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The Role of ECA's Forest Resources in Climate Change Mitigation

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The World Bank

DRAFT REPORT

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ECA Countries and Sub-regions

Taking into account current and predicted climates, the extent, specifics of forests and forest management, current and expected economic and social conditions, the regional groupings of the region's countries has been used in this report (Table 1, Figure 1). This grouping (besides of Russia) coincides with those used in World Bank (2009). Russia has been divided in 6 sub-regions based on bioclimatic specifics of forests and the current (2011) administrative division of the country.

Table 1. ECA countries and subregions

Regional groupings	Countries
Southeastern Europe	Albania, Bosnia and Herzogovina, Bulgaria, Croatia, FYR Macedonia, Montenegro, Kosovo, Serbia, Slovenia, Turkey
Central and Eastern Europe	Czech Republic, Hungary, Moldova, Romania, Slovakia, Ukraine
Baltics	Belarus, Poland, Estonia, Latvia, Lithuania
South Caucasus	Armenia, Azerbaidjan, Georgia
Central Asia	Tajikistan, Uzbekistan, Turkmenistan, Kyrgyzstan
Kazakhstan	Kazakhstan
Russia sub-regions	**Oblasts, republics and okrugs**
European-Ural North	Arkhangelsk, Kaliningrad, Karelia, Komi, Kostroma, Leningrad (incl. St Petersburg), Murnansk, Nenetsk, Novgorod, Pskov, Tver, Vologda, Yamalo Nenetsk, Yaroslavl
European-Ural Central	Bashkortostan, Belgorod, Bryansk, Chelyabinsk, Chuvashia, Ivanovo, Kaluga, Kirov, Kursk, Lipetsk, Mari El, Mordovia, Moscow, Nizhniy Novgorod, Orel, Orenburg, Penza, Perm, Ryazan, Samara, Saratov, Smolensk, Sverdlovsk, Tambov, Tatarstan, Tula, Udmurtia, Ulyanovsk, Vladimir, Volgograd, Voronezh
European South	Adygea, Astrakhan, Chechnya, Dagestan, Ingush, Kabardino-Balkaria, Kalmykia-Khalmg Tan, Karachay-Cherkessia, Krasnodar, North Osetia-Alani, Rostov, Stavropol
Western Siberia	Kemerovo, Khanty-Mansi, Kurgan, Novosibirsk, Omsk, Tomsk, Tyumen
Siberian and Far Eastern North	Kamchatka, Magadan, Sakha-Yakutia
Siberian and Far Eastern South	Altay Republic, Altay Kray, Buryatia, Amur, Chita (incl. Aga-Buryat AO), Irkutsk (incl. Ust-Orda Buryat AO), Jewish, Khabarovsk, Khakassia, Kranoyarsk, Primorskiy, Sakhalin, Tyva

Figure 1. ECA sub-regions

Introduction: Climate Change Mitigation, Forest and Forestry

Decreasing the anthropogenic impacts on the Earth system necessitates active management of terrestrial carbon pools and greenhouse gas fluxes. Climate mitigation includes all economically relevant activities taken to permanently reduce or eliminate the long-term risk and hazard of climate change. Forests and forestry is estimated as a crucial biospheric tool in overall climate change abatements efforts. Realizing the extending program of mitigation in forestry could entail large changes in current paradigms of land use and land-use change as well as in paradigms and intensity of forest management (Alig *et al.*, 2010).

As it is stated in the Fourth IPCC Assessment Report (Nabuurs *et al.*, 2007), forestry mitigation options globally have the economic potential at costs up to \$100/t CO_2-eq to contribute on average from 2.7 Gt CO_2-eq yr^{-1} (due to regional bottom-up studies) to 13.8 Gt CO_2-eq yr^{-1} (based on global top-down models) by 2030. This substantial inconsistency shows both the large complexity of the problem and needs of regional studies as a source of "empirical" information and a basis for improving the global models.

The mitigation policies aim to reduce greenhouse gas emissions from individual countries in order to prevent climate change. Land use, Land-use change and Forestry (LULUCF) activities identified under Articles 3.3 (afforestation, reforestation and deforestation activities since 1990) and 3.4 (additional voluntary activities in land management - forest management, cropland management, grazing land management and revegetation defined by the 7th Conference of Parties to UN FCCC in Marrakesh) of the Kyoto Protocol, can be accounted for to fulfill national commitments on reduction GHG emissions.

There are two principal pathways of mitigating climate change by terrestrial ecosystem (and, particularly, forest) management: (1) by improving the greenhouse gas balance within the biosphere and (2) by managing for biomass production to substitute emissions from fossil fuels and sequester bio-carbon containing materials/substances outside the biosphere (Obersteiner *et al.*, 2010). Evidently, these strategies have different aims (Figure 2): the first one attempts to maximize carbon stock in the biosphere and the second – aims at maximizing efficiency of energy and material production compared to a fossil fuel reference case.

The mitigation activities aim at reducing emissions by sources and/or increasing removals by sinks in the forest and connected sectors. The Fourth IPCC Report presents a portfolio of forest mitigation activities grouped in the following four general categories (Nabuurs *et al.*, 2007):

- maintaining or increasing the forest area through reduction of deforestation and degradation and through afforestation/reforestation;
- maintaining or increasing the stand-level carbon density through the reduction of forest degradation and through planting, site preparation, tree improvement, fertilization, introduction of an appropriate stand management systems or other silviculture techniques;
- maintaining and increasing the landscape-level carbon density using forest conservation, optimal rotation, fire management, protection against insects and diseases; and
- increasing off-site carbon stock in wood products and enhancing product and fuel substitution using forest-derived biomass to substitute products with high fossil fuel requirements, and increasing the use of biomass-derived energy to substitute fossil fuel.

Mitigation strategies could coincide partially or even differ dependently upon whether short-term or long-term goals are considered. For example, in order to reduce the long-term risk and hazard of climate change to managed forests, such options of management strategies have been recommended: the selection of tree species and provenances adapted to future climate patterns; reduction of the rotation cycle to speed the establishment of better adapted species; use of germplasm mixtures with high levels of genetic variation; and establish long-term multi species/seedlot trials to test improved genotypes across a diverse array of climatic environments (Seppällä et al. 2009)

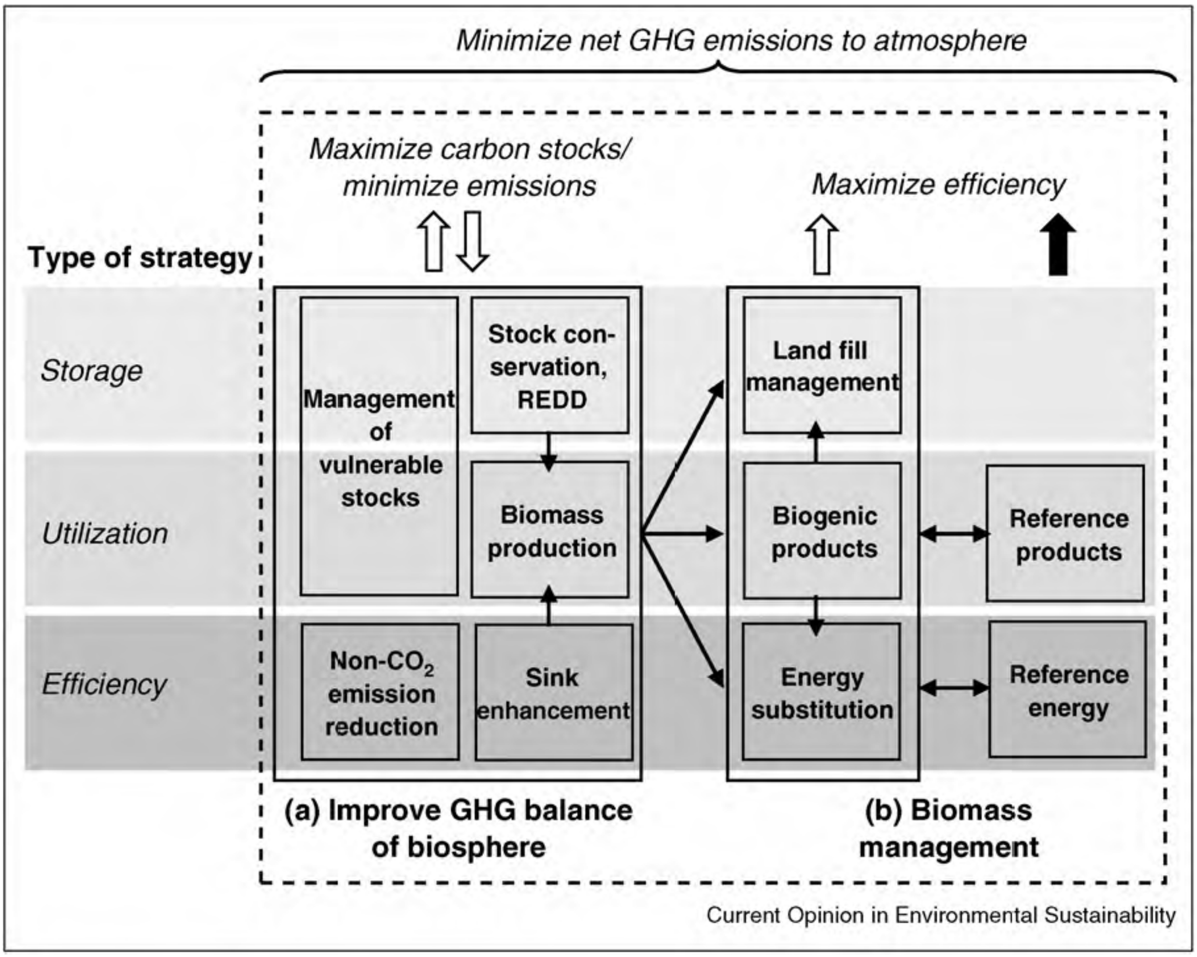

Figure 2. Overview of principle pathways and strategies of forest ecosystems management for climate change mitigation (Obersteiner *et al.*, 2010)

Forest mitigation strategy should be considered within the sustainable forest management paradigm. Sustainable forest management has to address the multiple functions of forests demanded by various stakeholders such as timber production, carbon sequestration, biodiversity, protection or recreation. Carbon management is an important but only one forest service. Forest management can be focused on different objectives including profit maximization, biodiversity conservation, recreation, protection from natural hazards. Thus, any mitigation strategy should take into account the trade-off between multi-service paradigm of forest use and increasing forest ecosystems carbon stock.

There are two different ways to develop forest policies and mitigation strategies: sectoral and integrated approaches. Management of forests has been addressed in a number of integrated studies which considered mitigation costs by integrating energy, climate and terrestrial systems (e.g., Wise *et al.*, 2009). An overall conclusion of such studies is that coordinating the management of different systems may lower mitigation costs, although many problems of the integrated modeling are not overcome yet.

Specific of relevant policies; characteristic time sequence of actions, benefits, and costs; relative importance of individual actions within the entire system of forest management; climate impacts on mitigation strategies; interactions between mitigation and adaptation; permanence and leakage are strongly defined by specifics of forests, social and economic structures of countries, and level of impacts of climate change on life of population. While reducing GHG emissions is vital for stabilizing the global climate, mitigation interventions must also balance this with the need to provide access to affordable energy; opportunities for mobility of people goods and services; and protection for those dependent on carbon-intensive livelihoods.

A very important question deals with possible synergies between mitigation and adaptation. Two fundamental response options to human-induced climate change – mitigation and adaptation – has three major differences: (1) a difference in the spatial and temporal scales on which they are effective (global versus regional & local); (2) the extent to which their costs and benefits can be determined, compared and aggregated; and (3) the concerns of the actors and types of policies involved in their implementation (Klein *et al.*, 2005). However, an idea to implement climate policy by carrying out mitigation and adaptation activities seems relevant, as well as combining these with natural resource management, biodiversity conservation and measures to combat desertification. A number of studies and projects have been realized aiming at understanding of synergies between adaptation and mitigation, mostly by combining the protection or development of forests with improved land use and watershed management, agroforestry and nature conservation. However, a number of analyses showed that the optimal mix of and balance between mitigation and adaptation vary by country and over time, depend on the decision criteria and how much such a mix is justifiable from a social, environmental and economic perspectives.

Four roles are currently identified for climate policy: (i) to control the atmospheric concentrations of greenhouse gases; (ii) to prepare for and reduce the adverse impacts of climate change and take advantage of opportunities; (iii) to address development and equity issues, and (iv) to facilitate the successful integration and implementation of mitigation in sectoral and development policies. In order to introduce relevant policies, three following questions should be answered: (1) what constitutes a socially, economically and environmentally attractive portfolio of mitigation, adaptation and development policy and how can it be achieved? (2) how can capacity be developed in order to seize opportunities to and overcome constraints on implementing mitigation and adaptation options as part of sectoral policies? and (3) how can existing financial instruments for climate policy best be used in a broader context of sectoral investments, official development assistance and other policies aimed at risk reduction and sustainable development (Klein *et al.*, 2005).

This report attempts to survey climate change mitigation issues related to forest and forestry in the Europe and Central Asia (ECA) region. ECA region includes a wide variety of climatic, ecological and economic conditions, different role of forests in landscapes, different impacts of climate change on ecosystems, their responses and feedbacks. Reducing the impacts of Greenhouse Gas Emissions (GHG) on global climate is important for many ECA countries to meet their international obligations, and to reach community-wide policy goals. Some of the region's countries have a high level of GHG emissions. The Russian Federation is a number three (behind the U.S. and China) among 25 largest carbon dioxide emitters globally with Ukraine, Poland, Turkey, and Kazakhstan which hold positions at numbers 20, 21, 24 and 25, respectively. Today, five ECA countries rank among the world's top ten highest greenhouse gas emitters per unit of GDP (Uzbekistan (1), Kazakhstan (3), Ukraine (6), Russia (7), Azerbaijan (8)).

