon (i.e. not aggregated). In 2011, the reasoning for litter and soil organic carbon is again based on the same peer-reviewed article Cienciala et al. (2008), but explained much more in detail in the NIR.

Dead wood

For dead wood, no specific entry was made in Paragraph 11.3.1.2 and it was considered NO, i.e. not-a-source, based on Tier 1 assumptions. Tier 1 methods are designed to be the simplest to use, for which equations and default parameter values (e.g., emission and stock change factors) are provided by IPCC. Country-specific activity data are needed, but there are often globally available sources of activity data estimates (e.g. FAO), although these data are usually spatially coarse. The Tier 1 method assumes the litter and dead wood pools to be in equilibrium as long as land is not converted to another land use category.

For the carbon stock change in dead wood, the ERT did not accept the Tier 1 assumption in the ARR 2010. In response, the Czech Republic provided additional data that were accepted by the 2010 review committee. In 2011, the Czech Republic included this information in the NIR, i.e. in the NIR 2011, Paragraph 11.3.1.2 contains information on dead wood, litter and soil organic carbon. For dead wood, a combination of sound reasoning and empirical data is used to justify 'not-a-source'. The reasoning states that as (1) the long term dead wood pool is roughly proportional to the growing stock and (2) the growing stock is steadily increasing over the reporting period, there will be an increasing dead wood pool over the reporting period. This means removal of carbon, and thus no net emissions. This is further substantiated with empirical data from two independent statistical inventories, one conducted in 2001-2004 (reference year 2003) and one in 2008-2009 (reference year 2009). Both provided information on lying dead wood using the same four decay classes and sampled using the same protocols. Simple bookkeeping showed that for the entire Czech Republic, there was an increase in carbon stored in lying dead wood between 2003 and 2009.

Evaluation

For the Czech Republic, the proof for the 'not-a-source' principle for soil was based on a reviewed article with a modelling study (EFISCEN + YASSO). Such a model study is currently not available for NL, only on European scale. Furthermore, carbon stock change in dead wood based on Tier 1 assumptions was not accepted but empirical data from two independent statistical inventories were accepted. In the Netherlands, there is only one statistical inventory with national coverage that has information on dead wood (MFV). This should be repeated, but currently there is no budget available.

References

Cienciala, E., Z. Exnerova and M.J. Schelhaas, Development of forest carbon stock and wood production in the Czech Republic until 2060. Annals of Forest Science 65: 603, 2008

2.3 Greece

In both NIR 2010 and NIR 2011, Greece states that forest litter and soil carbon stocks have not been assessed yet and will be provided in the future.

2.4 Hungary

Soil

Both in the NIR 2010 and 2011 Hungary justifies that the soil organic carbon pool is not-a-source based on an approach for which they refer to the IPCC 2006 Guidelines, despite the fact that the guidance for reporting in this 1st Commitment Period under the Kyoto Protocol is the Good Practice Guidance (IPCC, 2003).

For soil organic carbon stock, Hungary stratifies its forests according to stages/processes that bring about carbon stock changes. They distinguish:

- Re/Afforestation on croplands.
- Re/Afforestation on grasslands.
- Forest Management where final cutting and artificial regeneration following professional standards occur.
- Forest Management where harvesting and natural regeneration is made following professional standards.
- Forest Management that is between regeneration and final cutting, and that may be affected by normal silivicultural practices such as thinnings.

For each of these categories an estimate is made for the net carbon stock change per year, based on a series of publications (Somogyi-Zamolodchikov, 2007; Horváth, 2006; Somogyi, 2006; Somogyi, 2005). Additional reasoning is provided to explain that all assumptions were conservative. In the ARR 2010 the ERT concluded that 'Hungary has reported the soil, dead wood and litter pools as 'NE' and has provided the required information to demonstrate that these pools were not a net source of emissions in 2008' (ARR, 2010, comment 157). Interestingly, 'not-a-source' is accepted over <u>the sum of Re/Afforestation and Forest Management together</u>. Based on the values provided, Forest Management on itself would be a source. However, the NIR 2010 was (re)submitted **after** the review as the annotated NIR was lacking in the original submission, and the ARR 2010 is based on the resubmission but also on the in-country presentations. Thus, it is only in the ARR 2011 (not available yet) that will become clear whether this approach is truly acceptable.

Litter and dead wood

Justifications for litter and dead wood are based on some measurements, but mostly on sound scientific knowledge and reasoning.

For litter and dead wood, some empirical data are available from ICP monitoring plots (4 km x 4 km grid). These indicate an increase in dead wood of almost 1% in the period 2000-2005. These data are further substantiated by the reasoning that the silvicultural approach has changed more towards 'close-to-nature' management over the last two decades, leaving more dead wood in the forest. This increases the amount, and thus the carbon stock, of dead wood and consequently also litter.

Evaluation
Hungary justifies that the soil organic carbon pool is not-a-source based on a combined budget for land under re/afforestation and forest management.

In the Netherlands, a similar aggregation would make it possible to offset a small source under forest management, as the sink under re/afforestation is known and reported. To our knowledge, there are no equations developed for the Netherlands describing the carbon pool over time for grassland or cropland converted to forest.

Justifications for litter and dead wood being no source are based on empirical monitoring data in combination with reasoning based on the change of management towards a system leaving more wood in the forest. In the Netherlands, a similar transition has been made towards 'close-to-nature' management over the past decades. Additionally, it would be possible to calculate the changes in the dead wood pool for a few sites with repeated measurements for some individual sites (from the study on Bosreservaten).

