Greenhouse gas management in European land use systems

Reporting

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GHG EUROPE

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Final Report Summary - GHG EUROPE (Greenhouse gas management in European land use systems)

Executive Summary:
The GHG-Europe project aimed to improve our understanding and capacity for predicting the European terrestrial carbon and greenhouse gas budget. The project attributed the fluxes of CO2, N2O and CH4 in European land ecosystem to human versus natural driving factors.

Updates of the European carbon and greenhouse gas budget confirmed the previously published values. Europe remains a net carbon sink, which is more than compensated by N2O and CH4 emissions from agriculture. These updates do not fully include yet the greenhouse gas (GHG) sources from drained organic soils (peat soils). Despite a high uncertainty in the area and drainage status anthropogenic emissions from drained organic soils are likely underestimated by at least factor two or three in the European greenhouse gas inventory under the United Nations Framework Convention on Climate Change.
For the first time, European estimates have been made based on fully consistent in spatio-temporal driver fields with common time periods, frequency, and spatial resolution. New driver fields have been developed for important direct and indirect human drivers: nitrogen deposition, agricultural management, and age class distribution in forests. The driver fields are publically available for further use at the project database.
The classical approach to constrain the terrestrial carbon and greenhouse gas budget by independent top-down and bottom-up methods has again been successfully applied at European scale. The application at regional scale, however, revealed considerable uncertainty in the atmospheric top-down method so that so far, only the bottom-up method was considered robust to monitor success in GHG mitigation at regional scale.
Management effects override the impact of interannual variability in climate drivers on the ecosystem carbon balance when more than 20% of the net primary production is harvested. This threshold is likely exceeded in most land-use systems and regions of Europe except for pastures and young forests.
Land-use changes have occurred on 25% of the European land area since 1900 and on 15% since 1950. There is a strong asymmetry in soil reactions to land-use change. Soils lose carbon fast within 20 years but take more than 100 years to recover. The long legacy of land-use change effects on soil carbon may mask effects of recent management changes.
Sensitivity and attribution analyses based on data synthesis and modelling agreed in the most effective options for GHG mitigation. They confirmed previous scientific findings and policy recommendations for mitigation measures in croplands, grasslands, forests and managed peatlands.
Scenarios of future carbon and GHG emissions were developed. They demonstrate the importance of consistent cross-sectoral policies for agriculture, energy and other fields that affect land-use decisions so that clear incentives for low emission land-use systems can be set up. Land-use decisions, economic and political drivers will remain the dominant drivers of European carbon and greenhouse gas fluxes in the coming decades.

Project Context and Objectives:
1.1 The science context

Biological systems have their intrinsic dynamics, and interact with climate change in a complex way that is not completely understood. This makes climate change mitigation measures in agriculture, forestry and other land-uses more complicated and uncertain than in any other human sector. Ultimately, the scientific challenge is to determine how, and to what degree, the carbon cycle and GHG emissions in terrestrial ecosystems can be managed. This requires a much improved understanding of the response of biogeochemical processes in ecosystems to changes in natural and anthropogenic drivers.
The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2013) states: “It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century“. Fossil energy use and net land-use change emissions have been the dominant sources of anthropogenic CO2. Globally, only 43% of the anthropogenic CO2 emissions have accumulated in the

atmosphere. The remainder has been absorbed by oceans and land biosphere at about equal parts (IPCC, 2103). In Europe, the land biosphere has absorbed 13 % of the fossil fuel emissions of EU-25 over the last decade (Schulze et al. 2008). This net carbon sink has mainly been located in forests and grasslands, while croplands are relatively carbon neutral, and managed peatlands are a carbon source (Janssens et al. 2003, Schulze et al. 2008). This net carbon sink, however, was almost compensated by N2O and CH4 emissions from agriculture (Schulze et al. 2008). The role of land-use change as net carbon sink or source remains uncertain in Europe.

European land-use and management can and must make a significant contribution to the mitigation of climate change. But the challenge is to determine how much of the biospheric greenhouse gas emissions and sinks are anthropogenic and how much driven by natural factors such as climate, which are beyond human control.

To guide European land-use decisions for climate change mitigation science needs to provide robust answers to the following questions: Will the carbon sink persist? How will the other GHGs evolve? How much of the observed greenhouse gas emissions and sinks can be managed? What measures are most effective? While knowledge has considerably increased over the last two decades and robust qualitative answers have informed policy about promising mitigation measures it remains an unresolved challenge to quantify direct management induced mitigation effects.

The large-scale average trends by land-use types have a large uncertainty because of widely diverging observations at the level of individual sites. A major scientific challenge is to understand the reasons and underlying mechanisms of spatial patterns in carbon and greenhouse gas fluxes. This involves the major methodological challenge how to bridge the scale gaps between different types of observations, and between observations and the representation of key processes in models, and between observations and spatio-temporal model resolution.

Site level observations have pointed to hotspots of anthropogenic greenhouse gas fluxes by land-use change and from drained peat soils. The spatial extent of these hotspots and temporal patterns in drivers are largely unknown. Mediterranean shrublands and Eastern European forests bear a significant potential for carbon sequestration which has not yet been explored.

To better guide land-use decisions our causal understanding of carbon and greenhouse gas fluxes needs to be improved. How much of the past European land carbon sink was due to natural processes, and how much due to land-use and management? Has past management contributed to, or mitigated anthropogenic climate change? How much, and for how long do past land-use decisions determine current observed trends? Will continued climate change and the rising pressure on productive land compromise the potential contribution of land-use to greenhouse gas mitigation?

1.2 The policy context

The science questions raised above address the core of European agricultural, energy and climate policy. Land-use has to fulfil various contrasting demands for food, feed, fibre, bioenergy provision, and other ecosystem services. Climate change has added new demands for mitigation and adaptation.

Agriculture and forestry already contribute to national and European climate change mitigation targets under the Kyoto Protocol and the EU Regulation 525/2013 “on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at national and Union level relevant to climate change and repealing Decision No 280/2004/EC” (EU 2013a). So far, only CH4 and N2O emissions from agricultural activities and the carbon sinks and sources in forests are mandatorily included in quantitative terms, but not the hotspots from land-use changes and drained peat soils outside forests. From 2013 onwards, these hotspots have to be monitored and mitigation activities reported under EU Decision 529/2013/EU "on accounting rules on greenhouse gas emissions and removals resulting from activities relating to land-use, land-use change and forestry and on information concerning actions relating to those activities" (EU 2013b) with a view on a potential inclusion in future quantitative commitments. European energy policy will further expand the share of renewable energy in electricity and heat provision and in transportation. The fast expansion of bioenergy has resulted in marked land-use changes. Although the European Commission proposes in COM(2014) 15 final (EU 2014) to phase out support for food-based bioenergy the agriculture and forestry sector will remain an important source of renewable, yet with improved greenhouse gas efficiency. This will trigger significant further changes in bioenergy production chains and land-use.