A common and specific feature of the region is that its forests include two ecotones – transition to forestless climatic zones – a tundra domain in high latitudes in the north and steppes and deserts in the south. Substantial areas are covered by extremely vulnerable forests growing at the limits of their natural range. It defines specifics of forest management, adaptation and mitigation strategies, and possibility to strengthen the adaptive capacity of forests by planned mitigation activities

Reliability of available information including national official documents (reported in such aggregated sources as FAO Global Forest Resource Assessment (2010), recent National Communications to the UN FCCC Secretariat, State of Europe's Forests (2011) etc.) is different and the reported data are often inconsistent. Some countries report obsolete or contradictive data. In cases when the authors of this report have available information more reliable than the official sources or publications, the most accurate information was used.

Unfortunately, information from a number of countries, particularly from Caucasus and Central Asia, are limited included obsolete data of forest inventory, poor forest monitoring systems, very uncertain estimates based on default IPCC approaches, and lack of scientific knowledge on impacts of climate change on forest ecosystems. It impacts clarity and quality of some conclusions. In order to get a solid scientifically based picture of effective adaptation and mitigation systems in these countries, a number of questions should be put on a scientific area (*cf*. Mátyás, 2010): (1) development of monitoring and inventory systems which would be able to present the satisfactory information on state and dynamics of forests under global change including assessing the extent and nature of climate induced changes in forests; (2) studies on changing in status of forest health in connections with climatic extremes; (3) development of regional impact models; (4) studies of the environmental role of forests in landscapes of arid and desert zones taking into account a two facet role of forest there – as a water protective element and as a high consumer of water; (5) studies on ways to increase resilience of forest ecosystems in the face of climate change; (6) information on and assessment of consequences of illegal harvest; (7) scientifically solid forest carbon account; (8) law enforcement problems and legislation for transition to sustainable forest management, (9) impacts of increasing aridity on wildfire; and (10) public dissemination of knowledge on the ecological, economic and social role of forests and forestry.

1. Recent and Predicted Climate Changes in the Region

1.1.Introductory notes

A number of analyses of ongoing and future climates for the ECA region have been published recently, particularly by the World Bank (e.g., Westphal, 2008, Katsov *et al.*, 2008). Trying to avoid repetition, in this section we briefly enumerate the major facts and tendencies with a special emphases to those which are important for assessing impacts, responses and feedbacks of forests to global change.

By its climate, vegetation, landforms, amount of forests, and level of transformation of natural landscapes, ECA is very diverse and spatially heterogeneous. Thus, available information is considered by regional groupings as it is described above. For some typical regions and countries we present more detailed information in order to highlight specific regional features.

1.2.Climate of recent decades

There is a statistically significant trend of ***increasing temperature*** in the region during the last century: from 0.5°C in Southeastern Europe to 1.6°C in South Siberia in 1980-2002 comparative to 1901-1920 (Westphal 2006). The trend increased during the second half of the 20th century. In Siberia, the warming trends were estimated at above 0.2°C/10 years and - in some "hot spot" regions – up to 0.5°C /10 years; these hot spots are mostly located in East Siberia. The process is spatially heterogeneous. In Northern Eurasia, maximal warming take place in continental regions, less – in maritime regions, over the Arctic coast (Gavrilova, 2007; Onuchin and Burenina, 2008). The average warming in high latitudes was 1.5 fold higher than in Southern Siberia and 3 fold higher than in Mongolia. The highest rate of warming is indicated in central Siberia: during the last century winter temperature increased by 10 °C in Jakutia, 7°C in Pribaikalie, and 5°C in Mongolia with the increase of the annual average temperature in the range of 2-3.5°C. The growth period (with daily temperature > 5°C) increased by 1-2 weeks over the high latitudes, more in the south than in the north, less in more humid climate than in dry climate. In Europe, the average annual growing season was lengthened by 10.8 days during early 1960s-2000s (Menzel and Fabian, 1999). After the 1970s, the intensity of warming in boreal territories was 1.5-2 times higher than during the first half of the 20th century.

Besides of Russia, there were no recent significant trends in dynamics of ***precipitation*** in the ECA. Major increase of precipitation was observed in North of European Russia and West Siberia. In major continental regions, trends of the annual and seasonal amount of precipitation had different direction by seasons: there was a positive trend in winter (of 2-5 mm/10 years) and a negative one in summer (about – 2 to -7 mm/10 years). The annual amount of precipitation in continental regions of Middle and East Siberia had a tendency to decrease (e.g., of -4.1mm/100 years for areas around the Lake Baikal). The increase of snow depth in some regions of East Siberia shifts to the south. It may indicate a weakening of the Siberian anticyclone. Increasing aridity of climate is typical along the southern border of the region. For instance, amount of precipitation in Azerbaijan during 1971-1997 decreased at 12% (Ibragimov, 2010)

In spite of a large spatial heterogeneity of climate change over the region, the increase of temperature in major its parts was not compensated by the change of precipitation. The Palmers Drought Severity Index decreased in 1981-2005 versus 1961-1980 for major part of ECA territories (Dai *et al.*, 2004; Westphal, 2008). For the last 50 years this trend increased substantially in continental regions of Russia, particularly in its Asian part (Lapenis *et al.*, 2005; Vaschuk and Shvidenko, 2006). This indicates the increase of dryness of climate.

Interannual and interseasonal variability of weather grew over the last decades. Instability of weather and frequency of extreme climatic events (heat waves, long droughts) was growing.

Weather related natural disasters cause large had growing economic losses on the ECA Region, particularly for mountain regions of the Caucasus and Central Asia (Westphal, 2008). The losses caused by an unexampled temperature and drought anomaly in summer 2010 in central regions of European Russia and following acceleration of vegetation fires are estimated at level at ~$10 billion. Southern arid regions are especially vulnerable to droughts which could generate losses of about 5-7% GDP per year.

Observations and climate models show that the present-day changes in the radiation forcing affect the surface heat, moisture budgets and hydrological regimes of vast territories, particularly in the boreal zone. There are substantial changes in permafrost and seasonally frozen ground in high latitudes during recent decades. Permafrost temperature increased approximately at 1°C at the depth between 1.6 and 3.2 m from the 1960s to the 1990s in East Siberia, and about 0.3°C to 0.7°C at the depth of 10 m in northern West Siberia. Long-term monitoring of the permafrost has shown that active layer over the period 1956 to 1990 exhibited a statistically significant increase of about 21 cm. Results of permafrost monitoring provided by the Institute of the Cryolitozone (Yakutsk) in 1989-2002 in Sakha-Yakutia Republic indicated that under present-day warming trends, fast degradation of the upper part of ice-rich soils of both undisturbed and disturbed permafrost landscapes with 5-30% losses of ground ice resources is observed, and the degradation on disturbed sites is most intensive (Gavriliev, 2003). However, such an impact is not registered everywhere due to complicated interactions between air temperature and depth of the active layer, as well as different landscape factors (Anisimov, 2010). There are evidences that the zone of continuous and discontinuous permafrost has shifted to the north at ~20km in plain tundra of European Russia and several times more in the Ural Mountains. An important consequence of warming in Russian Arctic is physical destruction of the coast with high content of ice. Such coasts retreat at 0.5 to 25 m year-1 and this process impacts northern landscapes on large distances from the shoreline (Anisimov, 2010).

Climate change intensifies unfavorable geocryological processes on permafrost which impact forests in two ways. One is direct destruction of landscapes including solifluction, landslides, gully formation etc. Second – anthropogenic accidents, mostly destruction of infrastructure of oil and gas extraction and transportation. About 35000 accidents occur annually in West Siberia with oil and gas pipelines, and 21% of these are caused by mechanical impacts and deformations due to permafrost's change (Anisimov and Belolutsaya, 2002).

1.3.Climate predictions for the 21st century

Comprehensive projections of future climates in the ECM Region based on ensembles of global coupled atmosphere-ocean global circulation models (AOGCMs) and regional climate models (for some regions) are provided by Westphal (2008), IPCC (2007), and could be found in a number of publications (e.g., Christensen *et al.*, 2007; Shkolnik *et al.*, 2007; Shiklomanov and Georgievsky, 2007; Katsov *et al.*, 2008; Meleshko *et al.*, 2008; Milly *et al.*, 2005; Milly *et al.*, 2008). In spite of some differences in the modeling predictions, AOGCMs have the potential to provide geographically consistent estimates of regional climate change due to increased GHG concentration in the atmosphere. Using the three IPCC Emissions Scenarios (Nakicenovic *et al.*, 2000) – A2, A1B, and B1 (reflected, respectively, the upper, middle and lower impacts of future world's developments on climate change - major tendencies of future climates could be aggregated as following.

Continued warming is expected everywhere in the ECA region. Relative to the base line climate (1980-1999), the mean annual temperature is projected to increase from 1.6°C to 2.6°C by the middle of the century. By end of the century, the increase of the area averaged annual mean temperature varies from 3.0±1.0°C (IPCC B1 scenario) to 5.5±1.2°C (A2) for Russia with a clear increase towards the north and from 2.6±0.7°C (B1) to 7.2±1.2°C (A2) for Central Asia. A substantial decrease of frost days (from 10 to 30-35 days) is expected over the entire region. The most intensive summer warming is expected in southern parts of the region and during winters – in its northern parts. Weather extremes and heat waves will be more frequent over the region, particularly in the south of West Siberia, Kazakhstan and Central Asia. By mid-21st century, the number of days with extremely high temperatures (above 90th percentile of daily maxima in the baseline climate) will increase in Russian Far East by 5-10 days, the Black sea region by 10-20 days, and in Northern Caucasus by 20 and more days per year. For west and central regions of Russia and north of East Europe, such an increase is expected substantially less (in range of 2-5 days). The growth period will increase, particularly in the north of the region.

The predictions promise a wetter north and a drier south. An increase of precipitation is expected in most of Russia (mostly in winter), in Kazakhstan (winter and spring) and a decrease in Southeastern Europe (the annual amount). Over the Russian territory, the average for country mean annual precipitation will increase in the range from 11.3±3.1% (B1) to 17.7±3.7% (A2), substantially different for different parts of the country. For Central Asia, the increase of precipitation is in limits of annual variability. There is substantial inter-model disagreement for annual and seasonal precipitation for Central Asia, Caucasus, Central Europe and the Baltics (Westphal, 2008). River runoff is projected to substantially increase in Russia (+25-30%) with substantial regional redistribution but will decrease over the rest of the territory with the most dramatic decrease in Southeastern Europe (-25%). Projections of the Palmers Drought Severity Index show increase in drought conditions over the entire region besides of northeastern Russian Far East. The increase of intensity of precipitation, as well as of precipitation from extreme storm events, is expected everywhere. It may increase threat of floods, which already occur often now.

Modeling studies on permafrost behavior in 21st century predict decreasing the total area of permafrost by 16-25% and 20-42% by 2030 and 2050, respectively (Scenario B2, models CGCM2, CSM-1.4, ECHAM4/OPYC3, GFDL-R30c, and HadCM3, Anisimov, Rankova *et al.*, 2003; Anisimov, 2010). BY 2050, the southern boundary of permafrost in Russia will shift by north-east by 150-200 km. Intensive development of thermokarst, gully formation, landslides, solifluction, floods, paludification (or aridity depending on geographical distribution and landscape peculiarities) is expected for large areas, especially for those continuing ice-rich soils (which cover about 35% of Yakutia and 35-40% of north-eastern part of Russia). Due to predictions made by the Institute of Cryolitozone in Yakutsk, lake and swamps cover may increase (at 1.3-3 times for a future moderate warming by +3°C), differently in different regions of northern Asia. If the currently observed warming trend $\Delta t_0 \geq 0.06\text{-}0.09°C\ yr^{-1}$ sustains, the unprecedented changes in geocryological, landscape and ecological conditions are very likely in high latitudes of Siberia (Ivanov and Maximov, 2003).

The warming will likely provoke an explosive increase of emissions of carbon stored in permafrost, wetlands and alas territories (of the total amount of 500-700 Pg) (e.g., Desyatkin and Desyatkin, 2007). In particular, Russia has in permafrost areas about 0.7 million km2 of frozen wetlands. Some models show that the methane emissions in Northern Eurasia could increase at 50% by 2050. This additional emission accounts about 8-10 Tg CH4 annually that will cause the increase of global warming more that 0.1°C (Anisimov, 2010). Under the increase of global warming more than 0.8-1.2°C and amount of precipitation, the methane emissions will be substantially higher.

Box 1. Climate and climate change in the Ukraine

During the last 100 years, (1) the warming trend over the country was similar to the global trend (0.4-0.6 °C C), more intensive in winter (1.2°C) and spring (0.8°C); the summer warming was 0.2-0.3 °C C; (2) the temperature trend had a cycling character over the period with the highest warming during the recent period (+0.4°C/decade for the period 1979 to 2003); (3) for a major part of the territory, the precipitation trends were rather weak and different in different regions; overall, the annual amount of precipitation remained stable or slightly decreases; (4) instability of weather increased, and periods of long droughts, heat waves and intensive precipitation became more frequent and destructive (Lipinsky 2002; Climate… 2003; Jones and Moberg, 2003). During the last two centuries, frequency of droughts increased on average at 2-3 times. Dust storms, particularly in the southern and south-east parts of the country have been becoming more intensive and destructive. During the last 100 years large-scaled dust storms happened 23 times.

Predictions of future climates in the country's territory indicate similar tendencies. Both of two major tools of climate predictions – regional semi-empirical models (RSM, e.g., Boichenko et al. 2005; Boichenko 2008) and GCMs have evident strengths and weaknesses. RSMs accumulate existing regional knowledge on the topic and are developed based on long period observations. However, they are not able to explain drivers of expected changes and to describe complicated interactions within the Earth climate system. DGVMs are a very rough tool for regional predictions as they are not sensitive enough to regional specifics.

