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Opportunities for land-based carbon sequestration in Slovakia

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Summary

It is generally accepted that agriculture and forestry practices may contribute to climate change mitigation initiatives by increasing biotic carbon storage, by producing biomass as a substitute for fossil fuels, and by reducing emissions of greenhouse gases (GHG) into the atmosphere. To address land-related mitigation options, the Kyoto protocol (KP) creates opportunities for countries to meet their commitments by increasing their biological sources and sinks. For the first commitment period, 2008-2012, land-based mitigation options include afforestation, reforestation and reducing the rates of deforestation since 1990. Forest management may also contribute to mitigation under the KP, for instance by increasing the area devoted to forest plantations, regenerating secondary forests, and producing wood for fuel. Mitigation from agricultural management may be allowed in future commitment periods, i.e., after 2012. The implementation of these mitigation activities presents a challenge for Central and Eastern European (CEE) countries.

Slovakia lies in the heart of Europe. Nearly 41% of the country is covered by forest, while 50% is agricultural land; the fraction of agricultural land that is arable is 61%. Economic transition significantly impacted agriculture, resulting in crop and animal production reductions of -30% on average, compared to 1990 levels. Similarly to other CEE countries, this resulted in the increase of land abandonment (+13% compared to 1990; see Keenleyside, 2004) and created a need to consider diverse development and policy options. This includes activities such as increasing levels of afforestation, biomass plantations and their use as renewable resources, with the displacement of fossil fuels, that could create ‘win-win’ solutions, providing the country with viable rural development alternatives for growth in depressed areas while contributing to KP emission reduction requirements.

The assessment of different land-use activities with respect to their carbon sequestration potential and related costs is an important indicator, useful for the selection of optimal GHG abatement policies. To this end, carbon sequestration supply curves are often employed. This work contributes to current assessment efforts by developing carbon sequestration supply curves for Slovakia, relative to reforestation and short rotation forest plantation. Four scenarios were considered for further analysis, three of them addressing marginal areas affected by decline in agricultural production reaching less than 60% and 40% of average yields and pastures. Cost estimates of these alternative activities on marginal land in Slovakia, in competition with option for biomass energy production, were needed in order to prepare improved scenarios for agriculture and forestry.

The results of this study indicate that the theoretical maximum C-sequestration potential on agricultural land by reforestation would account for approximately 10% of all CO_2 emissions in Slovakia. More realistic scenarios, focusing on lower quality and marginal

lands, suggested that carbon sequestration by reforestation in Slovakia could represent 1.7%-2.4% of total CO_2 emissions. Furthermore, we computed that converting all agricultural land to bio-energy production would generate about 64% of total energy consumption (with respect to the period 1997-2002). Realistically, our results suggest that bio-energy generation from available lower quality marginal land could generate about 15% of renewable energy consumption in Slovakia. However, the scenario targeting marginal areas, which has the highest local and regional development potential in Slovakia, has lower plant production potential not only for conventional agriculture, but also for reforestation and short rotation systems. For this reason, high economic investments are necessary to operate short rotation systems on lower quality lands, in order to provide adequate nutrient inputs and obtain economically viable yields.

The estimated price per tonne of carbon per hectare varies from $15 to $34 for reforestation across all scenarios and it is between $16 and $60 for short rotation forest plantation. The price for the accumulation of one unit of carbon under short rotation systems is higher compared to reforestation, although results indicate that short rotation systems could produce about 6% of total energy consumption even using only the low quality land. In case of comparison of the two activities for Scenario 3 and 4, the short rotation forest plantation is found to be more effective in the short and medium–term, resulting in higher levels of sequestered carbon and additional energy generation. In the long–term, reforestation leads to higher levels of carbon sequestration and therefore larger mitigation of climate change.

The work presented in this paper investigates the cost of carbon sequestration in Slovakia, at a regional level by applying novel modeling approaches involving spatially explicit analyses of land biophysical and economic productivity. Carbon sequestration supply cost curves were derived as a result, and for the first time in the literature, for all Slovak regions. Future assessments will require studies with higher resolution in regions with short-rotation forestry potential. Importantly, our results indicate a need to complement pure biophysical-economic approaches with local socioeconomic indicators, in order to improve projections and develop more realistic scenarios. Specifically, identifying actual management options at local and regional levels requires the direct involvement of key stakeholders in scenario development and data analysis.

Abstract

Land use and land cover change practices contribute to climate change mitigation initiatives by increasing biotic carbon storage, and by producing biomass for bio-energy, as a substitute for fossil fuels. In this paper we examine opportunities in Slovakia for two land use activities, reforestation and short-rotation forest plantation, using four scenarios. In order to evaluate alternative GHG emission reduction policies, of carbon sequestration supply curves were constructed for both activities, for all regions in the country. Our regionally detailed results apply novel modeling approaches involving spatially explicit analyses of land biophysical and economic productivity that are easily applicable to other transition countries.

The overall theoretical maximum sequestration potential on agricultural land by reforestation in Slovakia accounts for approximately 10% of national CO2 emissions. More realistic scenarios, focusing on lower quality marginal land have a potential for carbon sequestration of approximately 1.7%-2.4% of total CO2 emissions. In our estimations, potential maximum use of biomass for bio-energy, using all available agricultural land, would be 64% of renewable energy consumption, with reference to average usage during 1997-2002. Realistic potentials of bio-energy generation on lower quality land may cover about 6% of total demand. We conclude by discussing needs to integrate biophysical and economic model estimates of carbon sequestration potential with local and regional information collected through a stakeholder engagement process. Overall, we argue that there is a necessity to embed carbon sequestration activities within regional development plans, and to back up land use and forest policies with adequate economic incentives and public engagement in environmental decision-making.

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Opportunities for land-based carbon sequestration in Slovakia

Lívia Bíziková and Francesco Nicola Tubiello

Introduction

Global warming, characterized by the increase of the Earth's mean surface temperature, as well as by changes in precipitation patterns and the frequency of extreme events, is one of the most pressing global environmental challenges of the 21st century. Atmospheric concentration of carbon dioxide, the dominant greenhouse gas (GHG), is now 30% higher than it was about 200 years ago (Houghton et al., 1996). Major international efforts to combat climate change led to the adoption of the Kyoto protocol (KP) in 1997, which became legally binding for its 128 Parties on 16 February 2005 (UNFCCC, 2004). In addition to addressing the need for direct emission reduction from energy and industry, articles 3.3 and 3.4 of the KP state that biological sources and sinks may be used for meeting commitments, limiting allowed land-based actions during the first commitment period (2008-2012) to afforestation, reforestation, and reduction of the rates of deforestation since 1990, including some forestry management practices. In particular, the possibility of using additional land use change and forestry activities such as increasing the area devoted to forest plantations, regenerating secondary forests, and producing wood for fuel can assist the countries to respond to the KP.

At the European level, activities that can be considered include those that add to the increase of carbon sinks by maintaining and/or increasing existing C pools by improving existing forest; forest protection and sustainable management; the expansion of forest area through afforestation of agricultural land (with species adapted to local conditions); the replacement of fossil fuels with fuel-wood from sustainable managed forests; and the replacement energy intensive products with industrial wood products (EC, 1998). These activities are potentially beneficial for transition countries, although careful planning is required to identify project areas as a function of both their biophysical and socio-economic stage of economic development and transformation to a market economy. This suggests that, in particular for transition economies, climate change measures need to be seen as development issues.

In transition countries, the current level of GHG emission is significantly below their KP commitments (30.7% on average in 2000) (Petkova and Faraday, 2001). However projected emissions may well reach their actual Kyoto targets in several countries[1]. Changes undergone by transition countries of Central and Eastern Europe have had

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[1] Countries such as Slovenia, Slovakia, Czech republic, Poland and Hungary will reach their current Kyoto proposal target till 2015 if no mitigation policy is implemented (National communications on the UNFCCC on Climate Change Czech republic (2005), Slovakia (2006), Hungary (2002) and Poland (2001).)

tremendous impacts on framing development priorities, selection of development goals and management of natural resources. The transition process to market economies, including changes in regulatory and institutional framework was accompanied with dramatic decline of trust in formal institutions; this may have significant impact on the effectiveness of planned climate policies. On the other hand, the transition process created opportunities for decentralization and fiscal reforms and provided a venue for bottom-up development strategies. Moreover, many of the priorities that will guide the future development in transition countries are being set up currently.

This paper focuses on analyses of land-based carbon sequestration potentials based on biophysical potentials, different land-use management practices, and species selection at the regional and local level.

Specifically, the paper addresses the following themes:

- Presenting a framework for the estimation of carbon sequestration potentials as scenarios for local development;
- Estimating the potential for carbon sequestration in Slovakia;
- Addressing and strengthening the linkages between international agreements, EU and national policies.

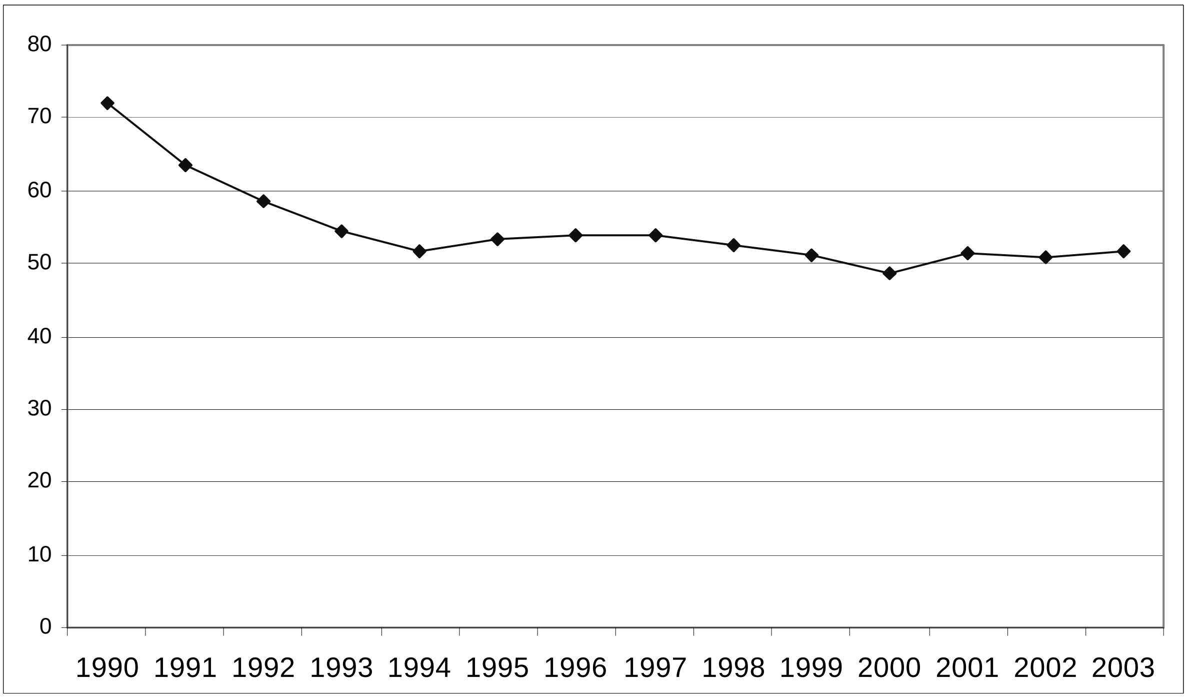
To this end, we analyzed data describing biophysical and socio-economic characteristics at the regional level in Slovakia. Scenarios were thus formulated estimating potential for short-rotation biomass plantation (SRBP) and reforestation by mixed species. The resulting biophysical potentials were combined with currently available assessments of land values to construct and quantify carbon sequestration supply curves for policy analysis. Four distinct socio-economic scenarios involving diverse land-use types such as all agricultural land, pastures, lower quality and marginal land was analyzed. Information resulting from the analyzed opportunities, instruments and assessed potentials in each of the scenarios were synthesized within a national comparison. We paid special attention to capture the convergence of carbon sequestration and development policies in Slovakia.

GHG emissions in Slovakia

The share of global anthropogenic emissions for Slovakia is about 1.5%. Annual per capita CO2 emissions are approximately 8.2 ton/cap, i.e., below the OECD average. CO2 emissions contribute about 81% of the total greenhouse gas emissions; CH4 emissions contribute by 12% and N2O emissions about 7% (compared in CO2 equivalent).

Total CO2 emissions in Slovakia were highest at the end of the 1980s. After 1990, the decline in economic production decreased emissions to the level of 1987. Since 1994, a slow increase in emissions was estimated, followed by their rather constant level during the period 1997-2002; since 2003 a slight increase of emissions has occurred. Based on the assessment from 1999, total anthropogenic emission of CO2 reached 44,875 million ton (in 1990 they had reached 59,606 M ton). Total carbon dioxide emissions are presented in Figure 1. The primary source of atmospheric CO2 in Slovakia is fossil fuel combustion, which accounts for 94% of total Slovak CO2 emissions. Cement (lime) production is another important source. Changes in land use and forestry generally act as sink of CO2. Approximately 83% of energy in Slovakia is produced through the combustion of fossil fuels. The remaining 17% comes from other energy sources such as nuclear energy, hydropower and other renewables.

Figure 1. GHG emissions in Slovakia excluding land sinks (in Mt of C02 eq.).



