Title: **Land Use and Carbon Mitigation in Europe: A Survey of the Potentials of Different Alternatives**

Short-title: Land Use and Carbon Mitigation in Europe

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Abstract

This paper surveys studies applied to Europe that analyse carbon emission mitigation alternatives involving the use of land. We analyse a variety of alternatives, that include land use changes, forest management and bioenergy production. Our aim is to approximate the aggregate amount of carbon offsets that can be achieved through these alternatives and to show to what extent the results of the different studies are compatible and take into account the fact that land is a finite resource. Finally, based on the surveyed studies, we estimate the potential contribution of these alternatives to the goals proposed by the European Union for the years 2020 and 2050.

Keywords: carbon, land use change, forest expansion, bioenergy.

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1. Introduction

Land use changes have significant impacts on the dynamics of terrestrial ecosystems and are the main factors influencing biodiversity on a global scale (Turner et al., 1995; Sala et al., 2000). Land use change (especially deforestation) has been historically responsible for a large part of the cumulative human-induced greenhouse gas (GHG) emissions (IPCC, 2007; Watson et al., 2000). Likewise, forest and agricultural lands may play a key role in the overall strategy for slowing the atmospheric accumulation of GHG.

The basic ways in which forest and agricultural lands can directly or indirectly contribute to GHG mitigation efforts are the conversion of non-forestland to forest, preserving and increasing carbon in existing forest and agricultural soils, growing biomass to substitute fossil-fuel based products and altering agricultural and forestry fossil fuel usage patterns (Richards et al., 2006).

Land use, land use change and forestry (LULUCF) alternatives are a fundamental part of the Kyoto Protocol and the Marrakesh Accords (UNFCCC, 1998, 2001). Forest, cropland or grazing land management as well as afforestation, reforestation or revegetation are all alternatives that can be used to achieve the target that each developed country has under the Kyoto Protocol. In addition, growing biomass and recovering forestry or agriculture residuals have emerged as promising alternatives for the production of renewable energy (Paustian et al., 2006, Vries et al. 2007) and can also be used to reach the Kyoto target. Thus, there are a number of available options for carbon mitigation that imply the use of land. However, since the agriculture and forestry sectors are linked through a single land supply, the potential of one land use practice is not independent of the level of other land-based GHG mitigation alternatives (Antle and McCarl, 2002; Schneider et al, 2007). Bioenergy, biomaterials, afforestation and food production should ideally be studied jointly because they compete for scarce land resources (Gielen et al., 2003). Unfortunately, as we will show in the survey below, most studies analyse certain land-based carbon mitigation options without allowing for a combination of competing alternatives. Nevertheless, the main objective of this study is to provide an overview, based on results offered in recent literature, of the carbon sequestration and mitigation that could be achieved through the different alternatives involving land use in Europe.

The rest of the survey is organized as follows. Section two provides an overview of general approaches used for estimating carbon sequestration or biomass energy potentials. This is followed, in section three, with the survey of studies focused on carbon sequestration practices and then moves on to studies focused on bioenergy production. Implications of these practices on the overall land budget available are analysed in the third part of section three. Section four examines the likely contribution of land-based GHG mitigation strategies to the goals agreed by the Council of the European Union for 2020 and 2050. Section five concludes.

2. Land-based carbon mitigation approaches

General approaches used to estimate the potential of carbon sequestration practices and costs are the bottom-up engineering oriented analysis, the sector optimization models and the econometric analysis of revealed preferences of landowners (Richards and Stokes, 2004). A bottom-up approach can rely on highly detailed databases but this technical orientation often imposes a restriction on estimates at the local levels, since they do not generally account for how one market will adjust to changes deriving from a carbon sequestration program. Such feedbacks are predicted by sectoral (e.g. Alig et al., 1997, Sohngen et al., 1999) and general equilibrium approaches (e.g. Burniaux and Lee,

2003) that account for the behavioural response to broad GHG emission abatement policy designs. Computable general equilibrium models analyse the global economy and are built top-down from the world level to regional or sub-regional levels, guaranteeing the market closure. Both sector optimization and econometric models could have some elements of top-down models when they endogenize relevant elements such as prices or land owner decisions and consider the effect of the carbon sequestration project on some sectors or on the whole economic system (van Kooten and Sohngen, 2007).

Outcomes from the agriculture and forestry sectors are strongly dependent on site-specific environmental conditions. Thus recent developments integrate methodologies that couple econometric-process simulation with environmental models and/or agricultural sector models (e.g. Antle et al., 2002; Gillig et al., 2004). Another group of integrated models estimates carbon sequestration potential by linking economic optimization models with integrated climate assessment models for evaluating and allocating land resources (Klijn et al. 2005; Strengers et al., 2006).

Additionally, bioenergy and carbon sequestration potentials could be addressed focusing principally on the demand (demand-driven) or supply (resources-focused) sides (Berndes et al., 2003). The demand-driven approach analyses the competitiveness of biomass-based energy [or carbon sequestration] to meet exogenous climate mitigation goals. Population growth, economic and technological development assumptions are the main demand drivers, whilst resources-focused approaches evaluate the possibilities of utilising the resources base for climate mitigation purposes, considering the competition between different uses of resources. However, demand-driven assessments commonly include considerations on resources supply by reference to other studies (Berndes et al., 2003).

3. Land use and GHG mitigation potential in Europe

Studies analysing the role of terrestrial ecosystems in the global carbon balance are relatively numerous (e.g. Sands and Leimbach, 2003; Sohngen and Mendelsohn, 2003; Strengers et al., 2006; Tavoni et al., 2007). However, the different methods hamper any comparison (Richards and Stokes, 2004; van Kooten and Sohngen, 2007). The same is true for studies applying to Europe, although they are less numerous. The potential contribution of biomass to energy supply at global and regional levels has also been widely analysed (see Berndes et al. (2003) for a survey on this issue). Once again, different methodological approaches and assumptions make the comparison far from obvious.

The potential of agricultural and forest land-based carbon abatement in Europe depends primarily on judgements about the areas that can be converted from agriculture to forest or energy crops. About 84% (412.6 Mha) of the total land area in Europe and 88% (339.8 Mha) in the EU-25 are classified as 'useable land' (forest and agricultural lands), i.e. it can potentially be used for GHG emission abatement practices (Table 1). How much will eventually be used depends on relative costs and climate, energy, food and rural policies.

[Table 1]

3.1. Potential carbon sequestration in European agriculture and forest lands

Table 2 summarises the main characteristics of the studies that deal with the forest expansion and bioenergy crops climate change mitigation potential in Europe, based on their geographical scope, time horizon, predicted land resources for implementing different practices, analysed scenarios, modelling framework and approach.

[Table 2]

3.1.1. Carbon sequestration from expanding the forest area

First we analyse studies that address the conversion of agricultural land to forest, by coupling economic optimization models and global environmental integrated assessment models (Klijn et al. 2005; Strengers et al., 2006). We then survey studies that analyse carbon sequestration in land and energy sectors, by linking forest sector optimization models with integrated climate-economy models (Sohngen and Mendelsohn, 2003; Tavoni et al. 2007).

Strengers et al. (2006) and Klijn et al. (2005) analyse the potential conversion of agricultural land to forest, under different explorative scenarios built upon IPCC/SRES scenarios (see Strengers et al., 2004 and Klijn et al., 2005). Strengers et al. estimate the total abandoned agricultural area that can be used for 'carbon plantations' and the marginal abatement curves (MAC) of mitigating CO_2 through this practice in 17 world regions, including Europe (OECD and Eastern Europe), based on the land-use scenarios of the IMAGE 2.2 model (IMAGE team, 2001). These MACs are analysed as part of a multi-gas abatement strategy and used directly as input in the FAIR model, along with MACs from the energy system and non-CO_2 GHGs. Klijn et al. analyse the carbon sequestration regimes in different land use scenarios derived from a land use allocation model (CLUE) in the EU-25, within the framework of a scenario study on Europe's rural areas for the period 2000 – 2030.