Several earlier attempts to apply DGVMs to Ukrainian territories (Buksha 1998, 2002, 2009; Vasilchenko et al. 1997; Dixon et al. 1999) confirmed substantial increase the temperature in the Ukrainian territory in the 21th century (higher than the global trend), but were no consistent enough in the prediction of precipitation. Based on the ensemble of 21 DGVMs within the IPCC scenario A1B, the IPCC Fourth Assessment Report (IPCC, 2007) predicted for the Ukrainian territory increase of the annual average temperature at 3-4^{o}C, less in summer and more in winter (with a slight increase from south to north) for 2080 to 2099 compared with the period of 1980 to 1999. The prediction of annual precipitation is close to 0. While winter precipitation somewhat increases, there is a clear tendency of decreasing precipitation in summer, by 15-20%. However, the variability of predictions by different models and for different IPCC scenarios is high. For instance, using 6 DGVMs and 4 IPCC scenarios (A1F1, A2, B2 and B1), the summer temperature change for Southern Europe by 2070-2099 was predicted from +1.9°C to +9.5°C and precipitation – from +11 to -61% (Ruosteenoja *et al.*, 2003). Practically all models predict increase the type, frequency and intensity of extreme events (e.g., heat waves, droughts and floods).

The forecasts made by a regional numerical model of atmospheric circulation and semi-empirical model of climate change and scenarios of emissions are in the line with the IPCC temperature prediction. These regional models predict the increase of the annual temperature by 2050 at 1.5-2.0^{o}C, mostly in winter with a smaller increase in summer (at 0.5-1.0°C in July on average over the country). However, summer precipitation is predicted within the climatic norm with a substantial variability (Lipinsky 2002).

Application of the transient model HadCM3 within IPCC Scenario A2A for three periods: 1950-2000 for describing a "current climate" and predictions for 2020 and 2080 lead to the following conclusions.

● A substantial increase of temperature is expected over the entire country, particularly in its southern parts. The annual average temperature expects to increase at 20% (from 7.5°C to 9.0°C) by 2020 and by 13.5 °C by 2080 (the increase about 80%).

● There is a weak tendency of decreasing precipitation for the nearest decades. However, lack of the precipitation increases substantially by end of the century – the average monthly precipitation decreases from 53 mm to 44 mm (or by 17%). The decrease of sum of precipitation during the vegetation period reaches 50 mm by 2080 (averaged for the entire country's area).

● Both dynamics – temperature and precipitation – become stronger towards south and south-west parts of the country.

● The difference in the summed degree-days during the growth season exceeds 1000 °C by 2080.

Due to these predictions, by end of this century Ukraine will live in a different climate – it will become substantially more hot and drier. The tendency of increasing climate aridity becomes more evident if we compare the change of the heat and hydrological regimes during the growth period. Figure 3 contains the difference of hydrothermal index between "current" and "future" climates HTI = 10 Σ P/sumT where P and sumT are total amount of precipitation and sum of daily temperature for the period from April to September, respectively (this indicator is a simplified analogue of the Palmers Drought Severity Index). For the entire area of Ukraine, the difference is negative that clearly shows increasing climate aridity over all the country. This tendency becomes stronger towards south and south-east in the long-term – between middle and end of the current century.

The predicted climate change for Ukraine is rather similar to those which are expected in neighboring countries of South East Europe.

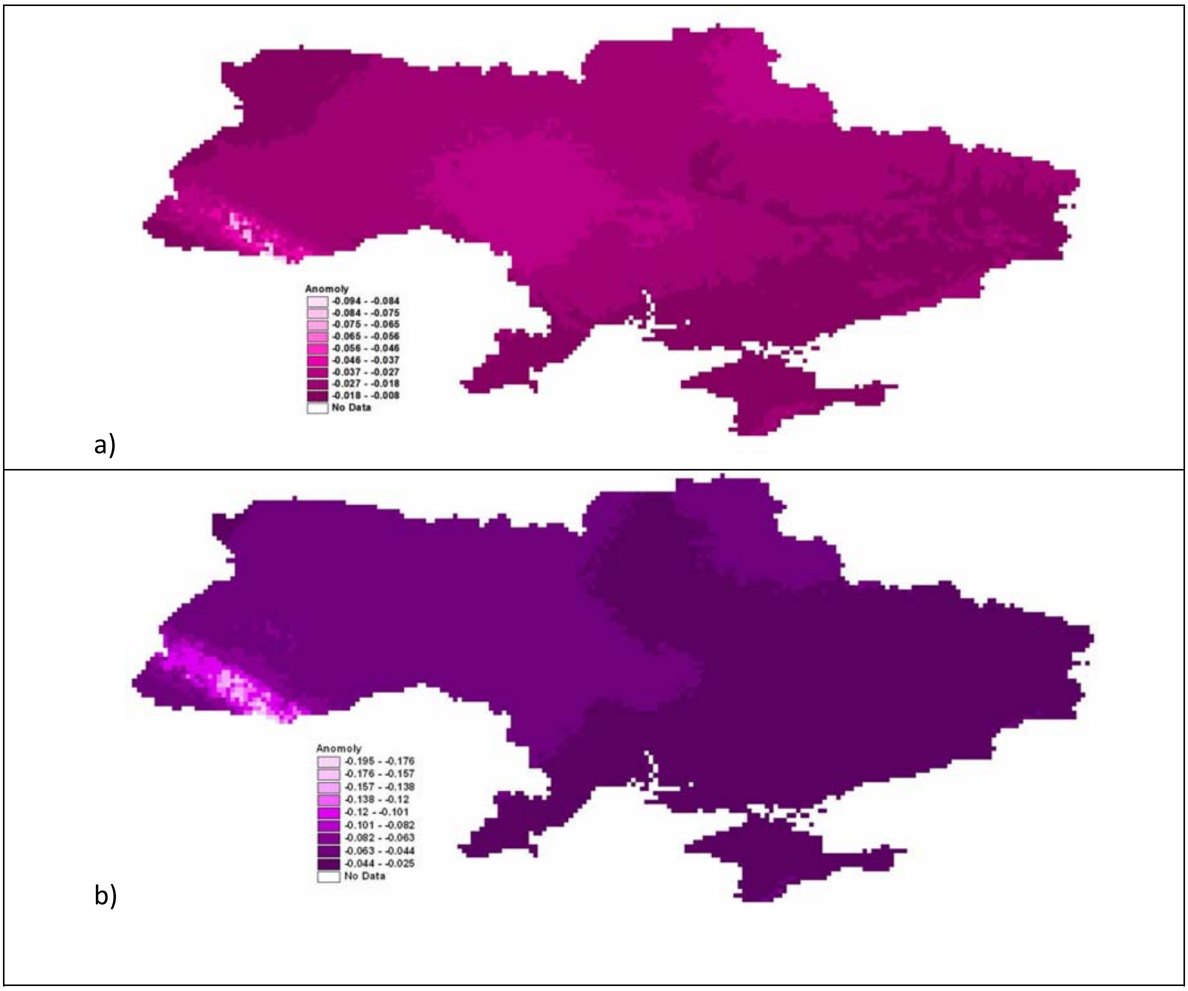

Figure 3. Difference in growing season (April – September) precipitation/temperature index for Ukraine between a forecast (HADCM3 A2A) and 1950-2000 average: a) 2020; b) 2080

2. ECA forest resources and climate change

General characteristics of land area, population and its incomeby the subregions are presented in the Table 2. Russia covers 71% of the ECA Region territory but has only 30% of population. The most populated regions are Central, Eastern and South-Eastern Europe with more than 90 people per square kilometer of area. The least populated area is Siberian North with 0.3 people per km^2. Average population density is 20 people km^{-2}. Gross national income also varies substantially: from 1365 USD PPP in Central Asia up to 13233 USD PPP in Siberian North.

Table 2. Gross domestic product, population and land area

NN	Region	GDP 2009, billions US$	GNI, PPP US$	Population, millions	Land area, 1000 ha
1	Southeastern Europe	865.62	8,044	107.61	117,016
2	Central and Eastern Europe	686.93	7,080	97.02	105,720
3	Baltics	561.61	10,258	54.75	68,117
4	South Caucasus	62.47	3,875	16.12	18,032
5	Central Asia	61.61	1,365	45.15	122,709
6	Kazakhstan	115.31	6,920	15.89	269,970
7	European-Ural Russian North	174.64	10,050	17.38	263,681
8	European-Ural Central Russia	677.61	9,106	74.41	190,230
9	European South Russia	92.44	4,553	20.30	47,844
10	Western Siberia	159.73	10,629	15.03	175,632
11	Siberian and Far Eastern North	19.93	13,233	1.51	473,174
12	Siberian and Far Eastern South	107.54	8,098	13.28	559,263
	Russia total	1,231.89	9,340	141.85	1,709,824
	Grand total	3,585.44	7,495	478.39	2,411,388

Source: World Bank Country Statistics (http://data.worldbank.org/country)

Overall, the ECA Region has large amount of forest: 38.8% of area is covered by forest (Table 3). However, the diversity is high. Siberia is covered by more than 50% by forest, Europe – from 20 to 40%. Kazakhstan has the least forested area percentage (1.2%). The average growing stock varies for 10 m3/ha in Central Asia up to 202 m3/ha in Central and Eastern Europe.

Table 3. Forest area and growing stock

NN	Region	Forest area		OWL area	Growing stock	
		1000 ha	%	1000 ha	mln m3	m3/ha
1	Southeastern Europe	25,649	21.9	12,475	4,004	156
2	Central and Eastern Europe	23,283	22.0	271	5,199	223
3	Baltics	25,698	37.7	846	5,181	202
4	South Caucasus	3,940	21.9	150	627	159
5	Central Asia	8,767	7.1	1,406	91	10
6	Kazakhstan	3,309	1.2	16,479	364	110
7	European-Ural Russian North	105,126	39.9		13,986	133
8	European-Ural Central Russia	60,285	31.7		11,052	183
9	European South Russia	3,589	7.5		818	228
10	Western Siberia	88,735	50.5		10,971	124
11	Siberian and Far Eastern North	221,777	46.9		11,566	52
12	Siberian and Far Eastern South	366,088	65.5		39,268	107
	Russia total	845,600	49.5	73,220	87,660	104
	Grand total	936,246	38.8	104,847	103,126	110

Sources: *State of Europe's Forest*, 2011; FRA, 2010. Taking into account that ~50% of Russian forests have been inventoried more than 20 years ago, forest information for Russia in this report has been modified based on remote sensing data and conservative models for updating growing stock for areas with obsolete inventory data at the regional basis (Shvidenko *et al.*, 2010; Schepaschenko *et al.*, 2010).

2.1.Recent dynamics and major drivers

Major international sources of extent and dynamics of forests by countries over the region include FAO FRA 2010, UN Economic Commission for Europe, and State of European Forests (*State of Europe's Forest*, 2011), an aggregation prepared by the Ministerial Conference on Protection of Forests in Europe (Oslo, June 2011). While these sources are based on national official data, their reliability is different for different countries and periods due to a number of reasons – different systems of forest inventory, incompatible periods of reported data, different – and changing over time – definition of forests etc. Substantial uncertainties are generated by accounting for temporarily unforested areas as forest (e.g., burnt and harvested areas) that follows from the FAO definition of forests. Overall, the temporal dynamics of real forest cover is high. For instance, Hansen et al. (2010) showed that of the areas covered by forest in Russia in 2000, 13.6 million ha has been transformed in (temporarily) unforested areas during 5 years (2000-2004).

Some sources provide different trends of forest area change in some countries (e.g., Russia). One of the most substantial gaps in the information is the lack of proper separation between forest area change due to natural forest expansion and afforestation activities. Analyzing forest area change and afforestation in Europe, Znachi et al. (2007) concluded that available information is good enough in order to estimate the general trends but not satisfactory for accurate by-country analysis.

Overall forested area of the ECA Region increased by 37 million ha during last 20 years (Table 4). The biggest changes occur in Russia (+31 million ha), but it is only +4% of the country's forest area. Southeastern Europe gains 11% of its forest and Baltics - +7%. Losses of forested area tooke place in South Caucasus and Kazakhstan (-3%).

Carbon stock also was growing during the last 2 decades: +4.1 billion tons of carbon in total (or 205 Tg C yr^{-1}). Russia supplies 2.6 billion tons of carbon sink, but substantial relative changes occur in Eastern Europe (+25-38%). The most relative changes was reported in Central Asia (+84%), particularly in Uzbekistan (+137%), but the absolute values of the carbon sink in these countries are negligible.