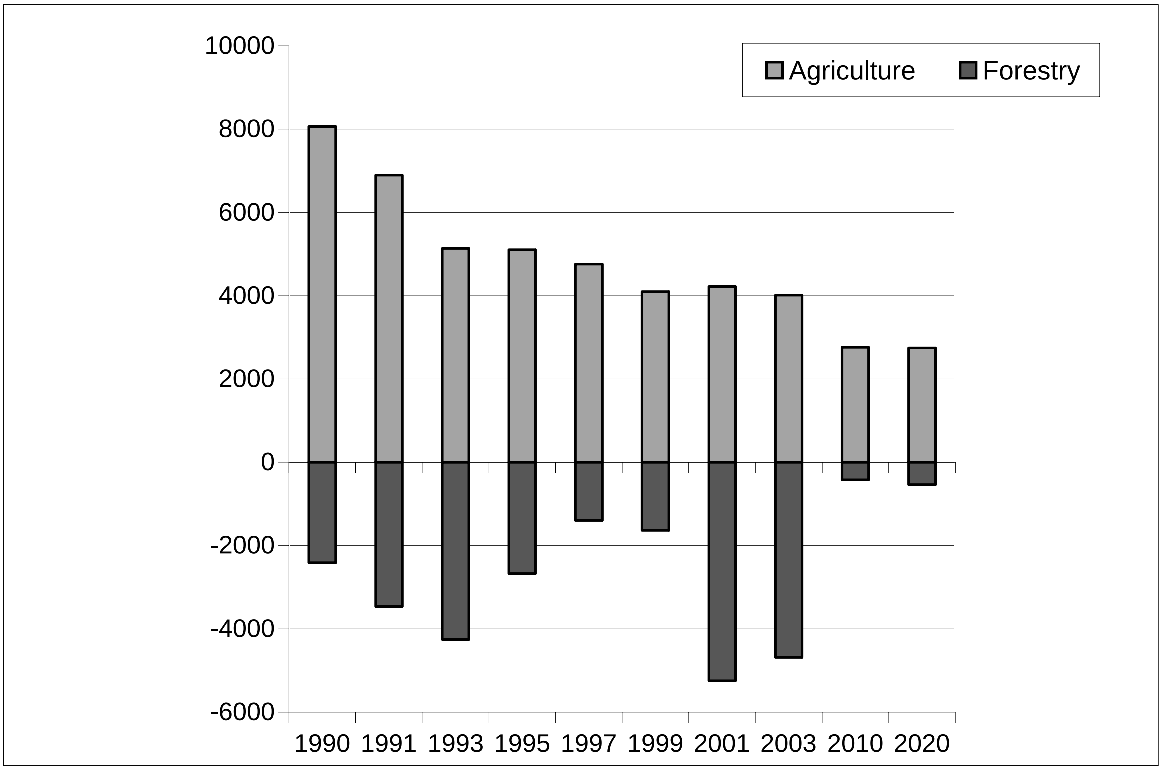
Source: Fourth national climate change communication for UNFCC Slovak republic, 2006.

Land use related GHG emissions in Slovakia

Forests are one of the most important natural resources of Slovakia; nearly 41% of the country (49,036 km2) is covered by forest. Agricultural activity is also important; the fraction of agricultural land is 50%, of which 61% is arable land. The area of agricultural land is currently stable at about 2,439,408 ha, from which arable land is 1,441,164 ha. The most significant land use changes of the last decade are visible in the case of pastures, specifically agricultural land was converted to pastures; this pattern is particularly significant for mountain areas with agricultural land of medium to low quality. In the last ten years, changes in the composition of cultivated crops have happened as well. The planting of cereals decreased by about 15% and the cultivation of potatoes decreased by more than 20% [Blaas (ed.), 1999].

Carbon dioxide emissions from agriculture represent approximately 6% of total CO2 emissions in the last decade. GHG emissions and sinks from land use (agriculture and forestry) have been estimated for arable land, pastures, urban and forest land (Figure 2.) The total sink varies in the period from 1990 to 1999. The estimated sink is around 2.8 – 5.0 M ton/y, or 5-10% of total national emissions, that presents are relatively modest contribution to overall GHG mitigation in the country. Taking into account the GHG emissions from agriculture, net emissions (in CO2 equivalents for methane and N2O) from land-use change and agricultural activity decreased from the 1990 level. This was due to the sharp decrease of the emissions from animal production. Since 1900, part of agricultural land has been converted back to forestland. In the period from 1950 to 1991, the total amount of sequestered carbon increased by about 50 M ton, a combination of increasing area of forests and increase of the wood storage per hectare.

Figure 2. Aggregated GHG emissions in 1990 – 2004 and sinks form LULUCF (in M ton CO_2 equivalent).



Source: Fourth report on climate change for UNFCC Slovak republic, 2006.

The increasing terrestrial carbon uptake is recognized in national policy documents of Slovakia as an important option for climate change mitigation. Therefore the following measures are proposed: decrease of the level of permanent deforestation; afforestation of non–forested areas; increase the level of wood utilization and the efficiency of its utilization; utilization of biomass as a substitute for fossil fuels and protection of existing carbon storage in the forests (Stratégia SR plnenia záväzkov Kjótskeho protokolu, 2001).

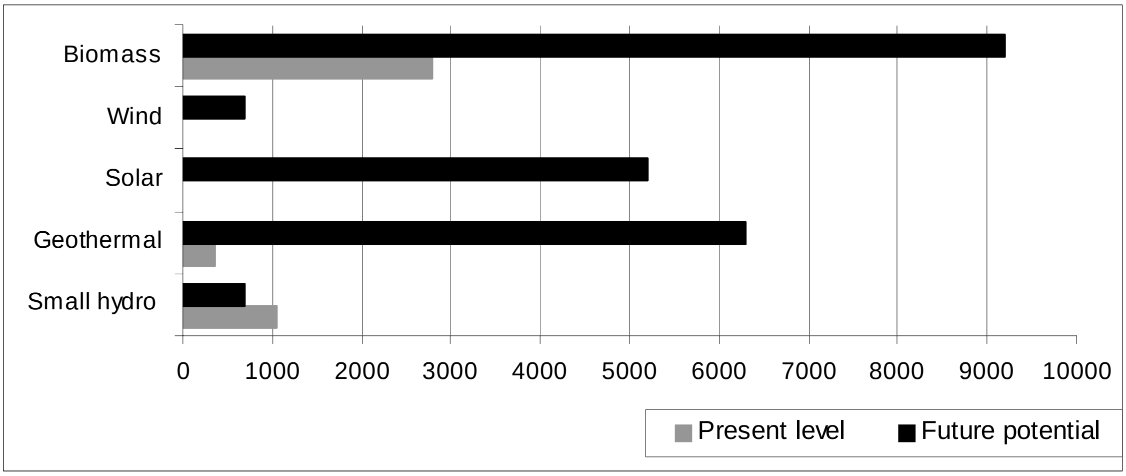
The increase of afforestation of non-forest land is a very effective way of increasing sequestered carbon, because the carbon is sequestered in biomass as well as in soil. The potential of land for reforestation is relatively high in Slovakia. However, it is not supported by incentives in an effective manner. As a response to the program of afforestation for 1994 – 2000 together with its institutional framework (law no. 550/1994), the area of afforested land during the period 1994 – 2000 was only about 877 ha (the expected area according to the program was about 50,000 ha until 2000). The implementation of the program was negatively influenced by the unclear land ownership structure, which led to problems with the allocation of the subsidies to the land–owners resulting in the low level of achieved afforestation.

Renewable energy sources in Slovakia

In 1997 the EU agreed on a renewable energy strategy and established a target to double the share of renewable energies in gross domestic energy consumption, from 6% to 12% by 2010 (EC, 1997 and also see EC, 1995). In 2001, Member States agreed on national (non–binding) targets for electricity production from renewable sources, to expand the aggregate proportion of electricity from renewable sources in the EU from 13.9% in 1997 (3.2% excluding large hydroelectric power plants) to 22.1% by 2010 (12.5% excluding large hydroelectric power plants). Individual member states have different current levels of renewable energy use, and therefore have different potential targets to 2010 (Ecotec, 2002).

Presently only 1.5% of the Slovakian energy demand is met from renewable energy. In the perspective of increasing the contribution of biomass, as part of the required increase in renewable energy shares, it implies that more area is required to intercept solar radiation, requiring land–use changes from present situation. The contribution of each type of RES in the energy balance at their present and future potential in Slovakia is presented in Figure 3. The estimated potential of RES for energy generation was estimated as a minimum figure with respect to the current economic conditions and for the introduction of innovative technologies for the utilization of RES (Bedi, 1996; Rafaj et al., 2001). An increase of the utilization of RES depends mainly on the development of electricity prices and/or on the extent supportive measures (state incentives).

Figure 3. Present level (2001) and estimated technically feasable potential of RES in Slovakia in GWh.y^{-1}.



Source: Rafaj et al., 2001.

According to the National Energy Policy, the financial needs for enhancing energy efficiency are about 120 M. EUR and 160 M EUR for renewable energy production (National Energy policy, 2000). The higher utilization of RES for energy generation will result in reduced impacts on the environment from the power generation, in the creation of new jobs (almost 500 jobs) in the construction industry and as operating staff in the new power plants. Moreover additional jobs will be created in the engineering and consulting sector, (Rafaj et al., 2001).

Biomass is currently the most important RES in Slovakia. The biggest producer of available biomass is the wood-processing industry, producing on average 1.3 M ton waste biomass yearly. From this amount 805,000 t is mechanical processing waste and 460,000 t is black liquor. Assuming an energy content of waste biomass of about 14 GJ/ton, it follows that the total annual energy value of available waste from the wood-processing industry is approximately 16,000 TJ. The biggest producers of waste are large wood-processing enterprises, which themselves have large requirements for energy consumption (electricity and heat). They have appropriate conditions for building their own energy systems based on utilization of wood waste (Rafaj et al., 2001).

Biomass residues from agriculture and from forestry are from residues equally produced in all regions in Slovakia. Annual available potential of biomass is 0.9 M tons, with an energy content of about 8,800 TJ (Energy centre Bratislava, 2002). In the case of a total rebuilding of energy sources in the woodland industry on using biomass, the sector will consume a maximum of 15% of the available potential of wood biomass. The remainder could potentially be used in other industrial and communal sectors. Available plant biomass (straw, plant residues and wastes) from agricultural production is located mainly in the most productive agricultural regions of the country. In comparison with forest biomass, energy utilization of agricultural biomass has some disadvantages such as unstable annual harvests and changes in the structure of commodities grown. In addition the low relative weight of agricultural waste implies high transportation expenses and there is a need to dry biomass before energy utilization (Energy centre Bratislava, 2002). As a result, it is most appropriate to use the agricultural plant biomass for production of heat for agricultural enterprises and neighboring centers, focusing on areas with rather stable annual over-production.

The demand for alternative energy sources is growing in Slovakia. The ultimate potential in biomass energy lies between 100–400 PJ annually. A well-established market for bio-energy is still lacking in Slovakia. However, biomass energy is expected to become increasingly competitive in the coming years, as domestic prices for natural gas and electricity continue to rise to international market level (Energy centre Bratislava, 2002). The utilization of biomass will depend on the development of each region and implementation of regional energy plans in the future.

Short overview of Slovakia’s obligations from the Kyoto protocol

Under the Kyoto protocol, the European Union agreed to reduce its greenhouse gas emissions by 8% by 2008 – 2012 from 1990 levels. The implementation rules for the Kyoto protocol were agreed at the sixth Conference of the Parties held in Bonn in 2001 (Bonn agreement) and further elaborated at the seventh conference of the parties held in Marrakech in 2001 (Marrakech Accords). The EU and Member States ratified the Kyoto protocol on 31 May 2002. The overall target of 8% GHG emissions reductions below 1990 levels was distributed on a differentiated basis to individual Member States under the so-called “EU burden-sharing” mechanism (EC, 2002).

In Slovakia, as a result of 13 years of economic transition process, carbon dioxide emissions are more than 20% below the country's commitment under the KP. The UN framework on climate change came into force in November 1994. Slovakia assumed all obligations of the convention, including the reduction of GHG emissions to the level of 1990 by 2000. Next, as its internal goal, Slovakia decided to reach the "Toronto objectives" – 20% reduction in emissions by 2005, compared to 1988. At the conference of signatories to the UNFCCC in Kyoto, Slovakia undertook the responsibility to reduce the production of greenhouse gases by 8% by 2010 (51,066 Gg), compared to 1990.

Currently, the EU adopted the directive regulating trading of GHG emission allowances (EC, 2001). The key element for the utilization of the directive is to achieve cost–effective reduction of emissions committed under the Kyoto protocol. The instruments will be used in the EU from 2005 to 2007 (training period) and then in the period 2008 – 2012. In the first phase only CO2 emissions are included. In Slovakia, the emissions trading scheme for SO2 was already implemented (2002). The Slovakia national emissions trading scheme for GHG was adopted by amendment of air act in 2001 and 2003. Allocation schemes for both SO2 and CO2 are based on grandfathering, i.e., allocation according to historic emissions since 1990, but decreasing cap is applied for both SO2 and CO2 emissions.

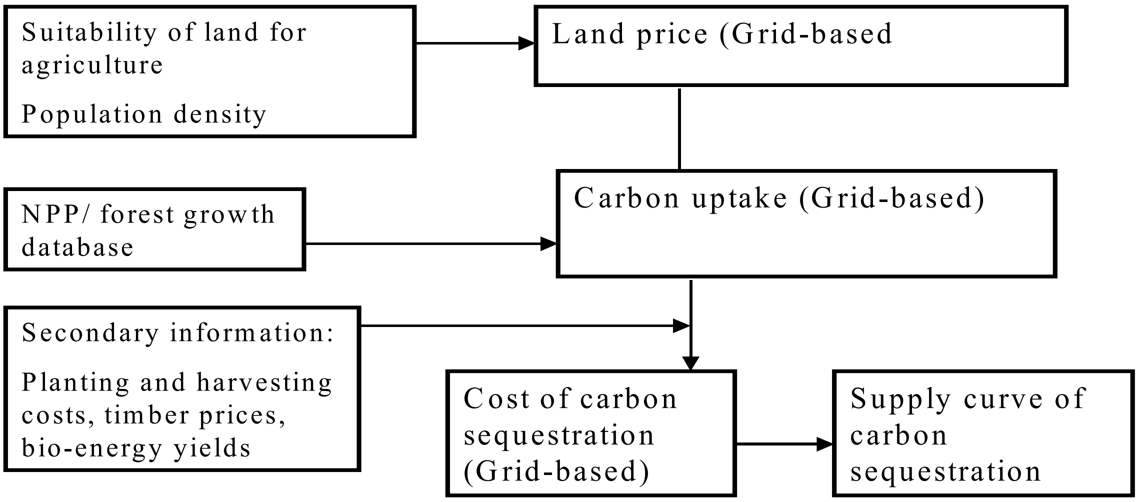
Methodology

The aim of this paper is to estimate a supply-cost curve of carbon sequestration by model simulation. Detailed description of the model used herein is available in Benitez & Obersteiner (2003) and Obersteiner (2004). According to the developed methodology, we use a bottom – up approach, where costs of carbon sequestration are estimated at the grid – level and than aggregated regionally or nationally to generate a single carbon supply curve. The analysis is based on the estimation of the break even price of carbon, i.e., the cost of carbon sequestration beyond which forestry becomes more profitable than agriculture (NPV forestry ≥ NPV agriculture). Box 1 presents an overview of the model as it is presented in Benitez & Oberstainer (2003).