References
Horváth, B., 2006. Kohlenstoff-Akkumulation im Boden nach Neuaufforstungen: Beitrag zur Reduzierung der C-Emission in Ungarn? (C-accumulation in the soil after afforestation: contribution to C-mitigation in Hungary?) Forstarchiv v. 77(2) p. 63-68.

Somogyi, Z., 2005. Guidelines and improved standards for monitoring and verification of carbon removals in afforestation/reforestation joint implementation projects. Results of the monitoring case study in the test site in Hungary. CarboInvent, WP8.5 report, http://www.joanneum.at/carboinvent/D_8_5.pdf

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Somogyi, Z. andB. Horvath, 2006b. Detecting C-stock changes in soils of afforested areas in Hungary. Presentation at the workshop Development of Models and Forest Soil Surveys for Monitoring of Soil Carbon. April 5-8, 2006 at Koli, Finland, www.metla.fi/tapahtumat/2006/soil2006.)
Somogyi, Z. and D. Zamolodchikov, 2007. Forest Resources and their contribution to global carbon cycles. In: MCPFE, UNECE, FAO (2007): State of Europe's Forests 2007 - the MCPFE report on sustainable forest management in Europe, Köhl, M. and E. Rametsteiner (eds.), Ministerial Conference on the Protection of Forests in Europe, Liaison Unit Warsaw, Warsaw, pp. 3-17 URL: http://www.mcpfe.org/publications/pdf

2.5 Portugal

Soil
In 2010 and for what concerns soil organic carbon, work is on-going to develop a model which determines whether carbon stationary, decreasing or increasing in managed areas, including the parameters that should be taken into account. In 2011 Portugal reported soil emissions from Forest Management based on this model described in Rosario et al. (2010).

Litter and dead wood
In 2010 the Portuguese submission was still quite incomplete and they were still analysing data from the last National Forest Inventory. In 2011, they used these data to estimate dead wood and litter in forest management.

Evaluation
Portugal did not use the not-a-source principle but was in 2010 not ready to report on soil carbon, dead wood and litter.

References
Rosário, L., C. Ferreira, T. Avelar, J. Paulino and A. .EPina, 2010. Bases para a avaliação do sequestro e sinks de carbono orgânico total nos solos florestais e agrícolas Portugueses - Dados da Rede ICP Forest (1995), LQARS (1999) e Projecto BioSoil (2005).

2.6 Slovenia

In 2010, Slovenia did not report litter and soil carbon stock changes (NA, i.e. 'not available'), and was encouraged by the review team to do so. In 2011 it again reported NA again and stated that 'Estimates under FM for carbon stock changes in litter and soils were not reported.'

2.7 Spain

Soil carbon and dead wood.
In the NIR 2010 and 2011, Spain justified 'not-a-source' for dead wood, litter and soil carbon using a combined approach based on the following key elements (taken from NIR 2010):

1. Since the 1970s to the present day, the forest in Spain has undergone a growth in its surface area and an increase in the density of tree biomass.
2. Timber cutting in managed forests has remained practically stable in the inventoried period from 1990-2008.
3. Forestry management practices have changed with regards to the treatment of residues from timber cutting, with a decrease in on-site burning in favour of a chipping of the residues and their subsequent incorporation into the soil.
4. This annual contribution of dissolved organic matter from both natural origin and derived from forestry management shows an increasing trend over the years, due to the combination of elements 1), 2) and 3) above.
5. The time profile (years i towards the past, $i = 0, 1, 2, \ldots$) relating to each year t of reference of the inventory; $t = 1990, 1991, \ldots, 2008$) for the fractions of dissolved organic matter remaining from the past i, are assumed to remain stationary when t varies.

It then thoroughly substantiates each of the statements 1-3 based on national forest inventory data, statements 4 and 5 are not amplified and therefore not clear to us. This was included only in the resubmission of the NIR, after the 2010 review, and was approved by the 2010 review team. For us, it is not clear why this reasoning is accepted.

Evaluation
In the Netherlands, forest surface has been increasing as well, but good data on the density of tree biomass over the last years are lacking. Though it is one of the most researched countries, statistically sound national

monitoring of changes carbon pools in the Netherlands are scarce and usually not of very recent date. The combination of measured data and assumptions, however, could be used for the Netherlands.

2.8 Switzerland

Soil and litter combined
In the 2010 NIR, Switzerland states that the **combined pool of litter and mineral soil** is a sink. The explanation is given for all forests and reporting years and is included in Chapter 7 (LULUCF under the Convention). Based on an inventory in 1993, they have calculated forest soil C stocks stratified by NFI region (8 km x 8 km grid, 136 soil profiles in forests). Additionally, they refer to measured (two sites, Ruhr and Eugster, 2009) and modelled (Thurig et al., 2005) soil respiration rates, indicating an increase or no change in C stock in Swiss forest soils. Finally, they reason that Swiss forests are not a C source based on the following arguments (NIR Section 7.3.4.9):
- Within the last decades, no drastic changes of management practices in forests have been taken place because the Swiss forest law (Swiss Confederation 1991) is very restrictive.
- Fertilization of forests is prohibited by the Swiss forest law and adherent ordinances (Swiss Confederation 1991, 1992). Drainage of forests is not a permitted practice in Switzerland.
- As growing stock has increased since many years, soil carbon is assumed to increase due to increasing litter production.
- As shown in the study by Thürig et al. (2005), wind-throw may have a slightly increasing effect on soil carbon. However, this study neglected the effect of soil disturbances (Rusch et al., 2009) which could equalize those effects. This was planned to be further substantiated using Yasso modelling.