Table 4. Forest area and carbon stock dynamics

NN	Region	Forest area 1000 ha				Carbon stock in living forest biomass				
						mln tons				t/ha
		1990	2000	2005	2010	1990	2000	2005	2010	2010
1	Southeastern Europe	22,812	23,554	24,498	25,649	1,479	1,666	1,766	1,955	76.2
2	Central and Eastern Europe	22,316	22,665	22,891	23,283	1,688	1,929	2,018	2,117	90.9
3	Baltics	23,869	24,836	25,306	25,698	1,572	1,837	1,989	2,169	84.4
4	South Caucasus	4,062	4,008	3,974	3,940	263	272	275	279	70.8
5	Central Asia	8,416	8,607	8,701	8,767	49	62	70	90	10.3
6	Kazakhstan	3,422	3,365	3,337	3,309	137	137	137	137	41.4
7	European-Ural Russian North	101,235	102,167	103,647	105,126	5,339	5,516	5,600	5,737	54.6
8	European-Ural Central Russia	58,054	58,588	59,437	60,285	4,112	4,248	4,312	4,418	73.3
9	European South Russia	3,456	3,488	3,538	3,589	357	369	374	383	106.8
10	Western Siberia	85,450	86,237	87,486	88,735	4,073	4,208	4,272	4,377	49.3
11	Siberian and Far Eastern North	213,568	215,535	218,656	221,777	5,566	5,751	5,838	5,981	27.0
12	Siberian and Far Eastern South	352,537	355,784	360,936	366,088	15,453	15,964	16,207	16,604	45.4
	Russia total	814,300	821,800	833,700	845,600	34,900	36,055	36,602	37,500	44.3
	Total	899,197	908,835	922,407	936,246	40,088	41,958	42,857	44,247	47.3

Source: *State of Europe's Forest*, 2011; FRA, 2010; Shvidenko *et al.*, 2010; Pan *et al.*, 2011 (Russia)

2.2.Climate change and forests of the region: Impacts, responses and feedbacks

Impacts of climate change on forest differ substantially for different geographical location of the region, land forms, forest types and regime of forest management. Overall, the impacts could result in (1) geographical and landscape changes of areas suitable for the growth of certain tree species (shift or disappearance of some tree species); (2) increase or decrease of stability, vitality and productivity of forest ecosystems; (3) water and heat stress during weather extremes; (4) alteration of ecosystem ecological functions (e.g., impacts on biogeochemical cycles; impacts on biodiversity); (5) increase or decrease in nutrient retention and turnover; (6) changes in species' reproduction cycles, regularities of succession dynamics, and changes in environmental and social services (e.g., changing values of forest ecosystem as a tourist attraction); (7) changes in hydrological regimes, particularly in arid and permafrost territories. Uncertainty of understanding of responses and feedbacks of the region's forests is high.

State and dynamics of forest ecosystems are a product of the sophisticated interplay and mutual conditionality of impacts, responses and feedbacks of natural, economic and social components, environment and human society.

Current productivity of forests is impacted by four major drivers – climate and climate change, increasing concentration of CO_2, nitrogen deposition and forest management. It is extremely difficult (if possible at all) to separate the impact of each driver. Climate change can impact productivity of forests in different way. Last IPCC assessment reports state that forests may be impacted dramatically by climate change with increase or decrease vitality and productivity of forests but that overall uncertainty is high. Regional specifics are large that hinders understanding of required actions of adaptive forest management and connected mitigation potential (Karjalainen *et al.*, 2003; Nabuurs *et al.*, 2002; Pussinen et al., 2003; Gustafson *et al.*, 2010 etc.).

Global changes provide direct and indirect effects on ECA forest ecosystems, and these interact with multiple natural and anthropogenic disturbances and other ecological processes. Some of these changes may be irreversible on century time scales, and have the potential to cause rapid changes in the earth system (McGuire *et al.*, 2006). The impacts of both global and regional change on ecosystems often cannot be understood within the simple "cause-and-effect" paradigm. Perception of the dynamics of a changing world necessitates simultaneous considering many climate-forming factors of cosmophysical (including heliospheric), geospheric, biospheric and anthropogenic origin, to determine not only changes of state of the climatic system, but also evolution of these physical processes and phenomena, which may be regionally specific. Forest ecosystems of the region more and more become socio-ecological systems. Predicting the cumulative impacts of such complex interactions is difficult, and usually requires an integrative modeling approach (Vygodskaya *et al.*, 2007; Milne *et al.*, 2009) that would combine different types of models (empirical, process-based etc.) and involve different dimensions of the surrounding world - ecological, social, economic. However, there is a very few attempts of such a kind.

Vulnerability of forests to future climates is high. A further increase in mean temperature (about 2–4 8C globally) is associated with significant drying in some regions (Christensen *et al.*, 2007), as well as with the increase in frequency and severity of extreme droughts, hot extremes, and heat waves (IPCC, 2007). The effects of climate change on forests include both positive (e.g. increases in forest vigor and growth from CO2 fertilization, increased water use efficiency, and longer growing seasons) and negative effects (e.g. reduced growth and increases in stress and mortality due to the combined impacts of climate change and climate-driven changes in the dynamics of forest insects and pathogens) (Ayres and Lombardero, 2000; Lucht *et al.*, 2006; Scholze *et al.*, 2006; Lloyd and Bunn, 2007). Furthermore, forests are subject to many other human influences such as increased ground-level ozone and deposition (Karnosky et al., 2005).

Vulnerability of southern mountain forests (Caucasus, Central Asia) is substantial. In Azerbaijan, the area of oak and beech forests will likely decrease, and hornbeam and shrubs will occupy the larger area. The climatic models predicts substantial shift of forest borders (from ~100 to 500 m, less in piedmont areas, more at the upper tree line). It will negatively impact biodiversity. However taken into account the high anthropogenic impact on forest border, experts make a conclusion that the climate-induced shift of the actual forest belt borders will be not significant (Ibragimov, 2010). Mountain ecosystems in Kazakhstan are include in most vulnerable regions of the country.

The Russian Federal Forest Agency has mapped zones of forest health risk (''threat'') across the Russian Federation, showing 338 million ha as ''low threat'', 260 million ha as ''medium'' threat, and 76 million ha of ''high'' threat, predominantly in southerly portions of the country (Kobelkov, 2008), where forest health problems due to drought appear to be concentrated (Ermolenko, 2008).

Considerable uncertainty remains in modeling how drougt and other relevant processes will affect the risk of future tree die-off events (Loehle and LeBlanc, 1996). Although a range of responses can and should be expected, recent cases of increased tree mortality and die-offs triggered by drought and/or high temperatures raise the possibility that amplified forest mortality may already be occurring in some locations in response to global climate change. Examples of recent die-offs are particularly well documented for southern parts of Europe (Breda et al., 2006).

Up-to-now, forest science accumulated many evidences of negative impacts of drought and high temperatures on forest ecosystems of ECA Region. A severe drought in 2000 seriously deteriorated forests of *Abies cephalonica* (Tsopelas et al., 2004) and *Pinus halapensis* —the most drought tolerant species of the Mediterranean pines—in Greece (Körner et al., 2005). Substantial die-back has been reported in forests of mortality of *Quercus robur* in Poland (Siwecki, Ufnalksi 1998). Severe die-back of *Picea obovata* due to drought with following infestation of bark beetles have been reported for Russian North-West where the affected area comprised 1.9 x 10^6 m^3 with the death of 208 x 10^6 m^3 of wood (Chuprov 2007; Krotov 2007; Tswetkov, Tswetkov 2007). Further north, summer drought paired with biotic stressors has been linked to mortality of *Quercus robur* in Poland (Siwecki, Ufnalksi 1998), and with a severe die-off of Picea obovata in northwest Russia.

The observation that climate-induced tree mortality is happening not only in semi-arid regions but also in mesic forests suggests that the global rise in temperature may be a common driver (van Mantgemet al., 2009; Adams et al., 2009). The mechanisms by which rising temperature in the absence of severe precipitation deficits may result in increased tree mortality include impacts on both host physiology and biotic agents.

In addition to hydraulic failure and carbon starvation, a third physiological mechanism predisposing plants to mortality may exist—cellular metabolism limitation. This hypothesis suggests that low tissue water potentials during drought may constrain cell metabolism (WuË rth et al., 2005; Ryan et al., 2006; Sala and Hoch,2009), thereby preventing the production and translocation of carbohydrates, resins, and other secondary metabolites necessary for plant defense against biotic attack.

Boreal zone

Major drivers which impact boreal forest ecosystem of ECA include: (1) dramatic increasing temperature coupled with diverse regional trends of changes of precipitation; (2) increasing aridity of climate in vast continental regions; (3) increasing seasonal and interannual variability of weather; (4) changes in surface albedo due to regional variations in snow cover and vegetation type; (5) changes in disturbance regimes, basically in extent and severity of wild fire and insect outbreaks; (6) changes in hydrological regimes connected to permafrost thawing and land use changes; and (7) increasing and mostly unregulated anthropogenic impacts (McGuire *et al.*, 2006; Soja *et al.*, 2007; Vygodskaya *et al.*, 2007; Shvidenko, 2009; Quegan *et al.*, 2011).

An important feature of the region is fragility of ecosystems which evolutionary developed under a stable cold climate over millennia. Ecological thresholds and buffering capacity of ecosystems under rapid climate change had no analogues in recent history and are poorly understood. This generates major challenges for understanding the current and future state, vitality and resilience of forest ecosystems of Northern Eurasia. The region is one of the most vulnerable vast territories of the planet and indicated as a “hot spot” by the IGBP Global Carbon Project.

Practiced today methods of industrial exploitation of northern territories in the region are wasting and often provide extremely negative impacts on environment and ecosystems. For instance, the company “Norilsk nickel” that emits about 2 million tons pollutants per year, mostly sulfur dioxide, during the last 40 years generated about 3 million ha of technogenic desert around the plant (Kharuk *et al.*, 2007). In regions of intensive oil and gas extraction of West Siberia, (1) up to 35 000 breaks of oil pipe lines occur annually; of this number, about 300 accidents are officially registered with oil spills >10 000 t of each; (2) tundra surface is destroyed more than at 15%; and (3) physical destruction of natural landscapes exceeded >30% of the total area in territories of middle and southern taiga. By different estimates, from 15 to 25 billion m^3 of soil casing-head gas is burnt in torches annually (Krukov and Tokarev, 2009). Soil pollution and water contamination is widespread in some regions, and high in industrial populated territories (Shvidenko, 2009).

Some bioclimatic models predict a substantial shift in vegetation cover by end of this century, particularly in northern (forest-tundra) and southern (forest-steppe) ecotones. Based on the SibClim3 model, within the harsh HadCM3 A2 scenario, the northern vegetation types (tundra, forest-tundra, and taiga) was predicted to decrease from 81.5% to 30%, with southern (forest-steppe, steppe and semidesert) vegetation prevailing on 67% of Siberia. According to the B1 Scenario, habitats for northern vegetation classes would decrease from 81.5% to 50% enabling southern habitats to expand from 18.5% to 50% (Tchebakova *et al.*, 2003). However, based on an ensemble of GCMs, an application of fine resolution detailed landscape & succession model LANDIS-

II for a middle taiga region in Central Siberia led to a conclusion that previously untouched forests will be more strongly influenced by timber harvest and insect outbreaks than by the direct effects of climate change. The effect of the expected future climate on species composition and productivity of forests was significant, but its effect was substantially less compared to impacts of harvest and insects outbreaks (Gustafson *et al.*, 2010; Gustafson *et al.*, 2011a). These two examples show large uncertainty of modeling predictions of future trjectories of the region's forests.

It is worthy to note that indicated shifts of climatic zones have a little common with the future real migration of vegetation. Natural rate of migration of major tree species in northern hemisphere does not exceed 0.3-0.5 km per year, i.e. the rate of warming discussed above is at least about one order of magnitude higher than the possible shift of forests. It means that forests along the southern boundary of the forest zone will experience high stress, impoverishment and death, but shifting the northern tree line will be very slow.

Altered land cover would generate additional regional forcing and feedback to the climate system resulting in a potential non-linear response to changes in climate. Predicted significant changes in land cover across Siberia by the end of the century would initiate change in surface albedo and thus energy fluxes between the biosphere and the atmosphere. Possible effects of feedbacks of vegetation-induced albedo change to net radiation change will provide an additional forcing of accelerating/mitigating shifts of climatic zones over Siberia,

Studies provided in Siberian mountains showed that coniferous tree species growing in the alpine forest-tundra ecotone are already strongly responding to warming by an increase of increments, stand densification and regeneration density, upward altitudinal tree line shift, and transformation of krummholz to arboreal forms (Shiyatov *et al.*, 2007; Kharuk *et al.*, 2010). Similar processes are observed for the northern forest-tundra ecotone.

Climate change is considered as a major reason of changing the allometric relationships in boreal forests. It has been showed a pronounced increase in the share of green parts of forest ecosystems and decrease of the share of above ground wood in Russian forests over 1960-2000s (Lapenis *et al.*, 2005). The shift has been largest within the European Russia, where summer temperatures and precipitation have increased. On the contrary, in the northern and middle taiga of Siberia, where the climate has become warmer but drier, the fraction of the green parts has decreased while the fractions of aboveground wood and roots have increased (Figure 4).

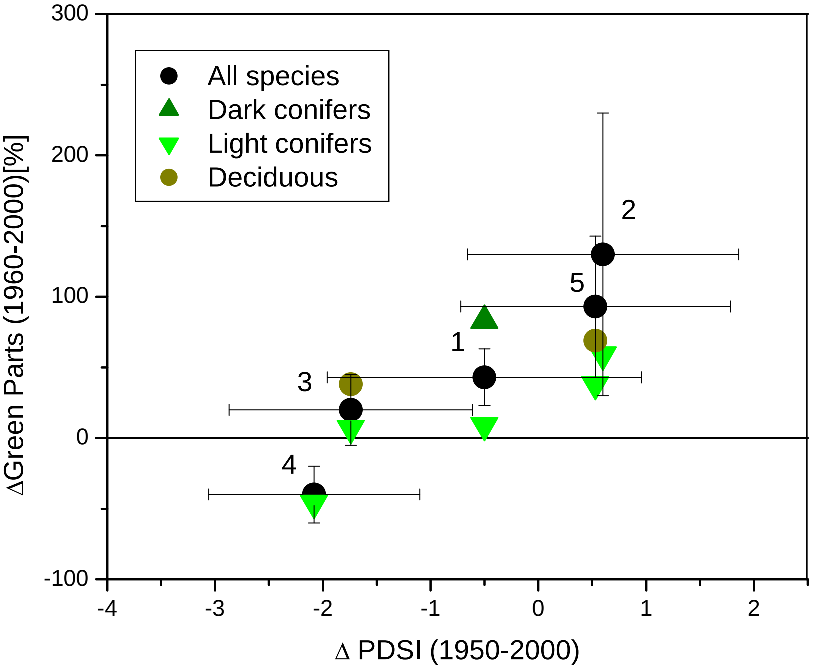

Figure 4. The area-averaged trends in green parts versus PDSI trends as estimated over Russian regions Trends in green parts are shown for groups of species with statistically significant trends ($p < 0.05$). Horizontal and vertical error bars represent the 95% confidence interval of estimates for PSDI and the green parts, respectively.