The recent reform of the Common Agricultural Policy (CAP) has mentioned climate change measures as one of the major rationales for continued support to farmers. It offers opportunities for integrating climate change abatement into the CAP. The measures in the 1st pillar are unlikely to have a measurable impact on greenhouse gases (Freibauer et al. 2012). Success largely depends on the implementation of measures under the much smaller 2nd pillar at Member State level. But there is a clear potential to initiate regionally adapted mitigation and adaptation measures in agriculture and forestry.

1.3 Objectives of GHG-Europe

The GHG-Europe project aims to improve our understanding and capacity for predicting the European terrestrial carbon and greenhouse gas budget. In particular, GHG-Europe aimed to advance our quantitative understanding in the attribution of the variability in the fluxes of CO2, N2O and CH4 to multiple interacting human and natural factors.

Against the background of scientific and political challenges, the collaborative research project GHG-Europe - Greenhouse gas management in European land-use systems aimed to:

1. Quantify the annual to decadal variability of CO2, N2O and CH4 budgets of terrestrial ecosystems in Europe (Workpackages 1, 5).
2. Obtain a better and more comprehensive understanding of terrestrial carbon cycle and responses of CO2, N2O and CH4 fluxes to variability in natural and anthropogenic drivers (climate, N deposition, land-use, management) and pressures (global markets, European climate and land-use policies) for European forest, grassland, cropland, peatland and shrubland ecosystems (Workpackages 2, 3, 4, 6).
3. Identify the carbon pools and GHG processes most sensitive and vulnerable to changes in individual drivers and in driver combinations, and the associated risks of positive feedbacks with climate change in the 21st century (Workpackages 2, 4, 5, 6).
4. Assess, in economic, societal and environmental terms, the impact of possible post-2012 strategies / policies on future carbon pools and CO2, N2O and CH4 fluxes in Europe and possible synergies by coordination of different land-use related policies and of cross-sectoral climate policies (Workpackages 6, 8).

GHG-Europe focused on the full CO2, N2O and CH4 budgets of terrestrial ecosystems and on the impacts of anthropogenic drivers and their interactions with climate on C and CO2, N2O and CH4 budgets as the most critical and least characterized processes in the vulnerability assessment of European ecosystems.

1.4 The GHG-Europe approach

Improved quantification of the annual to decadal variability in the European terrestrial carbon and GHG budget requires
1) consistent temporal and spatial domain coverage,
2) the full exploitation of all available data streams,
3) strong data-model integration, and
4) complete consideration of error propagation at all calculation steps.
Therefore, GHG-Europe used an approach focusing on coherence, consistency and data mining to make best use of existing data to reduce uncertainty and improve model performance for a robust attribution of carbon and greenhouse gas fluxes to human or natural drivers, by
1) the collection and synthesis of the fast growing observational evidence of ecosystem response to individual drivers,
2) improved representation of climate variability AND land-use and management in ecosystem models, and
3) a coherent approach to address the interactions between drivers from local to continental scales.

1.5 A large interdisciplinary consortium and science partnership

GHG-Europe was built by a large consortium with diverse complementary expertise. It comprised 41 project partners and 6 cooperation partners, who voluntarily contributed to project tasks. The 41 partners were based in 15 European countries. The 6 cooperation partners came from 3 European countries and a European research body. Workshops and data synthesis activities included more than 100 external scientists.

1.6 Workpackages and methodologies

GHG-Europe was structured in 8 Workpackages (WPs).
WP 1: Quantification of spatial and temporal variability of the main factors driving GHG fluxes (Trends in drivers). The objective of WP 1 was to provide standardized gridded fields of natural and anthropogenic drivers for EU27+ with uncertainties as far as possible, which were used as input to modelling and data analysis in WP 2, WP 4, WP 5 and WP 6 via the GHG-Europe database (WP 7). Hot spots and hot moments and time span of major changes in the driver fields and responses by carbon fluxes were analysed by break point analysis.
WP 2: Quantitative understanding of the response and vulnerability of ecosystem C and GHG fluxes to changes in external drivers (Critical processes). The objective of WP 2 was to quantify the response of terrestrial ecosystems to anthropogenic and natural drivers by multi-site analysis of observational evidence and to better quantify and understand GHG fluxes in so far undersampled ecosystems and regions.
WP 3: Impact of land management on the regional scale GHG balance of selected, data rich regions in Europe (Regional variability). The objective of WP 3 was to undertake case studies in selected, data rich regions of Europe representative of typical regional trends in land-use and management. WP3 further developed methods for systematic uncertainty estimates in scale representation over heterogeneous landscapes and tested a top-down verification of the carbon budget of a region at high resolution

(Netherlands).
WP 4: Attribution of annual to decadal variability of carbon and GHG budgets in managed European ecosystems to human and natural driving processes (Sectoral attribution). The objective of WP 4 was to attribute (with uncertainty) the annual and decadal variability of carbon and GHG budgets in managed European ecosystems to anthropogenic versus natural driving processes.
WP 5: Quantification of the annual to decadal magnitude and variability of the C and GHG budget of European terrestrial ecosystems for EU 27 (EU-27 GHG budgets). The objective of WP5 was to quantify and update the full European carbon balance and its annual-to-decadal variability in an integrated approach.
WP 6: Future vulnerability of sources and sinks and risk of positive feedback with climate change and European politics – post-2012 scenarios (Post-2012 scenarios). The overall objective of WP 6 was to draw guidelines and recommendations on land-use practices to be promoted by EU policies based on scenarios of future climate and socio-economic drivers.
WP 7: Scientific consistency, uncertainty methods and data base (Database). The objective of WP 7 was to facilitate data – model integration via a central database with quality control and the provision of uncertainty analysis tools.
WP 8: Coordination and dissemination. WP 8 was dedicated to the organization, management and administration of the project and to disseminate the project results to science, policy and society.
Project Results:
2.1 Major breakthroughs

2.1.1 Methodological

• Open data policy: GHG-Europe has adopted an open data policy, which made the results available to the research community already in the course of the project. As a result, several researchers joined GHG-Europe as associated partners involved in modelling and many more have contributed with own data. The following data products are available to the wide research community:
o Much extended open access database of site measurements with management information where possible, quality control routines extended from eddy covariance measurements to other relatively standardized data types
o Spatio-temporal driver fields of natural and anthropogenic parameters at European and regional levels
o Background data of policy consultation as far as not restricted by confidentiality requirements

• New driver fields for carbon and GHG modelling:
o Consistent spatio-temporal driver fields of natural drivers and N deposition were produced.
o New spatio-temporal fields of management drivers were developed for forests, croplands and grasslands and land-use changes at a consistent 1 km grid.
o Very detailed driver maps land-use and land management information was collected for six diverse data-rich regions of Europe, which represent the diversity of land-use strategies across Europe.