On the other hand, both Sohngen and Mendelsohn (2003, S&M) and Tavoni et al. (2007) analyse the potential role of the forestry sector in global GHG abatement efforts. These models combine a global forestry sector model (Sohngen et al. 1999) with two integrated climate-economy models, DICE (Nordhaus and Boyer, 2000) and

WITCH (Bosetti et al. 2006), respectively. S&M's optimal control model is run over nine regions, including Europe (without former Soviet Union (FSU) countries, since FSU is analysed as a separate region). The global forestry model solves optimal harvest ages, optimal timberland management intensity and the optimal area of land to be maintained in forests in response to carbon prices under expected (S&M Min) and uncertain (S&M Max) climate change damage scenarios. Tavoni et al. (2007) develop an intertemporal optimization model of carbon abatement in the energy and land use sectors to analyse the potential role that forests may play in a climate stabilization policy (550 ppm of CO_2 by 2100). This model is applied to 12 regions, which include two regions for Europe: Old Europe (Western Europe) and New Europe (that considers the new EU-10 Member States).

Since the geographical scope of Europe differs between the studies considered (Table 3), we have rescaled all of them to a common territorial basis (the EU-25). We do this simply by dividing the figure estimated by a given study of the 'useable agricultural land' of the area considered by the 'useable agricultural land' of the EU-25 (Table 1) and then multiplying this ratio (correction factor) by the estimated land resources or carbon mitigation potential offered by the study. We acknowledge that the outcome can only be seen as a rough approximation but we think it has some interest (in any case, this is only done for the figures since the results in Table 3 refer to the original areas analysed by the different studies).

Figure 1 shows the land resources that would be available for afforestation and reforestation (AR) and other practices that imply an expansion of the forest area in the EU-25 over the next 90 years. Klijn et al. (2005) estimate a cumulative change in EU-25 forest. According to this study, Global Cooperation (B1) and Regional Communities (B2) scenarios would result in a net increase in forest area of a total of 14 Mha and almost 11 Mha by 2030, respectively. The Global Economy (A1) scenario would lead to a net increase in forest area of 6.7 Mha in this period, whilst the Continental Markets (A2) scenario would imply a deforestation of more than 5 million ha in total by 2020.

[Figure 1]

The main results of Strengers et al. (2006) are presented for the B2 scenario (Regional Communities). In this scenario, the conversion of abandoned agricultural land to forest in Europe would potentially reach a total of 13 Mha by 2025 and a total of nearly 20 Mha by 2100, depending upon carbon prices. Sohngen and Mendelsohn (2003) predict substantial changes in European forest cover in the period 2010 – 2100: 8.5 – 25.9 Mha in the expected climate change damage scenario (S&M Min) and 23 – 66 Mha in the uncertain scenario (S&M Max). Finally, Tavoni et al. (2007) estimate a cumulative change in European forest area of nearly 14 Mha by 2022 and 63 Mha by 2092.

More conservative estimates (Strengers et al., 2006 and S&M Min), after rescaling the results to the EU-25 (Table 3), indicate that changes in EU-25 forest cover would fluctuate between 17 and 23 Mha by 2100 (Figure 1). These latter figures imply that 10% to 13% of agricultural land could be converted to forest in the EU-25 by 2100. Nonetheless, forest expansion does not necessarily address just the conversion of agricultural land but also other wooded lands, such as those with low tree canopy cover.

[Table 3]

According to S&M Max and Tavoni et al. (2007), the European forest area increases to 30% (Table 1). In several countries (e.g. Finland, Sweden, Austria) forest already covers more than 50% of the land (United Nations, 2000) so further increases are less likely. However, in countries with a low forest cover (e.g. Ireland, Denmark, Poland and Mediterranean countries), an increase in the forested area is already on the political agenda (Bosello et al., 2007).

Regarding the carbon sequestration potential, Klijn et al. (2005) estimate that in the EU-25 the biological potential related to LULUCF would vary from 85 Mt C y^{-1} to 108 Mt C y^{-1} by 2030, whilst what can be achieved with AR and considering that forestry contribution is limited to some 10% is around 24 Mt C y^{-1} by 2030. Strengers et al. (2006) estimate that carbon plantation in Europe can supply up to 41 Mt C y^{-1} by 2025 at a cost of less than 350 \$ tC^{-1}, whereas by 2100 more than 160 Mt C y^{-1} can be obtained at a cost of less than 600 \$ tC^{-1}. Tavoni et al. (2007) estimate that in Europe 45 Mt C y^{-1} could be sequestered by 2022 at a carbon price of 57 \$ tC^{-1} and 151 Mt C y^{-1} by 2092 at a carbon price of 271 \$ tC^{-1}. Sohngen and Mendelsohn (2003) do not provide annual figures for carbon sequestration, giving instead cumulative carbon sequestration at a given year and carbon price (Table 2). In the case of S&M's Min scenario, this cumulative carbon sequestration amounts to 200 Mt C by 2010 and 1,700 Mt C by 2100. For the S&M's Max scenario, the cumulative carbon sequestration is 300 Mt C for 2010 and 4,300 Mt C for 2100. We estimate that the average annual carbon sequestration in the period 2050 – 2100 is close to 20 Mt C y^{-1} in the expected scenario (S&M Min) and 60 Mt C y^{-1} in the uncertain scenario (S&M Max). The carbon prices with carbon sequestration of Sohngen and Mendelsohn (2003) are lower than those of Tavoni et al. (2007). Differences in the results of both studies seem to be related to the analysed scenarios which, in the case of Tavoni et al. (2007), refer to the efforts needed to meet a strong climate stabilization policy. Taken together, the studies reported predict that from 20 to 150 Mt C y^{-1} can be sequestered by increasing the EU-25 forest area by 2100, denoting great variability (Figure 2).

[Figure 2]

3.1.2. Agricultural soil carbon sequestration

Management practices to sequester carbon in European agricultural soils were examined by Smith et al. (2000) and Freibauer et al. (2004), including organic amendments (animal manure, sewage sludge), no-tillage or reduced tillage systems and other options. Considering constraints on available land, biological resources and land-suitability, Freibauer et al. (2004) suggest that agricultural soils in the EU-15 can sequester up to 16 – 19 Mt C y^{-1} during the first Kyoto commitment period (2008–2012), while Smith (2004) suggests a figure of 46 Mt C y^{-1} for continental Europe. Nevertheless, it is important to highlight the fact that these studies lack a proper economic analysis of the consequences of these practices.

The main soil carbon sequestration potential (excluding forest plantations and bioenergy crops) is obtained by reduced tillage systems. Smith et al. (2000) suggest that no-tillage systems could be implemented in 86% of European arable lands, with a total carbon sequestration potential of 40.4 Mt C y^{-1} over a period of 50 to 100 years. It is estimated that in the EU-15 63 Mha could be put into no-tillage farming systems, with a total carbon soil sequestration potential of 24 Mt C y^{-1} (Freibauer et al., 2004).

There are a number of other alternatives in the agricultural sector that could mitigate net carbon emissions; however, as they do not necessarily imply changes in land use but in the way agricultural production is carried out, we have decided to keep them out of this survey (see, however, De Cara and Javet (2001) and Perez et al. (2003)).

3.2. Potential carbon offsets from bioenergy crops in Europe

The land area potentially available in Europe for bioenergy crops has been estimated in a number of studies (see Table 2 and Figures 3 and 4). Since differences in the geographical scope of Europe once again hinder the comparison, we apply the correction factors described above to yield figures for the EU-25 (Table 4). Figure 3 shows the estimated land demand for bioenergy crops/plantations for the period 2000 – 2100 in the EU-25.

[Figure 3]

The European Environmental Agency (EEA, 2006a) estimates that, after setting aside 30% of arable land for environmentally compatible farming systems (i.e. organic farming), maintaining extensively cultivated agricultural land as grasslands, olive groves and meadows, and setting aside 3% of intensively used farmland for natural conservation proposes, the land available for bioenergy crops by 2030 will be near to 7 Mha in the EU-14 and 19 Mha in the EU-22. These estimates are derived from the CAPSIM model, which is a partial equilibrium model designed to analyse economic development in the EU Member States.