The review team in 2010 was not convinced by this reasoning, and in response Switzerland submitted further documentation including repeated measures of soil organic carbon concentrations (Swiss Soil Monitoring Network (NABO) data) and a reference to the paper of Perrouch et al. (1999). However, the review team commented that the repeated measurements (NABO data) span from 1985 to 2006 and the Perrouch et al. paper reports soil carbon stock changes up to 1985, while soil carbon sinks and sources during 2008 should be reported under the Kyoto Protocol (ARR-CHE, 2010). As Switzerland confirmed its ability to estimate soil carbon stocks in future emissions, the review team did not proceed with an adjustment procedure for 2010. The review team believed Switzerland to improve sufficiently, which is really needed in the coming years. Without the improvements, the Swiss method is not accepted.

In 2011 Switzerland basically uses the same reasoning as in 2010, extended with the information from Perrouch (1999), i.e. a modelling study showing, and the data from the Swiss Soil Monitoring Network (NABO). It is planned to strengthen this approach using Yasso modelling (NIR-CHE, 2011).

Dead wood
Dead wood is quantitatively reported and thus no use is made of the not-a-source principle.

Evaluation
The Netherlands also has the problem of many national survey data being rather old and repeated measures of soil carbon pools are scarce. Combining data with modelling could be a good option for the Netherlands as well.

References:

Perruchoud, D., F. Kienast, E. Kaufmann and O.U. Bräker, 1999. 20th Century Carbon Budget of Forest Soils in the Alps. Ecosystems 2: 320-337. http://dx.doi.org/10.1007/s100219900083

Thürig, E., T. Palosuo, J. Bucher and E. Kaufmann, 2005. The impact of windthrow on carbon sequestration in Switzerland: a model-based assessment. Forest Ecology and Management 210: 337-350. http://dx.doi.org/10.1016/j.foreco.2005.02.030

2.9 Ukraine

As the Ukrainian NIR is not available in English, we could only read the review report. Ukraine did not report carbon stock changes in soil, and did not justify this in a way that was acceptable to the review team.

2.10 Screening of other countries that did not report carbon stock changes in soil organic matter under FM

From Table 7.3(e) of the S&A reports, it is obvious that although fourteen countries report 'R' for carbon stock changes in soil, only ten countries have an implied emission factor. Additionally, there were a few countries that reported 'R' in 2010 but changed to 'NR' in 2011. Thus, we screened the submissions of Croatia, Denmark, France, Germany, Latvia and Romania and the respective reactions of the review teams in the ARR2010.

Croatia does not report carbon stock changes from dead wood, litter and soil. For dead wood and litter, reasoning is based on the legal framework, allowing few to no removal of dead wood and litter from the forest. For dead wood, data are presented that show an increasing dead wood pool. For soils, reasoning is based on data from a national soil survey (1990-2000). A 'humization index' is calculated from data for the first and the second period. As these do not differ significantly, it is concluded that there is no significant carbon source from the soil. The review team considers this insufficient. In 2011, the same data and reasoning are basically presented, but especially the data on soil are presented more detailed and transparent.

Denmark reports all pools from the Danish territory, but does not report carbon stock changes in soils from Greenland. This is justified by (i) the cold climate and (ii) regeneration practices (planting by hand). No data or measurements are provided. The magnitudes of areas and fluxes in managed forests in Greenland are totally insignificant compared to the Danish forests. There are no comments from the review team.

France indicates in paragraph 11.3.1.2 (both in 2010 and 2011) that forests remaining forests are assumed to have a stable or growing carbon stock in soil and litter, as the living biomass increases. This is in correspondence with measurements for the ministry of agriculture (for the 5th National Communication). There is no comment from the review team on carbon stock changes in soils. Still, in 2011, they indicate that studies are on-going to better justify this.

Germany indicates in paragraph 11.3.1.2 (NIR 2010 and 2011) that carbon stock changes for mineral soils and litter do not change under existing forest management and that the reported 'NO' should be read as 'NR'. A detailed motivation is given in Chapter 7, based on two nation-wide surveys. The first was carried out in 1986-1992; the second is still on-going (data will be available in 2013). Apart from the latest incomplete inventory, a number of methodological issues still need to be clarified. However, preliminary calculations show that there is no chance of a carbon source from the litter and the soil. Germany will most likely report values in its last submission. The data and calculations were considered sufficient to the review team in 2010.

For Romania, there are no estimates available yet for dead wood, litter and soil.

Evaluation
The Netherlands does not have the repeated soil carbon measures that both Croatia and Germany use to support their claim of 'not-a-source'. The current trend in growing stock is increasing, allowing a similar reasoning as Spain or France. However, on the one hand neither Spain nor France considers this a sufficient support, and it is (Spain) or will be (France) complemented by further study and reasoning. Furthermore, the increase in growing stock in the Netherlands is based on a comparison between the periods 1988-1992 and 2001-2005, along with extrapolations and low harvesting rates. There are no more recent data to sustain this.

2.11 Conclusions

Very few countries have been able to justify their reporting of soil carbon stock change under forest management as 'not-a-source' in a way that was totally acceptable to the review team as presented in the ARR2010. The few cases were the review team expressed satisfaction were countries that during the review presented additional information and later resubmitted in accordance with the review team. The review reports of 2011, expressing the views of a new and independent review team, are not available yet. No comments were made where the omitted emissions were totally negligible to the overall emissions (Denmark) or where further studies were on-going (France, Germany). It is expected that the ARR2012 will be more or less the final judgements for the vast majority of countries whether the pool is not a source is accepted.