• Model development
o Data driven response functions and simple process models were developed for spatio-temporal assessments of carbon and GHG fluxes, e.g. for land-use change, bioenergy, natural and managed peatlands

o The generic ecosystem model ORCHIDEE has been further developed to versions that include management for particular land-use types
o For policy analysis within and beyond the land-use sector, model coupling was improved in terms of spatial resolution, realism and consistency.

• Understanding of spatial correlation lengths in atmospheric approaches has been systematically improved.

2.1.2 Scientific

• Consistency across scales: For the first time, in cooperation with parallel EU research projects, consistency in spatio-temporal driver fields has been achieved, including common time periods, frequency, spatial resolution.
• The dominant role of management as driver of carbon and GHG fluxes at local, regional and European scale has been demonstrated and quantified by diverse scientific approaches, ranging from observational evidence, analysis of spatio-temporal patterns via fingerprinting and break-date analysis, and targeted sensitivity analyses with sectoral and generic models using harmonized protocols and – as far as possible – harmonized input. The approaches all confirmed the important role of management for the GHG balance in Europe, although different views and uncertainties remain about carbon sinks in grasslands and the role of forest age versus site productivity in forests.
• For the first time, gross land-use changes have been determined for the past 110 years. According to these maps, there have been surprisingly large historical gross land-use changes in Europe, which have affected a quarter of the European land area. There are typical regional pattern and timings which reflect the legacy of political disruptions such as war and the fall of the iron curtain. The most widespread land conversions are from cropland to grassland and vice versa. They can also happen several times on the same land.
• There is a very long legacy of land-use change in soil C trends when land-use change leads to carbon sequestration. Soils turn into disequilibrium for decades up to few centuries. For a large fraction of European cropland and grassland soils, the equilibrium hypothesis used in most ecosystem models is unrealistic. The same holds for afforestations.
• Gaps in process understanding were filled with regard to N deposition effects on forest carbon cycling, peat carbon and GHG vulnerability to drainage, and the previously unknown, but important role of karst ventilation in Mediterranean shrublands that disturbs the biogenic CO_2 signal of eddy covariance measurements.
o Nitrogen deposition does not increase the productivity of forests, but rather changes the carbon allocation from belowground to aboveground. This process may make forests more vulnerable to drought in the future.
o Detailed analysis of the ongoing forest inventory in Romania showed that in the very important and diverse biome of East European beech forests, site productivity overrides all management effects.
o For the first time, a comprehensive EU-wide analysis has tried to quantify the GHG sources in managed and unmanaged organic soils. While the final results are still outstanding it is likely that the GHG sources from drained organic soils may compensate the carbon sink in European forests on mineral soils.
o The ventilation process turned out to be very important in Mediterranean shrublands on calcareous soils, which dominate on the Spanish peninsula. Eddy covariance data were used to separate ventilation from

biogenic CO_2 fluxes. But a general separation of half-hourly fluxes is impossible so that in consequence, the eddy covariance data may not be used for calibrating empirical or generic ecosystem models of Mediterranean shrublands, which only include the biogenic flux component.

• High resolution regional bottom-up versus top-down assessment of the carbon balance at country scale: A case study in the Netherlands has underlined the high uncertainty in regional atmospheric inversions, which is driven by uncertainty in atmospheric boundaries and spatial correlation length. These reasons for uncertainty are very difficult to overcome in terms of resource needs and methodological challenges.

• IPCC: Many project partners have directly contributed to the IPCC Fifth Assessment Reports and the two updates of the IPCC Guidelines, feeding preliminary GHG-Europe results directly into the ongoing IPCC processes.

2.2 Policy relevant results and their implications

As the management signal dominates, the carbon and GHG balance in European ecosystems appears to be manageable in a predictable way so that it can be integrated in future climate policies. This finding supports the attempt of the European Commission to include land-use in future climate policies by the DECISION No 529/2013/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2013 on accounting rules on greenhouse gas emissions and removals resulting from activities relating to land-use, land-use change and forestry and on information concerning actions relating to those activities.
Management implications of the GHG-Europe results:

• Vulnerable drained organic soils: wet management strategies are probably the largest direct mitigation wedge of EU land-use. Research, innovation and mitigation policies would need to be considerably strengthened to explore this wedge.

• Land-use change: The legacy of past land-use changes has put many soils into disequilibrium of carbon. The soil carbon equilibrium assumption, which is still the basis of ecosystem models, is obsolete in a large fraction of the European land surface. This poses an extra challenge to MRV in land based mitigation because past disequilibrium may mask more recent trends in management. As a clear policy recommendation avoided expansion of croplands is the safest way to keep the carbon in the soil.

• Maximize NPP on fertile land. Continuous cover croplands are uncommon in Europe. Continuous vegetation cover would, however, allow maximum light use for GPP and NPP through the entire year. Model experiments showed the potential NPP increase by continuous cover croplands. The results were supported by potential NPP estimated by a generic grassland model of, which was higher than NPP on croplands.

• Enhanced nitrogen use efficiency is critical to reduce the strong N_2O footprint of European agriculture. Regionally adapted strategies are necessary because the sensitivity of soils to form N_2O varies widely. Organic fertilizers help to stabilize and sequester soil organic carbon stocks, but are so far inefficiently used for N and P supply, due to partly unpredictable nutrient mobilization. Nitrogen loss from agriculture leads to N deposition and eutrophication of forest soils, which may make forests more vulnerable to drought in the future.

2.2.1 Update of the European greenhouse gas balance

An updated estimate for 2001 t o2005 confirms earlier studies for the 1990s: The European biosphere absorbs carbon but the net sink is compensated by CH_4 and N_2O emissions from agriculture. Managed agricultural land is a clear greenhouse gas source with additional significant embedded emissions from energy consumption for fertilizers and machinery.

Ten years after the first estimate of the European carbon balance (Janssens et al. 2003) an updated estimate was made based on a compilation of recent estimates of landscape and carbon pool component fluxes using the same approach of comparing independent data streams from land inventories, bottom-up flux studies and top-down atmospheric inversions. Some assumptions were needed to fill gaps or uncertainties. The update addressed the period from 2001 to 2005. It included new elements, in particular aquatic ecosystem types, harvested products, lateral carbon fluxes and atmospheric chemistry. More detail was available for carbon in freshwater ecosystems, for disturbance in forests. Updated information on emissions from land-use change was used. Harvested products and their fate, their lateral transport and CO2 release after use were considered in unprecedented detail, including biofuels and decay in landfills. Changes in sediment, soil and biomass carbon stocks were explicitly balanced. Lateral import of carbon dissolved in rain was included as well. Atmospheric processes such as oxidation of carbon compounds to CO2 were fully considered as well, since they need to be corrected to match the atmospheric concentration signals with bottom-up estimates of CH4, CO and CO2.