In the model the carbon storage in biomass and products is included, but excludes carbon uptake in soil. The carbon storage in products is divided between long-lived and short-lived.

The model was previously applied to Latin America. We apply it herein to Slovakia. In previous applications, model results were based on data obtained from GIS. We used various statistical data from Slovakia and extend regional details to the county level.

Box 1. Methodological overview.



Input data

The land suitable for reforestation or for the cultivation of short rotation systems was determined using the CORINE land–cover database (LCL, 2000). The database recognizes 44 different land-use categories. The spatial distribution of different land–use types in Slovakia is presented in Fig. 10. We worked with several classes of for non–forested land, namely: non–irrigated arable land, permanently irrigated land, pastures, annual crops associated with permanent crops, complex cultivation patterns and land principally occupied by agriculture, with significant areas of natural vegetation and agro-forestry.

We performed analyses for both reforestation and short-rotation systems under four different scenarios:

Scenario 1: Pastures

This scenario considers reforestation of pastures from the CORINE database for Slovakia. The average potential for short rotation systems on pastures is about 60% of maximum attainable annual yields. This assumption is based on national estimations that include quality expressed in the national 100-point scale with application of the best available technology (Green report, Agriculture, 2002).

Scenario 2: Agricultural land

This scenario considers reforestation of all the categories for non–forested land from CORINE database.

Scenario 3: Low quality land

This scenario considers reforestation of low-quality land, based on the normative economic assessment of the quality of land in Slovakia (Materiál z rokovania vlády, 2004). We tried to follow the national criteria for the selection of less-favored areas, although, due to the nature of the GIS structure employed herein, we were only able to select two criteria from all proposed indicators at national level: yield of crops per hectare on agricultural land is less than 80% of national average (3.89 t/ha); average population density is less than 72 persons per km2 (less than 65% of national average).

Land was selected according to its potential for crop production (Fischer et al., 2003) and population density per grid. We introduced a modified scenario 3 as well, covering land with less than 60% of crop yields per hectare on agricultural land and average population density of less than 72 persons per km2.

Scenario 4: Marginal land

This scenario considers reforestation of medium or lower quality land from whole agricultural land evaluated in the previous three scenarios. Land was selected according to its potential for crop production (Fischer et al., 2003). In this analysis we included land with moderate or less potentials, which means 0 – 40% of maximum attainable annual crop yields. The selected area represents also land with medium or lower quality for short rotation systems.

The first two scenarios were used to indicate maximum sequestration potentials for Slovakia. By contrast, the last two scenarios can be useful in practice, i.e., for evaluating the feasibility of carbon sequestration enhancing activities in Slovakia, with some regional detail, provided it is recognized they focus on land quality regardless of the actual land–use type.

Discount rate

Analyses for both reforestation and energy biomass forest plantation were conducted with a 5% discount rate, which is typical for projects related to energy savings and efficiency measures in CEE countries (Obersteiner 2003 personal commutation). The discount rate of 5% has been suggested for bio-energy projects, including reforestation projects (Gustavsson, et al., 2005).

Estimation of the carbon uptake (C t $ha^{-1}y^{-1}$)

The rate of carbon uptake was estimated as a function of current NPP for each grid. In our analysis, we assumed a carbon uptake is 50% of the NPP of each grid (Benitez & Obersteiner, 2003). The calculation of the grid–based NPP, was done according to the model described by Xinshi & Guangsheng (1995). The calculated NPP in this methodology does not depend on the condition of soil in each grid. As a result, the computed NPP levels were consistently higher than the data available from for forestry statistics for the country (EUROSTAT, 1999). We calibrated the calculated NPP data according to the average level in the statistics mentioned above, recognizing that by doing so our methodology cannot capture differences in NPP due to heterogeneous soil distributions, but depends entirely on climatological parameters. However, this limitation is in part overcome by usage of potential yield data from the IIASA-LUC database (Fischer et al., 2003), which allows determination of different land productivity categories based on soil characteristics as well.

Time period (years)

The time period in our projections is up to 2100. In the presentation of the results, we selected shorter periods in order to specifically analyze conditions of Kyoto and post-Kyoto time horizons, as well as for evaluating the impact of implemented activities on the RES.

Rotation interval (years)

We used the same methodology for the estimation of rotation intervals for reforestation and for short rotation systems. The optimal rotation period is computed by determining the age when current yield equals the average yield. This leads to the computation of the biologically optimal rotation length, which is price-independent (Obersteiner, 2004).

Wood volume (m3/ha)

The wood volume extracted from the forest due to harvesting operations is directly derived from the stem volume assuming an efficiency factor for harvest of 85% (Obersteiner, 2004).

Plantation costs ($/ha)

The plantation costs were estimated for each county as average plantation cost available from reports and studies listing statistical data (Green report, Forestry, 2002; Energy centre Bratislava, 2002). We used different plantation costs for reforestation and for short rotation systems. Due to the relatively high population and road density in Slovakia, transportation costs account for less then 5% of total costs (Renewable energy in Slovakia, 2001). Additional plantation costs due to terrain characteristics and slope were omitted in this analysis.

Wood price ($/m3)

The wood price was estimated for each county as a function of GDP of each county and average price of wood for whole country. For the reforestation projects, we used the average wood price based on national statistics. For the short-rotation systems, we used the average prices for fuel wood from national statistics (Green report, Forestry, 2002).

Fraction of carbon stored in products

For the estimation of the amount of short and long-term products we followed the methodology used by Obersteiner (2004). On the other hand, we expected that the wood produced by short-rotation systems be mainly used as fuel wood. In that case, we do not have precise information about the life–cycle of the wood and about the storage in long-lived products. Therefore we assumed, perhaps conservatively, zero storage in long–lived product.

Land price, $/ha

In general land prices under well-functioning markets should reflect the profitability of parcels, which can be further linked to the quality of the land and incentives to select a proper species in order to maximize benefits (Currie, 1981; Polsky, 2004). The observation that the land value reflects on its net production value is called Ricardian approach, named after David Ricardo (1772-1832). Mendelsohn et al. (2000) applied this principle by linking crop output and prices, purchased inputs and prices, economic variables (i.e. market access), water availability, and a quadratic formulation of climate attributes in a function that maximizes achievable yields under changing climate. In our model, to address the importance of land price in farmers planting decision, we included official and market land prices as well.[2]

In the estimation of the land prices, we used the approach of Benitez & Obersteiner (2003), defining the land price as a function of two variables: the variable S (suitability of the land for agricultural use, incorporating soil, climate and other environmental conditions; here we use grid-level values estimated by Fischer et al., 2002 for Slovakia) and the variable D, referring to infrastructure and access of products to markets. Using a Cobb-Douglas function as applied in Benitez & Obersteiner (2003), land price is estimated as,

$$L = K \cdot (S \cdot D)^{\alpha}.$$

The parameter D was estimated as a function of population density P. Where the population density has large values, such as in cities, developed infrastructure and good access to the market may be expected, and vice-versa. In the original approach, the population density was known on a grid with a spatial resolution of 0.5 degree. The parameter D was then computed as the aggregation of the population density on a grid with a spatial resolution 3.5 degree in order to take into account the influence of population density in near surroundings of cities. With this approach a grid cell with large population density influences the prices of land in surrounding grid cells up to some distance and then the impact cuts down to zero.

By contrast, in this study we model the population density impact on land price using a Gaussian function. The shape of this function represents the expectation that the impact of population density at grid (k,l) is highest in the surrounding of (k,l) and smoothly declining with the distance from the grid. In this case the population density $P(k,l)$ in the grid with spatial coordinates (k,l) creates an impact $D_{k,l}(x,y)$ on the price of land in the grid with spatial coordinates (x,y), which is given by

$$D_{k,l}(x,y) = P(k,l)\frac{1}{2\pi\sigma^2}\exp(-\frac{(x-k)^2+(y-l)^2}{2\sigma^2})$$

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[2] Unlike the Mendelsohn et al (2000) approach, the model does not include data about future climate change, but instead reflects on the quality of land and costs of both inputs and outputs.

where σ is a parameter controlling the width of the Gauss function. The total impact of the population density from all grids (k,l) on the price of land in the grid with spatial coordinates (x,y) is given by a sum[3]

$$D(x,y)=\sum_k\sum_l D_{k,l}(x,y)=\frac{1}{2\pi\sigma^2}\sum_k\sum_l P(k,l)\exp(-\frac{(x-k)^2+(y-l)^2}{2\sigma^2})$$

The parameter σ has to be determined from data in order to express the influence of the distance from sites with high population density on the land price correctly. This estimation step is described below.

Taking the logarithm of the price of the land, the logarithm of the Cobb–Douglas function is a linear function with parameters K and α. These two unknown parameters could be estimated using a linear regression model, if we could know the values of variables S, D and L values in a sufficient number of areas with different values of the product $S \cdot D$ in different counties. Unfortunately, there was no database with this information available for us. Another approach was applied in Benitez & Obersteiner, (2003), where a system of two linear equations – one for the maximum land price and the other one for the minimum land price was solved and in this manner the unknown parameters were calculated. In this assumption the maximum land price corresponds to agricultural land with highest suitability and with highest population density. Similarly, the minimum land price corresponds to land with low agricultural quality agricultural and population density.

For Slovakia, this approach did not lead to good results, because the lowest land price is set to fixed value (5000 SKK) and the highest land price is probably distorted by speculation, in the near surroundings of large towns. When we computed the average land price in each county based on this approach the results did not correlate well with observed average prices. (Table 2, Model 1).

Table 1. Comparison of normalized results from two different methods of estimating land price model 1 – parameters K and alfa estimated at the national level; and Model 2 – parameters K and alfa – estimated at the county level based on average suitability for agriculture and average value of the filtered population density; sigma = 28,73).

County	Average land price	Estimation by Model 1	Estimation by Model 2		
		K = 31,7; alfa = 0,26	Price	K	Alfa
Bratislava	1.58	1.25	0.78	29,4	0,21
Trnava	1.92	1.23	1.97	33,2	0,19
Trecin	0.74	1.36	0.69	24,3	0,29
Nitra	1.79	1.24	1.90	31,7	0,17
Zilina	0.30	1.04	0.24	20,1	0.39
Banska Bystrica	0.54	1.15	0.57	21,8	0,24
Presov	0.41	1.10	0.47	18.9	0.32
Kosice	0.74	1.40	0.70	27,2	0.22

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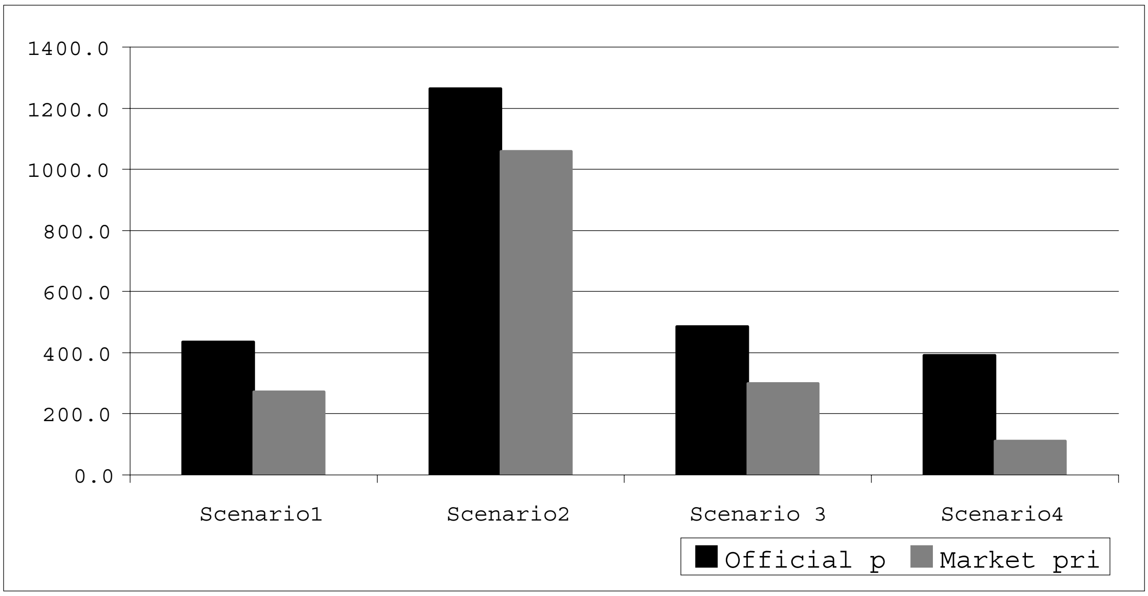
[3] For details see Barlow (1989) and Olano & North (2000).

Therefore a different method was developed. From data of the Statistical Office, we know the average prices of pastures and arable land in each county. From GIS database, we could estimate the average suitability for agriculture and average value of the population density for pastures and arable land, respectively. Based on these values we could solve the system of two linear equations and estimate the K and parameter for each county. This method leads to a good correlation with average land prices except for Bratislava county, where the real land prices are much higher than estimated using the model. (Table 2, Model 2). The land price model has been estimated several times with different values of the parameter σ of the Gaussian convolution kernel until the optimal parameter σ was found resulting in the best correlation between real and estimated land prices. In this way we determined the function, which best describes the influence of the population density on the price of the land.

Figure 4. Average land price for the analyzed scenarios ($/ha) based on the model simulation.



Note: Prices are based approximately on $1=45skk exchange rate.

Another important aspect of the assessment of the land price is the consideration of the market prices for land. In Slovakia, the land market is quite poorly developed and there is no official database of the market land prices. These prices are distorted by speculation and the supply of agricultural land is much higher than demand.