Kavalov (2004) estimates the land resources required in the EU-25 to meet the transport biofuel targets defined by Directive 2003/30/EC. This author estimates that using the available technologies (based on bioethanol and biodiesel), the 2% biofuel market share target in 2005 would need between 5% and 9% of the EU-25 arable land (4 – 8 Mha, according to this author's available arable land figures) to be used for growing bioenergy crops. Meeting the 5.75% transport biofuel target for 2010 will most probably require significant changes in the agricultural production patterns in the EU, due to the need for a much larger area – between 14% and more than 27% of the EU-25 arable land (11 – 22 Mha). This latter area could fall to 8% – 9% of the EU-25 arable land if bioethanol is the only fuel used, with this share being similar to the EU-25 set aside land (Kavalov, 2004).

Ericsson and Nilsson (2006), using a resource-focused approach, estimate that in the EU-27 (excluding Cyprus and Malta) the available surface for energy crops in the short term (10 – 20 y) will be near to 11.6 Mha, whilst in the medium term (20 – 40 y) it will be near to 29 Mha. According to the B1 and B2 explorative scenarios of the IMAGE 2.2 model (IMAGE team, 2001), from 12.8 to 15.2 Mha could be used for growing biomass for energy in OECD Europe by 2050. Leemans et al., (1996), who develop a bottom-up approach implemented within the land use and energy models of the IMAGE 2.1 model, predict that in the LESS BI scenario this area would amount to 19 Mha in OECD Europe and 9 Mha in Eastern Europe by 2050. Smeets et al. (2007), using a bottom-up approach, estimate that by 2050 in both Western and Eastern Europe from 16 to 38 Mha would be available for biomass crops considering mixed (intensive and extensive) animal production systems, whereas in landless animal production systems (industrial farming systems) this figure could be more than 100 Mha.

Earlier estimates suggested relevant amounts of agricultural land (surplus) that could be used for bioenergy crops, e.g. 41 Mha in Western Europe by 2050 (Hall and House, 1995). Faaij (2006), based on the estimated surplus land in the EU-12 of an older study (WRR, 1992) – from 50 to 100 Mha in a period of 20 to 25 years, estimates that the bioenergy crops contribution might range from 20% to 40% of the total primary energy use of the EU-12 at that time. A more conservative earlier estimate suggested that from 15 to 20 Mha would be available in Western Europe for growing bioenergy crops in the period 2000 – 2010 but the land base required for satisfying energy demands at that time represents 63% – 68% of the total Western Europe land area (Scurlock et al., 1993). Land constraint in EU is apparently not significant in itself, due to the predicted agricultural land surplus (Rounsevell et al., 2005). However, when maintaining extensively cultivated agricultural lands or extensive livestock farming systems is a policy goal, the available land for bioenergy crops would be smaller than anticipated (e.g. EEA, 2006a; Smeets et al., 2007).

A number of studies (EEA, 2006a; Ericsson and Nilsson, 2006; Hall and House, 1995; Kavalov, 2004; Vries et al., 2007[1]) offer estimates of the potential energy that could be derived from using bioenergy crops for liquid biofuels or electricity but none of them analyses the potential GHG emissions mitigation that can be derived from fossil fuel substitution (see Table 2). To overcome this limitation, we have estimated the carbon mitigation potential considering the carbon mitigation factors for different bioenergy sources given by Sims et al. (2006: 2057) and assuming the theoretical distribution of land amongst different bioenergy crops (i.e. short-rotation coppices, crops for ligno-cellulosic ethanol, crops for biogas, etc) assessed by the EEA (2006a: 26) in the EU-22 by 2030, except in the cases of Kavalov (2004), which estimates are based on crops for bioethanol and biodiesel, and Ericsson and Nilsson (2006), which estimates are based on short rotation plantations. These figures were then rescaled to a common EU-25 basis (Table 4). It is worth noting that real carbon mitigation related to bioenergy crops should also consider other non-CO_2 emissions (CH_4 and N_2O, mainly) for growing biomass, in order to estimate their effective GHG offset potential. In addition, some studies (Leemans et al., 1996; Strengers et al., 2004) do not provide simultaneously data of the land demand for bioenergy crops and the resulting carbon or energy offsets (at least for Europe) and could therefore not be included in Figure 4.

[Figure 4]

On the basis of Kavalov (2004), we estimate that meeting the EU Directive 2003/30/EC target for increasing the market share of biofuels for transportation could generate a carbon mitigation potential ranging from 19 to 59 Mt C y^{-1} in the period 2005-2010. In the medium and long terms, considering the most conservative estimates of energy yields and bioenergy crop areas (EEA, 2006a; Ericsson and Nilsson, 2006; Vries et al., 2007), we estimate that in the EU-25 these crops could generate near to 100 – 130 Mt C y^{-1} of carbon offsets in 2030 (and 200 Mt C y^{-1} in 2050). Some estimates on energy yield from bioenergy crops (Hall and House, 1995) indicate that this potential could be notably higher. Thus, the uncertainty surrounding the carbon mitigation potential of bioenergy crops in Europe is huge and the results presented should be considered as a rough approximation.

3.3. Combined land use scenarios in the EU-25

Figure 5 shows the mean percentage of agricultural and useful land that could be potentially diverted to forest or devoted to reduced or no-tillage farming systems and bioenergy crops in respect of the current agricultural land in the EU-25 by 2020 and 2050. It is estimated[2] that 9.3% (±4.1%) and 20.1% (±9.0%) of EU-25 agricultural land could be used for growing bioenergy crops between 2020 and 2050, respectively, whilst 6.8% (±3.0%) to 15.4% (±10.1%) in the case of forest expansion address only agricultural lands. In any case, both forest expansion and bioenergy crops could demand 4.9% (±2.2%) of useful land resources by 2020 and 10.6% (±4.8%) by 2050.

[Figure 5]

The main constraint is that these estimations come from different sources, so adding them up is a risky exercise. Most studies analyse some land-based GHG mitigation options but not all the competing options. In any case, Smith et al. (1997) suggest that 20% of the agricultural land is the maximum available for afforestation in Europe. Although the figures for 2020 fall into this margin, the aggregated land resources demand for new forest and bioenergy crops by 2050 may exceed the available land at that time. Yet, it is predicted that agricultural land (grass and crop lands) will anyway undergo a large decline in Europe – from the current 40% joint share of grass and crop lands to a 30% – 37% share by 2020 and a 20% – 32% share by 2050 (Rounsevell et al., 2005).

Furthermore, non-tillage or reduced tillage systems (ignoring economic restrictions) could potentially be implemented in a large part of European arable lands: up to 86% according to Smith et al. (2000). Assuming that this practice were to be widely adopted by 2100, we estimate that from 17.7 to 44.2 Mha of arable lands could be put under no-tillage systems in the period 2020 – 2050. This represents a share of 9.9% – 24.7% of current EU-25 agricultural land (Figure 5).

3.4. Contribution of land-based carbon offsets under hypothetical post-2012 agreements in Europe

There is a considerable potential for sequestering carbon or mitigating carbon emissions in European agricultural and forest lands but many of the Table 2 and Figures 2 and 4 land-based carbon offsets are estimated for the medium (20 y) or long (>50 y) terms. Thus, for the first Kyoto Protocol commitment period (2008 – 2010), the overall contribution of LULUCF activities is predicted to be relatively small. On the basis of ongoing activities, this contribution is estimated to achieve roughly 10% of the EU-15 GHG reduction target (COM, 2006).

Subsequent to the Kyoto commitment period, the Council of the European Union has recently agreed upon an independent commitment to achieve at least a 20% reduction in greenhouse gas emissions by 2020 compared to 1990 (CEU, 2007). It has also stated that “the European Council endorses an EU objective of a 30% reduction in greenhouse gas emissions by 2020 compared to 1990 as its contribution to a global and comprehensive agreement for the period beyond 2012, provided that other developed countries commit themselves to comparable emission reductions and economically more advanced developing countries to contributing adequately according to their responsibilities and respective capabilities" (CEU, 2007: 12).

