Greenhouse gas management in European land use systems

FP7 Project GHG-Europe
Grant agreement No 244122

Deliverable 4.1			
Title	Complete sectorial model evaluation using data collated from previous projects		
Delivery date from Annex I (project month)	12		
Actual delivery date	15/12/2010		
Lead participant	WP	Nature	Dissemination level
UNIABDN (5)	4	R	RE

Deliverable description

For the production of D4.1 sectoral models were evaluated against existing datasets from previous projects (e.g. CarboEurope, NitroEurope, CCTAME, CARBO-Extreme), and additional data, particularly from WP2, and site level data from WP3.

Sectoral model comparisons made on existing datasets were collated and accessed for completeness and a subset chosen for attribution experiments. The sites and model are listed in Tab. 4.1. The models were applied to those sites at which all necessary model input was available. As input requirements differ the choice of sites differed accordingly.

Table 1. List of models and data sets used for site-level evaluation

Model, responsible participant	**Ecosystem, Sites evaluated**
DNDC, UNIABDN	Arable: Oensingen, Aurade, Gebesee, Grignon, Klingenberg
DNDC, UNIABDN	Grassland: Oensingen,
MoBiLE-DNDC, UNIABDN	Arable: Grignon, Gebesee, Paulinenaue, Oensingen
MoBiLE-DNDC, UNIABDN	Grassland: Oensingen, Paulinenaue
ECOSSE, UNIABDN	Arable: Grignon,Gebesee, Paulinenaue
ECOSSE, UNIABDN	Grassland: Oensingen, Easterbush, Bugac
DailyDayCent, UNIABDN	Forest: Höglwald, Klausenleopoldsdorf, Soroe, Hyytiälä
DailyDayCent, UNIABDN	Arable: Grignon,Gebesee, Paulinenaue
DailyDayCent, UNIABDN	Grassland: Oensingen, Easterbush, Bugac
Yasso07 (EFICEN), SYKE	Forest: Pirkanmaa (Norway spruce)
PASIM, INRA	Grassland: Oensingen, Easterbush, Laqueuille

Model evaluation report

MoBiLE-DNDC model (Grote et al., 2010; Grote et al., 2011) was run for arable and grassland sites: Grignon, Gebesee, Oensingen (2 sites), Paulinenaue (3 sites) with input data on climate, soil properties and site management available from Nitroeurope IP project (http://www.nitroeurope.eu/). The model outputs were compared with experimental measurements of aboveground plant biomass and greenhouse gases emission as shown on Figures 1-5.

The model evaluation was completed with the help of following goodness of fit tests provided in MODEVAL package 2.0 (Smith et al., 1996): correlation coefficient (R2), Residual mean square error, RMSE, Mean difference, Lack of Fit (LOFIT) Model outputs were evaluated versus data on N_2O emission from soil, and ecosystem respiration and several examples are presented in tables (Tables 2-6). The model captures good seasonal and yearly trend, but overall success varied for different sites according to statistics (no site specific parameter fitting was done). Thus, the model matches N_2O data good for Gebesee, but underestimates the N_2O values for Oensingen, especially in the first year (missing the peak following massive manure application): R, mean difference and LOFIT are good; RMSE and relative error show bad statistics. The model also overestimates the Ecosystem respiration values for Oensingen: R, LOFIT are good; RMSE, mean difference and relative error showed bad statistics.

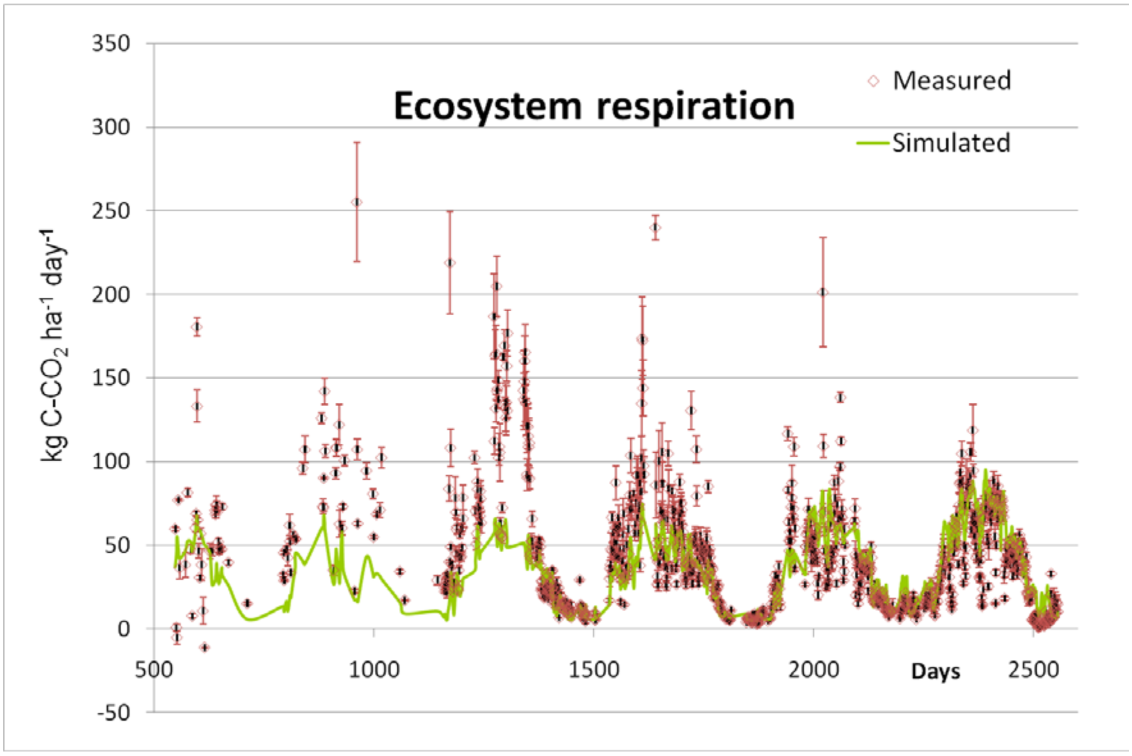


Figure 1: Ecosystem respiration simulated by Mobile-DNDC model for grassland site (Oensingen).

Table 2: Statistical evaluation of Mobile-DNDC output for ecosystem respiration simulated for grassland site (Oensingen).