The main patterns of the market prices compared with the official prices are (Green report, Agriculture, 2002):

- Higher prices for land near big cities;
- For the higher quality agricultural land, the prices are at the level of official prices;
- The prices for land with lower quality are lower by about 1/2 – 1/3 compared to official prices.

To take these land price in the model, we multiplied the estimated land prices obtained based on official prices by a linear function of the normalized value of suitability for agriculture, resulting in a correction factor in the range of 1 for good agricultural land, to 0.3 for poor agricultural land.

Results

Introduction

The aim of this study was to estimate the cost of carbon sequestration through reforestation and through short rotation systems. We considered different types of competing land activities in four scenarios. In the presentation of results we use two types of figures. The first type of charts presents the carbon sequestration supply curve, i.e., supply potentials of sequestered carbon corresponding to different carbon prices. This type of figure can be easily transformed to show the amount of produced biomass. We decided to use this type of result presentation, because it allows for comparison of produced biomass regardless of the wood quality. The second type of charts presents the cumulative carbon storage in biomass in the time period considered.

We calculated carbon costs associated with the four main land scenarios. We also performed simulations with two different land prices, i.e., based on government-specified “official” prices, as well as on market prices. The results were calculated using a 5% discount rate. The impact of alternative discount rates is discussed separately. In addition, analyses were conducted with and without assuming carbon storage in products. Results assuming the exclusion of uptake in products are more appropriate in the case of short rotation systems, in which the produced wood used mostly as a fuel wood without possibilities of carbon storage in products. In the model simulations, we assumed that forest or short rotation systems are harvested periodically.

We simulated two types of carbon sequestration activities, and compared these two options from the perspective of sequestered carbon, prices and land requirements.

Sequestered carbon and the price of carbon

For all scenarios, we conducted the simulation for both types of alternative activities to enhance carbon sequestration. The results are presented in the following figures: Figure A.1 (Scenario 1), Figure A.2 (Scenario 2), Figure A.3 (Scenario 3) and Figure A.4 (Scenario 4) in the Annex. The figures represent the carbon sequestration potential for a continuous range of prices with land price based on official prices and market price together with storage in long-lived products. For all scenarios, the average revenue per unit of sequestered carbon is higher than zero; the cost curves begin at prices greater than 0 per unit of carbon (Figures A.1 – A.4). It indicates that the direct revenue generated by the mitigation option from the sale of timber and other products does not exceed its planting costs. The average price of carbon is significantly higher without inclusion of carbon in long–lived products.

For instance, the prices[4] relative to an average carbon sequestration rate of 1 tonne under reforestation Scenario 1 varies from $ 30 t C/ha (official land price) to $ 34 t C/ha (market land price); Scenario 2 varies from $ 31 t C/ha (official land price) to $ 22 t C/ha (market land price); Scenario 3 varies from $ 34 t C/ha (official land price) to $ 29 t C/ha (market land price) and Scenario 4 varies from $ 22 t C/ha (official land price) to $ 17 t C/ha (market land price). The estimated price of sequestered carbon under short rotation plantation varies with each scenario. In the case of Scenario 1 the estimated cost of tone of carbon by using official land prices is approx. $ 23 and $20 when market land price is applied. For Scenario 2, the estimated price is about $17 per tonne of C on hectare of land with official price and $16 market land price. For Scenario 3 the following prices were calculated $24 t C/ha with official price and $21 t C/ha with market price and for Scenario 4 $60 t C/ha (official land price) and $59 t C/ha (market land price).

From the charts in the Annex, it is clear that initially the production of biomass (carbon accumulation respectively) is more profitable for short rotation systems. This is due to the nature of species used in that kind of activity, which during a short rotation interval accumulate a relatively high amount of carbon into biomass (high carbon density). On the other hand, if the accumulated carbon reaches the potential of the species, further accumulation becomes very expensive and strongly depends on the quality of land and the intensity of cultivation. Generally speaking, agricultural and forestry productivity correlated quite well, indicating that in areas with high quality arable land the estimated forestry activities lead to higher yields and vice-versa.

In the case of Scenarios 3 and 4, we examined the potential of low quality and marginal land use for the alternative activities. It can be concluded that short rotation systems have higher yields on agricultural land than on pastures. Therefore the price per tonne of sequestered carbon is lower on the former. The potential for short rotation systems on agricultural land is higher in terms of obtainable yields, because of better quality land. For all scenarios, projected revenues from carbon-sequestering forestry activities exceed zero. It is apparent that the initial production of biomass is more profitable in case of short rotation systems. In case of Scenario 4, which considers only land with very low quality, activities enhancing carbon sequestration have higher costs per unit of carbon than in the other simulated scenarios. Especially, and importantly, short rotation systems are found to become very expensive with increasing demand for sequestered carbon. For that kind of land and options, reforestation seems a more suitable choice.

Cumulative carbon sequestration

Data for cumulative carbon sequestration, at given time horizons (2010, 2020, 2050 and 2075) are presented in Table 2. Cumulative curves of carbon sequestration in continuous time are respectively presented in Figure A.5 (Scenario 1), Figure A.6 (Scenario 2), Figure A.7 (Scenario 3), Figure A.8 (modified Scenario 3) and Figure A.9 (Scenario 4) in the Annex.

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[4] The price estimates are based on averaged calculated data generated from the model.

The cumulative curves show the importance of land quality[5] for the level of sequestered carbon. From these curves, it is clear that the maximum potential of carbon accumulation is reached approximately at the mid-point of rotation intervals of the short rotation system (about 2020). The overall cumulative estimated potential up to 2010 for all agricultural land is about 12 million t C and approx. 40 million t C up to 2050 t C. For Scenario 1, up to 2010 the level of sequestered carbon is about 60,000 t C. In this case the maximum potential level of sequestered carbon is reached approximately in 2050 at about 175,000 t C. In terms of practical applications, scenario 3 considered herein is the most important. This scenario uses lower quality land. In this case, the sequestered carbon on land regardless of the land use type (normalized per hectare of arable land/pasture) is approximately the same. The total estimated potential up to 2010 for short rotation systems is about 120,000 t C and 230,000 t C in 2050.

Table 2. Cumulative carbon sequestration (in 10^5 t C) in years: 2010, 2020, 2050 and 2075.

	Uptake in products	2010	2020	2050	2075
Short rotation forest plantation					
Scenario 1	Yes	0.6	0.7	1.75	1.4
	No	0.4	1.2	0.7	0.85
Scenario 2	Yes	120	220	395	356
	No	120	180	195	205
Scenario 3	Yes	1.2	1.8	2.3	2.3
	No	0.9	1.3	1.05	1.3
Scenario 4	Yes	0.2	0.75	1.35	1.23
	No	0.18	0.35	0.39	0.45
Reforestation					
Scenario 1	Yes	0.6	1.25	2.45	2.7
	No	0.5	1.2	2.05	2.15
Scenario 2	Yes	120	210	490	520
	No	110	195	395	410
Scenario 3	Yes	1.3	1.85	2.9	3.3
	No	1.1	1.8	2.4	2.5
Scenario 4	Yes	0.32	0.75	2.0	2.3
	No	0.32	0.75	1.4	1.7

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[5] Land quality is reflected through calibration of calculated NPP data according to the average level in the statistics (EUROSTAT, 1999), recognizing that applied methodology cannot fully capture differences in NPP due to heterogeneous soil distributions, but depends entirely on climatological parameters.

The overall estimated potential up to 2010 for land in the Scenario 4 is about 20,000 t C. The potential level of sequestered carbon for this scenario is reached approximately in 2050 at about 135,000 t C. This scenario covers the lower quality land and, as discussed above, reforestation is the better option. In case of reforestation, the overall estimated potential up to 2010 in the Scenario 4 is about 32,000 t C. The potential level of sequestered carbon for this scenario is reached in 2075 at about 230,000 t C. In spite of the higher results obtained at the level of produced biomass during the short rotation systems, the comparison of cost for two alternatives clearly shows the feasibility of reforestation on land.

In all scenarios, the character of curves for biomass forest plantation is also influenced by the short rotation intervals for this type of forestry. The plateau of the sequestered carbon (or produced biomass) for that kind of activity is lower than for the conventional type of forestry. It comes to the basic pattern of short rotation system, for which is typical the relatively high level of sequestered carbon during the short rotation period. The cumulative curves are more suitable for the estimation of impacts on the land use related emissions and their changes over time, because the impact of different land prices and storage in products are clearly presented.

Scenarios and competition between land uses

As mentioned earlier, the land price is the only indicator, which represents the economic performance of agriculture on the land. All simulations were done for official and market prices of land (for details see Chapter 6). Generally, the price per unit of carbon for both activities is higher with land price based on official prices, because these are on average higher than market prices. The distribution of land price for all evaluated scenarios is shown in Figure 4. The highest fluctuation in prices can be detected in case of Scenario 4, which covers land with low physical qualities.

The differences in the quality of the land as well as the distance from larger settlements, have a significant impact on the market prices of land. The land considered in the third and fourth scenario has a very low official price (remote areas and lower quality land) and the market prices are even lower. The quality of the land in Scenario 4 is insufficient to permit the higher level of sequestered carbon by short-rotation systems. For that reason this scenario presents the most suitable option for activities enhancing carbon sequestration by reforestation. In Scenario 3, there is potential for both the alternative activities.

Discounting is the mechanism by which a value for time is normally translated into economic decision–making. Time preference, expressed by means of a discount rate on carbon can strongly influence economic decisions and the social and environmental impact and/or benefits of the favored mitigation options (Fearnside et al., 2000). The length of the time horizon has a strong effect on the importance of discounting. The impact of using different discount rate 1%, 3% and 5% in the simulation is presented on Figure A.10 and Figure A.11 in the Annex.

The analysis is generally conducted with a discount rate of 5%, which is the usual level for energy efficiency projects in Slovakia. To study the robustness of the findings, we completed the analysis also for lower discount rates (1% and 3%), which benefits especially for forestry projects with long rotation intervals. Moreover, the lower discount rates decrease the price of per unit of carbon, which provides more viable options especially for lower quality land.

Table 3. Alternative scenarios of carbon sequestration and biomass production on non–forested land based on Energetics 2001 (2003).

Area available (10^3 ha)	Area available (% of total)	Production (PJ yr^{-1})	Potential share (% of total)
Scenario 1			
496.8	10.2	94.6	13.1
Scenario 2			
2360	48.3	462.9	63.9
Scenario 3 (crop yield per hectare < 80% of national average; average population density <72 persons per km2**)**			
712	14.6	119.7	16.5
Scenario 3 (modified; crop yield per hectare < 60% of national average; average population density <72 persons per km2**)**			
504	10.3	98.8	13.7
Scenario 4 (crop yield per hectare < 40% of national average; average population density <72 persons per km2**)**			
412	7.8	42.3	5.8

Including carbon storage in products has an impact on the overall results for estimating sequestered carbon, in which the storage in products causes a delay in the release of the accumulated carbon. The accounting of the storage of carbon in products is natural in case of forestry; where the harvested wood is only partially burnt in the short term. Accounting for stored carbon in forestry products is meaningful from the perspective of estimation of carbon sinks and consequently for the estimation of the carbon budget of the country. In case of short rotation system, the produced wood is used for energy and heat production, in which case the carbon storage in product is negligible. However, in order to understand the degree of uncertainty associated with variations in predicted levels of carbon storage in products, we performed all scenario simulations with and without carbon storage in products. As mentioned above, from the practical point of view of economic decisions between the two simulated carbon sequestration activities that includes reporting and monitoring of sequestered carbon, results without carbon storage should be given priority.

Extents and impacts of alternative land–use activities for carbon sequestration are presented in Table 3. The results are focused on the estimation of influence of the selected scenario on the overall consequences of sequestered carbon and biomass available as RES at the country level. In these estimations, we included also the results obtained from a modified Scenario 3, which included lower quality and cheaper land,

Table 3 also shows changes in produced biomass (suitable for RES) and their potential as energy sources against overall energy consumption.

In our estimations, the use of total agricultural land for carbon sequestration could generate nearly 64% of (current) energy consumption. The average level of renewable energy generation for Scenario 3 is about 15%. The possible energy offset is lower in the modified Scenario 3, because it includes less land and with lower quality. From the comparison of baseline and both activities, the reforestation and biomass forest plantation can produce higher carbon storage in biomass therefore more biomass is available as sources of RES. However, the land included in Scenarios 3 and 4 is of lower quality not only for conventional agriculture, but also for reforestation and short rotation systems. For that reason, obtaining reasonable yields from the short-rotation systems in lower quality land requires higher economic investments. As noted earlier, while short rotation systems could produce 5,8% of total energy consumption (Scenario 4), the resulting unit carbon price is the highest for all scenarios.

Comparing the two alternative carbon sequestration activities for Scenario 3 and 4, the short- rotation forest plantation is more effective in the short and medium-term perspective because of the higher level of sequestered carbon and additional energy generation. In the long-term, reforestation can achieve higher effects on carbon sequestration and therefore on the mitigation of climate change.

Discussion and Conclusions

Carbon sequestration potential and relevant policy implications

Although changes in land use and land cover can contribute only modestly to reduction of atmospheric CO2 concentrations, there is however little scientific knowledge about the potential sinks in relation to forest ecosystems and their impact on GHG emissions. According to estimations of IPCC, it can be inferred that up to 12–15% of projected carbon emissions from fossil fuels can be absorbed by slowing deforestation by proper forest management, up to about 2050, or by establishing biomass forest plantations [Watson (ed.), 2001]. The overall sequestration potential on agricultural land (Scenario 2) by reforestation is in line with these general estimates, showing that reforestation can absorb approximately 10% of all CO2 emissions of Slovakia.

The time path of the included economic and other scenario factors influencing carbon sequestration has a significant impact on the estimated cost because of the relatively high discount rate employed (Sathaye et al., 2001). According to published estimations, it is expected that half of the cumulative C potential can be implemented at costs lower than the excepted benefits and the other half at costs ranging up to 100 $/tC [Metz & Davison (eds.), 2001]. Although our cost estimations are above zero, they are still consistent with this upper limit. The positive cost potential may be compared with carbon prices that would be needed to implement other options. Simulated cost of carbon sequestration is presented on Figure 5.