These targets for 2020 are estimated to imply in the EU-25 a reduction[3] of 351.8 Mt Ceq y^{-1} (20%) and 498.4 Mt Ceq y^{-1} (30%). The potential carbon offsets from forest expansion average 43.6 Mt C y^{-1} (±33.8 Mt C y^{-1}) in the EU-25 by 2020. Concurrently, bioenergy crops could further contribute to the target with 86.9 Mt C y^{-1} (±39.3 Mt C y^{-1}). In the case of a wider adoption of no-tillage systems in the EU-25 (see sub-section 2.3), by 2020 near to 18 Mha could be under this agricultural management system. Freibauer et al. (2004) suggest that this practice can potentially add 0.3±0.1 t C ha^{-1} y^{-1}, contributing 5.3 Mt C y^{-1} (± 2.3 Mt C y^{-1}). If we assume that these potentials are realizable and that we can add them up, land-based carbon mitigation practices could be responsible for 39% of the 20% GHG emission reduction target (Figure 6). Under a more stringent global climate policy (30% GHG emission reduction target), the combination of the alternatives discussed above could contribute 27% of this policy objective.

[Figure 6]

Figure 6 also shows the parts of the 2050 targets that could be covered. These 2050 targets would imply a GHG emission reduction in the EU-25 of 982.2 Mt Ceq y^{-1} (60%) and 1,275.4 Mt Ceq y^{-1} (80%). The mean carbon mitigation potential through forest expansion that could potentially be realized by 2050 amounts to 57.0 Mt C y^{-1} (±51.3 Mt C y^{-1}) in the EU-25. In addition, mean bioenergy carbon mitigation totals 231.4 Mt C y^{-1} (±79.4 Mt C y^{-1}) with 13.3 Mt C y^{-1} (±5.8 Mt C y^{-1}) for non-tillage farming systems. Together, the overall contribution of these land-based carbon mitigation options could be about 31% of the 60% emission reduction target, or 24% in the case of the 80% emission reduction target (Figure 6). The mean aggregated carbon offsets from forest cover expansion and fossil fuel offsets fit into the range of the realistic carbon mitigation potential (250 – 400 Mt C y^{-1}) estimated by Canell (2003) for the EU-15 over the next 50 to 100 years but is higher than the conservative potential that the same author estimates could be achievable when historic constraints on land use change persist (120 – 250 Mt C y^{-1}).

The variability in the predictions of the carbon mitigation potential of forest expansion and bioenergy crops is high; thus, the uncertainty surrounding the potential contribution of land-based practices to the EU climate stabilization goals is large (especially for 2050). In any case, even using only the minimum values given by the different studies, land-based carbon mitigation alternatives may contribute about 15% of the 20% target by 2020 (11% of the 30% target).

A full carbon cost supply curve for all the competing land-based GHG mitigation alternatives in Europe is not available. There are, however, estimates of carbon cost supply curves for carbon plantations (Strengers et al., 2006) and estimates of the marginal costs of reducing GHG emissions from the agricultural sector at national (De Cara and Javet, 2000) and European (De Cara and Javet, 2001; Pérez et al., 2003) levels. In this survey we have not analysed land-based carbon mitigation costs due to the reduced number of carbon cost estimates and methodological differences (see however Figure 7). Nonetheless, forestry activities with emission reduction are likely to be less competitive in Europe when compared with other world regions (van Kooten and Sohngen, 2007). Moreover, the current costs of implementing European domestic biofuel targets seem to be higher compared with other available CO_2 mitigation strategies (Ryan et al., 2006).

[Figure 7]

4. Conclusions

Taking into account the results of the different studies analysed in this survey, land-based alternatives can contribute about 40% to the European target of a 20% reduction in GHG emissions by 2020 (and about 30% to the 30% reduction by 2020). The implementation of these alternatives would require up to 16% of EU-25 agricultural land to be afforested or diverted to bioenergy crops by 2020 (36% by 2050). This share of land is certainly relevant. Therefore, the impact of these practices on biodiversity and land use patterns has to be monitored and taken into account (Caparrós and Jacquemont, 2003).

Most studies analyse some land-based GHG mitigation options but not all the competing alternatives. Thus, the results of the different studies should not simply be added together. Consequently, the next steps should compare the potential of bioenergy crops and the expansion of forest cover, allowing competition amongst these (and other) options. In addition, the studies analysed do not fully consider the difficulties inherent in such a large-scale change in land use. Land use change decisions, apart from maximizing monetary returns from land, involve irreversible investments in the face of uncertainty (Schatzki, 2003) and other unobserved benefits and costs of alternative land uses (i.e. aesthetic and recreation), or simply liquidity constraints and some decision-making inertia (Stavins, 1999). These considerations could reduce the new land devoted to climate mitigation practices and consequently the carbon offsets obtained, and a comprehensive analysis that takes them into account is not yet available for Europe.

Endnotes

[1] For estimating the bioenergy potential Vries et al. (2007) assume that croplands are not available, forestlands are to be preserved and low-productivity land will not yield competitively priced biomass but do not provide land resources figures for biomass crops.

[2] This mean value (as well as the mean carbon mitigation potential) is estimated considering one point for each one of the studies that assess the land resources that could be allocated for growing forest or bioenergy crops by 2020 and 2050 (or alternatively the carbon mitigation potential associated with those practices). For studies that provide more than one estimate we use average values. For studies that do not provide point estimates for periods 2020 and 2050 but for other years in the 2000 – 2100 period, we predict the point estimates for 2020 and 2050, assuming annual linear increases for the known periods. We also provide the confidence intervals, which are given at 95% level, assuming the independence of the different observations.

[3] The EU-25 GHG base year (1990) emissions are estimated to be 5,380 Mt CO2 equivalents (EEA, 2006b), while EU-25 baseline GHG emission projections for 2020 and 2050 are +4% and +7% compared to 1990, respectively (EEA, 2005).

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Table 1. Land uses in Europe (1000 ha)

Class	Total land area [1]	Forest and other wooded land [2]			Agriculture land [1]			
		Forest	Other wooded land	Total	Arable land	Perma-nent crops	Perma-nent pastures	Total
1. EU-15	313,156	113,567	22,637	136,204	73,969	11,094	55,859	140,922
2. EU+10	71,864	23,493	574	24,067	29,027	1,074	8,517	38,618
3. EU-25 (1+2)	385,020	137,060	23,211	160,271	102,996	121,68	64,376	179,540
4. EU-27	419,054	146,951	23,904	170,854	115,903	12,947	71,129	199,979
5. Other Countries [a]	70,861	16,493	7,192	23,684	8,304	747	9,063	18,114
6. Total (4+5)	489,915	163,444	31,096	194,539	124,207	13,694	80,192	218,093
7. Western Europe[b]	357,854	123,487	26,089	149,575	75,284	11,119	59,390	145,793
8. Eastern Europe[c]	114,425	32,962	4,515	35,737	43,204	2,433	19,559	65,196
9. Other Countries [d]	17,636	6,995	492	7,487	5,719	142	1,243	7,104

[a]Other countries include: Albania, Bosnia-Herzegovina, Croatia, Iceland, Liechtenstein, The FYR-Macedonia, Norway, Serbia and Montenegro and Switzerland.
[b] Western Europe (Austria, Belgium, Denmark, France, Finland, Germany, Greece, Iceland, Ireland, Italy, Liechtenstein, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and UK).
[c] Eastern Europe (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Hungary, FYR of Macedonia, Poland, Romania, Slovakia, Slovenia and Serbia and Montenegro).
[d] Other countries include: EU Baltic Sea countries (Estonia, Latvia and Lithuania) and Cyprus.
Source: [1] FAOSTAT (http://faostat.fao.org), data for the period 2000; [2] TBFRA (United Nations, 2000).