Overall, it seems that there is no full harmonization yet between reviewers how strict the justification for "not-a-source" should be judged[1]. In general, countries that are able to justify (more or less) satisfactorily that the carbon stock change is not-a-source have measured data (Germany, France, Switzerland) or estimated quantities (Hungary) or extensive modelling (Czech). Simple reasoning is accepted only for Spain. There is currently much debate on how to interpret the not-a-source principle, and whether the requirements on data and studies are just as strict as would be needed for quantification. It seems from the current overview that country specific data may be combined with modelling or reasoning to overcome problems of non-representative data or too old measurements. However, it will be only in the 2011 or possibly 2012 review reports that there is harmonization between different review teams on what to accept.

In the Netherlands, several data sets with relevant information are available (see Paragraph 2.1.2.1), but only one set with repeated measurements with in fact a too short interval to allow changes to be significant. From the above, it becomes clear that a combination of several data sources with sound reasoning and/or modelling specifically for the Netherlands in the period 2013-2020 (assuming that is the 2nd commitment period) would be a potential option. Models like EFISCEN and YASSO, which were successfully used for the argumentation for the 'not-a-source' principle, are available in the Netherlands. We have different models that can be used for this purpose in the Netherlands, such as SMART2 (Kros et al., 1995) and VSD+ (Bonten et al., 2009). Both models include effects of environmental changes on soil processes and have been applied on Dutch scale, but not yet with the purpose of C sequestration. In the next Chapter we describe arguments for assuming the Dutch forest soils 'not-a-source' of carbon.

[1] The report of the lead reviewers meeting 2012 might give more guidance on this, but this report is not available yet.

3 Arguments for increases in soil carbon stocks in the Netherlands

The stock of organic carbon in soils is a result of the difference between litter input and decomposition of soil carbon over time. Carbon retention, which stands for the change in soil C pool, equals the difference in C input by litterfall and root decay and the net C decomposition or mineralization (mineralization minus immobilisation). More numerous and larger trees can produce more litter, and, thus, soil carbon stocks may be expected to increase with increasing biomass as long as decomposition rates do not increase simultaneously. The retention or sequestration of carbon in forest soils can be derived from various measuring and modelling methods as summarized in Section 3.1 for the Netherlands. In Section 3.2, we include argumentation for soil pool changes based on expected changes in CO2 concentration, N deposition, ozone exposure and climate change. Since more than 96% of the Dutch forests occur on mineral soils (see Appendix 1), this Chapter is focussed on mineral soils.

3.1 Approaches to assess changes in soil carbon stocks in time

The retention or sequestration of carbon in forest soils can be derived from (De Vries et al., 2006):
- Measurement of the net CO2 exchange flux (Net Ecosystem Exchange, NEE) to the forest ecosystem, corrected for litterfall, tree growth and harvest (paragraph 2.1.1).
- Measurements of the carbon input to the soil by litterfall and root decay and carbon release by net mineralization.
- Repeated soil inventories, chronosequences and radiocarbon (14C) measurements (paragraph 2.1.2).
- N retention in the soil, assuming that the soil C/N ratio stay constant (paragraph 2.1.3).
- Dynamic modelling exercises (paragraph 2.1.4).

In the Netherlands, information is more or less available for each of those methods, except for measurements of carbon release from the soil (second method) and the radiocarbon measurements. A summary of the information is given in the subchapters below, including related literature information where relevant.

3.1.1 Estimate based on measured Net Ecosystem Exchange (NEE) for Loobos

Since 1994 Alterra is running a flux / weather station at the Loobos site near Kootwijk, the Netherlands. In 1996 this site became part of the Euroflux project and CO_2-flux and profile measurements CO_2 and H_2O were added. In 2000 the site became part of the Carboeurope project. These projects were / are funded by the European Commission. The Scots pine (Pinus sylvestris) forest, where the Loobos site is located, was planted on sand dunes in the beginning of the past century and is now almost 100 years of age. There is an under-storey of Deschampsia flexuosa, a grass that can reach a height of 50 cm. The soil is a sandy soil (humuspodzol) with a 10 cm top layer of organic material.

To answer the question if the soil carbon content is increasing or not, we used measurements of the carbon exchange of the forest ecosystem with the atmosphere (Net Ecosystem Exchange, NEE) over the period 1997 - 2010 in combination with standing biomass measurements from 1996 - 2008. The net input of CO_2 over this period was 422 ± 32 gC m^{-2} a^{-1}. The tree growth, based on stem diameter measurements in the period 1996 - 2008, was on average 122-126 gC m^{-2} a^{-1}. Litter fall was measured from 2001 - 2010 and was on average

255 ± 65 gC m^{-2} a^{-1}. Harvest was accounted for 12 gC m^{-2} a^{-1}. Leaching of carbon was assumed negligible. The net carbon input to the soil can be calculated as NEE minus tree growth minus litter fall minus harvest. This results in an input of 31 gC m^{-2} a^{-1}. It is reasonable to assume that the net carbon increase in the soil is higher, because the part of the litter that is not decomposed can be added to the soil carbon pool. The result of this calculation is in line with Schelhaas et al. (2004), who calculated for the same area but with a slightly different method and over shorter period a net increase of 21 - 53 gC m^{-2} a^{-1}.

The tree species at the Loobos site represents about one third of the forests in the Netherlands, but the age is more than 30 years older than 50% of the Dutch forest. Assuming that the carbon sequestration is decreasing by age, one can expect that for the coming years Dutch forest floors will sequester carbon.

3.1.2 Repeated soil inventories and chronosequences

3.1.2.1 Repeated soil inventories

One way to assess a net sink of carbon in the forest soils is to make used of repeated measurements of C stocks. The changes in litter and soil carbon pools are, however, difficult to monitor because the carbon pool changes in forest soils are very small compared to the size of carbon stocks. Furthermore, the relatively small changes are difficult to distinguish from effects due to spatial variability, since carbon pools in forest soils are also highly heterogeneous (Liski et al., 2002). Consequently, large numbers of samples and monitoring sites, or a long-time interval, are required until a significant change in soil carbon can be detected (e.g. De Vries et al., 2009a). Repeated inventories are thus a much less accurate approach to assess the soil carbon sink as compared to the tree carbon sink, whose changes are quite accurately known on the basis of this approach.