	Statistics
r = Correlation Coeff.	0.60
Assuming no model parameters adjusted, (i.e.k=1), ...	
t = sqrt((n-2) r^2) / (1-r^2)	4.74
t-value at (P=0.05)	2.02
Significant association?	Yes - Good
RMSE = Root mean square error of model	66%
RMSE (95% Confidence Limit)	7%
Significant total error?	Yes - Bad
M = Mean Difference	7
t = Student's t of M	7.76
t-value (Critical at 2.5% - Two-tailed)	1.96
Significant bias?	Yes - Bad
E = Relative Error	13
E (95% Confidence Limit). = +/-	4
Significant bias?	Yes - Bad
LOFIT = Lack of Fit	20358344
F = MSLOFIT/MSE	0.06
F (Critical at 5%)	1.09
Significant error between simulated and measured values?	No - Good
ME = Maximum Error. Best = ABS(M)	113
RMSE * Obar/100 (average total error)	29
Number of Values	1080

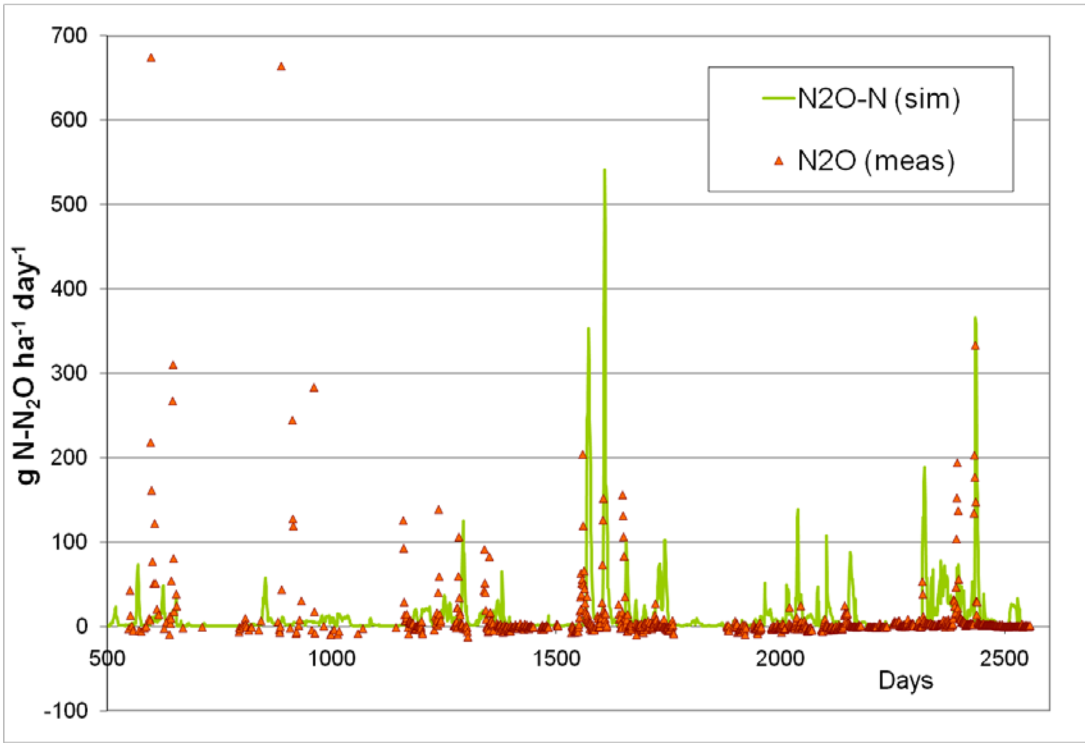


Figure 2: Ecosystem N_2O flux simulated by Mobile-DNDC model for grassland site (Oensingen).

Table 3: Sta
simulated fo

	Statistics
r = Correlation Coeff.	0.10
Assuming no model parameters adjusted, (i.e.k=1), ...	
t = sqrt((n-2) r^2) / (1-r^2)	3.17
t-value at (P=0.05)	1.96
Significant association?	Yes - Good
RMSE = Root mean square error of model	678%
RMSE (95% Confidence Limit)	73%
Significant total error?	Yes - Bad
M = Mean Difference	-11
t = Student's t of M	-5.68
t-value (Critical at 2.5% - Two-tailed)	1.96
Significant bias?	No - Good
E = Relative Error	-120
E (95% Confidence Limit). = +/-	17
Significant bias?	Yes - Bad
LOFIT = Lack of Fit	100672061
F = MSLOFIT/MSE	0.51
F (Critical at 5%)	1.09
Significant error between simulated and measured values?	No - Good
ME = Maximum Error. Best = ABS(M)	668
RMSE * Obar/100 (average total error)	63
Number of Values	1012