Table 2. Carbon mitigation potential of land-based practices in Europe

References	Region considered	Land resources (million ha)	Potential carbon mitigation rate t C ha^{-1} y^{-1}	Potential mitigation estimates Mt C y^{-1}	Time horizon or period	Approach[§] Models	Approach[§] Scenarios	Carbon prices \$ tC^{-1}
				Forest expansion				
Klijn et al. (2005)	EU-25	6.7-14[1]		24	2030	IMAGE 2.2/CLUE GTAP (IM, RF, DD)	IPCC/SRES	
Strengers et al. (2006)	OECD and Eastern Europe[2.a]	~13[2.b] ~20	2.2-3.4	~41[2.b] ~160	2025 2100	IMAGE 2.2/GTAP/ FAIR (IM, RF, DD)	IPCC/SRES	<350 <600
Sohngen and Mendelsonh (2003)	Europe (excluding FSU States) [3.a]	8.5 12.8 25.9		Cumulative[3.b] 200 700(12.5) 1,700 (20.0)	2010 2050 2100	Global Timber Model and DICE Model (SEM, RF, DD)	Expected climate change damage (Min)	7.14 29.87 61.34
		22.3 39.8 66.0		300 1,300 (25.0) 4,300 (60.0)	2010 2050 2100		Uncertain climate change damage (Max)	21.8 92.19 187.54
Tavoni et al. (2007)	Europe (Western Europe and New Europe –EU-10–)	14.1 42.7 63.5		45 100 151	2022 2052 2092	Global Timber Model and WITCH (SEM, RF, DD)	BaU CO_2 stabilization 550 ppm	57 113 271
				Bioenergy crops				
EEA (2006a)	EU-22 (except Cyprus, Malta and Luxembourg)	13.0 19.3	26.6-214.5 GJ ha^{-1} (sugar beet and maize whole plant)	~31-129 [4] (47-142 MtOE)	2010-2030	CAPSIM, (SEM, RF)	Bioenergy production compatible with environmental protection	
Kavalov (2004)	EU-25	~7-22 (5-27% of arable land)	25-150 GJ ha^{-1} (EU-15) 19-33 GJ ha^{-1} (EU+10)	19.1-58.7 [5.a] (5.9-18.2 MtOE)	2005-2010	B-UM, RF	Current and Optimal technical potentials [5.b]	
Ericsson and Nilsson (2006)	EU-27 (except Cyprus and Malta)	11.6 29.1	5.2-8.4odt [6.a] 7.2-11.2 odt	~41 [6.a] (1.5 EJ y^{-1}) ~112-144 (4.3-5.5EJ y^{-1})	10-20 20-40	B-UM, RF	5 land use and energy crop yield scenarios	
Leemans et al (1996)	OECD and Eastern Europe[2.a]	28-33 34-36		ne (for Europe)	2050 2100	LESS BI/IMAGE 2.1 (B-UM, RF, DD)	LESS Biomass LESS Changed Trade	
Sims et al. (2006)	OECD and Eastern Europe[2.a]	7.8-21.5	4-12 odt	13.6-110.4 (Carbon eq)	2025	IMAGE 2.2 (IM, RF)	IPCC/SRES	

Continues...

Table 2 continues...

References	Region considered	Land resources (million ha)	Potential carbon mitigation rate t C ha^{-1} y^{-1}	Potential mitigation estimates Mt C y^{-1}	Time horizon or period	Approach[§] Models	Approach[§] Scenarios	Carbon prices \$ tC^{-1}
Vries et al. (2007)	OECD and Eastern Europe[2.a)]	ne (for Europe)	10 ton (biomass)	~8.5-13.5 EJ y^{-1} ~185-293 Mt C y^{-1} [(4)]	2025	IMAGE 2.2 (IM, RF, DD)	IPCC/SRES	< 691-921 (<15- 20 US\$ GJ^{-1})
Hall and House (1995)	Western Europe	27.6[(7.b)]	10odt	5.6 EJ y^{-1} ~120 $MtCy^{-1}$ [(4)]	2020	B-UM, RF	Achievable potential	
		41.4	10-15 odt	12.4 EJ y^{-1} ~269 $MtCy^{-1}$ [(4)]	2050			
Scurlock et al. (1993)	Western Europe	15-20	6 t C ha^{-1} y^{-1} or 12 odt	90-120	2000-2010	B-UM, RF	Achievable potential	
Smeets et al. (2007)	Europe (Western and Eastern Europe)	16-101 [(8)]	20-35 odt	~8-61 EJ y^{-1}	2050	Quickscan Model (B-UM, RF)	4 animal production system scenarios	

[(§)]BaU: Business as usual; B-UM: Bottom-up model; DD: demand-driven; IM: integrated assessment model; RF: resource-focused approach; SEM: sectoral equilibrium model.
[(1)] Net change in forest area estimated for A1 and B1 EURURALIS implementation of the IPCC/SRES scenarios in 2030 (Klijn et al., 2005)
[(2.a)] Excluding the European microstates, OCDE and Eastern Europe cover a utilised agricultural land area close to 211 Mha (Table 1). [(2.b)] Approximated (~) values taken from Strengers et al. (2006) figures for the B2 IPCC/SRES scenario.
[(3.a)] European territory excluding former Soviet Union Countries (Estonia, Latvia and Lithuania) embraces close to 204 Mha of utilised agricultural lands. [(3.b)] Our own estimates of annual carbon sequestration based on Sohngen and Mendelsohn (2003) cumulative carbon sequestration values by 2010, 2050 and 2100 are given in parentheses.
[(4)] MtOE: million tons of oil equivalent equal to 0.04184 exajoules (EJ) or 41.84×10^9 mega-joules (MJ) A carbon mitigation potential of 0.02 kg C MJ^{-1} is assumed, based on Sims et al. (2006) carbon mitigation potentials (2006: 2057) when 48% of bioenergy crops consist of short rotation coppices (SRC) and 52% annual crops for biogas and ethanol production, as per EEA (2006a:26) estimates for EU-22 by 2030.
[(5.a)] Kavalov (2004) examines the land resources required in the EU-25 to fulfil EU Directive 2003/30/EC targets for biofuel (based on bioethanol and biodiesel) market share in the transportation sector in the period 2005-2010. The explored scenarios are the current technical potential (SNF), based on a summary of national and country-by-country projections and optimal technical potential (OTP). [(5.b)] Carbon mitigation potential is estimated using Sims et al. (2006: 2057) carbon mitigation figures for bioethanol from wheat and sugar beet (0.022 kg C MJ^{-1}) and biodiesel from rapeseed oil (0.02 kg C MJ^{-1}).
[(6.a)] Ericsson and Nilsson (2006) odt (oven dry tonnes per hectare and year) yields are referred to short-rotation forestry and herbaceous crops. [(6.b)] Carbon mitigation potential is estimated using the Sims et al. (2006: 2057) carbon mitigation figure for wood (short rotation coppices –SRC), which is equivalent to: 0.026 kg C MJ^{-1}.
[(7)] Own estimations excluding Turkey.
[(8)] Mixed intensive and extensive animal production systems (1 and 2) and landless animal production systems (2 and 3) of the Smeets et al. (2007) model.

Table 3. Change in forest cover and carbon sequestration estimated for the EU-25

Reference	Region of reference	Period	Current UAL [(1)] (Mha)	EU-25_{UAL}/ UAL correction factor (%)	Change in Forest cover (Mha)		Carbon sequestration potential (Mt C y^{-1})	
					Total	EU-25	Total	EU-25
Strengers et al. (2006)	OECD and Eastern Europe	2025 2100	211.0	85.1	13.0 20.0	11.1 17.0	39.5 100.0	33.6 85.1
Sohngen and Mendelsohn (2003) Min	Europe (excluding FSU States)	2010 2025 2100	204.0	88.0	8.5 12.8 25.9	7.5 11.3 22.8	13.3 46.7 113.3	11.7 41.1 99.7
Sohngen and Mendelsohn (2003) Max		2010 2025 2100	204.0	88.0	22.3 39.8 66.0	19.6 35.0 58.1	20.0 86.7 286.7	17.6 76.3 252.3
Tavoni et al. (2007)	Old and New Europe (Western Europe and EU+10)	2022 2052 2092	184.4	97.4	14.1 42.7 63.5	13.7 41.6 61.8	45.0 100.0 151.0	43.8 97.4 147.0