The update results in a net biogenic carbon sink of 205±72 Tg C yr−1 from Europe, constrained to EU-27 and some neighboring states. It confirms the numbers published in earlier estimates with a slight upward trend. Earlier studies used a larger European area but the comparison needs to keep in mind that the net carbon sink is not equally distributed across Europe, but rather concentrated in the regions dominated by forests and grasslands (Scandinavia, Central and West Europe; Janssens et al. 2005).

The update also confirms previous findings (Schulze et al. 2008) that CH4 and N2O emissions from agriculture turn the European biosphere from a net carbon sink into a net greenhouse gas source (Luyssaert et al. 2012).

In a second step a basic country-based life cycle analysis approach was used to add the CO2 cost of land management by the energy consumption for fertilizer production and application, field and harvest operations and transportation of harvested products. This CO2 cost for land management adds a source of 89 Tg C yr−1 equivalent to about 10% of the total European emissions from fossil fuels. Thus management activities override the net carbon sink strength of European ecosystems.

At regional scale, an attempt was made to reconcile bottom-up, high-resolution land-based estimates with atmospheric top-down inversions (Meesters et al. 2012) made at higher resolution than the European estimates. In the case study for the Netherlands, however, bottom-up and top-down estimates did not match well. The bottom-up estimate produced a realistic pattern. In contrast, the atmospheric approach seems to have its limitations at regional scale when either atmospheric transport processes or atmospheric boundary conditions cannot be adequately constrained.

High uncertainty in regional atmospheric constraints highlights importance of good bottom-up monitoring of GHG mitigation efficiency.

GHG-Europe has successfully increased the realism of land-use and management representation in various types of bottom-up models so that they can make robust predictions of future ecosystem vulnerability to socio-economic and natural drivers. Clearly, at time scales of few years to a decade, land-use and management decisions override the effects of climate trends in Europe. Markets for timber, energy, feed and food will drive the land-use dynamics.

Atmospheric inversions have demonstrated a robust capability to constrain the global carbon budget. At regional scale of the size of individual EU Member States, the case study of the Netherlands and the analysis of uncertainty in spatial correlation lengths of atmospheric concentration measurements in GHG-Europe have demonstrated the intrinsic difficulty of using atmospheric approaches as independent witness of regional GHG mitigation success. This finding calls for sustained efforts in bottom-up monitoring of GHG mitigation measures if a quantitative evaluation of climate policy success is desired.

2.2.2 Consistency and coherence in space and time: New harmonized European spatio-temporal fields of drivers of greenhouse gas emissions

Trends in drivers with consistent temporal and spatial domain coverage are available for the research community.
In the past, heterogeneous spatio-temporal resolution in important driver data was a significant source of uncertainty in the European greenhouse gas budget because data had to be modified to fit to the specific model requirements in European assessments. This source of uncertainty has been overcome in GHG-Europe. Standardized gridded fields of natural and anthropogenic drivers were produced for the period 1900 to 2010 and projections to 2100 for EU-27 plus Switzerland (Table 2). They were used as input to modelling and data analysis in the project but can also be publically accessed. Drivers include

- Socio-economic frame conditions
- Meteorological drivers
- Nitrogen deposition
- Land-use and land-use change
- Cropland management data
- Grassland management data
- Projected CO_2 emissions from all sectors
- Past and future scenarios of CO_2 sinks and sources from LULUCF activities.

All driver fields are available via the GHG-Europe database:
www.europe-fluxdata.eu/GHG-Europe/data/others-data

Harmonized European driver fields spatio-temporal fields of drivers of greenhouse gas emissions available via the GHG-Europe database:
Forest data: Global database with information about forest biomass and fluxes. Collected by Sebastiaan Luyssaert and described in Luyssaert et al. (2007). Users are requested to cite this paper.
Socio-economic driver maps: Driver maps for GDP and population on half degree resolution. Country scale information for population for this period distinguishes between rural and urban population. GDP indicators are in MER (Market exchange rate) and also distinguish between rural and urban. 2000-2020
Emission scenarios: Globally consistent scenarios of CO_2 sinks and sources from LULUCF activities in EU Member States. 1990-2030
Meteo driver maps: The dataset results from the harmonization and downscaling of the WATCH and ERA Interim datasets. It contains mean temperature (Tair), minimum temperature (Tmin), maximum temperature (Tmax), precipitation (Precip), short wave solar radiation downward (SHdown), long wave solar radiation downward (LWdown), wind speed (Wind), specific humidity (Qmean), atmospheric pressure at the surface (PSurf). 1901-2100
N Deposition driver maps: The data-set contains 1850-2010 reduced and oxidised downward nitrogen deposition velocities obtained from the TM5, NCAR, and EMEP CTMs, as well as a synthesis data set from the ACCENT project. Furthermore a scenario for 2005-2050 based on the EMAC model is also

presented 1901-2100
Land-Use Change driver maps: Data is a product of the HILDA model (HIstoric Land Dynamics Assessment) processed by Richard Fuchs and Martin Herold (Laboratory of Geo-Information Science and Remote Sensing, Wageningen University, Netherlands) 1900-2010
Forest Age driver maps: Data derived from forest inventory information 1950 to 2010 and backcasting using the method of Seidl et al. 2011 (GCB 17, 2842-2852). The data contain forest area per age class 1-20, 21-40, 41-60, ... 121-140, 140+ for 1950, 1960, ... 2010. Data after the most recent forest inventory were derived from EFSOS II projections of the EFISCEN model (UNECE/FAO 2011) 1950-2010
Crop data for Europe: These are crops for EU 27 on the 1km EU reference grid based on best practise and regional crop data on NUTS2 level. The reference grid is availabe from: http://eusoils.jrc.ec.europa.eu/library/reference_grids/reference_grids.cfm The crop is the crop HARVESTED in the year given. In case of a winter crop it needs to be planted in the year before. The N application is total fertiliser (Manure plus miniral) in kgN per ha.
Grassland management for Europe: The grassland management for Europe (0.25° x 0.25°, [29.125N ; 71.375N] x [-23.875E ; 45.375E] 170 x 278 pixels) was established after EU-FP6 NitroEurope data (as provided by Adrian Leip, European Commission Joint Research Centre). Based on regional and national statistics and a modelled part, three intensification levels (Low, Medium and High) were created. 1901-2100
Long term emission database: Long-term Climate Policy Scenario Results (Del 6.4) Major environmental, societal, market, and technological impacts in electronic data base format. Zipped folder includes excel file and a brief description of the data in a word file. 2000-2050