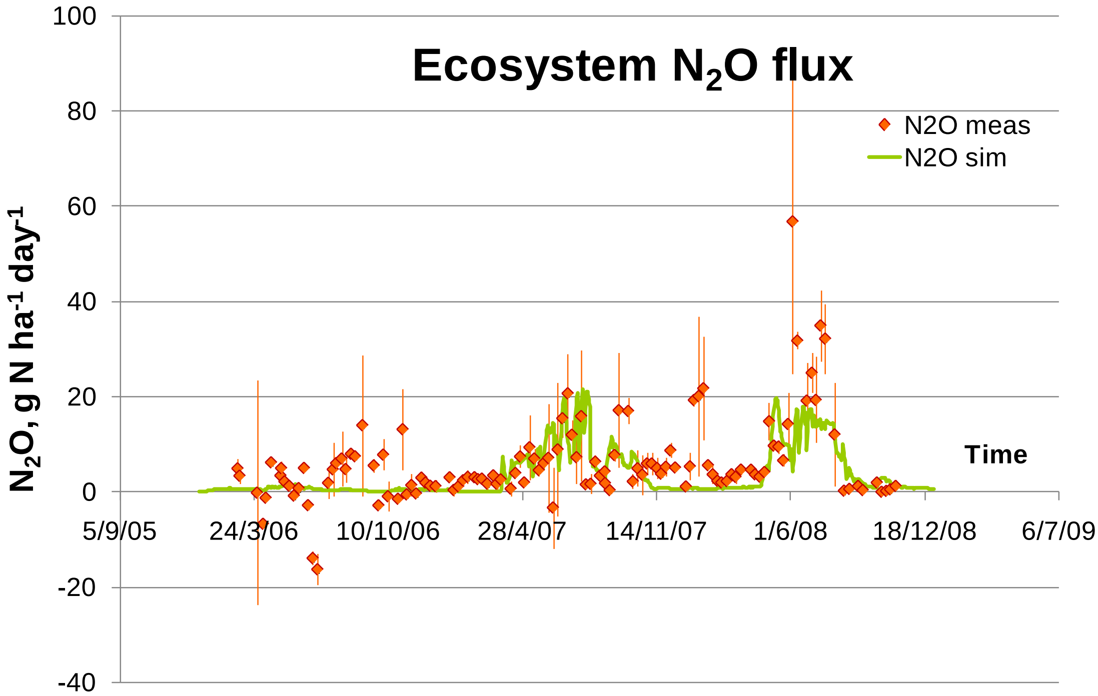


Figure 3: Ecosystem N_2O flux simulated by Mobile-DNDC model for arable site (Gebesee).

Table. 3. Statistical evaluation of Mobile-DNDC output for ecosystem N_2O flux simulated for arable site (Gebesee).

	Statistics
r = Correlation Coeff.	0.41
Assuming no model parameters adjusted, (i.e.k=1), ...	
t = sqrt((n-2) r^2) / (1-r^2)	4.91
t-value at (P=0.05)	2.01
Significant association?	Yes - Good
RMSE = Root mean square error of model	132%
RMSE (95% Confidence Limit)	677%
Significant total error?	No - Good
M = Mean Difference	2
t = Student's t of M	1.79
t-value (Critical at 2.5% - Two-tailed)	1.98
Significant bias?	No - Good
E = Relative Error	105
E (95% Confidence Limit). = +/-	1155
Significant bias?	No - Good
LOFIT = Lack of Fit	24041
F = MSLOFIT/MSE	0.00
F (Critical at 5%)	1.26
Significant error between simulated and measured values?	No - Good
ME = Maximum Error. Best = ABS(M)	17
RMSE * Obar/100 (average total error)	8
Number of Values	124

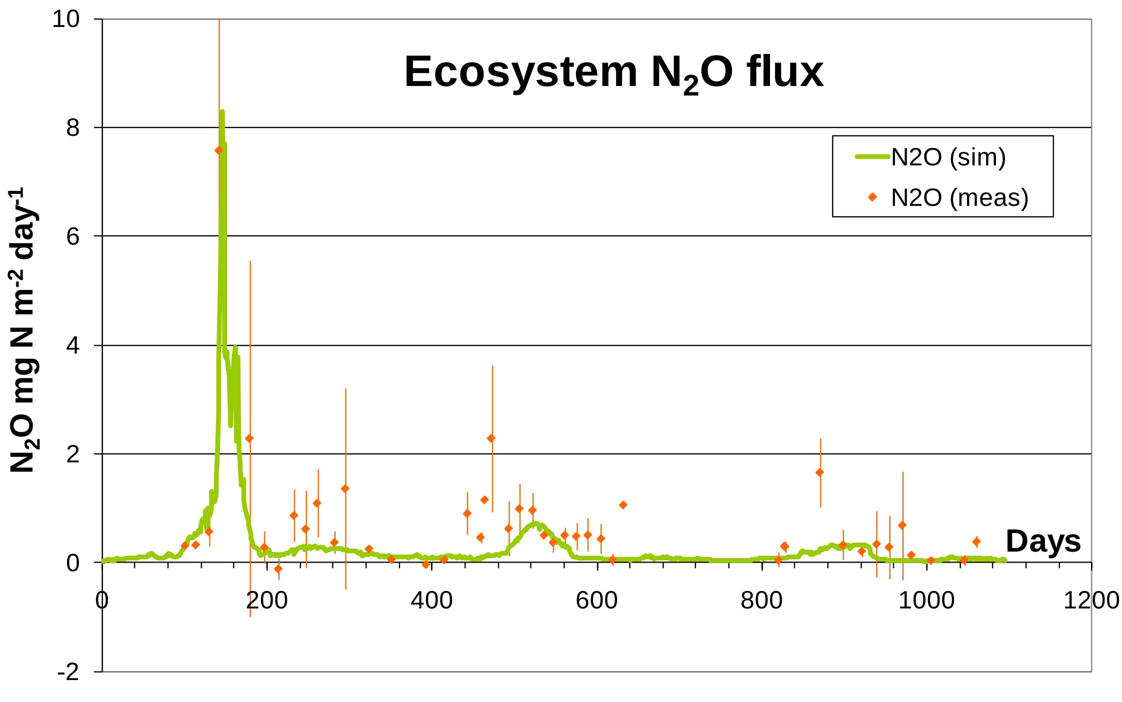


Figure 4: Ecosystem N_2O flux simulated by Mobile-DNDC model for arable site (Paulinenaue).

Table. 4. Statistical evaluation of Mobile-DNDC output for ecosystem N_2O flux simulated for arable site (Paulinenaue).

	Statistics
r = Correlation Coeff.	0.73
Assuming no model parameters adjusted, (i.e.k=1), ...	
t = sqrt((n-2) r^2) / (1-r^2)	7.00
t-value at (P=0.05)	2.02
Significant association?	Yes - Good
RMSE = Root mean square error of model	339%
RMSE (95% Confidence Limit)	1519%
Significant total error?	No - Good
M = Mean Difference	11
t = Student's t of M	1.60
t-value (Critical at 2.5% - Two-tailed)	2.02
Significant bias?	No - Good
E = Relative Error	75
E (95% Confidence Limit). = +/-	412
Significant bias?	No - Good
LOFIT = Lack of Fit	318419
F = MSLOFIT/MSE	0.02
F (Critical at 5%)	1.47
Significant error between simulated and measured values?	No - Good
ME = Maximum Error. Best = ABS(M)	321
RMSE * Obar/100 (average total error)	51
Number of Values	45