Dutch datasets
To examine the impact of atmospheric deposition on non-calcareous soils of Dutch forests, a survey of the chemical soil and soil solution composition below 150 forest stands, including seven major tree species, was carried out in 1990 by Alterra (formerly DLO Winand Staring Centre). In 1995, 124 of the stands have been re-visited for a comparison of the chemical composition of humus layer, soil and soil solution between 1995 and 1990. The results indicate a fairly constant carbon stock, while the organic carbon content decreased by approx. 17 g kg^{-1} (De Vries et al., 2002; Leeters and De Vries, 2001). This result implies that the mixing of mineral soil with litter in 1995 what was higher than in 1990. More detailed information can be found in Leeters and De Vries (2001).

Furthermore, there are some datasets available in the Netherlands with measured carbon stocks in Dutch forest soils: (i) Multifunctional Forest Inventory Network with measured thickness of the LFH litter layers (in cm) for about 1000 plots on (mainly) sandy soils) in 2004-2005; (ii) Dutch soil sampling set (LSK), which is the most representative set in land covering soil data with statistically determined values. Of all samples organic matter content has been determined and iii) Dataset of Schulp. In the summer of 2006, Schulp et al. (2008) have measured carbon stocks on five 60 year old stands in the Speulder forest area in the centre of the Netherlands. The tree species investigated were beech (Fagus sylvatica), Douglas fir (Pseudotsuga menziesii), Scots pine (Pinus sylvestris), oak (Quercus robur) and larch (Larix kaempferi). These tree species comprise two-thirds of all Dutch forests, making this study representative for forests in the Dutch sand area. Stands that were 60 years of age were chosen because this is the most abundant age class in Dutch forests. Historically, all study sites were occupied by forests. Additionally, a beech stand of 170 years was selected. This stand has been relatively undisturbed for the last 50 years and is therefore a reference for SOC pool development. None of these three datasets have repeated measurements, so the carbon stock change cannot be derived from these sets.

In the Protocol 11-032 Forest (2011), the datasets by Leeters and De Vries (2001) and by Schulp et al. (2008) were used to make an estimation of carbon storage by the Dutch forest soils. Differences between 1990 and 2004 have been estimated and uncertainties were calculated with a Monte Carlo uncertainty analyses. Although uncertainties were quite high, all simulations indicated a sink of carbon, which was the basis to report carbon emissions as zero. To reduce the uncertainties and to report the carbon storage by Dutch forests, forest stands have to be revisited to take new samples. The only dataset with repeated measurements is the set of the Dutch forest stands, albeit with a too short period between the measurements (only five years). Literature data indicate that you need at least two measurements in time with an interval of more than ten years and preferably longer. A time interval of ten years is expected to give a significant difference in C pools for approximately 25% (De Vries et al., 2009a) of near 800 European forested the plots, depending on the size of the pools and the number of samples that are taken.

Literature data

Lettens et al. (2005) quantified changes in soil organic carbon (SOC) stocks in Belgium between 1960, 1990 and 2000 for 289 spatially explicit land units with unique soil association and landscape units (LSU). The SOC stocks were derived from multiple non-standardized sets of field measurements up to a depth of 30 cm. The largest SOC gains were observed for LSU under forest (22 tC ha^{-1} for coniferous and 29 tC ha^{-1} for broadleaf and mixed forest in the upper 30cm of soil); significant changes are rare because of large variability. On average, the increase of carbon stock in the Northern part, where 21% of the Belgian forests occur, was 17 tC ha^{-1}. The soil of the Northern part of Belgium is quite comparable to the South of the Netherlands, with sandy soils. The forests, however, are younger than in the Netherlands, 55% of the Belgium forests are younger than 40 years old.

Bellamy et al. (2005) used data from the National Soil Inventory of England and Wales to compare resampled non-agricultural sites in 2003 with samples taken between 1978 and 1983. In soils where the original C content was less than 30 g kg^{-1}, they found an increase of organic C contents, whereas a carbon loss was found in soils where the original carbon content was higher than 30 g kg^{-1}. The soils of the Dutch forests have on average an organic C content of about 3 g kg^{-1} (between 100 and 150 ton ha^{-1}). These results would imply that Dutch these soils most likely still sequester soil organic carbon.

3.1.2.2 Chronosequences

Vesterdal et al. (2007) reported measured carbon stocks in several chronosequenses of spruce and oak forest sites in Denmark, the Netherlands and Sweden. For the total soil compartment studied, i.e. forest floor and mineral soil 0-25 cm, afforestation of cropland as a minimum resulted in unchanged soil C contents and in most cases led to net C sequestration. Rates of soil C sequestration ranged from being negligible in two of the Danish chronosequences to 130 g C m^{-2} yr^{-1} for the Dutch chronosequence, an oak forest on former agricultural soil. The allocation of sequestered soil C was also quite different among chronosequences. While forest floor development consistently led to C sequestration, there was no general pattern in mineral soil C sequestration. In the short term (30 years), tree species had little influence on total soil C sequestration. Afforestation of nutrient-poor sandy soils seemed to result in larger C sequestration in forest floors and the whole soil than afforestation of nutrient rich, clayey soils.