2.2.3 Attribution of European carbon and greenhouse gas fluxes to management or climate drivers

Complex and unclear response of the European biosphere carbon fluxes to trends in climate drivers

Spatial patterns in climate trends do not match photosynthesis patterns and trends in the last 30 years. A first complete quantitative assessment of the annual to decadal variability of photosynthesis in relation to climatic drivers was done by means of a break-point analysis. This method identifies changes in the trend slope of a time series and allows analysing the spatial patterns of trends. Two methodologically independent, data-driven approaches to estimate gross primary production (GPP) were calibrated by in-situ flux data derived from eddy covariance measurements across Europe and up-scaled with the new meteorological driver maps. The two GPP products showed consistent patterns for trends, which showed a rather small scale, patchy spatial variability in trends over about 30 years. In contrast, the climate drivers showed much larger coherent trend patterns. Patterns of changes in climatic drivers seem not to be directly translated into their responses. Obviously, biophysical properties of vegetation are the stronger driving factor. Management factors seem to be important for explaining trends and oscillations in vegetation dynamics (Tomelleri et al., in prep).

Management overrides climate impacts in land-use systems with significant harvest

Management exceeds the impact of inter-annual climatic variability on the net ecosystem carbon balance in most European land-use types.
Meanwhile there is a wealth of eddy covariance measurements across Europe with time series of several

years to decadal time scale. Most of these sites have seen management interventions so that the data can directly be used to test whether the interannual variability in carbon fluxes is driven by climatic variability or management. In this synthesis, data from 69 European sites (croplands, grasslands and forests) with 483 years of measurements were compiled (Poeplau et al., submitted).
We hypothesized that I) management increases the inter-annual variability of net ecosystem production (NEP) and II) net management carbon fluxes (i.e. C export by harvest and C input by organic manure) exceed the impact of inter-annual climatic variability on the net ecosystem carbon balance. Indeed, the inter-annual variability of NEP increased from unmanaged to managed sites, suggesting a strong disturbance effect of management. The mean annual net management carbon fluxes exceeded the inter-annual variability of NEP (which is the minimum likely sensitivity to climatic variations) in croplands, mown grasslands and older forest stands (>40 years). This was not the case in grazed grasslands with generally small net management carbon fluxes.
Across all land-use types, we calculated a threshold of 10 % of GPP or 20 % of net primary productivity (NPP), above which net management carbon fluxes exerts a stronger impact on the net ecosystem carbon balance than inter-annual climatic variability. The current European human appropriation of NPP (HANPP) is estimated to exceed 40 %. We conclude that under recent developments of land-use and land management in Europe, most ecosystems are dominated by management in a decadal time scale.
In other words, most of the carbon and GHG fluxes on land managed for economic returns are human-induced. This finding promises that greenhouse gas mitigation measures will have strong and immediate effects on carbon and greenhouse gas fluxes.

2.2.4 Understanding the greenhouse gas balance of agricultural land

Cropland sites with a measurement history of at least one rotation period were analysed to identify the major management drivers of GHG budgets. Annual Net Ecosystem Exchange (NEP) was a strongly related to the length of growing season and thus depending on climate and crop species. Long fallow periods led to losses of fixed C. These losses can be prevented by cover/ winter crops within the rotation (Figure 3). The amount of carbon exported at harvest was the main driver of the carbon and GHG budgets; sites and rotation where only grain was exported acted as sink of C, in contrast to sites where most of the aboveground biomass was exported (e.g. maize used for silage, or export of grain + straw for winter wheat), which were a source of C. In most cases imported C could not compensate C losses by export. Emissions from field operations, however, represented only a small component of the GHG budget but they always decreased the GHG sink activity or increased the source effect.

Grassland sites were analysed in a similar approach as the croplands described above to identify the major management drivers of GHG budgets. Grasslands generally were a net C sink with a median value of 71±13 g C m-2 yr-1. This value agrees remarkably well with the European mean C sink estimate of Janssens et al. (2003). The C sink was larger in grazed than in cut grassland, and higher in high N input sites than in low N input sites (<40 kg N ha-1 yr-1). Grazed sites had lower N2O emissions than cut sites. Temporary grasslands were too variable for clear trends, maybe because they are too diverse. In conclusion, grazed grasslands were more climate friendly than cut grasslands.
In a next step models were used to determine the impact of each driver on the modelled greenhouse gas emissions. Cropland and grassland models were improved and then used to change both the natural, such as climate, and human driver variables, such as crop management. In this way the relative importance of

each driver was determined at a site level and the importance of each to greenhouse gas emissions was attributed. The models were then used to perform a pan-European spatial attribution experiment by using the driver data sets provided by WP1 to understand the importance and impact of the drivers on a continental basis. This was complemented by a more detailed spatial attribution and sensitivity analysis in the “data rich” areas of Finland, France, Poland, Italy and the Netherlands.
The attribution analysis confirmed previous studies, which show a small impact of climate but significant impact of management, in particular crop rotation choice and grazing versus cutting in grasslands, on soil carbon. The results are immediately policy relevant and are further described below.

2.2.5 Understanding the greenhouse gas balance of forests
The legacy of nitrogen deposition
Based on a series of global review studies a new scientific perspective was found about the role of nutrient status and nitrogen deposition in forest productivity. As physiologically expected, N deposition does not increase the productivity of forests, but rather changes the carbon allocation from belowground to aboveground biomass. This process may make forests more vulnerable to drought in the future. The root biomass, however, seems to be relatively independent of nutrient status (Vicca et al. 2012), but aboveground biomass increases with nutrient supply.
At most forest sites there is a clear negative effect of nitrogen addition on soil CO2 fluxes, often despite increased primary productivity (Janssens et al. 2010, Vicca et al. 2012). The only exceptions were young, aggrading forests where nitrogen addition accelerates canopy closure. We propose the following mechanism to explain the effect: Forests under nutrient limitation need to invest more photosynthates in root exudates and root symbionts that help the trees accessing nutrients. There is no clear observational evidence for this mechanism yet. But in forest sites across the globe, a consistently larger fraction of GPP went into biomass production with increasing nutrient availability (Figure 4). Fertile forests used 58 % of GPP for biomass production while unfertile forests could only use 42 % of GPP. The difference cannot be explained by autotrophic respiration alone. Fertile forests produce biomass more effectively (Vicca et al. 2012).