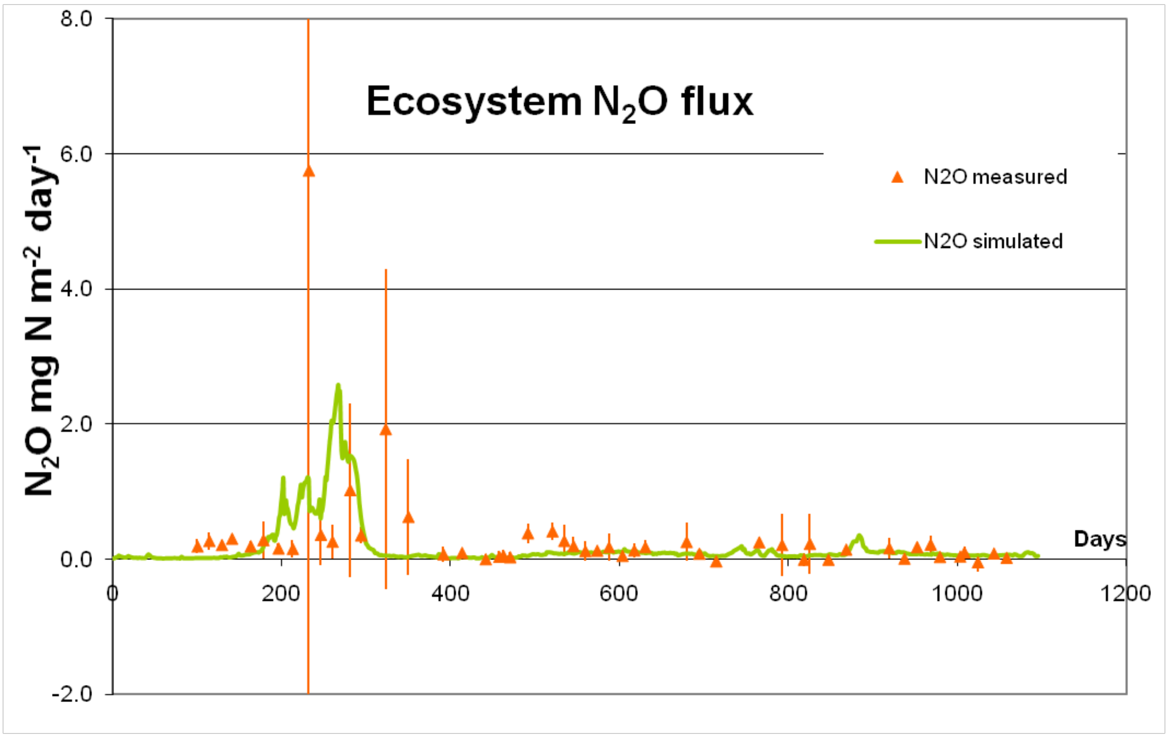


Figure 5: Ecosystem N_2O flux simulated by Mobile-DNDC model for grassland site (Paulinenaue).

Table 5: Statistical evaluation of Mobile-DNDC output for ecosystem N_2O flux simulated for grassland site (Paulinenaue).	
	Statistics
r = Correlation Coeff.	0.43
Assuming no model parameters adjusted, (i.e.k=1), ...	
t = sqrt((n-2) r^2) / (1-r^2)	3.28
t-value at (P=0.05)	2.01
Significant association?	Yes - Good
RMSE = Root mean square error of model	247%
RMSE (95% Confidence Limit)	3581%
Significant total error?	No - Good
M = Mean Difference	1
t = Student's t of M	1.08
t-value (Critical at 2.5% - Two-tailed)	2.01
Significant bias?	No - Good
E = Relative Error	25
E (95% Confidence Limit). = +/-	809
Significant bias?	No - Good
LOFIT = Lack of Fit	8638
F = MSLOFIT/MSE	0.01
F (Critical at 5%)	1.45
Significant error between simulated and measured values?	No - Good
ME = Maximum Error. Best = ABS(M)	45
RMSE * Obar/100 (average total error)	7
Number of Values	50

DAYCENT (the daily time-step version of the Century model) was used to simulate forest, arable and grassland ecosystems. DAYCENT is one of the most widely-used models in biogeochemical modelling (Parton et al., 2001).

Daycent simulates trace gas emissions and soil C and N dynamics on a daily time step, and plant parameters on a weekly time step. A major limitation of the model is its inability to simulate NEE and NPP at a daily time step. An improved version of DayCent (DailyDaycent) was therefore constructed. Whilst retaining most of the original parameters, those in the plant production sub-module were scaled down to work with a daily time step.

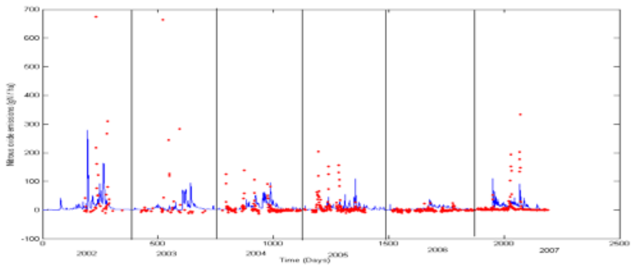
1) Grassland Ecosystem: DAYCENT model simulations were compared with measured data from the NEU Oensingen site. The simulations show that the Oensingen site is a net sink of atmospheric CO_2. The model is better at simulating grassland ecosystems subject to cutting and mixed fertiliser management. NEE, above ground biomass C and soil temperature were well simulated by the model. Inter-annual variability in N_2O emissions were captured well. The model was also applied to the EasterBush and Bugac sites. To handle grazing at EasterBush we developed a simple algorithm to account for biomass removal by cattle every day. Grazing is calculated by multiplying a specific grazing rate with the number of animals and average hours of intake. Example simulations are shown in the figure 6.

2) Forest ecosystem: Data from the Hoglwald site was available from 1994 onwards. DAYCENT successfully simulated leaf and above ground biomass. N gas emission (N_2O, NO, N_2) fluxes were simulated and tested at daily time scale against the measured data from 1994-2004. The model successfully simulated the annual fluxes of N gases, except in years with freeze/thaw events. Daily N_2O emissions were simulated reasonably during the growing season; the ratios between N_2O, N_2 and NO produced inside the soil layers were also reasonable. DailyDaycent was also used to simulate the Soroe, Hyytiälä and Klausenleopoldsdorf forest sites. The performance of the model in these sites will be presented in the final report.

DAYCENT model application at Oensingen grassland site

Goodness of fit for simulations to observed at Oensingen grassland site.