3.1.3 N retention in the soil

De Vries et al. (2006) calculated C sequestration in the soil based on calculated nitrogen (N) retention (N deposition minus net N uptake minus N leaching) rates in soils, multiplied by the C/N ratio of the forest soils, using measured data only (intensively monitored forest plots) or a combination of measurements and model calculations (6.000 forested plots in a systematic 16km x 16km grid). For the Netherlands they calculated a C sequestration by the forest soils of 150 to more than 300 kg ha^{-1} yr^{-1}. This approach is based on the assumption that the soil C/N ratio stays constant. N retention data for the Netherlands have been derived for the early nineties based on N inputs and N leaching and also for two forested plots for the period 2003-2005 (De Vries et al., 2010; Brus et al., 2010). These results indicate N retention, which most likely implies also C retention.

3.1.4 Dynamic soil modelling

There are no modelling studies focusing on soil carbon changes in the Netherlands, but publications exist in which simulation models were used to calculate changes in soil carbon stocks at a European scale including the Netherlands (Liski et al. (2002) and Mol-Dijkstra et al. (2009). Liski et al. (2002) calculated increasing carbon stocks in forest soil in Western Europe with the model YASSO, using inventory data from 1950 - 1990 and model forecast for the period 2000 - 2040. For the Netherlands, they calculated for 1990 a stock increase of 107 g m^{-2} yr^{-1}. In the future, the contribution of the soils to the carbon sink of the forests was expected to increase everywhere except in South Europe. In central and North Western Europe, the soil carbon sink was calculated to become as large as the tree carbon sink.

Mol-Dijkstra et al. (2009) compared three model approaches on 192 forest stands in North Western Europe. The limit value concept (Berg et al., 2001; Berg and McClaugherty, 2007) calculated the highest carbon sequestration, ranging from 160 to 978 kg ha^{-1} yr^{-1}, followed by the N-balance method (Gundersen et al., 2006) which ranged from 0 to 535 kg ha^{-1} yr^{-1}. With SMART2 (Kros et al., 1995) the lowest carbon sequestration from -30 to 254 kg ha^{-1} yr^{-1} were calculated. All the three approaches found lower carbon sequestration at a latitude from 60-70 degrees compared to latitudes from 40-50 and from 50-60. The calculated carbon sequestration for the latitude class 50-60, where the Netherlands is situated ranges from 70 to 455 kg ha^{-1} yr^{-1}.

3.2 Literature on effects of climate change, air quality and forest management to carbon sequestration in the soil

In the former Paragraph we have given arguments that the Dutch forest soils can be considered as 'not-a-source'. In this paragraph we argue that the 'not-a-source' principle can be maintained under the future expected changing environmental circumstances in the Netherlands like temperature rise, increase of CO_2 and nitrogen deposition. Although the deposition is still above the national target, the level is quite stable the last years and the newest estimation of future scenarios are higher than the estimations of 2010.

Much research has been done on effects of climate change and air quality on both forest and soil carbon sequestration that support the assumption of the 'not-a-source' principle, given the expected changes in the Netherlands. In this Chapter we show results about effects of climate change and N deposition found in literature about experimental data (2.2.1) and literature about model studies (2.2.2). In paragraph 2.2.3 we describe the effects of management on C sequestration.

3.2.1 Meta-analysis of experimental data

There are quite a lot of literature data on the effects of nitrogen deposition and climate on carbon sequestration. These show that increase in CO_2, temperature and nitrogen deposition in temperate climates lead to increased forest growth and thus increased carbon supply through leaf fall. Whether this also will lead to increased C sequestration in the soil depends on its effects on decomposition.

The literature, including multiple Meta data analyses (e.g. Liu and Graever, 2009; Janssens et al., 2010) and syntheses of research data (De Vries et al., 2009b), indicates that increased nitrogen supply reduces the decomposition mostly, due to increased recalcitrance of N-enriched litter. This leads to increased carbon sequestration in the soil. The increase of the CO_2 concentration seems to have little effect on the decomposition (e.g. Norby et al., 2001, Weatherly et al., 2003). In combination with increased C input this would be an increase of the C stock in the soil. Metadata analysis also shows that increasing the CO_2 concentration, particularly in combination with N deposition, mostly leads to increased C sequestration in the soil (e.g. Dijkstra and Morgan in press).

Conversely, increase in temperature leads to an increase in the decomposition. To what extent temperature increase leads to an increase or decrease of soil C, depends on the degree of increase in growth, on the one hand, and decomposition of leaf fall on the other hand.

3.2.2 Model data

Model calculations which indicate positive effects of CO_2 and N on soil C are described by Churkina et al (2009) and Zaehe et al. (2010a, 2010b, 2011). Wamelink et al (2009) also gives positive effect of CO_2 and N on soil carbon, while temperature effect is negative for soil carbon in North and South Europe and positive in Central Europe.

3.2.3 Effects of management

There is much scientific literature about the effects of forest management on growth, productivity and carbon sequestration. However, it is very difficult to derive general conclusions because the variation of site quality and the history of site development/disturbance events often obscure the differences in management-induced changes in carbon stocks (Lindner et al., 2008). Nabuurs et al. (2008) give an overview of how different forest management actions can affect C sequestration by forest soils. They distinguish four kinds of forest management: harvest related management, fertilization, reducing risks of natural disturbances and species mixture. These activities influence carbon pools, fluxes, and productivity on-site, either directly by, e.g. transferring carbon from "live growing stock" to the "product" pools (e.g. thinning, final harvesting), or indirectly by altering growth conditions of trees (e.g. liming, fertilizing). The effects can be instantaneous (e.g. thinning) or slowly "evolving' (e.g. fertilization).