The potential of land for reforestation is relatively high in Slovakia. By reforestation of lower quality land (less than 40% of average yield of crops, Scenario 4) the potential for carbon sequestration is about 32,000 t of carbon after five years of plantation and

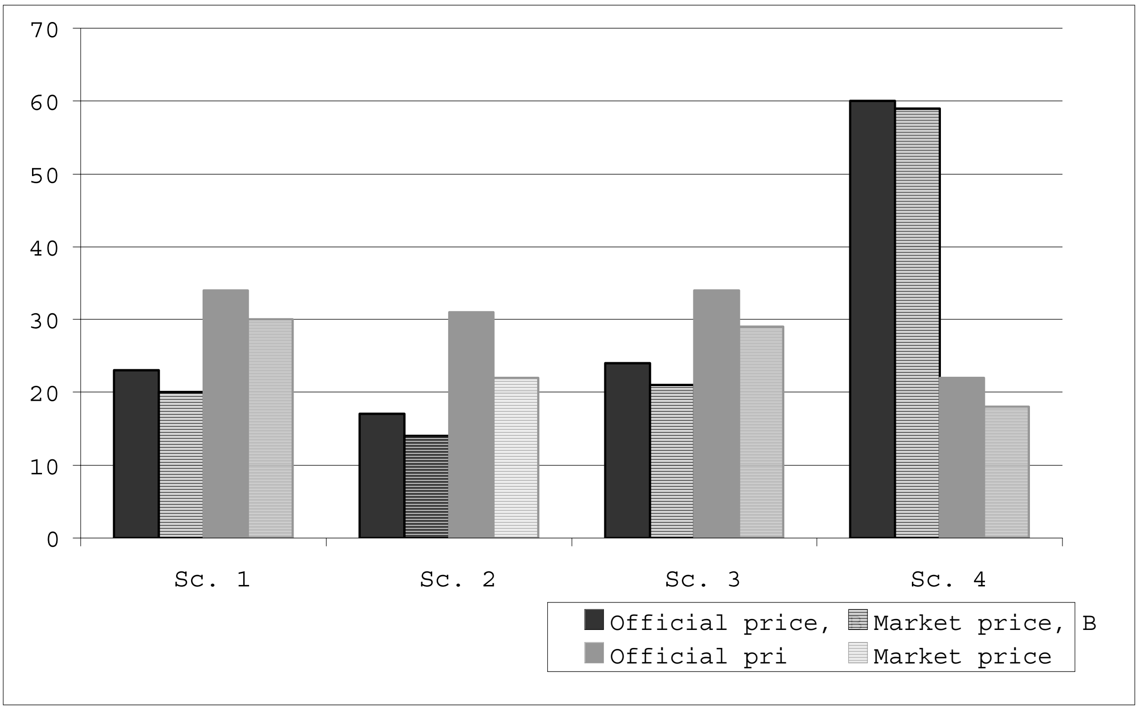


Figure 5. Average price per ton of carbon for different land prices ($/tC)

B = short rotation systems; F = reforestation

70,000 t after ten years. The implementation of the national program to support reforestation (1994) did not achieve its targets and of the planned amount of land only 1.5% was converted to forest. An important reason for the low response was the unclear land ownership structure and the problems with the allocation of the subsidies to landowners. Currently, the estimated reduction of CO2 emissions achieved by this option is less than 0,1% from current level of CO2 emissions. With the implementation of Scenario 4, which is based on marginal land only, the potential for CO2 emissions reduction is about 0.6%.

Reforestation of lower quality land is not understood as a priority option in Slovakia for the mitigation of climate change. Priority is currently given to the regulation of timber.

The impact of regulation of timber was estimated at about 330 – 660 Gg of CO2 yearly (Third report on climate change, 2001). According to our simulation of the potentials for the carbon sequestration in Slovakia, this estimation is rather optimistic (in the short-term about 1.7% and in the longer-term about 2.4% of total CO2 emissions). Slovakia should reconsider the priorities for climate change mitigation and support options, which could have wider socio-economic impacts (such as reforestation). This measure together with replacing fossil fuels by RES is among the main priorities in the EU forest strategy (EC, 1998). Estimated emission reduction potentials through carbon sequestration of different activities are presented in Figure 6.

Based on model simulations increasing the use of RES in energy production, it is expected to reduce emissions in 2000 by about 159,000 tons of CO2 equivalent, in 2005 by about 1.1 million tons, in 2010 by about 1.9 million tons (Third report on climate change, 2000). This amount of reduction is approximately about 4% of total CO2 emissions of Slovakia. With the implementation of Scenario 3 (or the modified Scenario 3) the potential for reduction is about twice as much, when taking into consideration not only sequestered carbon but replacement of fossil fuels as well. The carbon sequestered in soil, which was omitted in our model simulation, will result in some additional

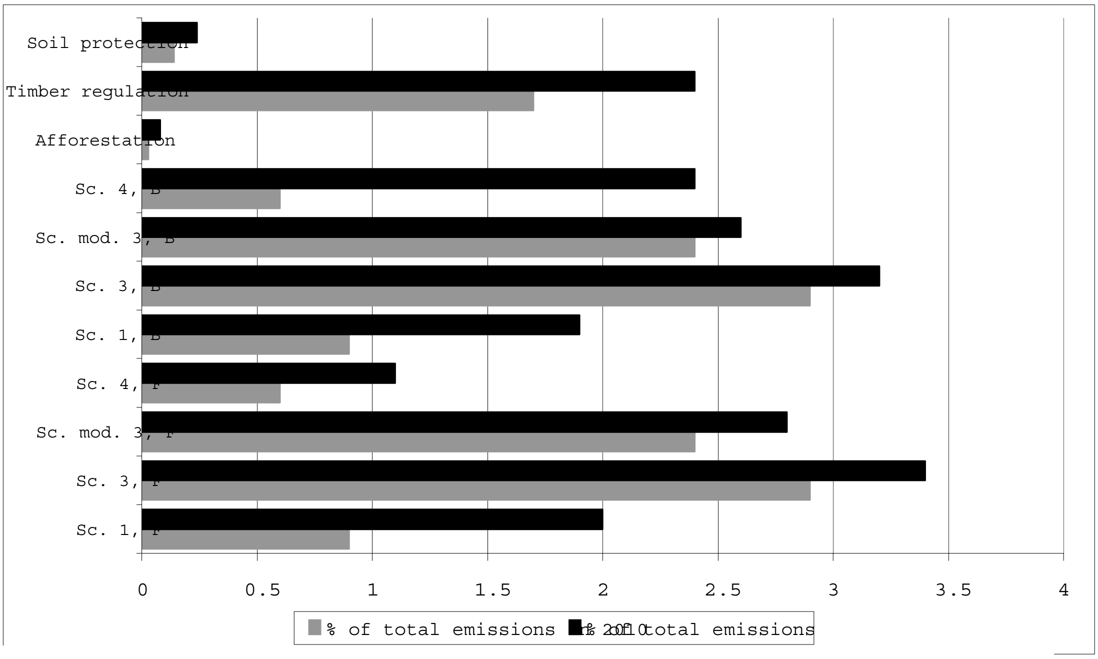


Figure 6. Emission reduction potential of modeled scenarios (F = reforestation, B = short rotation systems) compared to Slovakia's policy priorities. % of total CO2 emissions (Third National Report on Climate Change, 2001).

reduction.

In the CEE transition countries (including Slovakia), moving from large-scale agriculture established during the previous regime to smaller farm sizes resulted in an increase of abandoned land (Keenleyside et al., 2004), which has created opportunities for afforestation and short-rotation plantations. These trends can be supported in transition countries that joined to the EU by policy changes under the CAP reform, (Jilkova, 2003). An expansion of woodlands and consequently, a growing role of forestry in mitigation of climate change may therefore be predicted (Nijnik & Bizikova, 2007).

In order to fulfill the potential contribution of land use and land cover changes to national GHG emission reductions, individual landowners and land users should be given clear and adequate incentives. This can be reached by incorporating both positive and negative effects of certain land use types in the prices on which the land use decisions are based (Folmer et al., 1995). Therefore it is at least necessary to integrate climate change policies for carbon sequestration and other mitigation options with spatial planning, agricultural policy and policies for sustainable energy systems. In Slovakia, there is a strong division between environmental, economic and social issues of coping with a changing climate and between various sectors of the economy (MoE, 2001). As mentioned before, one example of such weak linkages was the low level of achieved afforestation under the national program due to a failure to allocate subsidies to landowners and managing land with diverse ownership structures.

However, the situation has improved due to the EU accession process. The reforms of public administration, involving the formation of regional governments with a decision-making power were completed in 2002. The leadership in the implementation of environmental policies at a regional level is developing slowly. There is a need for capacity building and for support of institutional structures at the regional level in order to address complex issues such as climate change. The development of carbon sequestration policies and their impact assessment should be conducted in close collaboration with major stakeholders, and substantial efforts should be put into increasing the awareness of farmers, forest managers and decision makers concerning various aspects of climate change (Olsen and Bindi, 2002). There is a need for information campaigns, training facilities and pilot schemes to demonstrate carbon sequestration forest management possibilities and to make them attractive for end-users involved in policy implementation.

Potential of biomass as RES

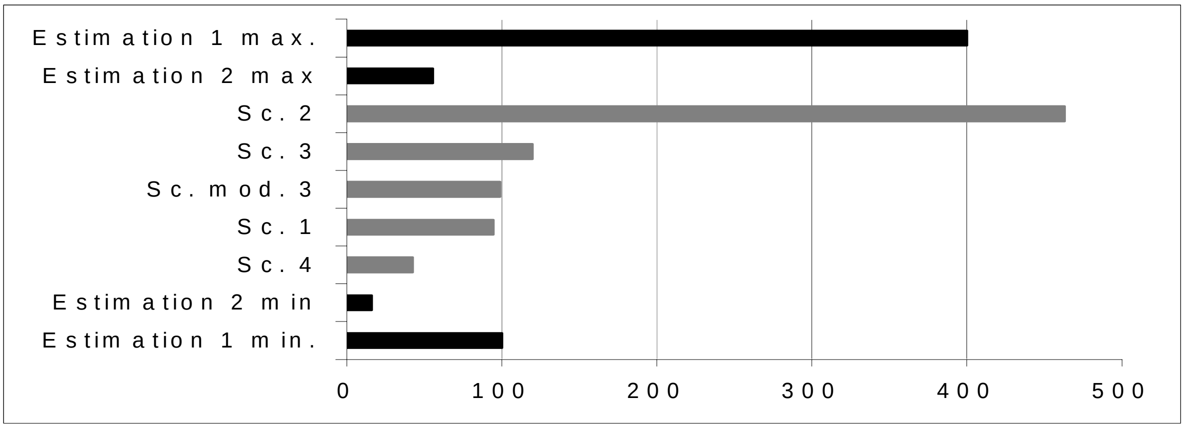
Biomass energy is increasingly being accepted as a possible alternative to fossil fuels. In EU Member States, the future of biomass energy as a renewable energy source has been strongly enhanced by its consideration in the climate change debate, as can be seen in the different issues identified in the Kyoto protocol (EC 1995, 1997, 1998, 2002 and 2005). Within the EU, the biomass discussion is in addition driven by considerations of rural development and job creation, increasing energy self-sufficiency and improving competitiveness.

Increasing the share of RES in energy production is one of the priorities for dealing with climate change mitigation in Slovakia. Biomass as a RES is particularly attractive, due to the large availability of land suitable for biomass forest plantations. To this end, our estimates of overall biomass energy potentials for Slovakia are within the range of previous studies, i.e., from 100 to 400 PJ (Energy centre Bratislava, 2002). The estimated range is very broad because it corresponds to different land utilization, from considering all agricultural land to only selected land use types such as pastures.

The energy policy for Slovakia estimates a realistic potential of renewable energy sources in 2010 of approximately 55.4 PJ. From that amount the contribution of biomass is about 40%, which represents 5 GWhy-1 (Energy policy of the Slovak republic to 2005, 1999). A comparison of the potential contribution of biomass as RES for each modeled scenario is presented on Figure 7.

The potential for energy biomass forest plantation for poplar, willow and miscanthus is estimated to be up to 13.1% of energy consumption, or 94.8 PJ (Fischer et al., 2001; Fischer et al., 2003). This estimation is based on an amount of land comparable with modified Scenario 3. This scenario as well as the original Scenario 3 provides an option for the areas with lower quality land and with lower population density. The renewable energy generated by these scenarios is nearly double the level estimated by the Energy Center to 2010. According to the above-mentioned Energy policy of Slovakia until 2010, the country is expecting increased use of biomass (including waste from agriculture and forestry) for energy production, reaching approximately 6% of total energy consumption. This number can be reached by biomass planted on land, and is close to half the level estimated for Scenario 3.

Figure 7. Potential contribution of biomass to energy production for each modelled scenario and published minimum and maximum potential in PJ.y-1.



Source: Estimation 1 - Energy centre Bratislava, 2002; estimation 2 - Energy policy of the Slovak republic to 2005, 1999.

A more realistic variant is the modified Scenario 3 with the exclusion of marginal land (Scenario 4). The energy equivalent of production by short-rotation systems on that land is roughly 7.7% of total energy consumption, or 56.5 PJ. This energy production potential refers just to newly established plantations and does not take into consideration those currently available, as well as it excludes processed agricultural wastes (from plant production). The extent of land required for the short-rotation systems could be decreased, if the exploitable waste from plant production is utilized. The available straw and other biomass, when used at the exploitable level is equivalent to approximately 6 –

7 PJ (Renewable energy in Slovakia, 2001). In conclusion, when using the available biomass waste, the implementation of national RES targets would require an amount of land equal to half of land under modified Scenario 3 (ca. 250 10 thousand ha). Exploiting the full potential for energy production of waste biomass from forestry and agriculture as set in the Slovak national target requires 180 thousand ha of short rotation systems.