There are evidences that site productivity in Northern Eurasia has increased (Kahle *et al.*, 2008). Increase of the increment of European forests at 52% has been reported for Europe for 45 years from 1950 to 1995 (from 2.9 to 4.4 $m^3 ha^{-1} yr^{-1}$) (FAO, 2000). There are publications which report increase of productivity based on long-period forest inventory data, e.g. for Russia at the level of 0.2-0.5% per year over 1960-2010 (Alexeyev and Markov, 2003; Shvidenko *et al.*, 2007b).

Pussinen et al. (2009) applied SSW (SMART-SUMO-WATBAL) model (Wamelink et al. 2009) to 166 intensive monitoring forest plots in Central and Northern Europe to assess the separate effects of (*i*) CO_2 fertilization effect, (*ii*) change of temperature and precipitation (derived from IPCC A2 Scenario evaluated with the HADCM3 model), (*iii*) nitrogen deposition and (iv) the combined effect of the above factors on net annual increment and biomass accumulation in mid- and high-latitude Europe. Management activities (thinning and final felling) have been simulated by EFISCEN model (Schelhaas et al. 2007). Major requirements to adaptive management included increase of increment under environmental change and decrease of risk from storm and insects. The scenario included increasing felling at 10% per 5 years that, in addition, would increase use of wood for bioenergy production, has been used. The simulations showed substantial impacts of both environmental changes and forest management on the region's forests. Under a no climate change scenario, an increased felling scenario resulted in increased wood demands from 3.8 to 5.3 $m^3 ha^{-1} yr^{-1}$ (or +50% to the current level in 2100) maintaining growing stock volume (GSV) at current ~170 $m^3 ha^{-1}$. Including climate change increases this possibility to 90% (to 7.2 $m^3 ha^{-1} yr^{-1}$). The GSV increased to 279 $m^3 ha^{-1}$ in 2100 under base felling and no environment change and to 381 $m^3 ha^{-1}$ under environmental change. The tree biomass increased at ~45% during 2005-2100 under no environmental change and base felling and at ~100% (from 72 $Mgha^{-1}$ to 143 M ha) under environmental change. Overall, the environmental change scenario resulted in the increase of increment of 35-45% (under base felling). The largest relative growth change (up to 75%) was predicted for the Nordic countries.

Modeling results suggest the CO_2 fertilization effect will impact forest structure, growth and productivity (e.g., Cramer *et al.*, 2001; Ciais *et al.*, 2005). Studies of enhanced CO_2 concentration experiments and dynamics of forest productivity over last decades showed a consistent and positive effect on NPP (Norby *et al.*, 2005; Boisvenue and Running, 2006; Shvidenko *et al.*, 2007a). However, water stress, weather variability, and connected to this alteration of forest disturbances could negatively impacts productivity of forests and increase forest dieback.

Climate change will dramatically increase extent, frequency and severity of natural disturbances, mostly fire and needle- and foliage- eating insects (see Section 2.3).

Temperate zone

Impacts of climate change on productivity of forests of southern part of ECA are more uncertain. The temperate zone of the ECA region, from Southeast Europe and Central Asia and to steppe in East Siberia and Russian Far East, is very diverse. Accordingly, the problems raised by predicted climatic changes are also manifold, from land use change, forest degradation and desertification to the substantial differences in disturbance regimes.

What makes the temperate zone of the region specific is the *presence of the xeric limit* of forests and forest tree species. Xeric (or rear, trailing) limits at the low latitude and low altitude end of distribution ranges of trees determined by climatic aridity (Mátyás *et al.*, 2009). In Southeastern Europe, the ecotone is a densely populated and agriculturally important zone. This belt reaches from East-Central Europe across the plains of Southeast Europe (Romania, the Ukraine and South Russia) and through Northeast Kazakhstan far into Southern Siberia and North China (Manchuria). The transition zone in flat lands is especially vulnerable due to differences in the magnitude of the *latitudinal and altitudinal lapse rates:* the first (i.e. the rate of change with increasing elevation) amounts to 6.9°C/1000 km and the second – 5.0-6.5°C/1000 m. Thus minor changes of temperature in flat regions affect disproportionately larger tracts of plains as compared to mountainous regions.

In the ecotone between closed forests and woodlands/ steppe regions (territories of xeric limits) surface albedo, evapotranspiration, and carbon budget are effected by land use change, afforestation programs and specifics of forest policies and forest management. Changing albedo will cause higher summer temperature increasing droughts. Forest productivity should decrease due the impacts of high temperature and water stress. CO2 fertilization effect and nitrogen deposition will confound this process. Overall, many studies report a substantial future decline in growth and productivity of forests in the xeric belt of the ECA region. However, there are not enough evidences that this could be considered as statistically significant general trends for the southern part of the region (Somogyi 2008). In addition, major part of modelling exercises does not include forest management as one of drivers.

Some models support increasing productivity of agriculture and forests in major parts of the southern part of Asian Russia (Sirotenko, Abashina, 2008) predicting that bioclimatic potential for agriculture will increase by 20% in the Russian Far East and up to 50% in West Siberia. However, analyses of extreme climate events predict that main food producing regions in the south will experience a substantial increase in the number of poor harvests – it will double by 2020 and triple that the number by the 2070 (Alcamo et al., 2003).

Finally, the continental Southerneast Europe and Central Asia are a marginal issue in climate mitigation policy. The specific features of theses territories include (cf. Mátyás, 2010): (1) high uncertainty of climatic predictions in opposite to those in the rest of the ECA region; (2) extremely high vulnerability of forests in this zones; (3) high probability of ecologically harmful processes (degradation and impoverishment of forest ecosystems, oxidation of soil carbon etc.) which could cause irreversible losses of forests); (4) major part of the region is in countries of intensive political and economic transition, which did not reach any stabilization; (5) most of the region has unsatisfactory structure of natural landscapes (a large share of degraded land, lack of stabilized components, e.g. forests etc.).

In many studies, increasing forest dieback is expected due to climate change over the entire ECA region (Solomon, Kirilenko 1997; Watson et al. 2000). Two major reasons for this could be pointed out. First, increase frequency, duration and severity of weather extremes will decrease vitality and stability of forests and make them more susceptible to different external impacts. Second, climate change very likely will increase extent and severity of disturbances (fire, insect outbreaks etc.). A substantial increase of dead wood in Northern Eurasian forests during two last decades has been recently reported (Shvidenko et al. 2009).

Increases in the frequency, duration, and/or severity of drought and heat stress associated with climate change could fundamentally alter the composition, structure, and biogeography of forests in many regions. Potential increases in tree mortality associated with climate-induced physiological stress and impacts of other climate-mediated processes such as insect outbreaks and wildfire. Existing projections of tree mortality are based on models that lack functionally realistic mortality mechanisms. Allen et al. (2010) presented the first global assessment of recent tree mortality attributed to drought and heat stress. The review suggests that at least some of the ECA region's forest ecosystems already may be responding to climate change and raise concern that forests may become increasingly vulnerable to higher background tree mortality rates and die-off in response to future warming and drought, even in environments that are not normally considered water-limited. This further suggests risks to ecosystem services, including the loss of sequestered forest carbon and associated atmospheric feedback and indicates a need of globally coordinated observation system.

Box 2. Specifics of forests and forest management in countries of Central Asia

Common features of countries of Central Asia are (1) harsh climatic conditions for growth of forests; (2) very low percent of forest cover (PFC); (3) relatively low level of forest management; and (4) lack of sufficient systems of forest inventory and monitoring. Forest vegetation in Central Asian countries is represented by relatively fragmented forest lands, located far from human settlements, often in hardly accessible areas. Substantial part of forest ecosystems is degraded. The ecosystem services of forests are often compromised, many species are losing their natural habitat, and forest gene pool is progressively impoverished under the influence of human activities. National systems of specially protected areas could play a substantial role in protection of forests and conservation of biodiversity. However, the specially protected areas on average cover only about 5% in the region. Areas of forests in Central Asia decreased on factor 4-5 after the beginning of 29th century (Turdieva et al. 2007)

Forest management in countries of Central Asia is far from sustainable. Over-exploitation and insufficient forest protection, misuse of forest lands, uncontrolled cattle grazing, uncontrolled harvest for firewood, over-harvesting of wild fruits and nuts, forest fires and other factors have adversely impacted forest resources (Mátyás, 2010).

Tajikistan: The total area of forest fund (i.e. all area under forest management) is 1.8Mha, of which 0.41Mha is covered with forest. The PFC is about 3%. In the beginning of 19th century, the area of tugay forests (riparian woodland) was about 1Mha, whereas now its area is only 120,000 ha or one-eighth of the original area (Akhmadov and Kasirov, 1999). There are four nature reserves with area of 0.17Mha, 13 nature refuges with area of 0.31Mha, two national parks (2.6Mha), and 26 nature monuments in the country. The level of management of specially protected areas is low.

Uzbekistan: forest covers 2.3Mha or about 5.1% of the total area of Uzbekistan. In comparison with 1996, forest area in Uzbekistan was reduced by more than at 1Mha by logging, converting forest lands to arable lands, and increasing impact of soil erosion. The area of tugay forests was reduced to less than one-tenth of the original area. Cutting saxaul, juniper and other forest trees for firewood has led to desertification of 6.5Mha of land previously covered with vegetation in Uzbekistan.

Turkmenistan: Arid Turkmenistan is one of the most forest deficient regions in Central Asia. All Forest Fund in Turkmenistan (9.996Mha) belong to the State (forests of state importance and forests in reserved land). The area covered by forests is about 4.13Mha. Forests in Turkmenistan are distinguished into three types: (a) desert forests, (b) mountainous forests, and (c) native floodplain (tugay) forests. There are eight nature reserves with a total area of 0.785Mha, 14 nature refuges with an area of 1.16Mha, and 17 nature monuments. Total area of specially protected lands is 1.98Mha or 4.0% of the total area of the country. About 62.6% or 72 species of plants are conserved in these protected areas (Turdieva *et al.*, 2007).

Kyrgyzstan: A national system of specially protected areas in Kyrgyzstan includes six nature reserves with total area of 0.22Mha and forested area of 20,262 ha, six national parks with total area of 0.22Mha, 52 nature refuges and 18 nature monuments. The total special protected area is 0.86Mha, or 4.4% of total area of Kyrgyzstan (Turdieva *et al.*, 2007).

The problem with water deficit is acute in Central Asia (Chub, 2007). Rivers of the region are supplied by water from mountain territories. However, the area of the glaciers is decreasing. The glaciation area of Hissar-Alai region was reduced 15.6% during the period 1957–1980, while in Pamir it was reduced by 10.5%. A 7.6% to 10.6% increase in the moraine area covered by glaciers was recorded in Pamir-Altai and a similar increase of from 4.8% to 11% was recorded in Pamir (Chub, 2007).Water is contaminated by persistent organic pollutants (e.g., the Lake Sevan). The catastrophic situation with the Aral Sea caused by irrigation for cotton production: currently 28 million people in the five Central Asia countries depend on irrigation agriculture

Principal constraints in sustainable management of forests in Central Asian region are (Mátyás, 2010):

- Weakness of the current national forest protection and management systems in the region;
- Lack of awareness on value and importance of forest conservation and sustainable use for national development at national and regional levels;
- Disparity of current forest enterprises to new economic conditions of the phase of economy transition in the region;
- Lack of qualified staff at forest enterprises trained to manage forests in effective way under market driven economy.

2.3.Natural and human induced disturbances

Natural and human induced disturbances (D) are widespread over the region although their structure, their importance and role in state and dynamics of forests are different in boreal and temperate zones. Economic losses due to D are high. The fire season-2010 in Russia, when large fires occurred in densely populated territories of European Russia, has brought economic losses of above $10 billion.

Table 5 contains an aggregated data on disturbances by the sub-regions used in this study. Other disturbances include *inter alia* insects and diseases outbreaks, grazing, and air pollution. The overall numbers are defined by Russia with its vast forest resources.

Table 5. Disturbances on forest land

NN	Region	Forest fire, 1000 ha	Other disturbances, 1000 ha
1	Southeastern Europe	38.6	662.0
2	Central and Eastern Europe	6.8	2,279.0
3	Baltics	14.2	807.0
4	South Caucasus	0.3	64.0
5	Central Asia	1.3	78.0
6	Kazakhstan	16.7	-
7	European-Ural Russian North	92.5	
8	European-Ural Central Russia	99.8	
9	European South Russia	0.4	
10	Western Siberia	407.3	
11	Siberian and Far Eastern North	1,082.7	
12	Siberian and Far Eastern South	3,671.1	
	Russia total	5,353.8	4,151.0
	Total	5,431.7	8,041.0

2.3.1. Wildfire in Russian forests

Disturbance (D) is an integral feature of the boreal world. They define vegetation mosaics of landscapes, structure and succession dynamics of forest ecosystems. During last decades D impacted on the average 10-25 x 10^6 ha of Russian forest land annually. D is an inherent geographical, landscape, ecosystem and site specific phenomenon. Major types of disturbance include fire, insect/ diseases outbreaks, harvest, pollution and industrial transformation. Official data on extent of D in Russia are incomplete.

Fire. Fire is a major natural disturbance in Russian forests, due to following reasons: (1) about 95 percent of Russian forests are boreal forests, and 71% of them are dominated by coniferous stands of high fire hazard; (2) a significant part of the forested territory is practically unmanaged and unprotected, and large fires (>200 ha) play an important role in this region; (3) due to slow decomposition of plant residuals, natural ecosystems contain large amounts of accumulated organic matter; and (4) a major part of forest is situated in regions with limited amount of precipitation and/or frequent occurrences of long drought periods during the fire season that often initiate fires of high severity.