In the past years, parts of the Dutch forests were planned to be managed according to the close to nature approach, which would lead to an increase of carbon sequestration in the forest soils (Schelhaas et al., 2002; Schulp et al., 2008). Very recently, however, was announced that the Dutch state forestry will increase the harvest of old trees for economic reasons. In the short term, there will be an increase of C sequestration, because harvesting will lead to an increase of litter production (branches). Harvesting of the eldest tree implies a decrease of age of the Dutch forests, which might lead to increasing C sequestration, because the sequestration rates in younger forests are higher than in older forests, due to higher growth rates. Disturbance of the soil by harvest activities might lead to faster decomposition of organic matter due to aeration (Schulp et al., 2008).

Another trend in Dutch forests is the expected change from coniferous to deciduous forest, which is expected to have a positive (increasing) effect on carbon sequestration (Schelhaas et al., 2002), although Schulp et al. (2008) found smaller carbon stocks under broadleaf trees than under coniferous trees.

3.3 Conclusions

Unfortunately, there are no data on soil C pool changes at an adequate time scale. There is only one data set with repeated data but this is at a five year interval only, which is too short to give adequate estimations of carbon stock changes. On the other hand, we have found studies that indicate net soil carbon increase in the Netherlands:

- First of all, at the Dutch intensively monitored research location Loobos, with a tree species that is representative for one third of the Dutch forests, a net carbon sink was found, during the past ten years. This is a strong indication that Dutch forest soils still sequester carbon, since the Loobos site is a relative old forest.
- Secondly, N retention data and dynamic modelling at the European scale, including the Netherlands, indicate the occurrence of soil C retention.
- Thirdly C changes in chronosequences also indicate C sequestration in humus layers and the same holds for literature information on repeated soil C pools in areas comparable to the Netherlands.
- Finally, different dynamic modelling studies show carbon stock increases in the Netherlands.

Increase in CO_2, temperature and nitrogen deposition in temperate climates lead to increased forest growth and thus increased carbon supply through leaf fall. In addition, the literature, including multiple Meta data analyses that increased nitrogen supply mostly reduces decomposition. This leads to increased carbon sequestration in the soil. Conversely, increase in temperature leads to an increase in the decomposition. In summary, literature data, including meta-analysis of experimental data and model calculations show that increase of CO_2 in combination with N deposition leads mostly to increased C sequestration in the soil. The effects of temperature rise are less clear, but in temperate climates temperature rise seems to indicate that this leads to an increase of C sequestration.

In the Netherlands, the CO_2 concentration and temperature is expected to increase, while there is a declining high nitrogen deposition, although the deposition levels seem to stabilise and newest N-deposition scenarios have higher estimated N-depositions than the estimations of 2010. These changes in climate and air quality, combined with the results from meta-analysis and modelling make it likely that soil carbon sequestration will continue in the future in the Netherlands. Given the expected management trends in the Netherlands, Dutch forest soils can still be considered as 'not-a-source' of carbon.

Conclusions

To give a scientific basis for the principle of carbon stock change being 'not-a-source' we first have made a review of methods how to report this and what is accepted. Second, we have investigated what sources are available in the Netherlands to argument that the Dutch forest soils are not a carbon source. These sources were searched in Dutch datasets with measurements and literature. Finally, we argued that changes in air quality and climate are most likely leading to increased soil carbon pools. The conclusions of our review are summarized below.

Review methods
To report a pool as 'not-a-source', a country is expected to show that the respective pool, usually in a non-aggregated way, is not-a-source for the specific situation in this country and in the years of the commitment period. Very few countries have been able to justify their reporting of soil carbon stock change under forest management as 'not-a-source' in a way that was totally acceptable to the review team in 2010. It is currently not clear how the experience gained by countries and reviewers has influenced the 2011 review process. In general, countries that are able to justify (more or less) satisfactorily that the carbon stock change is not-a-source have measured data or estimated quantities or extensive modelling (or a combination of those). 'Simple' reasoning is accepted only for Spain.

Available methods in the Netherlands to report 'not-a-source'
Although there are no datasets on soil C pool changes at an adequate time scale, there are various arguments to indicate net soil carbon increase in the Netherlands, including a combination of (i) measurements in Loobos, (ii) literature on soil carbon increases based on repeated measurement in comparable areas, (iii) N retention assessments, assuming that the soil C/N ratio stays constant and (iv) European scale modelling approaches on soil carbon changes including the Netherlands. Furthermore expected changes in climate and N deposition in the Netherlands, combined with the results from meta-analysis and modelling make it likely that soil carbon sequestration will continue in the future in the Netherlands. Literature data, including meta-analysis of experimental data and model calculations show that an increase in CO_2, temperature and nitrogen deposition in temperate climates leads to an increased C sequestration in the soil caused by increased forest growth and thus increased carbon supply through leaf fall and decreased decomposition. Temperature rise also increases forest growth and litterfall, but on the other hand, higher temperatures lead to higher decomposition rates. In temperate climates, temperature rise however seems to lead to an increase of C sequestration. These are strong arguments to make the plea of 'not-a-source' for Dutch forest soils.

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Appendix 1 Characteristics of Dutch forest

The Netherlands are occupied by 359,845 ha of forested area (Dirkse et al., 2007). Since 1982 the forested area has increased with an average of 1,434 ha per year. The greatest increase took place in rural areas in Groningen and Friesland. The Dutch forests consist of many small woodlands and some uninterrupted forested areas. There are 55,526 wood lots, 83% of which is smaller than five ha. Less than 1% is larger than 100 ha, but these complexes do occupy 30% of the total forested area.