The economic dimension of carbon sequestration through short-rotation systems and reforestation was presented at aggregated level in Figure 7 in the previous chapter and in detail in the Annex (Figs. 1 - 4). According to previously published estimates, prices for the heat production from biomass per tonne of carbon range from 20 $/t C for individual households to 40 $/t C for central heating systems, and the price of industrial energy production from biomass is on average 42 $/t C (Third report on climate change, 2001). These estimations did not assume additional costs for planting and processing of biomass. Including these additional sectors, our study indicates that the cost of a tonne of carbon ranges about 45-60 $/t C. The cost depends on the price of land, used for biomass cultivation. Lower quality land can decrease the price by about 5 $/t C. In comparison with the costs of alternative RES and related CO2 emission reduction, biomass is thus still the most promising RES option for Slovakia.

Utilization of biomass is expected at the regional level and depends on the development of each region and the implementation of future regional energy plans. Biomass plantations for energy purposes are of high importance for in agricultural policy, but no measures for supporting this option are yet proposed (Koncepcia agrárnej a potravinovej politiky, 2000). Utilization of alternative energy sources may also yield options for achieving significant environmental quality improvements. Energy generated from biomass is one possible solution for Slovakia and other new Member States, with the potential to address several environmental concerns while also providing social benefits. At the same time, since the price of energy can be a substantial component of manufacturing costs for some processes, promoting the use of biomass for energy must be balanced against the need to keep energy prices as low as possible.

Without regulatory incentives, competition is likely to steer investments away from RES and attainable potentials would remain unexploited. In Slovakia, the current energy market includes substantial institutional barriers, as well as long–term subsidies to conventional type of energy. Increasing the share of renewable energy can be supported by JI (Joint Implementation) that provides opportunities to benefit from experiences with clean energy in developed countries (Guidance for the Joint implementation project, 2002). In particular, European investors are clearly showing the interest to invest in JI in transition countries (Schwarze, 2000). However the potential gains from JI projects are not understood as priorities for climate change mitigation in Slovakia (Fankhauser and Lavric, 2003). Nevertheless, results show that bioenergy produced from biomass planted on marginal land can provide 6 – 17% of total energy consumption. Yet, unless the necessary institutional infrastructure is developed and barriers for investment are identified and addressed, Slovakia cannot expect to benefit widely from crediting JI systems. Clear government mandates for domestic JI objectives can reduce confusion and encourage project implementation (Petkova and Faraday, 2001). Currently, intra-European credits for the activities enhancing carbon sequestration will not be included in the carbon trading schemes (EC, 2003; Criqui and Kitous, 2003). Therefore Member States should create sound incentives for short-rotation plantation and afforestation, with a proper level of subsidies to be given to landowners for planting trees.

Overall, the implementation of flexible mechanisms would have positive effects on the integration of companies (business sphere), the improvement of knowledge of the stakeholders and for creating linkages with other national policies, as well as internationally (Nijink and Bizikova, 2007). The increased use of bio-energy can also bring with it direct social benefits, such as job and income creation in rural and/or remote areas. The actual impact is often difficult to estimate, requiring extensive modeling, and much more research is needed in this area.

For CEE countries, it is also necessary to mention the importance of stakeholder/public participation in the policy formulation, project planning and decision-making. It seems that the support of the education and the dissemination of the information regarding RES availability, the benefits and potentials for renewable energy are important pre–condition for any policy option. In particular, this can be promoted though information campaigns, training facilities and pilot schemes to demonstrate carbon sequestration forest management possibilities and to make them attractive for end-users involved in policy implementation.

Next steps

Agriculture and forestry in Slovakia have increasingly come to the fore of national and regional policy formulation with respect to sustainable development. Alternative land use activities have differential impacts in contributing to GHG emissions, such as opportunities for abatement as sinks, or use as alternative renewable energy sources (biomass, bio–liquid fuels etc.). The assessment of the potential of carbon sinks in forestry and agriculture is important information, needed for the selection of optimal GHG abatement policies. To this end, formulation of land-based climate mitigation goals needs to become increasingly integrated into natural environmental policy.

In the model we assumed, conservatively, current agricultural practices only; potentially higher support for implementation of RES in coming decades can be expected to foster forestry technology and efficiency, leading to higher yields than considered herein.

Some of the conclusions in this paper are derived from rather narrow perspective formulated from carbon sequestration and its potential. An economic analysis that considers additional factors might conclude that displacement of fossil fuel is not the most profitable usage of timber. Similarly, environmental impact assessments might conclude that establishment of short-rotation systems could have negative impacts on biodiversity in some areas, despite it being more profitable than reforestation.

Future work should focus on more detailed analyses for the regions with higher potential for short rotation systems. In order to provide realistic conclusions, such studies will need to seek the opinion of key stakeholders for scenario construction and for adjusting model simulation results, as the most recent research in the filed of climate change is beginning to recognize. The participatory approaches used for the presentation of opinions mainly the local participants allow us to create scenarios better reflecting the conditions of local and regional level. Implementing approaches that involve key stakeholders in the preparation of scenarios will allow to bring into the analysis important social dimensions that have been overlooked in current analyses.

References

Barlow, R. J. 1989. Statistics: a guide to the use of statistical methods in the physical science. John Wiley and Sons, New York.

Bedi, E., 1996. Possibilities of development of Slovak energy sector. The Swedish NGO Secretariat on Acid Rain, Ministry of Environment, Bratislava.

Benitez, P. & Obersteiner, M., 2003. Costs of carbon sequestration trough tree planting in marginal land: model simulations in Latin America. Interim report, International Institute for Applied Systems Analysis (IIASA), IR-03-019, Laxenburg.

Blaas, G. (ed.), 1999. Analýza vývoja poľnohospodárstva a potravinárstva v období rokov 1990–1998. Výskumný ústav ekonomiky poľnohospodárstva a potravinárstva, Bratislava.

Criqui, P. & Kitous, A., 2003. Kyoto protocol implementation. KPI Technical report: impacts of linking JI and CDM to the European emission allowance trading scheme (KPI – ETS). KPI for Directorate general environment, Brussels.

Currie, J., 1981. The economic theory of agricultural land tenure. Cambridge University Press, Cambridge.

Ecotec, 2002. Renewable Energy Sector in the EU: its Employment and Export Potential. A Final Report to DG Environment, Birmingham.

Energetics 2001, 2003. Štatistický úrad Slovenskej republiky, oddelenie odvetvových štatistík, no. 510 – 0090/2003, Bratislava.

Energy centre Bratislava, 2002. Trans–European Biofuel Transportation Analysis, Slovakia. Energy centre Bratislava, Bratislava.

Energy policy of the Slovak republic to 2005, 1999. Slovak Ministry of Economy, Bratislava, www.economy.gov.sk.

EUOSTAT, 1999. Forestry statistics Data 1995 –1998. Eurostat, Luxemburg.

European Commission, 1995. White paper on An Energy Policy of European Union, Brussels. COM(95)682.

European Commission, 1997. Energy for the Future: Renewable Sources of Energy. White Paper for Community Strategy and Action Plan, Brussels. COM(97)599 FINAL (26/11/1997).

European Commission, 1998. Communication from the commission to the council and European parliament on a forestry strategy for European Union, Brussels, COM(1998)649, 03/11/1998.

European Commission, 2001. Proposal for a directive of the European parliament and of the council – establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC, Brussels, 2001/0245(COD).

European Commission, 2002. EU burden sharing. Council decision 2002/358/EC, Brussels.

European Commission, 2003. Proposal for a directive o the European parliament and of the council amending the directive establishing a scheme for greenhouse gas emission allowance trading within the Community, in the respect of the Kyoto Protocol's project mechanisms. Brussels, SEC(2003)785.

European Commission, 2005. Winning the Battle Against Global Climate Change. Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee And The Committee Of The Regions, COM(2005) 35 final.

Fankhauser, S. & Lavric, L., 2003. The investment climate for climate investment: Joint Implementation in transition countries. Climate Policy 3, 417 – 434.

Fearnside, P. M., Lashof A. D. & Muora – Costa, P., 2000. Accounting for time in mitigating global warming through land – use change and forestry. Mitigation and adaptation strategies for global change 5, 239 – 270.

Fischer, G., Prieler, S. & Velthuizen van, H., 2001. Biomass energy from agricultural crops and plantation forestry; results and policy implication for North, Central and Eastern Europe. Proceedings of the System aspects of greenhouse effects versus sustainable rural development: biomass, biofules and fuel cells. System Research Institute, Polish academy of sciences, 26. – 29. September, Warsaw.

Fischer, G., Prieler, S. & Velthuizen van, H., 2003. Biomass potentials of miscanthus, willow and poplar: Results and policy implications for Eastern Europe, Northern and Central Asia. Biomass and Bioenergy, 28,119-132.

Fischer, G., Velthuizen van, H. T., Shah, M. M. & Nachtergaele, F. O., 2002. Global agro–ecological assessment for agriculture in the 21th century: Methodology and results. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, report RR – 02– 002.

Folmer, E., Gabel, H. L. & Opschoor, H., 1995. Principles of environmental and resource economics. A guide for students and decision–makers. Edward Elgar, Aldershot, Brookfield.

Fourth national communication for UNFCCC Slovak Republic, 2006. Ministry of Environment, Bratislava, Slovak Republic.

Fourth National Communication of the Czech Republic on the UN Framework Convention on Climate Change and Demonstrable Progress Report on Implementation of the Kyoto Protocol, 2005. Ministry of the Environment of the Czech Republic Czech Hydrometeorological Institute, Prague.

Framework Convention on Climate Change, Republic of Poland, 2001. The Polish UNFCCC Executive Bureau Department of International Cooperation National Fund for Environmental Protection and Water Management, Warszawa.

Green report. Agriculture, 2002. Ministry of agriculture, Bratislava. www.mphs.gov.sk.

Green report. Forestry, 2002. Ministry of agriculture, Bratislava. www.mphs.gov.sk.

Guidance for the Joint implementation project, 2002. Ministry of Environment, Bratislava, Slovak Republic. www.enviro.gov.sk.

Gustavsson, L., Mahapatra, K. & R. Madlener, 2005. Energy systems in transition: perspectives for the diffusion of small-scale wood pellet heating technology .Int. J. Technology Management, 29, 327 – 347.

Houghton, J. T., Filho, L. G. M., Callander, B. A., Harris, N., Kattenberg, A. & Maskell, K., 1996. Climate change 1995: the science of the climate change. Intergovernmental panel for climate change (IPCC). Cambridge University Press, Cambridge.

Jílková, J., 2003. Daně, dotace a obchodovatelná povolení – nástroje ochrany ovzduší a klimatu. Institute for structural policy (IREAS), Prague.

Keenleyside, C., Veen, P. & Baldock, D., 2004. Abandonment in the new Member States and Candidate Countries and the EU common agricultural policy. VEEN Ecology, background paper, Sigulda.

Koncepcia agrárnej a potravinovej politiky, 2000. Koncepcia schválená vládou Slovenskej republiky 13. 10. 2000. www.mpsr.sk.

LCL, 2000. CORINE land-cover database 2000, European Topic Centre on Terrestrial Environment, http://image2000.jrc.it/clc/index.cfm

Materiál z rokovania vlády, 2004. Návrh mechanizmu na podporu rozvoja trhu s poľnohospodárskou pôdou – nové znenie. Ministerstvo pôdohospodárstva (r. č. 3089/2003 – 100), číslo uznesenia 193/2004.

Mendelsohn, R., Morrison, W., Schlesinger, M. E. & Andronova, A. G., 2000. Country-specific market impacts of climate change. Climatic Change 45, 553–569.

Metz, B. & Davison, O., (eds.), 2001. Contribution to the Intergovernmental panel on climate change (IPCC). Third assessment report. Working group III. Cambridge university press, Cambridge.

MoE, 2001. Third report on climate change. Ministry of Environment, Bratislava.

National Energy policy, 2000. Slovak Ministry of Economy, Bratislava, www.economy.gov.sk.

Nijnik, M. & Bizikova, L., 2007. The EU sustainable forest management and climate change mitigation policies from a transition countries perspective. In: Sustainable Forestry: From Monitoring and Modelling to Knowledge Management and Policy Science, K. M. Reynolds (ed.), CABI publishers.

Obersteiner, M., 2004. Supply curve of carbon sequestration trough tree planting in Former Soviet Union and Poland. Interim report, International Institute for Applied Systems Analysis (IIASA), Laxenburg, in press.

Olano, M.& North, M., 2000. Normal Distribution Mapping. University of North Carolina, Chapel Hill.

Olesen, J.E. & Bindi. M., 2002. Consequences of climate change for European agricultural productivity, land use and policy. European Journal of Agronomy 16, 239 – 262.

Petkova, E. & Faraday, G., 2001. Good Practices in Policies and Measures for Climate Change Mitigation. A Central and Eastern European Perspective. The regional environmental center for Central and Eastern Europe and World Resource Institute, Szentendre.

Polsky, C., 2004. Putting Space and Time in Ricardian Climate Change Impact Studies: Agriculture in the U.S. Great Plains, 1969–1992. Annals of the Association of American Geographers, 94: 549–564.

Rafaj, P., Borseková, I., Hecl, V., Hadzhivanov, A. & Gregor, R., 2001. Energy sector of Slovakia. Energy centre Bratislava, Bratislava.

Renewable energy in Slovakia, 2001. Energy center, Bratislava, www.ecbratislava.sk.

Renewable Energy Policy Project, 2002. The work that goes into renewable energy. Research report number 13. Renewable Energy Policy Project (REPP), Washington, www.repp.org.

Sathaye, J. A., Makundi, W. R., Andrasko, K., Boer R., Ravindranath, N. H., Sudha, P., Rao, S., Lasco, R., Pluhin, F., Masera O., Ceron, A., Ordonez, J., Deying, X., Zhang, X. & Zuomin, S., 2001. Carbon mitigation potential and costs of forestry options in Brazil, china, India, Indonesia, Mexico, The Philippines and Tanzania. Mitigation and Adaptation Strategies for Global Change 6, 185 – 211.

Schwarze, R., 2000. Activities implemented jointly: another look on the facts. Ecological Economics 32, 255 – 267.

Slovenská agentúra životného prostredia, 2004. Environment of the Slovak Republic in 1993–2003 (Decade of Environmental Care in Slovak Republic), Slovenská agentúra životného prostredia, Banská Bytsrica, http://www.sazp.sk/slovak/periodika/sprava/skladacka/EN/uvod_en.html.