Relatively complete and reliable data on extent of vegetation fires in Russia exist since 1998 when remote sensing estimates became available for the entire territory . Official statistics is limited by fires on protective forest land and have been and now are incomplete and unreliable (Shvidenko and Goldammer, 2001). A specific feature of fires in Northern Eurasian (NE) territories is the dominance of on-ground fire. Numerical data on previous forest fire regimes in Russia could be found in Shvidenko and Nilsson (Shvidenko and Nilsson, 2000a, 2000b). Fire activity is basically driven by four major factors – weather/climate, amount and condition of fuel, ignition agents, and human activities.

On average, for basic forest upland types and geographical localities, the fire-return interval in Russian boreal forests including all types of fire is 25 to 70 years. However, the variation of fire frequency is very large: upper limits are 250 to 300 years for wet sites and dark coniferous forests (and up to 500-700 years for wetlands), lower limits are 7 to 15 years, and even less, usually observed in dry pine and larch forests in densely populated areas. In a historical perspective, areas in which no fires occurred during a single life cycle of coniferous taiga forests (200-300 years) are negligibly small in drainage sites of the taiga zone (Furyaev, 1996).

The majority of the fire events in Siberia are of human origin and about 20-30% in some regions (measured by fire extent) can be attributed to climate factors alone (mostly lightning). The majority of fires (~75-85%) are ground fires, either superficial or steady. Crown fire comprise about

20%, however in extremely severe fire years this share could be doubled (Shvidenko and Nilsson, 2000b; Achard *et al.*, 2008). Crown and peat fires are stand-replacing fires, while on-ground fires cause a partial dieback which is accounted for from 5-7% (by initial growing stock) to 70-90% after steady ground fires, particularly in usually wet sites and on permafrost. Indicators of fire regime depend on many factors: weather specifics during the vegetation period; fuel characteristics of forests and adjoining vegetation; type of forest formation; spatial structure of landscapes; their ecological regimes; inter-annual climate variability (recurrence of extreme droughts); density of population; accessibility of forests; level of forest fire protection, and others.

Climate specifics of recent decades pose a threat of large vegetation, primarily forest fires of high intensity, so called *catastrophic* or mega- fires. Catastrophic fire are defined as those which envelop a substantial part of a landscape (>20 000 ha) under conditions of a long-period anticyclone and the highest class of drought; resulting in post-fire dieback greater than 50% of growing stock; have the speed of increase more than 40km/24 hours, and time of combustion of fuel at fire edge more than 4 minutes (Sukhinin 2008). There is no economic sense in extinguishing of such fires due to the need of huge labor and financial resources, thus fire protection activity is limited to protection of settlements and elements of infrastructure. Multiple catastrophic fires lead to a catastrophic situation when increase of the total perimeter of burning areas exceeds the rates of fire localization.

Negative ecological consequences of catastrophic fires are large. Catastrophic fires result in substantial ecosystem degradation and impoverishment of biodiversity, create a specific condition in the atmosphere affecting seasonal weather over huge territories, provide large economic and infrastructure damage, substantially impact living conditions of the local population and the general health of people. For Russia, this situation is aggravated by substantial decline of forest governance in the country, degradation of civil self-consciousness and destruction of professional nature-protected systems (particularly, by practical elimination of the state forest guard).

Long-term consequences of catastrophic fires are the irreversible transformation of the forest environment, which is obvious beyond the restoration period of an indigenous forest ecosystem (i.e., ranging from 150-400 years for major forest forming species). They reveal in the following aspects (Yefremov and Shvidenko, 2004):

- a significant (up to several times) decrease of the biological productivity of forest lands due to the destruction of the indigenous ecotopes and replacement of indigenous vegetation formations;
- irreversible changes of the cryogenic regime of soils and rocks;
- change of long-term amplitude of hydrothermal indicators beyond natural fluctuation;
- changes of multi-year average hydrothermal and bio-chemical indicators of aquatic and sediment runoff, as well as of hydrological regimes and channel processes of water streams;
- accumulative impacts on atmospheric processes resulting in global climate change;
- acceleration of large scale outbreaks of insects and disease;
- irreversible loss of biodiversity including rare and threatened flora and fauna species;
- transboundary water and air transfer of pyrogenic products; and
- change of historical migration routes for migratory birds, ground and water animals.

There is a clear statistical link between deforestation of lands and a forest fire occurrence rate. In particular, the correlation coefficient between the share of unforested areas in forest landscapes and the forest fire occurrence rate was estimated at 0.49 (CI 0.95) (Sheingauz, 2001). At the level of forest enterprises, a 1% increase in a forest fire occurrence rate on average causes an 8.4% decrease in the percentage of forest cover.

During the last twenty years, catastrophic fire situations have occurred in different regions of Russia, generally in the Asian part, with a frequency of about 10 years. Meteorological conditions which initiated catastrophic forest fires occurred in 1954, 1968, 1976, 1988, and 1998 in the Amur

River Region, in 1979, 1985, 1998 and 2003 – in Eastern Siberia (from Krasnoyarsk Kray to Burjatia and Chita regions), in 1996 – in Amur Oblast and in the Republic of Sakha, in 2002 – in the Republic of Sakha, 2003 – in Central Siberia and Far East, and in 2010 – in European Russia. The occurence of years with catastrophic fire have been increasing during recent decades (e.g. Sokolova and Teteryatnikova, 2002; Shvidenko, Efremov 2004).

By estimates, catastrophic forest fires during the last two decades increased the total area deprived of forest in the Russian Far East region by 8 million ha. About one-third of area enveloped by catastrophic fires is transformed into not-productive territories where natural reforestation did not occur during 2-3 life cycles of major forest-forming species (e.g. 300-600 years) (Yefremov and Shvidenko, 2004). Such areas are basically represented by bogs (up to 70%), small shrubs and grasses (15%), open woodlands (10%), and stone fields and outcrops (5%).

Published estimates of forest fires in Russia vary substantially. For this study, we used the estimates from Shvidenko et al. (2011) as most reliable. They are based on an Integrated Land Information System (ILIS) of Russia that includes a hybrid land cover of Russia at a resolution of 1 x 1 km and corresponding attributive databases (Schepaschenko et al. 2011)). This system was developed based on a multi-sensor remote sensing concept (12 RS products from 8 satellites were used), measurements *in situ*, results of different inventories and surveys (including forest state account, state land account, ecological monitoring) and other relevant information. The ILIS includes a comprehensive description of type, amount and structure of potential fuel.

Burnt areas for 1998-2010 were estimated for each month of fire season based on 2nd, 3rd, 4th and 5th bands of AVHRR NOAA using the algorithm described in (Sukhinin et al. 2004; Soya et al. 2004) with correction of recognized biases. Distribution by types of fire (crown fires; superficial on-ground; steady on-ground; and peat fire), as well as share of combusted fuel (totally 12 types of fuel were used) monthly estimates were based on many year averaged data within bioclimatic zones and land cover classes (Shvidenko et al. 2011).

The total area of vegetation fire over the Russian territory between 1998-2010 is estimated as 106.9×10^6 ha, or on average 8.23×10^6 ha year^{-1}, varying from 4.2 (in 1999) to 17.3×10^6 ha year^{-1} (in 2003) (Figure 5). As a rule, more than 90% of burnt areas are situated in Asian Russia, mostly in its southern part. An exception is the year of 2010 when unprecedented temperature anomalies and drought initiated a catastrophic fire situation in central regions of the European part of Russia. During the last 13 years almost two-thirds of burned areas (5.31 Mha yr^{-1}) were in forests. A substantial part of low intensive fires is observed on agricultural lands, basically as a result of prescribing burning of different types (18.9% of the total area). The areas of fire in natural grass and shrub ecosystems were estimated at 8.7%, and on wetlands – 7.3% of the total area affected by fire.

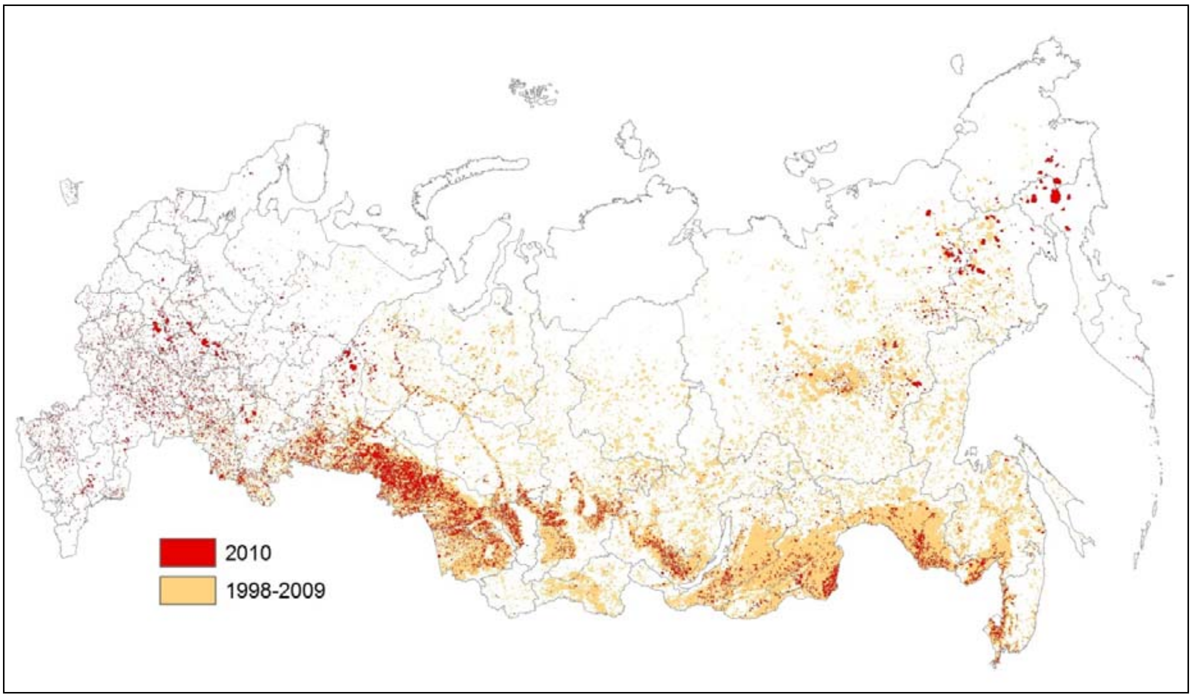

Figure 5. Burnt areas over Russian territories between 1998-2010

Overall, the presence of permafrost and wetlands accelerates fire activity, emissions of carbon, methane and other greenhouse gases, and post fire mortality. Very likely higher temperatures and permafrost thaw will increase the fire activity and vulnerability of terrestrial ecosystems to burning due to (1) changing hydrological regimes over vast territories due to decreasing water table and increasing evapotranspiration; (2) wider distribution of deep burning; and (3) more intensive post-fire dieback. Interactions between fire regimes, land use and climate may become increasingly important for carbon storage and fluxes in ecosystems.

Amount of organic matter consumed by vegetation fires between 1998-2010 is estimated at 1.57 x 10^9 t of carbon, or on average at 121.0 x 10^6 t C year^{-1} (Shvidenko et al. 2011, Figure 6). The interannual variability of carbon emissions is high – from 50 x 10^6 t C year^{-1} (2000) to 231 x 10^6 t C year^{-1} (2003). Forest lands deliver a major part of carbon emissions – 76.0% of the total. Wetlands are a second source (15.8%). An independent assessment of carbon emissions that were caused by vegetation fires in Russia has been recently presented in the Global Fire Emissions Database – GFDB3 (van der Werf et al., 2006, 2010). The assessment of areas was done based on different satellites, which were available during 1997-2009 (mostly TERRA/MODIS). The average burnt area in Russia for 12 years (1998-2009) was estimated to be 9.17 million ha, or +11.1% to the above estimate, and the carbon emission – 137 Tg C yr^{-1} (+13.2%). Other estimates are of the same magnitude, e.g. carbon emissions were estimated at 160-210 Tg C in 1998 and about 270 Tg C in 2003 (Kaiji et al., 2003).