Management and age-class trends in Europe

European forests have been an almost uninterrupted increasing carbon sink during the last six decades. Usual causes mentioned for this increasing sink are expansion of forest area, nitrogen deposition, changes in age class distribution, changes in management patterns and intensity and shifts towards more productive (coniferous) tree species. An important conclusion from the age class reconstruction was that despite the previously reported increased timber and carbon stocks in European forests, the average age is currently lower than it was in 1950. After a period of shifting towards younger forests, the average age has slightly increased from 1980 onwards, but is still 7 years below its 1950 value. The development of forest age structure thus contributed less to the carbon sink in European forests from 1950 onwards than previously thought. For the period 1950-1980, the sink has occurred mostly in existing forests, probably due to recovery of these forests after heavy cutting during the World War II. After 1980, the sink can mostly be attributed to post-war afforestations and forest expansion on abandoned agricultural lands. At the moment, first signs of a saturation of the sink are becoming visible, due to a combination of less forest area expansion and some gross deforestation, an increase in natural disturbances, and a slowing down of the annual increment (Nabuurs et al., 2013). Projections (UNECE/FAO, 2011) show that the sink can be maintained and even strengthened until 2030, but that natural disturbances are able to override this management effect on the sink (Seidl et al., submitted).

Beech forests – diverse management: the case of Romania

Detailed analysis of the ongoing forest inventory together with information about past management and tree rings in Romania was used to better understand the role of management and site productivity in the very important and diverse biome of East European beech forests. Surprisingly, site productivity overrides all management effects on above-ground biomass carbon stocks in this biome. The mean carbon stock per management type seems to be unaffected by the past biomass harvest. It remains open whether forest age, time since last harvest or the amount of tree carbon removal by harvest show clearer effects. Obviously, in Romania, forest management type is not a sensitive indicator of management impact on carbon.

2.2.6 Hotspot Land-use change

Land-use is one of the main drivers for carbon- and greenhouse gas fluxes in European ecosystems. The long legacy of land-use change effects on soil carbon has a strong potential to mask contemporary effects of management. A quantitative understanding of the legacy of land-use change effects is critical background information for potential future incentive schemes to sequester carbon in managed soils. Europe has seen major land-use changes in the last decades with clear regional and temporal hotspots and trends (Figure 6; Fuchs et al. 2013). Since 1900, 25% of the European land area has undergone land-use changes. Since 1950, more than 15% of the total European land area has been subject to land-use changes and are hotspots of human interventions and land-use decisions (Fuchs et al. 2013).

Land-use changes bring major risks of high carbon losses from biomass and soils, but also opportunities for emission reductions and carbon sequestration. Europe is characterised by a side by side of carbon accumulating land-use changes, such as the afforestation of croplands, and land-use changes that lead to carbon losses, such as conversion of forest to other land-use types. However, there is little consensus on the extent and the direction of carbon stock changes after different land-use change types, leading to inconclusive estimates of land-use change impacts on the European carbon balance.

In a data oriented approach we compiled existing data sets on the effect of land-use change on soil organic carbon (SOC) stocks. Carbon response functions were derived that showed the long legacy effect of land-use change. The conversion of forest or grassland to cropland caused a relative SOC loss of -32% and -36% respectively, with a new equilibrium being reached after 23 and 17 years. On the other hand, afforestation and grassland establishment on former croplands lead to 128% and 116% SOC accumulation over more than 120 years (Poeplau et al. 2011).

With a spatial-temporal geographical information system spatial and temporal pattern of carbon stocks change after land-use change were analysed. We found a net carbon sink in soils of 22 Mio t C in EU27+CH due to land-use changes 1990-2010. High soil carbon losses of 100 Mio t are reported under UNFCCC for the same period. The large discrepancy mainly derived from differences in the underlying activity data sets on the land-use change area. It is unclear which of the two different area data is more realistic. The main soil carbon changes came from conversion of grassland to cropland and vice versa as the most abundant land-use change. Soil carbon gains were found in the Baltic countries, the Iberian Isle and in the UK. In contrast Czech Republic, The Netherlands and Belgium lost soil carbon due to conversion of grassland into cropland. Also urbanisation caused significant soil carbon losses but with high uncertainties due to missing data on their effects on carbon stocks.

Soils lose organic carbon with years to decades after land-use changes, e.g. from grassland to cropland, but in the opposite direction, soil organic carbon accumulation is slow and takes centuries. The principal assumption of ecosystem models that soils reach equilibrium in organic carbon stocks is invalid for Europe. Management can only buffer trends induced by the legacy of past land-use decisions. The legacy of past land-use decision needs to be incorporated in data analyses of management effects and in ecosystem models to quantify the real, direct effect of management decisions against a dynamic background and will allow to resolve controversial findings of management impact on soil organic carbon. The attribution of carbon stock changes to present rather than past management decision is a prerequisite for effect-based incentive schemes ("measurable, reportable, verifiable: MRV").

Hotspot drained organic soils – an overlooked anthropogenic GHG source vulnerable to management and climate change

Drained organic soils (peat soils) are hotspots of CO2 and N2O released from the degrading peat. GHG-Europe prepared the first detailed, regionally differentiated greenhouse gas budget of drained organic soils based on functional relations to land-use, water table, climate, and soil properties. Activities included a strong search for measured data. The database was extended to global scale and made a strong contribution to the updated emission factors for drained organic soils in the 2013 IPCC Wetlands Supplement.

Carbon loss from degrading peat is by far the largest contributor to anthropogenic GHG emissions from organic soils in Europe. There is a very high uncertainty in the spatial extent of organic soils and their properties. Using the CO2 emission factors from the 2013 IPCC Wetlands Supplement yields first estimates 1,100 to 1,700 Tg CO2 per year from European drained organic soils depending on the spatial data source used. According to our first estimates, drained organic soils emit 11 % or more of the total anthropogenic GHG emissions of Europe. Most of these purely anthropogenic emissions are so far not accounted for in national greenhouse gas inventories under the United Nations Climate Change Convention and the Kyoto Protocol.

N2O emissions from drained organic soils have been estimated in a spatially explicit way by using a fuzzy logic approach. The result was compared with emission factor based estimates. Organic soils under cropland emit the highest N2O flux rates, followed by grasslands. The N2O emission rates per hectare forest and peat extraction area are comparatively low. N2O hotspots are concentrated on acidic soils and on systems with high N fertilization (Leppelt et al. in prep).

Uncertainty in the spatial patterns, however, is still very high. Depending on data source the area of organic soils differs considerably. Spatial data about water table and its seasonal variation is not available at European level. Water management is the key and new forms of wet land-use need to be developed. Experiments of new land management forms, data synthesis, additional measurements and upscaling methodologies will need to considerably improve the knowledge base, which currently hampers planning and implementation of greenhouse gas mitigation on drained organic soils.

Deep drained peat soils only cover a small fraction of the European land-use area. Rewetting or restoration is likely to be the largest single GHG mitigation option in European land-use, on a small land fraction. Synergies with other environmental targets for water, nitrogen and biodiversity have been shown to be larger than in any other greenhouse gas mitigation option.