Stratégia SR plnenia záväzkov Kjótskeho protokolu , 2001. Ministry of the Environment of Slovak Republic, Bratislava, http://www.enviro.gov.sk/minis/.

The first national communication on climate change, 1995. Ministry of the Environment, the Slovak republic.

Third national communication for UNFCCC Hungary, 2002. Edited by System Expert Consulting, Budapest, Hungary.

Third report on climate change, 2001. Ministry of Environment, Bratislava, Slovak Republic, http://www.enviro.gov.sk/minis/.

UNFCCC, 2004. Japan marks the Protocol's entry into force on 16 February. UNFCCC, Bonn. http://unfccc.int/2860.php

Watson, R. T. (ed.), 2001.Climate Change 2001: Synthesis Report, TAR of IPCC. Cambridge University Press, Cambridge.

Xinshi, Z. & Guangsheng, Z., 1995. A new Net Plant Production (NPP) model, pp: 197 – 202. In: Duzheng, Y. & Hai, L. (eds), China contribution to global change studies. Science Press, Beijing.

Annex

List of abbreviations

AIJ	Activities implemented jointly
C	Carbon
CDM	Clean development mechanism
GHG	Greenhouse gases
GWP	Global warning potential
GIS	Geographic information systems
JI	Joint implementation
NPP	Net primary productivity = Gross primary production – respiration
PJ	Unit of measurement for energy, 1 PJ (Peta Joule) = 106 GJ (Giga) = 277.8 GWh (Giga Watt hour)
RES	Renewable energy sources

Tables and Figures

Figure 1. Estimated price per unit of sequestered carbon for reforestation and short rotation systems for Scenario1.

(Official price F – reforestation, land price based on official price, market price F – reforestation, land price based on market price, official price F – short rotation system, land price based on official price, official price F – short rotation system, land price based on market price; price of carbon is in $ and uptake in t C/ha).

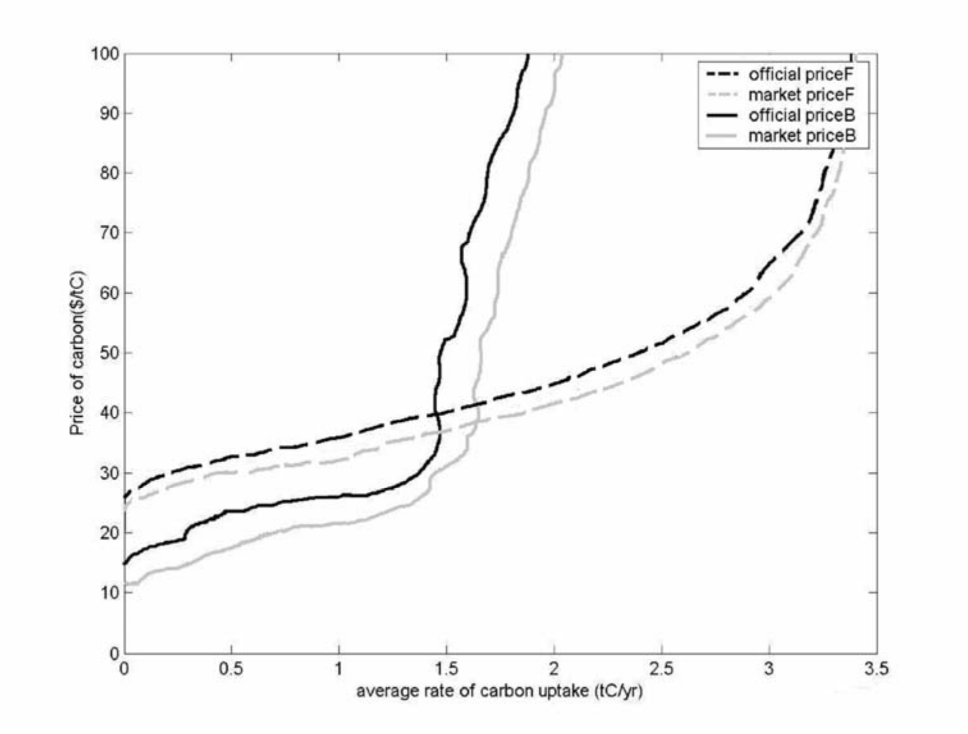


Figure 2. Estimated price per unit of sequestered carbon for reforestation and short rotation systems for Scenario 2.

(Official price F – reforestation, land price based on official price, market price F – reforestation, land price based on market price, official price F – short rotation system, land price based on official price, official price F – short rotation system, land price based on market price.)

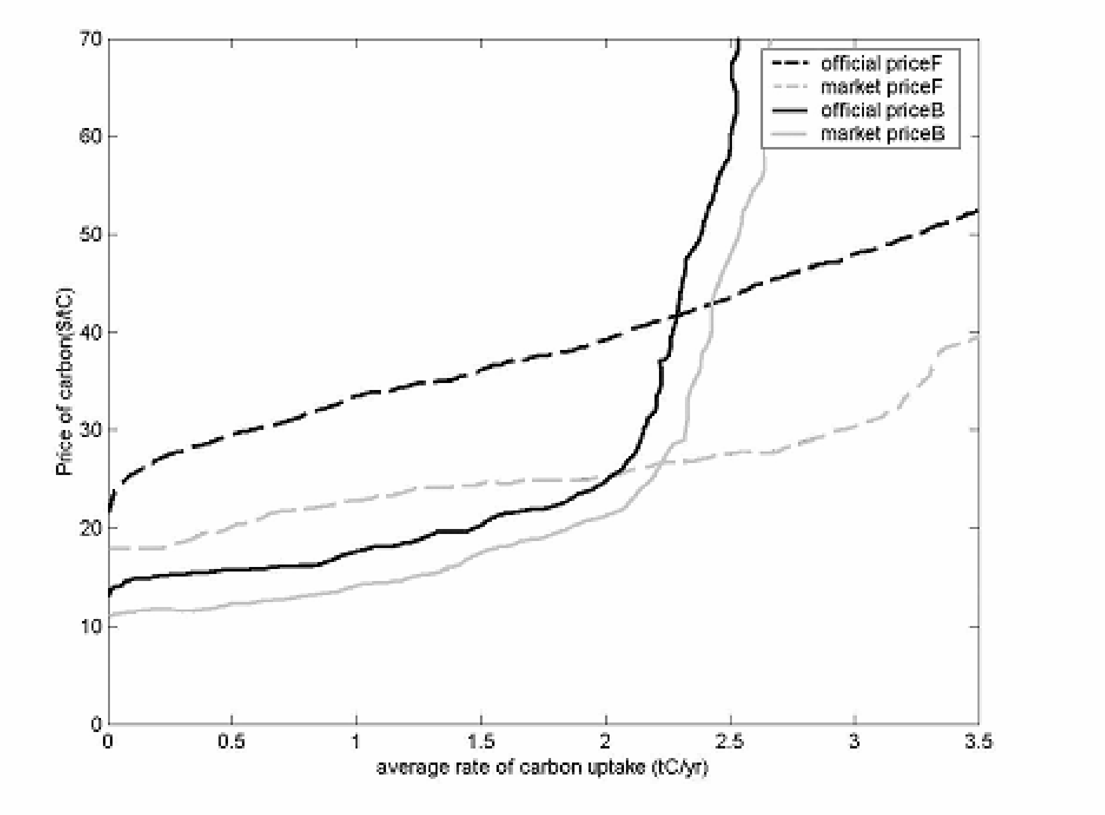


Figure 3. Estimated price per unit of sequestered carbon for reforestation and short rotation systems for Scenario 3.

(Official price F – reforestation, land price based on official price, market price F – reforestation, land price based on market price, official price F – short rotation system, land price based on official price, official price F – short rotation system, land price based on market price.)

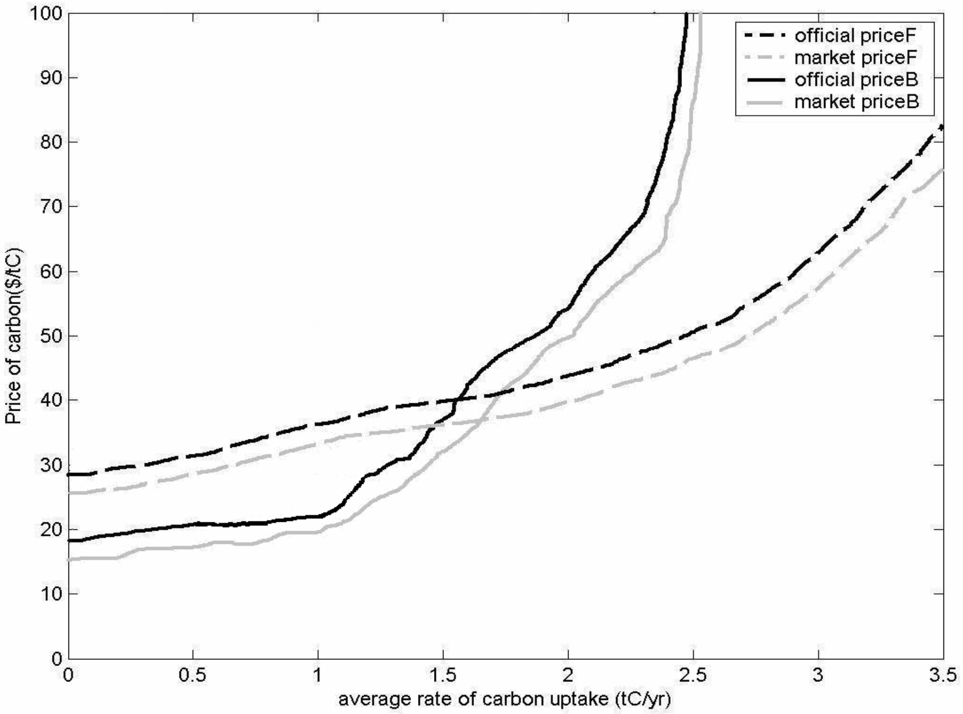


Figure 4. Estimated price per unit of sequestered carbon for reforestation and short rotation systems Scenario 4.

(Official price F – reforestation, land price based on official price, market price F – reforestation, land price based on market price, official price F – short rotation system, land price based on official price, official price F – short rotation system, land price based on market price.)

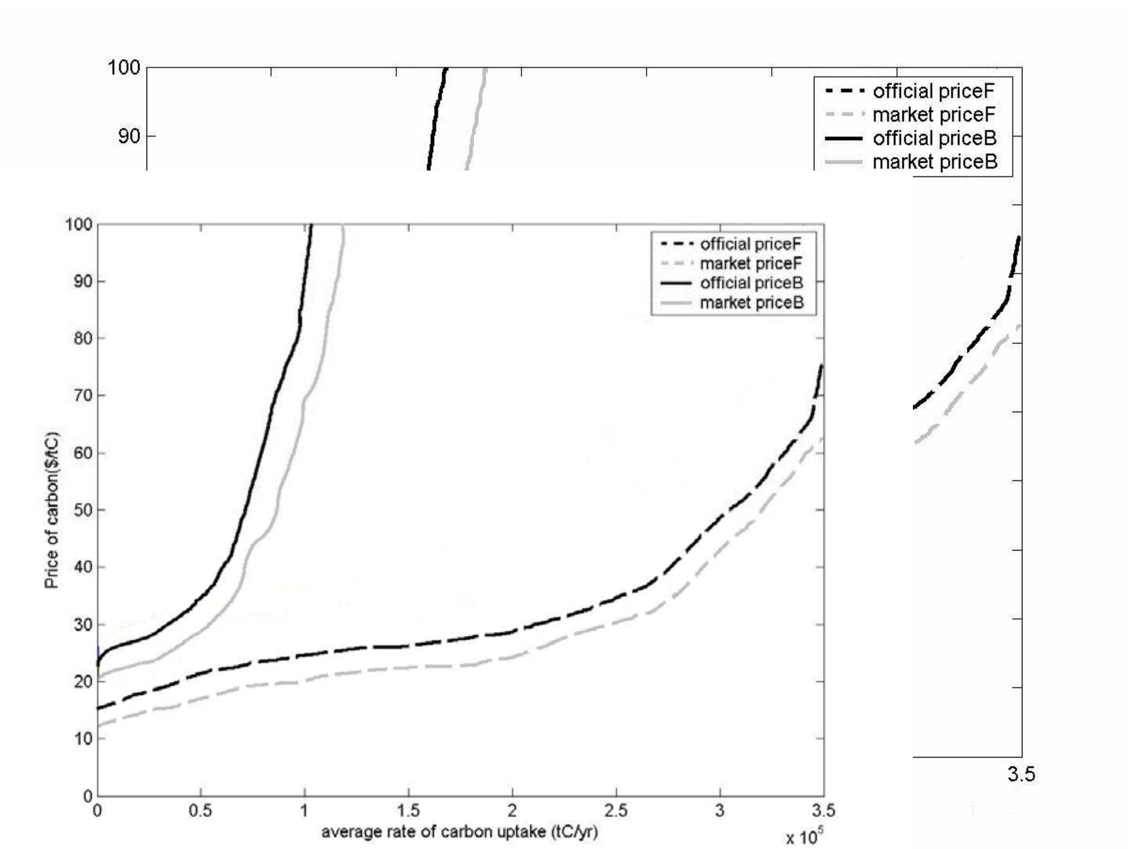


Figure 5. Cumulative carbon sequestration for reforestation and short rotation systems with land price based of official prices for Scenario 1 (in 10^5 t C)

.

(FP – reforestation, storage in product is included, BP – short rotation system, storage in product is included, FPN – reforestation, storage in product is not included, BPN – short rotation system, storage in product is not included.)