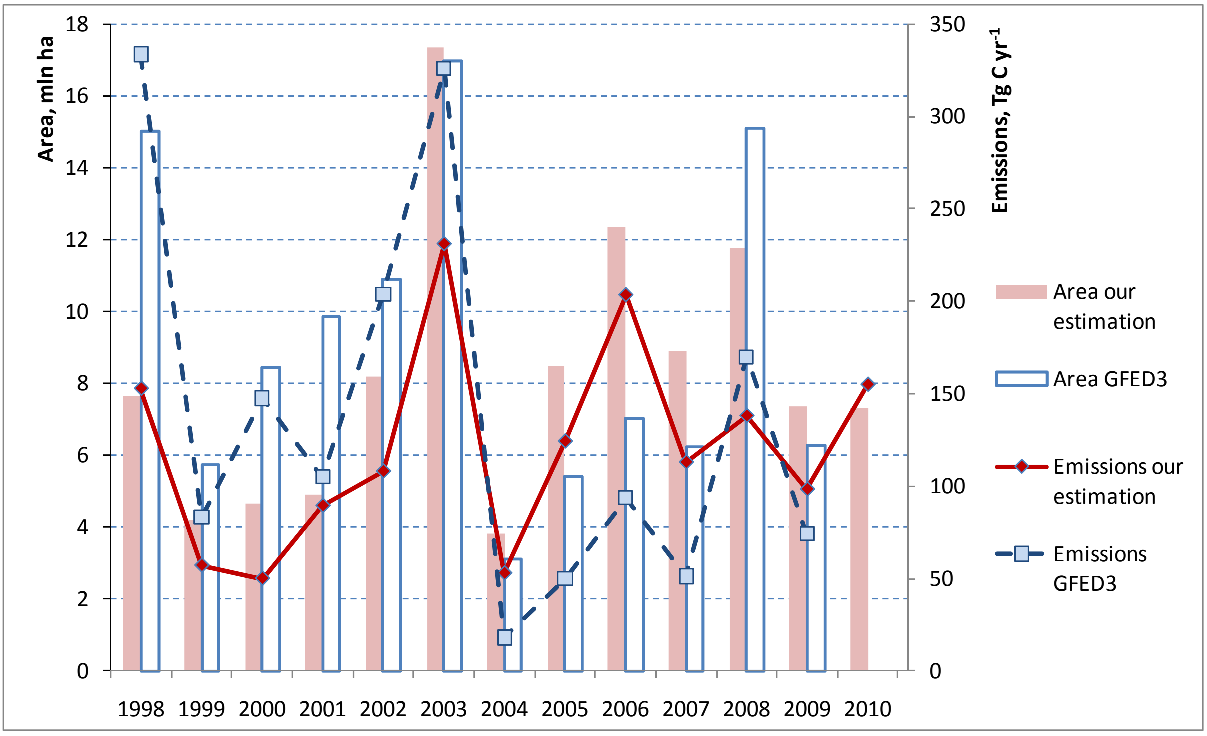

Figure 6. Carbon emissions of vegetation fire in Russia between 1998-2010 and comparison with data of GFED3 (Shvidenko et al. 2011)

Climate change accompanied by other pressures (such as industrial development and expanding populated areas) will provide a further profound effect on fire in boreal ecosystems. The expected change in fire danger potential for the 21st century that was estimated based on GSMs ensemble projections is characterized by a substantial increase of a number of days with high fire danger (e.g. Malevsky-Malevich et al., 2008). Gerten et al. (2007) using the index of biome-level water limitation showed that ecosystems of northern temperate latitudes will be at the greatest risk of increasing water limitation. Gerten D., Schaphoff S., Lucht W. 2007. Potential future changes in water limitations of the terrestrial biosphere. Climati Change 80, 277-299. Very likely, future fire regimes will be characterized by (1) increasing length of fire season, (2) accelerated fire activities – number of ignitions, large areas with extreme fire hazards etc.; (3) increased area burned, severity of burning, and amount of consumed fuel, (4) increased wider occurrence of disastrous and escaped fires; (5) increased post fire impacts on ecosystems and landscapes; and (6) wider distribution of "green desertification"

The ability of current Russian forest management to cope with these changes is very limited. Current forest fire protection operates with a narrow margin between success and failure, and disastrous fires of recent decades in Siberia clearly illustrated the scale of problems that arise. It requires substantial changes to forest management policies including setting of priorities, prevention programs, fire monitoring systems, initial attack capabilities, modification of some legislative and institutional aspects of forest management like access restriction policies.

Based on GCMs and different vegetation models, the substantial increase of fire hazard is predicted over the entire circumpolar belts mostly to warming, particularly in southern and continental regions (see also Le Goff et al. 2009; Balshi et al. 2009; Malevsky-Malevich et al., 2008; Chertov et al. 2009). There is a general tendency of increasing risk, extent and severity of forest fire, as well as length of fire season. For Siberia, fire danger may increase by a factor 3-4, with a peak in middle of August. By end of the 21st century the risk may be decreasing due to increase of precipitation (Mokhov, Chernokul'skaya 2009). Intensification of fire activities will be accompanied by substantial shift of bioclimatic zones northwards up to 600-1000 km. New climate and accelerated fire regimes may halve areas of Siberian forests by 2080 (Tchebakova et al., 2009). An earlier start of fire season, significant increases of area large fire in both Canada and Siberia has been predicted by Stocks et al. (1998). Many other studies predict increasing the area burnt, particularly due to increasing lightning-caused fires. Altered fire regimes, succession dynamics and permafrost behavior could result in a positive feedback intensifying rates of climate change (Kurz *et al.*, 1995; Lyons et al. 1998; Soja et al. 2007).

National programs of adaptation to, and mitigation of negative consequences of climate change in the boreal zone, should include fire protection as a cornerstone of current and future sustainable forest management. Development of long-period strategies of preparation of boreal landscapes to future climates is an urgent problem today. The inherent uncertainty of forecasts is a specific problem of such developments, and hence the need for use of win-win strategies which would be robust to a diversity of possible scenarios. International cooperation in further development of boreal fire protection becomes an issue of the highest priority.

2.3.2. Biotic and other disturbances

Among numerous biotic disturbances across the ECA region, insect and disease outbreaks are most important. Reported official data on biotic factors impacts probably underestimate the areas and losses but they remain only a source of information.

Warming temperatures have direct effects on insect population dynamics—in particular, outbreaks of some aggressive needle-eating and bark beetle species are closely tied to temperature (Logan et al.,2003; Berg et al., 2006; Rouault et al., 2006).

Higher temperatures can accelerate insect development and reproduction, increasing infestation pressure directly (e.g., Wermelinger and Seifert, 1999; Bale et al., 2002; Gan, 2004), while at the same time heat-induced drought stress may reduce tree vigor and increase host susceptibility to insect attack (Mattson and Haack, 1987; Rouault et al., 2006). Warming temperatures and drought-stressed trees also may foster increased mortality from non-insect pathogens, particularly fungi (Ayres and Lombardero, 2000; Desprez-Loustau et al., 2006; Garrett et al.,2006). However, fungal responses to climatic factors are complex and uncertain because of interactions with tree host susceptibility and insect vectors, and some fungi-tree relationships are difficult to assess because important belowground interactions between fungi and tree roots are not well studied.

By rather consistent opinions of Russian experts, the damage caused by insect and diseases in the boreal zone is of the same magnitude of that generated by fire (Isaev 1980; Petrenko, Kondakov 1980, Sheingauz 1989). In areas of insect and disease outbreaks, the trees are killed completely or partially, productivity and vitality of forests substantially decreased and large amounts of dead wood are accumulated. This increases frequency and severity of fires and negative post fire impact on ecosystems.

Outbreaks of most dangerous needle- and leaf- eating insects are most harmful in the boreal zone. As a rule, warmer and drier weather provoke large scale outbreaks. Under such conditions, outbreaks take on an eruptive (pulsating) character of the dynamics of insect populations, occupy vast areas measured by millions of hectares and cause significant economic damage, lead to deep ecological transformation, and result in changes of composition and structure of forest cover. For example, much warmer than usual weather conditions in Siberia during the last 3 years of the 20th century provoked an outbreak of Siberian silk moth over a total area of almost 10 million ha (2000-2001), mostly of larch forests far northward to the areas where this pest was usually observed before.

Official national data for the last decades shows an increase of the areas affected by biogenic factors in Russian forests. According to official statistics, the total area of outbreaks of insect and diseases in Russian forests during the period from 1973 to 1987 ranged between 1.5 $x10^6$ ha and 3.8 $x10^6$ ha, with an average 2.73 $x10^6$ ha (Isaev, 1991). During the decade 1988-1997 the average annual area reported was at 1.55 $x10^6$ ha with the seasonal variability of individual years from 1.43

to 2.28 x10^6 ha. The average for 1998-2010 was 5.48 x 10^6 ha with the peak of 10.39 x10^6 ha in 2001 (FAFMRF, 2010).

Climate change substantially impacts phenology, dynamics and injuriousness of forest pests including probability of surviving of populations, change of fodder conditions, shift of natural habitats, and change of seasonal dynamics of population (Meshkova 2009). Forest insects could also serve as a good indicator of environment and climate change. From other side, climate change increases the vulnerability of trees to insect damage. Warming and increasing aridity of climate generate favorable conditions for outbreaks of most dangerous insects of the boreal and temperate zone (Isaev 1999). The threat of vast outbreaks, particularly of alien insects is very likely in southern part of the country, specifically in single species pine stands.

Currently substantial areas of forests are affected by pests and diseases in countries of Southeastern Europe (e.g., about 1.5 million ha in Ukraine). Changing climate decreases resilience and vitality of forests in many large regions. Planted forest developed in harsh growing conditions (e.g., on bare sands) require specific anticipatory protection measures. Forest fire becomes more dangerous taking into account increasing aridity of climate. An absolute majority of ignitions is provided by population that evidences about insufficient level of ecological education of population. Forest protection monitoring needs substantial improvements.

Other large scale *D* processes, like dryness of large areas of forests, caused by complicated combinations of climatic and non-climatic factors, are reported periodically for different countries of the region. Dryness is observed across large areas for different goographical locations, e.g., in oak stands in Ukraine, Moldova and Russia, or in Far Eastern spruce-fir forests. During recent decades several waves of increasing dryness were observed here. During the large wave of the second half of the 1960s, the areas of drying forests were estimated to be 5.5 x10^6 ha in territories of the two administrative regions - Khabarovsk and Primorsk krays (44% of the total spruce-fir forests there) with the storage of dead wood of more than 360 x10^6 m^3, with average storage of dead wood at about 100 m^3 ha^{-1} (Ageenko, 1969). The next wave occurred between 1970-1980 in Sikhote-Alin where only in 7 forest enterprises 165 thousand ha of forest died with a growing stock of 14 million m^3. This process is accelerating now. A rather dangerous situation is arisen in the forbidden zone of the Chernobyl nuclear power station where substantial areas of pine forests (measured by tens of thousand hectares) are drying. Wildfire in this highly contaminated area could provide substantial radioactive contamination of East Europe.

Air pollution, industrial destruction of sites and unfavorable weather conditions also damage forests over large territories. As a rule, these data are not reported in any regular way. A special survey on impacts of air pollution (1991) indicated 321 x10^3 ha of dead forests with 465 x10^3 ha strongly disturbed due to this impact in Russia. Kharuk et al. (1996) estimated areas of forests declined in Siberia by pollution to 3-3.5 x10^6 ha, 3-4 times more than the officially reported data for all the country.

2.3.3. Harvest of wood

Availability of forest resources and developed infrastructure defines the amount of wood harvested in the ECA region (Table 6). Total harvest decreased for the region by about 120 million m^3 during the last two decades, mostly due to Russia where it decreases by 150 million m^3. Baltic countries substantially increased intensity of harvest after 1990s due to change of property rights and rules of forest management. Countries of Central and Eastern Europe provide mostly sustainable harvest. Amount of harvested wood in Southeastern Europe, Caucasus and Central Asia is rather stable and limited by availability of forest resources there. Kazakhstan substantially decreased amount of harvested wood during the last two decades due to economic and social changes in the country. Practically all countries mentioned above provide the harvest in limits defined by national forest legislation.

Table 6. Forest harvest in 1990-2005

NN	Region	Industrial roundwood, 1000 m3			Woodfuel,1000 m3		
		1990	2000	2005	1990	2000	2005
1	Southeastern Europe	23,284	23,615	25,510	21,990	16,793	17,301
2	Central and Eastern Europe	44,613	45,286	54,219	11,409	9,879	11,889
3	Baltics	42,797	60,402	65,283	10,391	10,227	11,981
4	South Caucasus	143	130	126	358	396	746
5	Central Asia	10	18	18	94	73	54
6	Kazakhstan	2,024	189	535	577	483	231
7	European-Ural Russian North	91,508	35,644	45,983	23,229	16,287	17,356
8	European-Ural Central Russia	66,009	25,712	33,170	16,756	11,749	12,520
9	European South Russia	788	307	396	200	140	149
10	Western Siberia	19,356	7,540	9,727	4,914	3,445	3,671
11	Siberian and Far Eastern North	2,500	974	1,256	635	445	474
12	Siberian and Far Eastern South	88,235	34,369	44,338	22,398	15,704	16,735
	Russia total	268,396	104,546	134,870	68,131	47,770	50,905
	Total	381,267	234,186	280,561	112,950	85,621	93,107

Sources: State of Europe's Forests 2011; FRA, 2010; FFS'RF, 2009

The level of sustainable harvest for Russia (Annual Available Cut, AAC) is defined at ~570 million m^3 of commercial wood (FFS'RF, 2009). The actual amount of harvested wood by all types of harvest during last three years is in range 160-180 million m3. Across the country the AAC is used at ~25%. However, about 70% of wood is harvested in European Russia where the AAC is used for 30-40%. The southern regions of Siberia with relatively developed infrastructure harvested ~40% of the AAC (maximum – in Irkutsk oblast – 83% and Khabarovsk kray -58%). In remote Asian regions, the harvest comprises 7-15% AAC.

Practically in all regions, the current level of harvest is limited by undeveloped infrastructure, primarily by lack of the roads, and to some extent - by large areas of low productive forests. In Russia, the officially reported area of forests available for industrial harvest comprised 45% of the total forest area of the country (FFS'RF, 2003). The Russian government took a number of decisions on construction of roads and development of forest industry. The realization of these decisions is far from the planned level.

Very likely, officially reported data on amount of harvested wood are also biased due to insufficient accounting systems and wide distribution of illegal harvest (at least in Russia, Central Asia, Caucasus, Kazakhstan and some other countries). Definition of ilrgal harvest could be defined differently (Sheingauz 2001, Efremov et al. 2011): Major reasons of illegal harvest are: imperfection of forest and civil legislation and regulation of forest relations as a whole, and domestic and international trade by forest products, particularly; weak administrative and international control for logging and marketing of wood; high level of corruption and criminalization of society; lack of real stimuli for civilized forest use; substantial deficiencies of custom control and others. These factors reveal differently in different regions. Insufficient strength, weak security and lack of real stimuli for state forest inspectors; insufficient influence of forest legislation on violators, growth of social tension in remote forest settlement where illegal harvest, gathering not timber forest products and poaching are major sources for surviving of local population, absence of unified system of account for and control of wood traffic. Official data of illegal harvest in Russia are limited by ~1% by major forest regions. Regional studies by 4 administrative regions reported from 10 to 20% (Efremov et al. 2011). In frontier regions of Russia (such Primorsky and Khabarovsk krays, Irkutsk oblast', Karelia Republic etc.) the level of illegal harvest is estimated at 25-30% of the officially reported amount of harvested wood (Sheingauz 2001; Vaschuk, Shvidenko 2006).