Peat soils are vulnerable to climate change as the area of these soils that water balance between precipitation and potential evapotranspiration drops below -300mm per year increases from current conditions (2010) to 2050. This will allow the water level to drop below 35 cm for a significant period of time and cause soil respiration to increase. The effect in Lapland may be alleviated by melting permafrost (Hastings et al. in prep).

Potential Impact:
2.3 Potential impact and use

2.3.1 From research to climate-smart land-use

GHG-Europe has much improved the systematic understanding of management effects on the carbon and greenhouse gas balance of land ecosystems. Management overrides climate effects at decadal time scale whenever land is managed for good economic return. This means that carbon and greenhouse gas fluxes on the intensively managed European land surface respond to management measures targeted at GHG emission reductions. This is good news as it allows finding solutions for a resilient, climate-smart, sustainable land-use in Europe that is needed to produce food and fiber in a resource constrained world (Freibauer et al. 2011) and to keep up production in a world with a -80% GHG reduction target by 2050.
GHG-Europe has confirmed the magnitude of GHG fluxes from the European land biosphere and in general the most promising and effective mitigation pathways. The project findings set the scientific basis for decision support from continental to regional level. The ecosystem responses could be translated into mitigation opportunity maps to support decisions for land-use options. Many options have clear synergies with other environmental targets.
The knowledge basis about area data in emission hotspots has turned out surprisingly poor. Consistent high-resolution time series of land-use and land-use change, spatial data on management systems, and the location and properties of organic soils are only available at European level at low quality. Spatially explicit water table data of organic soils are not available at all. Research must prioritize driver data and strong support from operational monitoring is needed to improve the capacity to quantify GHG emissions and prove the effectiveness of mitigation measures.
Many effective options have been proposed for years but have not been implemented at large scale yet. There is a clear need to activate the innovation bridge by on-farm studies and pilot region approaches with full integration of the stakeholders from the earliest stage onwards. Technical and organizational challenges need to be tackled, e.g. to improve feed and livestock production from grassland rather than from concentrates, to effectively cycle nutrients from organic manure and legumes.
Some effective options at GHG emission hotspots require relatively drastic regime shifts, such as wet farming systems on organic soils. These options bear particularly strong synergies with other environmental goals so that the barriers can be overcome more easily if additional incentives can be created, e.g. via payments for ecosystem services.

2.3.2 Common Agricultural Policy (CAP)

The CAP has set the aspiration to respond to climate change but fails to provide incentives for measurable

GHG mitigation in the area based payment schemes of the 1st Pillar (Freibauer et al. 2012). The agriculture sector is facing increasing pressure to reduce GHG emissions from the EC Climate and Energy Package and for mitigation commitments beyond 2020. Agriculture has significant potential for win-win and low-cost measures, in particular when synergies with other environmental goals are considered. The country specific implementation of the second pillar and the planned mid-term review can still set enabling conditions for mitigation, define clear targets and introduce powerful systems to monitor and verify results. It is also timely to prepare for steps reaching beyond 2020 and to develop a clear vision for mitigation pathways in the agriculture sector with short-, mid- and long-term targets. Specifically we conclude and recommend as follows.

Mitigating climate change is one of the cross-cutting themes of the 2nd Pillar. The current Proposal contains some relevant principles so that Member States have a toolbox. The magnitude and speed of mitigation will, however, depend on regional priorities in the implementation of the 2nd Pillar (Freibauer et al. 2012).

Based on the GHG-Europe results mitigation measures with high potential, low cost, and synergies with other environmental goals are highlighted in the following.

Drained organic soils are hotspots of greenhouse gas emissions. Key driver of the emissions is the drainage depth, which is related to land-use type. Developing options for rewetting and wet land-use systems on these relatively small areas must become a priority.

Forests have been a strong C sink over the last decades – first driven by management changes in existing forests and later by rapid growth of the post-war afforestations. Management will continue to exert a strong influence on the C sink but disturbances can override the management impact. It is therefore wise to invest in risk management and adaptation of forests to climate change.

Grasslands have been confirmed as a small net C sink in soil. Obviously, the soils are not yet saturated – or the concept of soil carbon saturation is to be questioned. GHG-Europe showed that soil can continuously sequester carbon at significant rates for more than a century. From a mitigation point of view, grazing is preferable to cutting. But the main challenge is to halt the conversion of permanent grassland to cropland to avoid substantial CO2 and N2O emissions from the loss of soil organic matter.

Croplands have the highest GHG intensity due to energy-intensive input and phases with bare soil. Improving nutrient use efficiency bears a significant mitigation potential and can also be economically attractive.

Developing continuous cover systems for cropland must become a priority, too. This includes more perennial crops, under- and cover crops. Continuous cover systems maximize carbon uptake by photosynthesis as they can operate over longer time spans than single crops. New cropping systems may help relax competing pressures on productive land by combining higher NPP with soil protection. Reduced bare fallow by catch crops, undercrops or crops with long growing season, or a higher share of perennial crops can have strong synergistic benefits for soil carbon sequestration, nitrogen recovery and climate change mitigation by albedo effects. Cover crops fit well in the incentive schemes under the Common Agricultural Policy. If more detailed research confirms the unexpected high albedo benefit (see below), cropland management offers an unexpected easy-to-implement, low-cost, high greenhouse gas mitigation potential.

Continuous cover cropping and a stronger role of inter- and undercrops also make maximum use of sunlight for GPP and NPP. They constitute an effective mechanism to increase biomass production per unit of cropland, which can either be used for raw materials, energy or feed, or be incorporated in the soil to sequester carbon. Continuous cover cropping has been overlooked so far as mitigation wedge, but is a relatively straightforward, no regret option with many environmental co-benefits. Research and innovation efforts would need to be considerably strengthened to move from the traditional European mono-cropping system to multi-cropping systems. Much practical expertise is available in organic farming and tropical farming systems.

Introducing cover crops can sequester carbon for decades. In a meta-study, time since introduction of cover crops in crop rotations was linearly correlated with change in soil organic carbon stocks with an annual change rate of 0.3±0.08 Mg C ha-1 yr-1 during the observed period of up to 54 years. Assuming that the observed linear SOC accumulation would not proceed infinitely, we modeled the average SOC stock change with the carbon turnover model RothC. The predicted new steady state was reached after 155 years of cover crop cultivation with a total mean SOC stock accumulation of 16.7±1.5 Mg C ha-1 for a soil depth of 22 cm. We estimated a potential global SOC sequestration of 0.12±0.03 Pg C yr-1, which would compensate for 8 % of the direct annual greenhouse gas emissions from agriculture (Poeplau and Don, submitted). The study confirms previously published C sequestration rates but shows as a new aspect that C sequestration will continue for a much longer period than expected.