Observed and modelled net ecosystem productivity



Annual variations of simulated and observed N_2O emissions.

Figure 6: DAYCNT model application at Oensingen grassland site.

3) Arable Ecosystem: Simulations were undertaken for the NEU Grignon site from 2004-2008. The model was initialized using site history provided by the site managers. Comparison with observations revealed that DAYCENT simulated the above ground biomass of most of the crops satisfactorily, except for maize. The model captured the trend in N_2O emissions well, but failed to capture the magnitude. Simulations were also undertaken for the Gebesee and Paulinenaue sites. N_2O emissions were simulated successfully at Gebesee, however there were not enough measurements from Paulinenaue to compare observed and modelled results plausibly.

<u>ECOSSE/SUNDIAL</u> *Model development:*

ECOSSE/SUNDIAL uses a pool type approach, describing soil organic matter (SOM) as pools of inert organic matter, humus, biomass, resistant plant material and decomposable plant material. Material is exchanged between these pools according to first order rate equations, characterised by specific rate constants for each pool, and modified according to temperature, moisture and pH of the soil. The N content of the soil follows the decomposition of SOM, with a stable C:N ratio defined for each pool at a given pH, and N being either mineralised or immobilised to maintain that ratio. Mineral N may be lost from the soil by the processes of leaching, denitrification, volatilisation or crop offtake. C and N may be returned to the soil by plant inputs or organic amendments. The soil is divided into 5cm layers to facilitate the accurate simulation of these processes down the soil profile. Each of the processes is simulated using only simple equations driven by readily available inputs, allowing ECOSSE to be developed from a field based to a national scale tool, without high loss of accuracy (Smith *et al.*, 2010 a&b). To improve the performance of the N gas module some modifications have been made: (1) Parameters in the dentrificaiton and nitrificaiton module were optimized (2) flaws in the equations due to coding errors were rectified (3) some of the processes in the N gas module were revised (4) The linear function of nitrification response to N fertilizer has been modified to an exponential function (5) The denitrification response to moisture content has been revised.

ECOSSE/Sundial was applied to three NEU arable sites: Grignon, Gebesee and Paulinenaue, using data provided by the project partners and soil water contents and PET were estimated using pedotransfer functions and the Thornthwaite equation.

Simulation of soil NO_3^- at depths of 0-15 cm, 0-10 cm, and 0-30 cm for the Grignon, Gebesee, and Paulinenaue sites respectively, is displayed in Figure 7. Simulation of soil NH_4^+ for the same depths is displayed in Figure 8, with simulation of N_2O emissions shown in Figure 9. ECOSSE is successful at simulating both the magnitude and timing of NO_3^- (Figure 1), with an r^2 of 0.45 and RMSE of 76 % for the Grignon site. A slight error in the timing of simulation, however, indicates that simulation on a daily time-step could be improved. Figure 8 shows a high degree of association between observed and simulated values of NH_4^+, with r^2 values of 0.62 and 0.61 for the Gebesee and Grignon sites respectively. Simulation of the magnitude of NH_4^+ is however less good. With only 4 measurements provided for soil N contents at Paulinenaue, rigorous model assessment at this site cannot be undertaken. Although slight improvements to the model are required to improve the simulation of soil N and ammonium contents, Figure 9 indicates that ECOSSE is successful at simulating N_2O emissions, with RMSE values of 8 g N/ha/day and 16 g N/ha/day for the Gebesee and Grignon sites comparing favourably to those produced by other process-based models. Calculation of the standard error of the measured data at Grignon indicates that the total error in the simulation is less than the total error in the measurements at the 95 % confidence interval. The simulation using ECOSSE is thus as good a measure of the observed values as the replicate observations themselves. As with the simulation of soil N contents, the simulation of N_2O on a daily time-step could be improved, however a requirement to correctly simulate annual total emissions may be considered more important. The MS was prepared for publication based on the presented results (Bell et al., 2011).