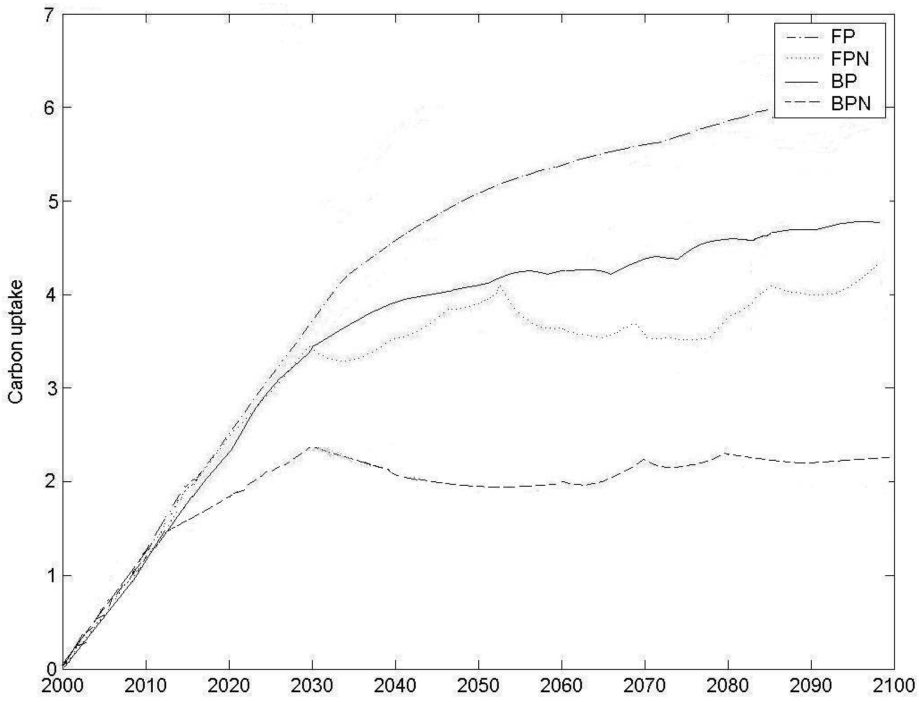


Figure 6. Cumulative carbon sequestration for reforestation and short rotation systems with land price based of official prices for Scenario 2 (in 10^7 t C).

(FP – reforestation, storage in product is included, BP – short rotation system, storage in product is included, FPN – reforestation, storage in product is not included, BPN – short rotation system, storage in product is not included.)

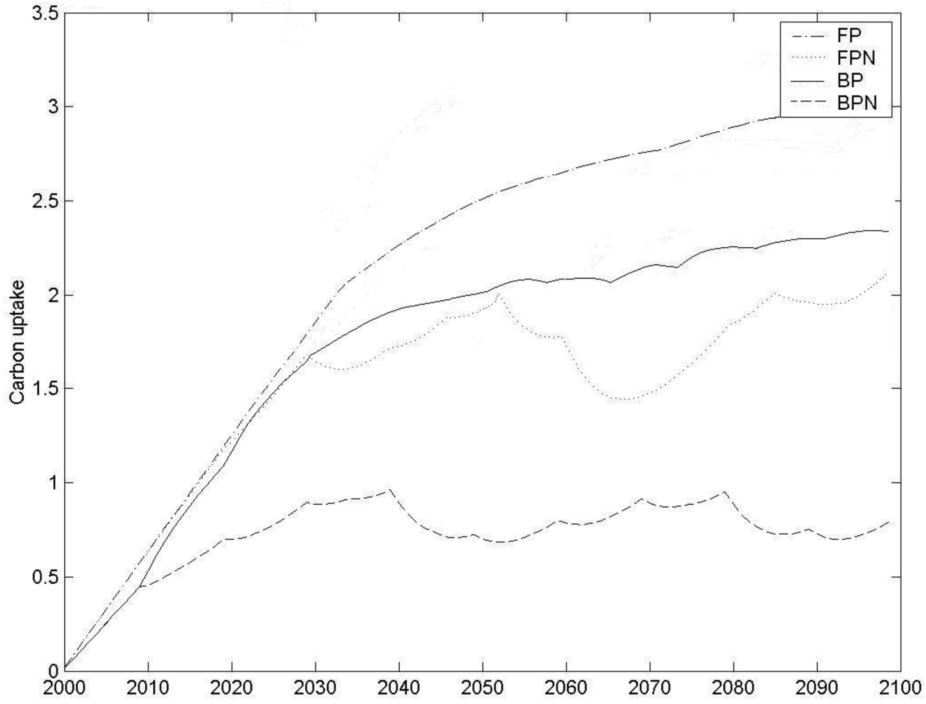


Figure 7. Cumulative carbon sequestration for reforestation and short rotation systems with land price based of official prices for Scenario 3 (in 10^5 t C).

(FP – reforestation, storage in product is included, BP – short rotation system, storage in product is included, FPN – reforestation, storage in product is not included, BPN – short rotation system, storage in product is not included.)

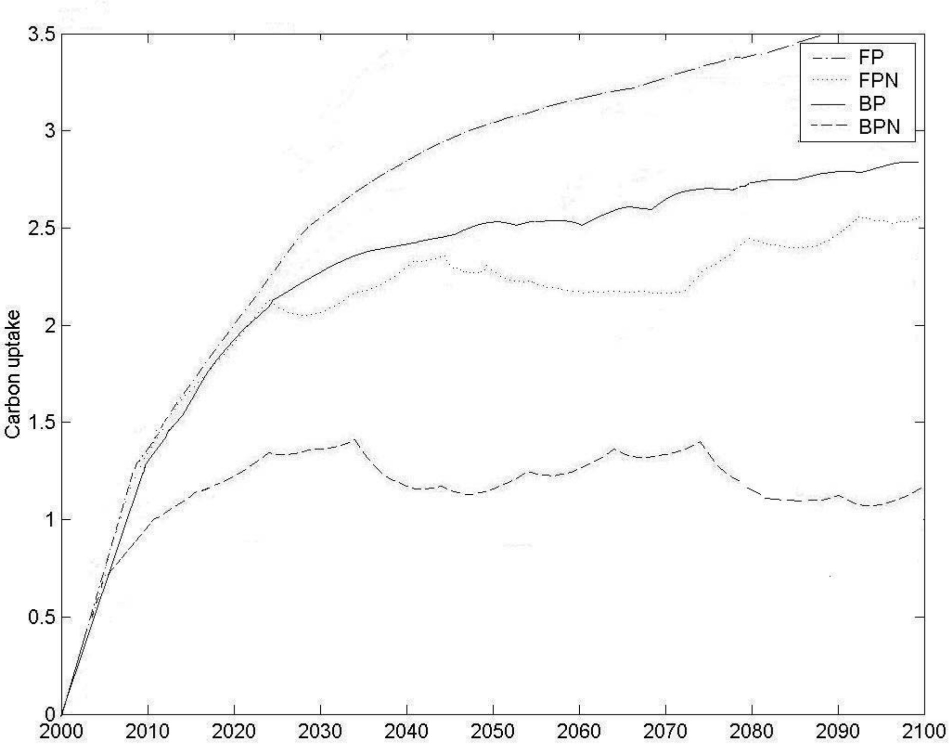


Figure 8. Cumulative carbon sequestration for reforestation and short rotation systems with land price based of official prices for modified Scenario 3 (in 10^5 t C).

(FP – reforestation, storage in product is included, BP – short rotation system, storage in product is included, FPN – reforestation, storage in product is not included, BPN – short rotation system, storage in product is not included.)

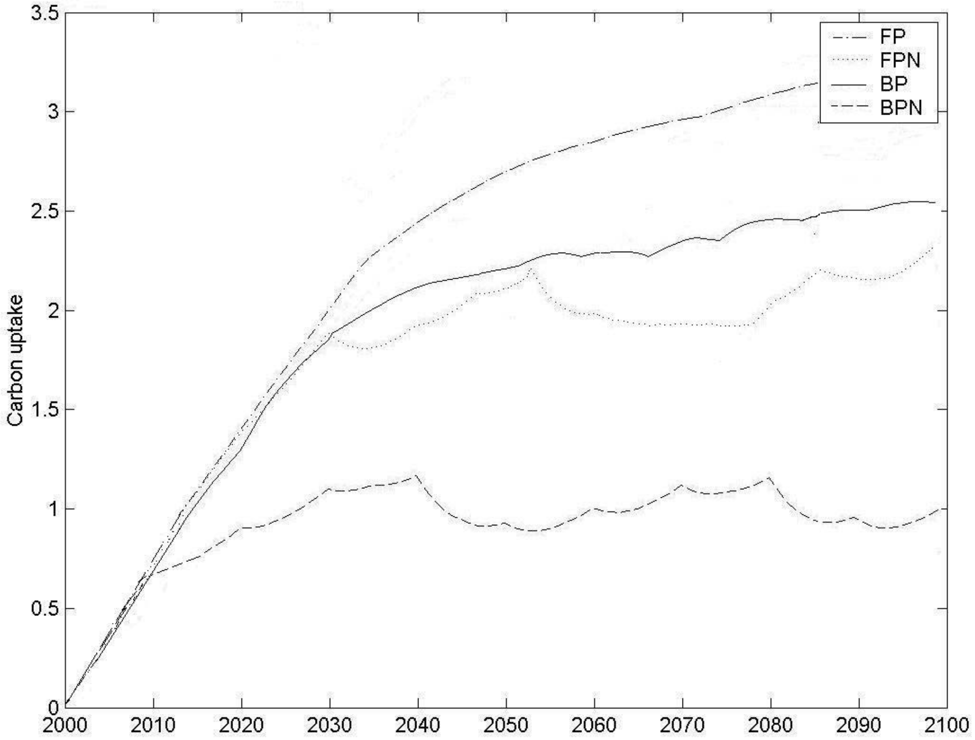


Figure 9. Cumulative carbon sequestration for reforestation and short rotation systems with land price based of official prices for Scenario 4 (in 10^5 t C).

(FP – reforestation, storage in product is included, BP – short rotation system, storage in product is included, FPN – reforestation, storage in product is not included, BPN – short rotation system, storage in product is not included.)

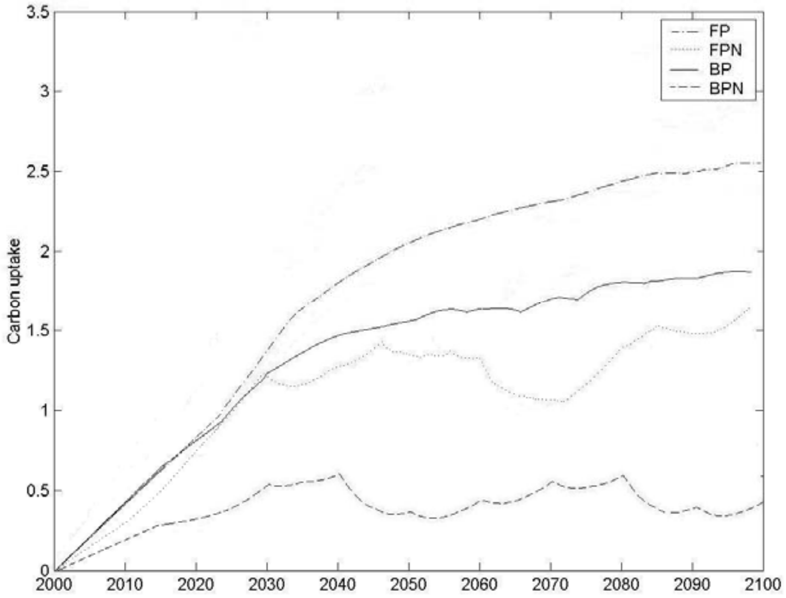


Figure 10. Impact of using different discount rate 1%, 3% and 5%in the simulation for short rotation systems for Scenario 1.

(Official price 1 – simulation is based on official price for land with 1% discount rate, official price3 – simulation is based on official price for land with 3% discount rate, official price 5 – simulation is based on official price for land with 5% discount rate.)

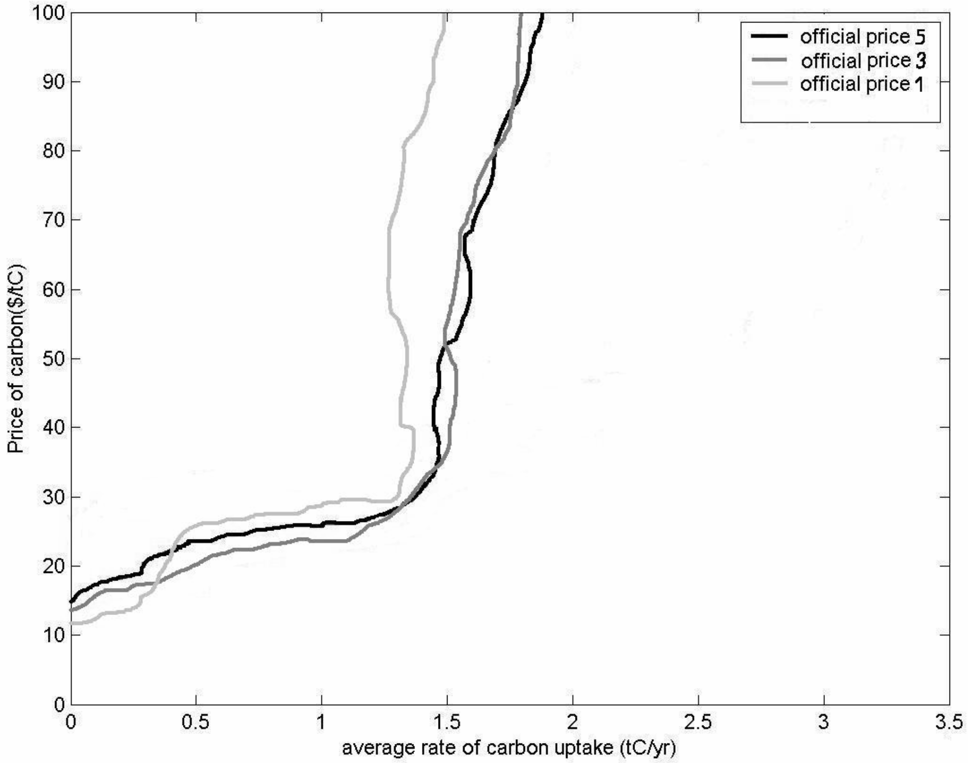


Figure 11. Impact of using different discount rate 1%, 3% and 5%in the simulation for short rotation systems for Scenario 3.

(Official price 1 – simulation is based on official price for land with 1% discount rate, official price3 – simulation is based on official price for land with 3% discount rate, official price 5 – simulation is based on official price for land with 5% discount rate.)