Roots are more effective for C sequestration in soils than shoots, compost and manure are more effective than slurry. This result was achieved by testing responses of soil organic carbon stocks on different types of organic amendments from long-term experiments on 29 sites with 439 treatments. The type of organic fertilizers (farmyard manure, farmyard manure compost, pig slurry, cattle slurry, waste compost, sewage sludge) determines the soil organic carbon sequestration more than the amounts (Dechow et al. in prep.). Most soil models, however, do not differentiate between above-ground and below-ground carbon input. Roots and below-ground carbon input is most effective for C sequestration. There is an unexplored potential in deep rooting systems, which may also be more resilient to drought stress. Cover crops and continuous cover systems also produce more roots with a good potential for refilling the depleted soil carbon pool in croplands.

Land-use decisions have strong effects on land surface albedo. In particular, it makes a big difference whether soil is bare or covered. The GHG-Europe case study showed that the albedo effect of crops versus bare soil was stronger than the carbon effect in SW France. A first rough extrapolation of plot scale findings suggests that the albedo effect of including a systematic cover crop in crop rotations before summer crops in Europe would represent an equivalent of 30 million tons of carbon storage per year (Ceschia et al. in prep.). Albedo effects need further investigation but strengthen the arguments for continuous cover systems.

2.3.3 Bioenergy

Bioenergy is produced from residues, forest biomass or agro-biomass. The source of the material decides whether or not bioenergy is effective in reducing GHG emissions from the energy sector. Wood contributes the largest share of bioenergy. Wood harvest for energy has increased, both in quantitative terms and as the share of wood harvest. Generally, the GHG footprint of wood for bioenergy is comparatively low. Nevertheless, if harvested material is first used as material before a use for energy generation the GHG-efficiency per unit of harvested product and per hectare could be strongly enhanced. This calls for strong policies that favour cascade use of raw materials, including renewable sources.

Much of the political and financial support, however, has gone to agro-bioenergy as fuel or gas. Annuals require a significant amount of nitrogen and other fertilizers associated with a large GHG footprint from the energy intensive fertilizer production and N2O from fertilizer application. Stricter thresholds of biofuel sustainability targets as foreseen in EU policies from 2017 onwards may rule out some of the present key sources of bioenergy such as rapeseed for methyl ester and others. However, the current GHG calculations for biofuel sustainability are incomplete, e.g. regarding indirect N2O emissions and soil C loss on high organic carbon soils. Some GHG sources were underestimated, e.g. by unrealistic assumptions of fertilizer rates.

Perennials grown on agricultural land only have a share of 3% of the current European bioenergy production. Field data reviewed in GHG-Europe suggest that perennials emit 40% to >99% less N2O than conventional annual crops. This is a result of lower fertilizer requirements as well as a higher N-use efficiency, due to effective N-recycling (Don et al. 2012). A new model was developed to predict the suitability of European climate and soil regions for perennial energy crops such as Miscanthus x giganteus or short rotation coppice willow or poplar (Hastings et al. in prep.). The model predicted that if perennial crops were grown on existing arable land with a topsoil soil organic carbon stock of less than 100 tons ha-1 the soil carbon would be stable or increase. Growing perennials on land with a topsoil soil organic carbon stock above this threshold would result in a carbon loss, which is likely to occur under annual crops as well. This means that only non histosol cropland can be converted to growing perennial bioenergy crops to preserve or sequester soil organic carbon. The biofuel criteria already define that biofuels cannot be sourced from land with high biodiversity or high carbon stock. This finding underlines the importance to extend the criteria for biofuels to other bioenergy types. GHG efficiency targets for all bioenergy types would favour high effective options (perennials, low-input cultures), would rule out bioenergy production on high organic carbon soils and would trigger high-effective use chains (per hectare, per substituted energy). The proposal of the European Commission in COM(2014) 15 final (EU 2014) to phase out support for food-based bioenergy already moves into this direction.

Indirect land-use change induced by converting land to bioenergy production has been intensively discussed in the international context. But indirect land-use change also occurs nationally and regionally – a process currently unaccounted for. Nevertheless, scenario analyses surprisingly showed that indirect land-use change effects compensate only 20% of the net carbon and GHG savings, which is much less than anticipated.

2.3.4 Climate Policy

Baseline projections for LULUCF

Climate policy must develop a clear vision how drastic GHG emission reductions by 50 % or 80 % can be realized by the present and next generation of people. Agriculture and forestry are included in the European climate change mitigation targets under the Kyoto Protocol and the EU Regulation 525/2013 (EU 2013a). The remaining carbon sinks and sources are covered under the EU Decision 529/2013/EU (EU 2013b) in a qualitative way. Due to the high spatial variability and complexity, the LULUCF sector strongly depends on a robust scientific basis for decisions.

GHG-Europe has produced scenarios calibrated at past trends for a baseline of carbon sinks and sources until 2050. Results of the models applied in GHG-Europe cover measures in all land-use activities relevant to the Kyoto Protocol: afforestation/reforestation, deforestation, forest management, cropland management and grazing land management. The baseline projection for LULUCF for EU-28 extends from 2000 to 2050. In total the models expect a decrease of the land carbon sink by about 20% between 2010 and 2050. The model did not fit well the forest trends in the past as reported by the Member States. This is partly due to different system boundaries and included processes such as disturbance, but there is also high uncertainty in drivers. Driver uncertainty can be much larger as the model moves further into the future. This is mainly due to the uncertainty of economic projections that drive activities and markets in the LULUCF sector. Figure 11 disaggregates the results of the baseline projection for LULUCF for EU-28 by land-use activities. Deforestation emissions will slowly decrease until 2030. While emissions and removals from cropland and grassland management will stay relatively stable, the sink of managed forests is going to decline quickly (to about 50% in 2030 compared to 2010). The decline in CO2 removals from forest management is partly compensated by an increasing CO2 sink of new forests. However, in 2030 forest management will still be the dominating term in Europe's LULUCF carbon budget.

Indirect land-use changes do not compensate GHG savings by production shifts in European land-use GHG mitigation measures are often associated with a lower production per unit of land, or a shift in production, e.g. from food and feed to renewable products or bioenergy. At constant demand, the originally produced goods have to be produced elsewhere, which leads to intensification and indirect land-use change. These indirect effects compensate only 20% of net carbon and GHG savings achieved by afforestation and extensification or inclusion of biodiversity goals – much less than anticipated. This questions the arguments by European farmers that they have to produce food for the world because they claim to be more climate friendly. The beneficial effect of GHG mitigation measures in the land-use sector in Europe is not questioned by indirect land-use changes.

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