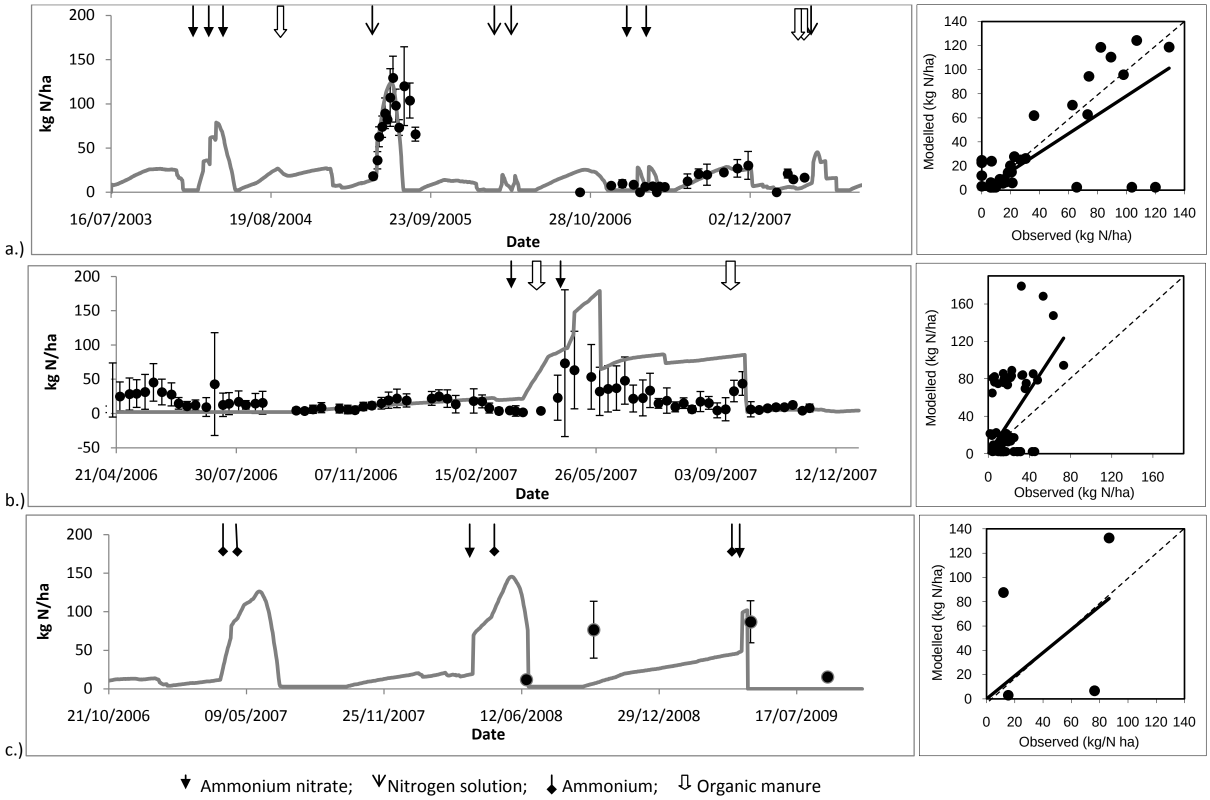


Figure 7: Measured and simulated NO_3^-N contents at a.) Grignon (0-15 cm); b.) Gebesee (0-10 cm); c.) Paulinenaue (0-30 cm). The solid grey line represents the simulated flux and the black circles represent the measured data. Error bars represent the standard deviation in the measured values.

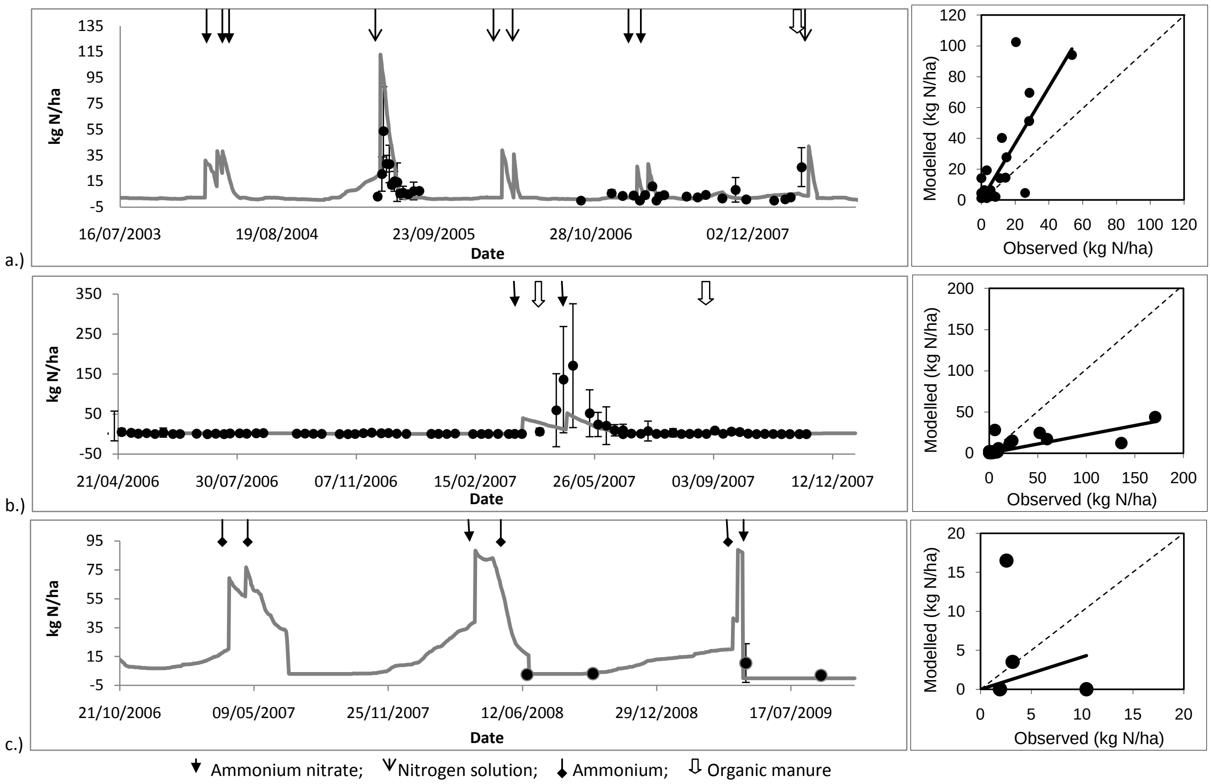


Figure 8: Measured and simulated NH_4^+ N contents at a.) Grignon (0-15cm); b.) Gebesee (0-10cm); c.) Paulinenaue (0-30cm).