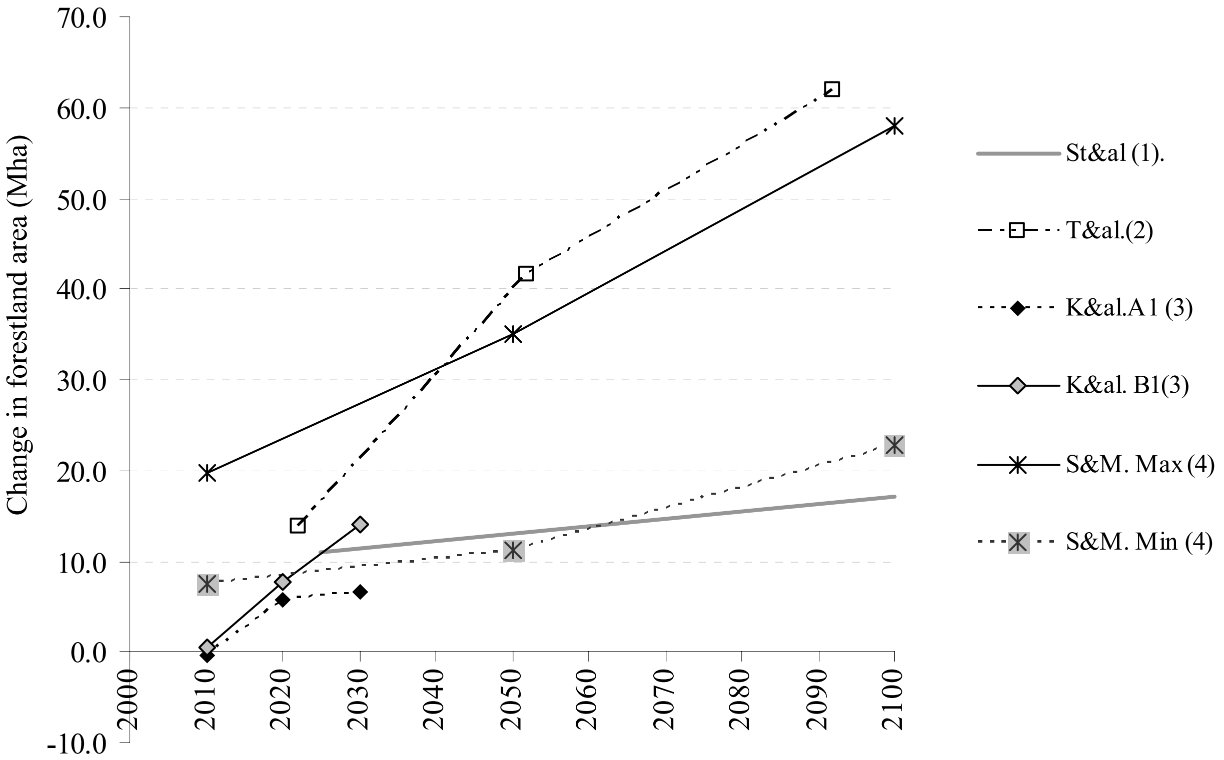
[(1)] Utilised agricultural land (UAL), estimated on the basis of FAOSTAT (http://faostat.fao.org) and TBFRA (United Nations, 2000) data, considering the countries that belong to the different European territorial entities.

Table 4. Estimated bioenergy crops area in the EU-25

Reference	Region of reference	Period	Current UAL [1] (Mha)	EU-25$_{UAL}$/ UAL correction factor (%)	Bioenergy crops area (Mha)	
					Total	EU-25
Scurlock et al. (1993)	Western Europe	2010	143.5	125.1	20.0	25.0
Hall and House (1995)	Western Europe	2020	155.0	115.8	27.6	32.0
		2050			41.4	48.0
IMAGE team (2001) (B2 scenario)	OECD Europe	2020	145.8	123.1	5.9	7.3
		2050			15.2	18.7
		2100			28.6	35.2
Strengers et al. (2004) (A1T and B1 scenarios)	OECD and Eastern Europe	2100	211.0	85.1	28.2	24.0
		2100			52.9	45.0
Leemans et al. (2006) (LESS BI)	OECD and Eastern Europe	2025	211.0	85.1	16.0	13.6
		2050			28.0	23.8
		2100			36.0	30.6
Sims et al. (2006)	OECD and Eastern Europe	2025	211.0	85.1	7.8	6.6
		2025			21.5	18.3
Smeets et al. (2007)	Western and Eastern Europe	2050	211.0	85.1	16.0	13.6
		2050			101.0	85.9

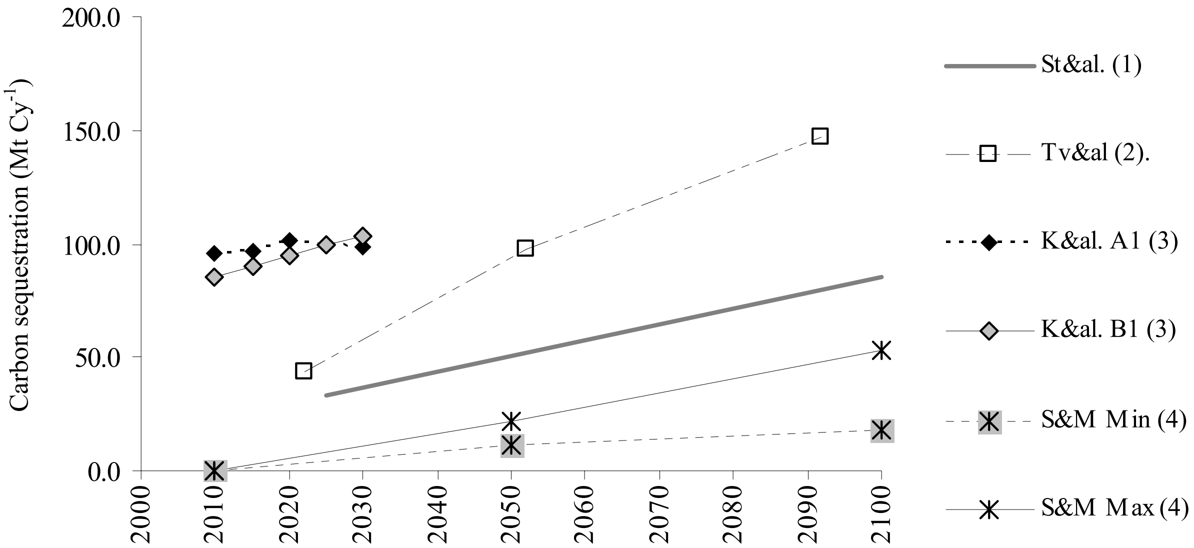
[1] Utilised agricultural land (UAL), estimated on the basis of FAOSTAT (http://faostat.fao.org) and TBFRA (United Nations, 2000) data, considering the countries that belong to the different European territorial entities.