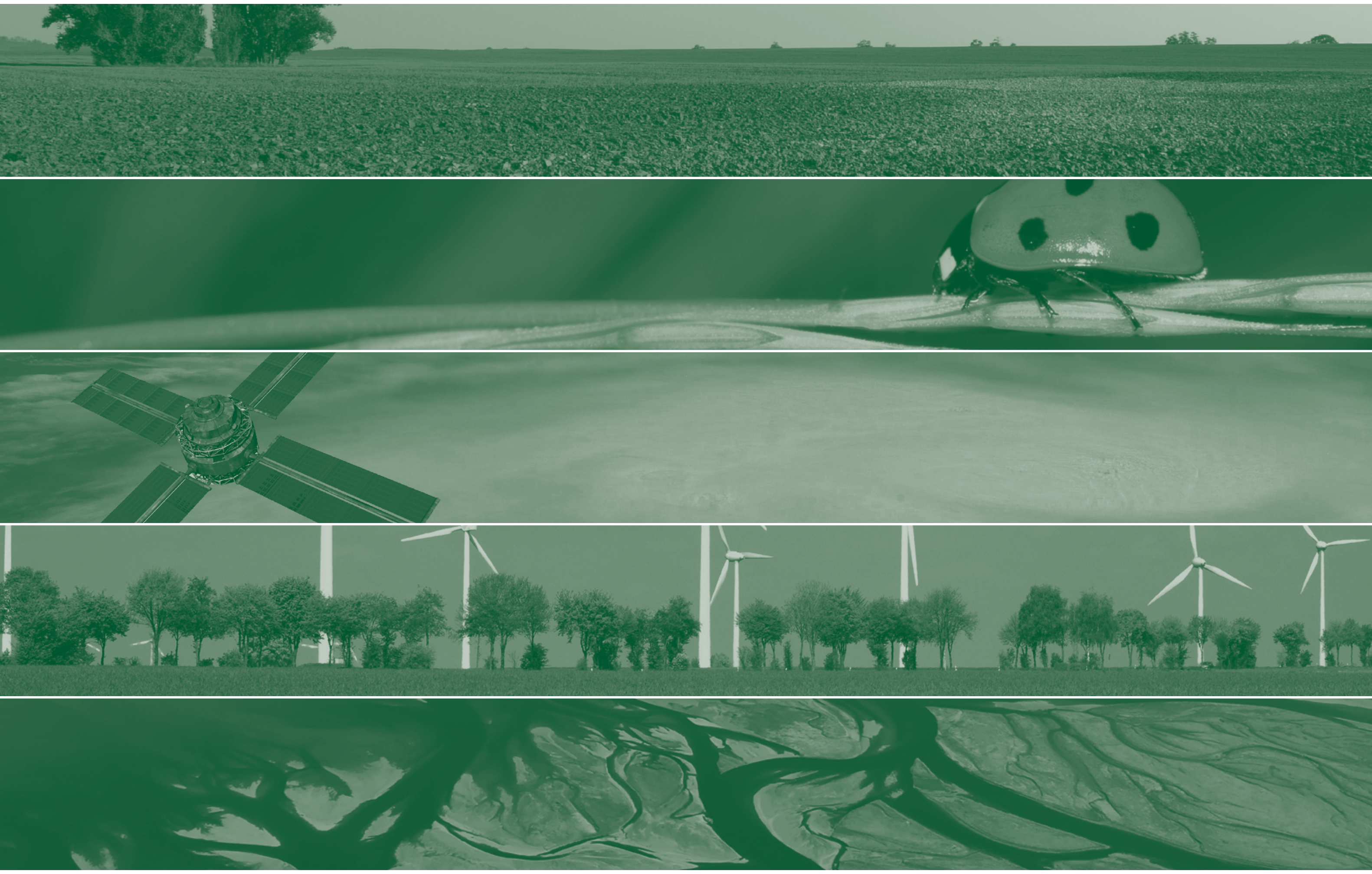
Scots pine is by far the most common tree species, about one third of the forested area (33 %) is dominated by Scots pine. Native oak (Quercus robur and Q. petraea) comes second with 18%. Other tree species are much rarer and each occupies a part of 6% at most. From 1983 onwards the area with Native oak has increased strongly. The percentage of coniferous forest strongly decreased in favour of deciduous forests. Douglas fir is an exception, the area with this tree species increased slightly after 1983.

Dutch forests are relatively young. 52% or more of the forested area has year of germination between 1940 and 1980 and consequently is 25-65 years of age. Private organizations for nature conservancy own relatively much old woodland, but little in germination years after 1980.

Table 2
Forested area (x 100 ha) by tree species and classes of germination decennia

Germination year	Scots pine	Other pine	Douglas	Larch	Spruce	Other coniferous	Oak	Beech	Poplar	Other native deciduous	Other exotic	Clean felling	Total
-1780	0	0	0	0	0	0	4	1	0	0	0	0	5
-1800	1	0	0	0	0	0	1	0	0	0	0	0	2
-1840	2	0	1	0	0	0	5	10	0	0	0	0	18
-1860	20	0	0	0	0	0	14	16	0	0	1	0	51
-1880	85	1	2	0	0	3	76	17	0	2	6	0	192
-1900	165	7	13	1	0	0	77	17	1	7	12	0	300
-1920	287	32	45	50	23	2	111	16	5	27	30	0	628
-1940	293	63	59	101	45	4	113	18	28	106	46	1	877
-1960	137	48	42	19	58	5	132	17	121	170	28	1	778
-1980	58	5	16	8	9	2	47	8	48	75	11	1	288
2000+	1	0	0	0	0	0	2	0	6	2	0	8	19
Total	1049	156	178	179	135	16	582	120	209	389	134	11	3158

By far most forests occur on sandy soils: 97% of the coniferous forests and 72% of the deciduous forest. The remaining 28% of the deciduous forests occur on clay (20%), peat (6%) and löss soils (2%).



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