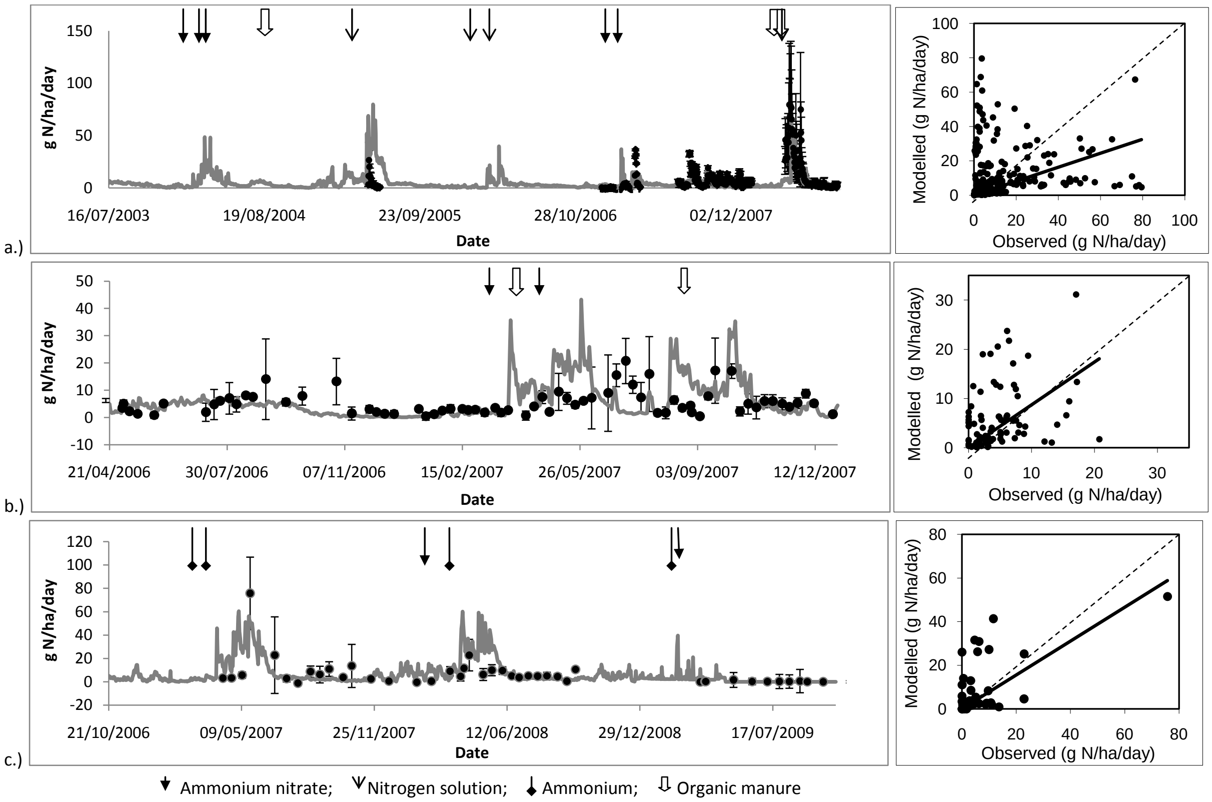


Figure 9: Measured and simulated N_2O fluxes from a.) Grignon; b.) Gebesee; c.) Paulinenaue.

The role of SYKE (participant 28) in the GHG-Europe project is to contribute to the soil carbon simulations using the EFISCEN-space model. SYKE provides the **Yasso07 soil carbon model** to be linked to the EFISCEN-space model, and participates in planning the simulations as well as analyzing and reporting the results.

SYKE has made sure that the Yasso07 soil carbon model is developed to be suitable for linking to the EFISCEN-space model by communicating with the other participants involved the EFISCEN-space calculations (Fig. 10). The Yasso07 model has been developed mainly in other research projects (www.environment.fi/syke/yasso). First, the structure of the Yasso07 model is now suitable for linking to the EFISCEN-space model and carrying out the simulations of the GHG-Europe project. Second, the computer code of the Yasso07 model has been made available for the programmers of the EFISCEN-space model. Third, the input information required by the Yasso07 model has been made available for the simulations using the EFISCEN-space model.

- Input
  - Carbon input to soil
    - Quantity
    - Chemical quality
    - Diameter of woody litter
  - Climate
    - Temperature
    - Precipitation
    - Annually or monthly
- Output
  - Variables
    - Soil carbon stock
    - Change in soil carbon stock,
    - Carbon flux out of soil
  - Mean estimate and uncertainty

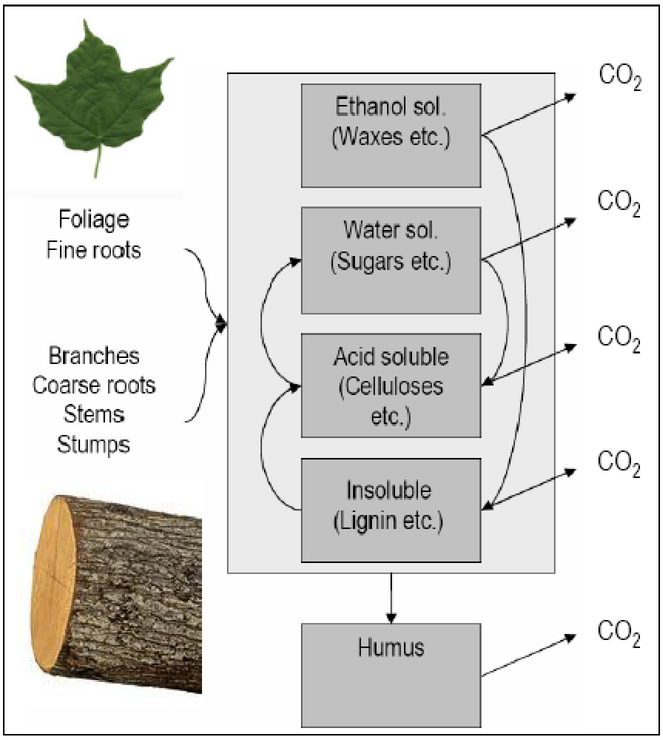


Figure 10: Flow chart of the Yasso07 soil carbon model and links of this model to the EFISCEN-space model in terms of input information received and results given.

Practices of forest management are important drivers of changes in the carbon balance of European forests. The ability of the Yasso07 soil carbon model to estimate the effects of a forest management practice with a growing importance, namely forest bioenergy production, was analyzed in a specific study (Repo et al. 2010) as a part of the GHG-Europe project.

Forest harvest residues are important raw materials for bioenergy in regions practicing forestry. Removing these residues from a harvest site reduces the carbon stock of the forest compared with conventional stem-only harvest because less litter in left on the site. The indirect carbon dioxide (CO_2) emission from producing bioenergy occur when carbon in the logging residues is emitted into the atmosphere at once through combustion, instead of being released little by little as a result of decomposition at the harvest sites.

The forest bioenergy study (1) introduced an approach to calculate this indirect emission from using logging residues for bioenergy production, and (2) estimated this emission at a typical target of harvest residue removal, i.e. boreal Norway spruce forest in Finland.

The removal of stumps caused a larger indirect emission per unit of energy produced than the removal of branches because of a lower decomposition rate of the stumps (Fig. 11). The indirect emission per unit of energy produced decreased with time since starting to collect the harvest residues as a result of decomposition at older harvest sites. During the 100 years of conducting this practice, the indirect emission from average-sized branches (diameter 2 cm) decreased from 340 to 70 kgCO_2 eq.MWh1 and that from stumps (diameter 26 cm) from 340 to 160 kgCO_2 q.MWh1. These emissions are an order of magnitude larger than the other emissions (collecting, transporting, etc.) from the bioenergy production chain. When the bioenergy production was started, the total emissions were comparable to fossil fuels. The practice had to be carried out for 22 (stumps) or four (branches) years until the total emissions dropped below the emissions of natural gas.