Figure 1. Forest area expansion in the EU-25 from 2010 to 2100



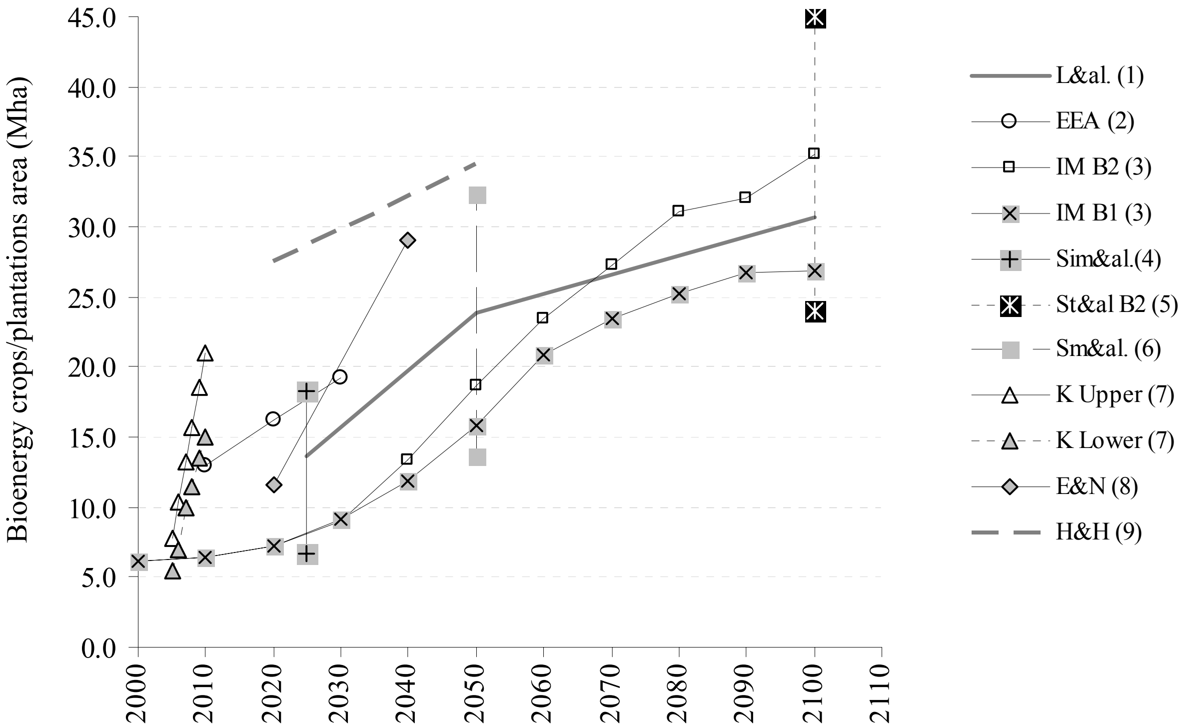
Notes: (1) St&et al: Adapted from Strenger et al. (2006) data for 2025, 2050 and 2100 in OECD and Eastern Europe. (2) T&al.: Adapted from Tavoni et al. (2007) changes in forest area in Western Europe and the EU-10. (3) K&al.: Klijn et al. (2005) changes in forest cover for A1 and B1 IPCC/SRES scenarios in the EU-25. (4) S&M: Adapted from Sohngen and Mendelsohn (2003), forest cover changes in Europe (excluding FSU countries) under expected (Min) and uncertain (Max) climate change damage scenarios.

Figure 2. Carbon sequestration through forest area expansion in EU-25 from 2010 to 2100



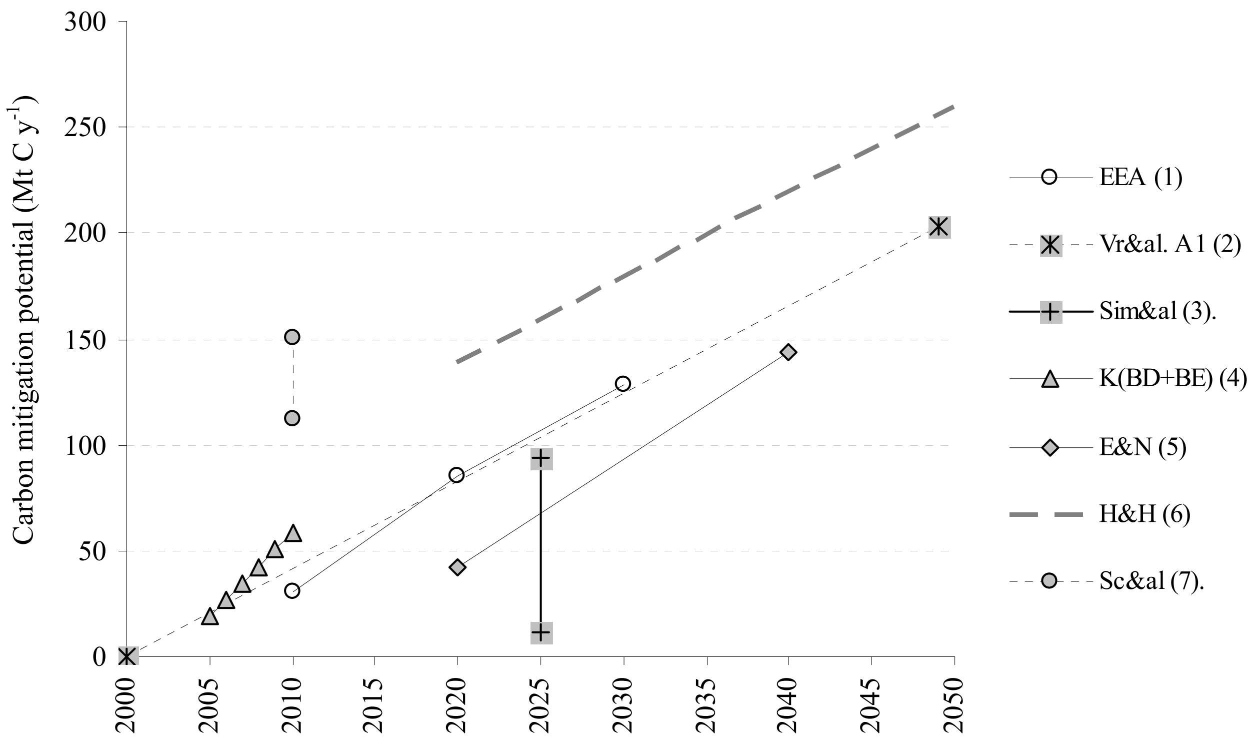
Notes: (1) Adapted from St&al: Strenger et al. (2006) data for 2025, 2050 and 2100 in OECD and Eastern Europe for carbon prices lower than €350 tC^{-1}. (2) Adapted from T&al.: Tavoni et al. (2007), carbon sequestration in Western Europe and the EU-10. (3) K&al.: Klijn et al. (2005) LULUCF carbon balance estimates for A1 and B1 IPCC/SRES scenarios in the EU-25. (4) Adapted from S&M: Sohngen and Mendelsohn (2003), carbon sequestration estimates for Europe (excluding FSU) the under expected (Min) and the uncertain (Max) climate change damage scenarios.

Figure 3. Bioenergy crops/plantation in EU-25 from 2000 to 2100



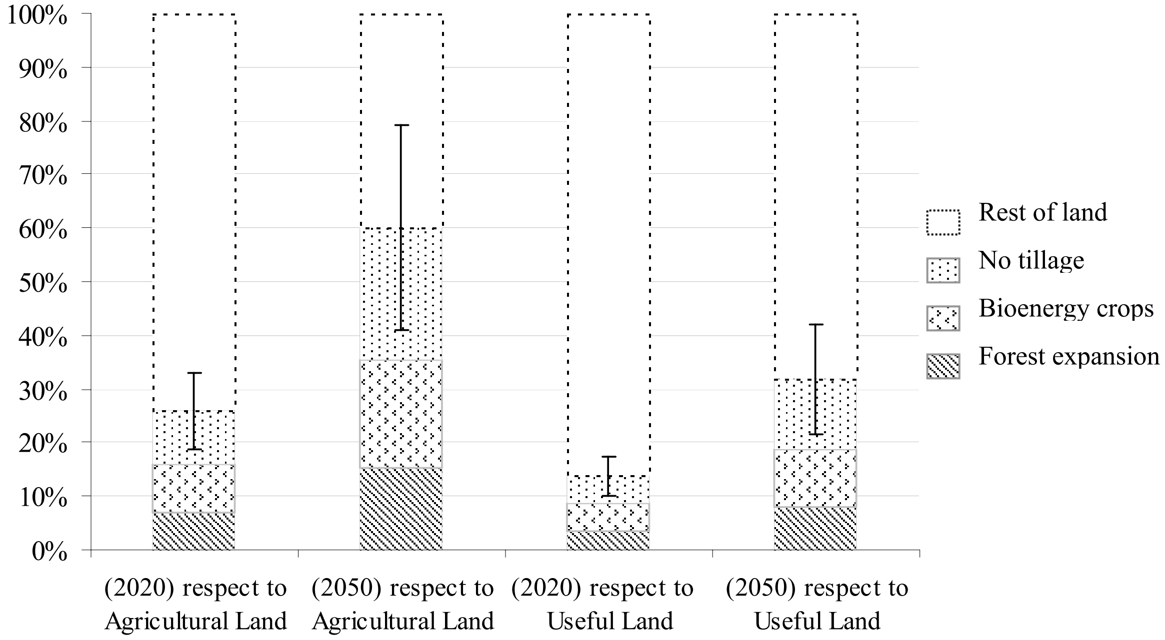
Notes: [(1)] L&al: Adapted from Leemans et al. (1996). Land demand for the biomass intensive scenario (LESS-BI) in OECD and Eastern Europe. [(2)] EEA: European Environmental Agency (2006a) for EU-22 (no data for Luxemburg, Cyprus and Malta) land demand for bioenergy crops from 2010 to 2030. [(3)] IM: Adapted from the IMAGE 2.2 (IMAGE team, 2001) B1 and B2 IPCC/SRES implementation scenarios. Data for the OECD Europe. [(4)] Sim&al.: Adapted from Sims et al. (2006), energy crop area projected by 2025, based on A1 and B2 IPCC/SRES scenarios in OECD and Eastern Europe. [(5)] St&al.: Adapted from Strengers et al. (2004). Biofuel crops area projected by 2100 in OECD and Eastern Europe. [(6)] Sm&al.: Adapted from Smeets et al. (2007). Biofuel crops area projected by 2050 in Western and Eastern Europe under mixed animal production systems. [(7)] K: Kavalov (2004). Land-resources demand to meet EU Directive 2003/30/EC target for biofuel for transportation in the period 2005-2010, for the Upper (U) and the Lower (L) Optimal Technical Potential scenario. [(8)] E&N: Ericsson and Nilsson (2006). Energy crops area in the next 10-40 years (we assume year 0 is 2000). [(9)] H&H: Hall and House (1995) for Western Europe by 2020 and 2050.