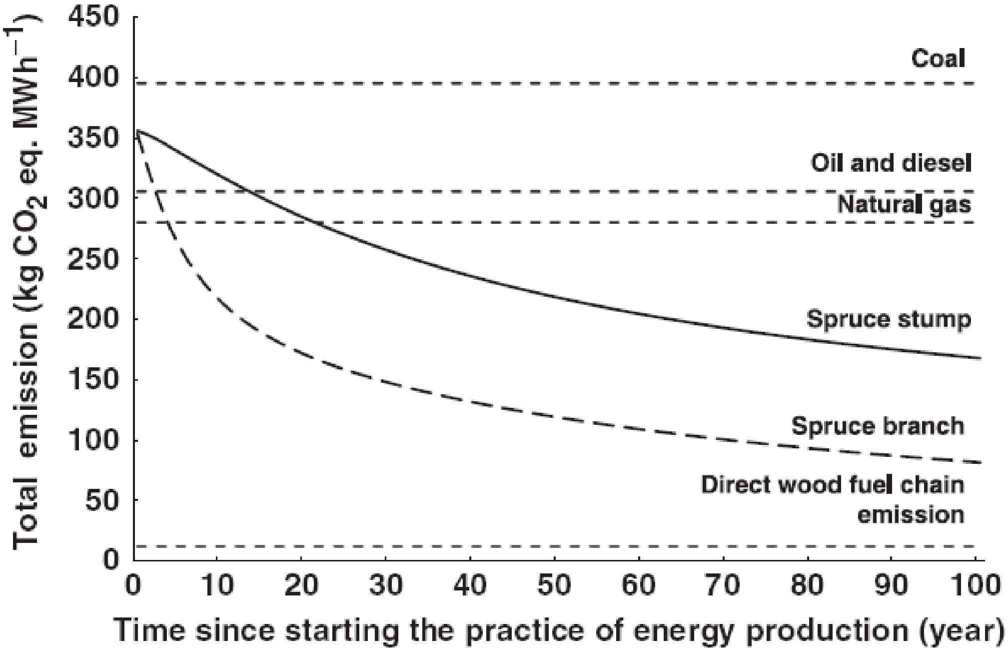


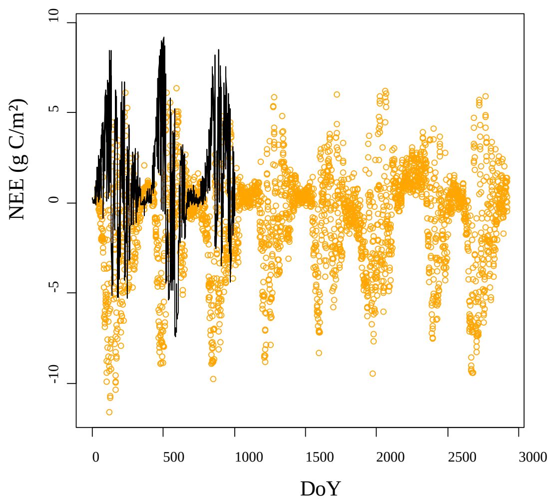
Figure 11: The total greenhouse gas emission per unit of energy produced from using Norway spruce branches (diameter 2 cm) or stumps (diameter 26 cm) for bioenergy over a 100-year period after starting this practice and the total emissions from various fossil fuels. The emission estimates of bioenergy production include both an indirect emission resulting from decreasing carbon stock and a direct wood fuel chain emission (equal to 12 kgCO_2) resulting from collecting, chipping and transporting the harvest residues, CH4 and N2O emissions from combusting the residues, fertilizing the forest to compensate for nutrient loss, and recycling of ash. The estimates of the fossil fuels represent entire fuel cycle emissions (Statistics Finland, 2006; Ecoinvent Centre, 2007).

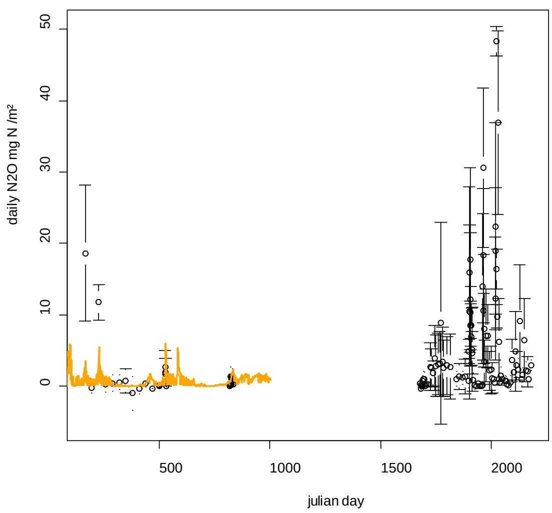
The results of this study emphasize the importance of accounting for land-use-related indirect emissions to correctly estimate the efficiency of bioenergy in reducing CO_2 emission into the atmosphere.

Europe's environmental news and information service (ENDS) published a piece of news referring to the results of the study on Feruary 2nd, 2011 (www.endseurope.com "Doubts over benefits of wood energy in Finland") and a information provider for the global forest products industry RISI on February 1st, 2011 (www.risiinfo.com "Finnish study finds wood energy undermines forest health"). The results received also considerable interest in Finnish national TV and radio as well as newspapers and magazines which published dozens of articles on the study.

PASIM (Pasture Simulation Model): https://www1.clermont.inra.fr/urep/modeles/pasim.htm, Riedo et al. (1998), Schmid et al. (2001), Vuichard et al. (2007) was evaluated using data from grassland sites (Oensingen, Easterbush, Laqueuille) of Nitroeurope IP. Most parameter values of the model were derived from the literature or from experimental data. For some key parameters the initial values thus obtained were adjusted to more realistically simulate the C and N turnover. The following model outputs were evaluated at daily resolution: ecosystem respiration (RECO), N_2O emission, NEE and GPP (Figs 12 - 14).

Satisfactory simulations of C and N components were observed. For N_2O, the annual mean and the fluctuations are often captured by the model, while individual peaks are not. At Laqueuille, dry soil conditions, which prevent soil from emitting N_2O are not interpreted by the model. Observed N_2O emissions are extremely variable, in space and time, which is reflected by high standard errors (as observed at Easter Bush). Improvements in the modelling are therefore required. A possible improvement would be considering dynamically SOM pools across soil layers. Indeed denitrification is proportional to SOM respiration. In order to get better SOM respiration profile, it will be necessary to precise SOM pools respiration into the different PASIM soil layers.





daily N2O mg N /m²
0
10
20
30
40
50
500
1000
1500
2000
julian day

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