Figure 4. Carbon mitigation potential for bioenergy crops in the EU-25 from 2000 to 2050



Notes Own carbon mitigation assessment based on estimates over the potential energy from bioenergy crops of: [(1)] EEA: European Environmental Agency (2006a) for EU-22 (no data for Luxemburg, Cyprus and Malta) from 2010-2030 and [(2)] Vr&al. A1: Vries et al. (2007), OECD and Eastern Europe for A1 IPCC/SRES scenario in 2050. [(3)] Sim&al.: Sims et al. (2006). Net GHG abatement projected by 2025 for energy crops, for a yield range of from 4 to 12 oven dry tonnes (odt) ha^{-1} y^{-1}, in OECD and Eastern Europe. Own carbon mitigation assessment based on estimates over the potential energy from bioenergy crops of: [(4)] K (BD+BE): Kavalov (2004) for the EU-25 in the period 2005-2010; [(5)] E&N: Ericsson and Nilsson (2006). Energy crops area in the next 10-40 years (we assume year 0 is 2000) and [(6)] H&H: Hall and House (1995) for Western Europe by 2020 and 2050, without including energy from residues. [(7)] Sc&al: Scurlock et al. (1993) for 17 Western European countries by 2010.

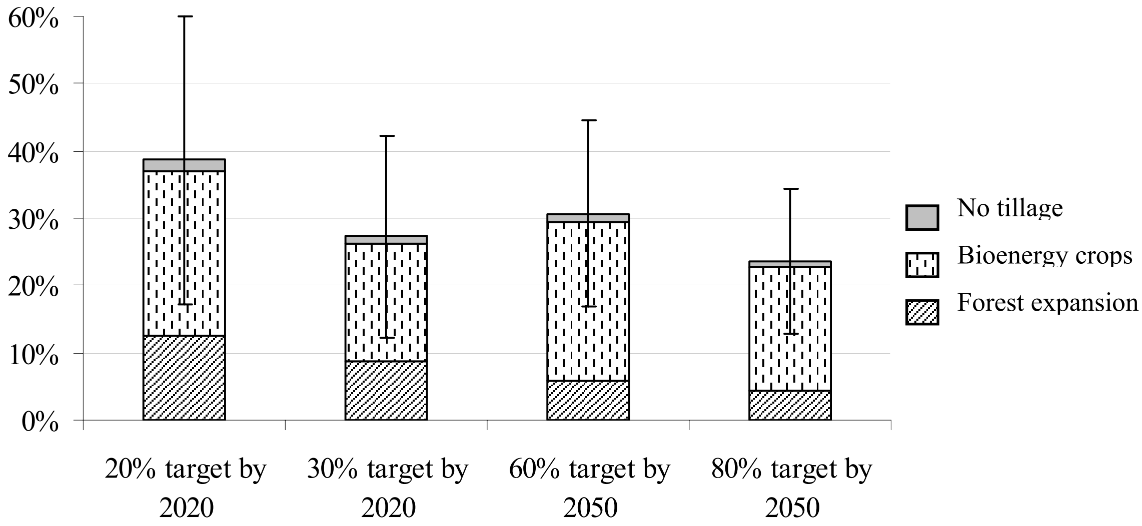
Figure 5. Land resources demand for forest expansion, no-tillage farming and bioenergy crops in respect of the available agricultural and useful land in the EU-25 (data for 2020 and 2050)



Source: *Own elaboration*, based on information presented in Figures 1 and 3 and Tables 1 and 2.

The confidence intervals are given at 95% level, assuming the independence of the different observations.

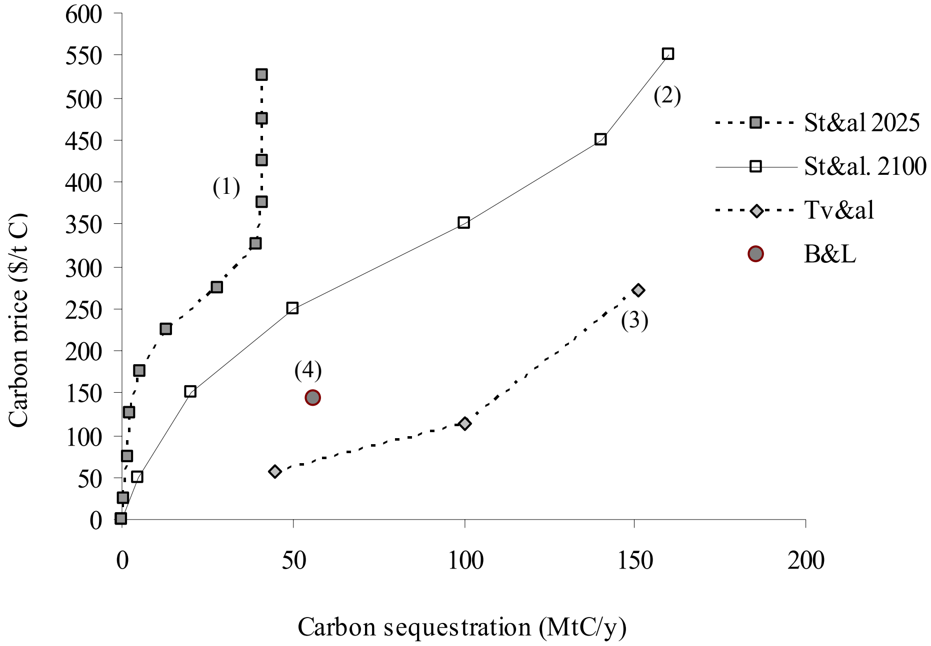
Figure 6. Potential contribution of forest expansion, non-tillage systems and bioenergy crops to the hypothetical post-2012 GHG emission reduction targets by 2020 and 2050 in the EU-25



Source: *Own elaboration*, based on information presented in Figures 2 and 4 and Table 2.

The confidence intervals are given at 95% level, assuming the independence of the different observations.

Figure 7. Carbon sequestration potential and costs in Europe



Notes: [(1)] St&al.2025: Strenger et al. (2006) B2 IPCC/SRES scenario. Marginal abatement curves (MAC) for Europe by 2025. [(2)] St&al.2100: Strenger et al. (2006) B2 IPCC/SRES scenario. MAC for Europe by 2100. [(3)] T&al.: Tavoni et al. (2007). [(4)] S&M Min.: Sonhgen and Mendelsohn (2003), under expected climate change damage scenario from 2010 to 2100. [(5)] S&M. Max: Sonhgen and Mendelsohn (2003), under uncertain climate change damage scenario from 2010 to 2100. [(6)] B$L: Burniaux and Lee (2003) simulation of a 30% reduction in GHG emission in the EU-15.