3. The Role of ECA's Forest Resources in Global Carbon Sequestration

3.1. Current carbon budget of forest ecosystems of the region

Knowledge of current and past impacts of forest on the global carbon cycle is necessary for solid predictions of future role of forests in functioning of the Earth system and evaluation of rational systems of mitigation as well.

The Kyoto Protocol and following decisions of Conferences of Parties introduced in the international practice the partial carbon accounting in terrestrial ecosystems limited to direct human activities. Such an approach is useful for international negotiations and development of a common platform for comparative analysis of national efforts in climate change mitigation. However, from a systems point of view, the approach has a number of gaps that substantially hinders the possibility of reaching the eventual goals of the UN FCCC. These major gaps are: (1) a distortion of the real picture of the role of individual countries in climate change mitigation efforts because a substantial part of emissions and removals of greenhouse gases are not included in the accounting regime; for the boreal biome the omitted part can provide emissions that exceed those from industry and "managed" part of the biosphere; (2) the exclusion of "climate friendly" investments in perspective fields of the biosphere (Land Use Land- Cover Change and Forestry sector; (3) a threat to the protection of some categories of "unmanaged" ecosystems, e.g. old growth forests; (4) an unsatisfactory consideration of large sources of emissions (e.g., wildfires); and (5) the restriction of opportunities for developing countries to participate in the international processes of climate change mitigation (Shvidenko et al. 2010).

Partial accounts do not also allow any comprehensive analysis of uncertainties due to the fact that considering the impacts on part of a system is not sufficient for assessing the responses and feedbacks of the entire system in any complete form. Substantial problems also arise from the large difficulties of strict definitions and unambiguous implementation of some key terms of the post Kyoto language like managed land, anthropogenic impacts, base-lines and additionality, etc., that raises doubts concerning some incentives and results.

The above considerations make relevant attempts to get a terrestrial ecosystems full carbon account (FCA), as an important part of a full greenhouse gases account, independently of future political decisions (after the first commitment period), how these estimates should be used – either for "accounting" in the Kyoto Protocol's sense or only for an "estimation" as auxiliary information for policy makers. However, a number of studies illustrate a high level of uncertainties of carbon accounting of ecosystems at different scales (Chen *et al*. 2000, Houghton 2003, Nilsson *et al.* 2007). Thus, uncertainties of the ecosystem carbon account which would allow the introduction of FCA's results in the international accounting regime should be explicitly estimated. It requires availability of methodologies which would be scientifically solid, practically applicable and which would deliver a reasonable knowledge of uncertainties.

The potential cost-effectiveness of carbon sequestration seems to be a major criterion for selection of the above methodologies. However, high accuracy increases cost of the account significantly. Thus, elaborating and maximizing functions describing the difference between the benefit of carbon sequestration and the cost of the account is theoretically most sound approach. However, it does not work in the real world of affairs due to (1) insuperable difficulties and practical inexpediency to separate carbon issues from other ecosystems services; (2) many unresolved economic problems in carbon crediting and offsetting; and (3) availability of hardly quantified but substantial political components. It leads to a conclusion that "perfect accuracy" does not exist itself, but should be "good enough" for scientific considerations, evaluation of "global utility" of ecosystems services including carbon credits, and finally crucially depends upon requirements and preferences of stakeholders (*cf* Waggoner, 2009). Analysis of a very limited available considerations on the topic (GCP 2003; Nevel and Stavins 2000) supported by simplified calculations for very pareddown averaged conditions of Northern Eurasia allows to conclude that the relative uncertainty of Net Biome Production (NBP) or Net Ecosystem Carbon Budget (NECB) at 20-30% (confidential interval, CI=0.9, assuming that the mean NBP/ NECB substantially differs from 0) could be satisfactory in terms of average carbon prices and major tendencies of the current post Kyoto market. One of very few possibilities to reach such a result is a system combination of major carbon accounting methods (landscape-ecosystem approach; flux measurements by eddy covariance; process-based models; and inverse modeling) with following harmonization and multiple constraints of independent results obtained by different methods (Nilsson et al. 2007, Shvidenko et al. 2010, Quegan et al. 2011). Unfortunately, of all countries of the FCA region such an estimate has been provided only for Russia. For other countries we present available results, mostly presented in National Communications to the Secretariat of the UNFCCC (Table 7).

Table 7. Carbon budget of forest land by sub-regions

Regions	Carbon budget of forest land, Tg CO2 eq.
Southeastern Europe	-95.3
Central and Eastern Europe	-92.5
Baltics	-113.8
South Caucasus	-4.2
Central Asia	0.9
Kazakhstan	-1.3
European-Ural Russian North	-577.9
European-Ural Central Russia	-425.0
European South Russia	4.5
Western Siberia	-189.5
Siberian and Far Eastern North	-192.7
Siberian and Far Eastern South	-689.6
Russia total	-2,070.1
Total	-2,376.3

Sources: UNFCC national reports (http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/5888.php); Janssens *et al.*, 2005; Forest and climate change …, 2010; Shvidenko et al. 2011 among many others.

As it is follows from Table 7, overall impacts of ECA forests on the global carbon budget is defined by Russian forests which serves as a substantial sink. Forests of all European regions serve as a moderate carbon sink during last years. Forests of Central Asia and Caucasus are neutral taking into account large uncertainties of the estimates.

3.2.Carbon budget of forests of Russia

Two recent studies (Shvidenko et al. 2011, Pan et al. 2011) presented most detailed results of carbon account of Russian forests. First of this publications presented the FCA for 2009 based on the flux-based approach, i.e.

$$NECB = NPP - HR - D - DEC - CON,$$

where NECB denotes Net Ecosystem Carbon Budget, NPP – Net Primary Production, D – flux to disturbances, DEC – flux due to decomposition of dead wood, CON – flux caused by consumption of forest (plant) products; all components are expressed in Tg C yr^{-1} (1 Tg = 1 million ton). The results of the carbon account are presented in Table 8. In this Table forest is defined by the Russian national definition.

Table 8. Carbon fluxes (Tg C yr-1) associated with biosphere by sources and land classes for 2009. Sign "-" means an efflux to the atmosphere [Shvidenko et al. 2011]

Land class and processes	Area, mln ha	Carbon flux, Tg C-CO2 yr-1 by source					
		NPP	HR	Dec	Fire	Insect	Balance
Forest	820.9	2,609.0	1,672.1	174.9*	56.5	50.7	654.8
Arable	77.8	409.1	330.4		0.4		78.3
Hayfield	24.0	109.1	79.5		1.1		28.5
Pasture	68.0	330.8	212		1.7		117.1
Fallow	19.0	21.2	16.7		0.3		4.2
Abandoned arable	29.9	151.6	104.5		1		46.1
Wetland	144.6	395.2	317.5	3.3	21		53.4
Open woodland	85.1	84.0	117.6	4.0	6.1	0.0	-43.8
Burnt area	23.7	32.0	38.0	12.0	1.3	0.0	-19.4
Grass & shrubland	315.7	618.8	611.4	13.2	9.2		-15.0
Water	44.0						-11.8
Consumption of plant products							-170.4**
Biosphere total	1708.6	4,760.80	3,499.77	207.47	98.56	50.78	722.02

* including site effect of forest logging (6.3 Tg C-CO$_2$ yr-^{1});

** including wood products (28.4 Tg C-CO$_2$ yr-^{1});

*** including unproductive areas (sands, populated areas, infrastructure etc.) which are not indicated in the total sink

As it follows from Table 8, forests of Russia provide a substantial net carbon sink at ~655 Tg C yr^{-1}. The results obtained by upscaled eddy covariance measurements and inverse models showed a rather close result: during the last decade Russian forests served as a net sink of ~0.55-0.65 Pg C yr-^{1} (Ciais et al. 2011; Shvidenko et al 2011). If we would use the FAO definition of forests, the sink is estimated to be about 15-20% less. Another study (Shvidenko et al. 2010a) using different boundaries of the account estimated the average carbon sink of Russian vegetation ecosystems for 2003-2008 at 567 Pg C yr-^{1}. Allmost all this sink was provided by forest.

Pan et al. (2011), using the pool-based method for data of forest inventory and the FAO definition of forests, reported an average net sink of Russian forests at ~0.5 Pg C yr-^{1}. Thus, the difference between flux-based and pool-based methods is in limits of 15%. Substantial part of this difference follows from different boundaries of the account. Taken into account that the mentioned studies reported final uncertainties of the NECB in range of 25-35%, the consistency of these two estimates is high.

Interannual variability of the carbon budget for the entire country is in limits of 10-15% due to weather specifics of individual growth seasons and connected regimes of natural disturbances; variability for large regions could be substantially higher (up to 30-40%).

In spite of the high overall sink that is provided by forests of Russia, substantial areas are indicated as C source (Figure 7), mostly in disturbed forests, forests and different vegetation classes on permafrost, and areas of southern arid territories. Very likely, this is a result of warming of the last decades and increasing disturbances, mostly fire.

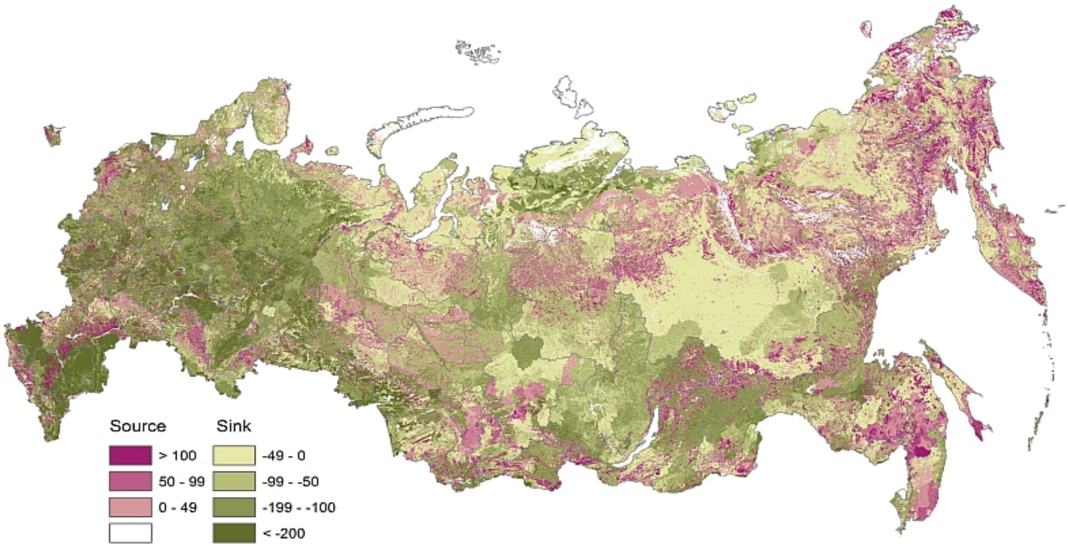

Figure 7. **Spatial distribution of carbon fluxes in territories of Russia**

The following conclusions, related to selection of climate mitigation policies could be done based on this analysis:

- of the total C sink on average provided currently by all terrestrial ecosystems of Russia at ~550-650 Tg C-CO_2 yr-^{1}, and more than 90% of the sink are provided by forest;
- introduction of sustainable forest management is among the most promising set of actions. This set should include *inter alia* actions oriented to increase productivity of forests and decrease extent and severity of natural disturbances;
- knowledge of spatial and temporal distribution of carbon fluxes presents important information on impacts of climate change on forest ecosystems and selection of regionally oriented mitigation strategies.

It is worth to note that the above estimates report the amount of carbon without a specific quantification of different carbon species. However, radiative forcing of different carbon-contained gases is different. Atmospheric methane provides the second-largest radiative forcing after CO_2. Wetlands are the major natural source of methane, and these CH_4 emissions are not accounted by the above approach. Previous estimates of methane emissions in Russia vary by order of magnitude. Recent study of methane budget for Russia estimated the annual total methane flux from the biosphere at 16.2 TgC-CH_4 including 10.5 TgC-CH_4 from wetlands and other wet soil, 1.5 TgC-CH_4 from agricultural sector (livestock and fertilizers), 1.1 TgC-CH_4 as part of direct fire emissions, and 3.1 is emitted from surface of water reservoirs (Shvidenko et al. 2010). These results are in part supported by comparison with independent regional estimates (e.g., Glagolev 2011, Kim et al. 2011). This allows us to consider some modelling results (e.g., 38 TgC-CH_4 from biogenic sources in boreal Asia, McGuire et al. 2010) as substantial overestimation. However, even under conservative estimate of methane emissions, forest-bog landscapes compensate substantial part of the mentioned above C-CO_2 sink if calculated by global warming potential. Thus, any system of adaptation and mitigation measures should account for the methane contribution to global warming.

3.3. Expected tendency of dynamics of forest carbon budget under predicted climate change

Predictions of future carbon cycling of forest ecosystems are rather uncertain. It causes by uncertainty of climate predictions and lack of knowledge of major processes and behavior of forest ecosystems under future climates. Evidently that dynamics of carbon cycling will be different in short to medium run (until 2050s) and by end of this century.

Different models have been used for prediction of vegetation dynamics and their role in future interactions of forests with global carbon budget. Although numerous Dynamic Global Vegetation Models (DGVMs) serve as one of most important tools for explanation interconnections of vegetation ecosystems and characteristics of the environment, they have substantial shortcomings for reliable predictions at regional level because they (1) cannot describe both regional peculiarities of vegetation (the amount of plant functional types used by majority of models is limited by 10 to 20) and regimes of their functioning (e.g., permafrost and its impacts on hydrological cycle); (2) mostly they consider *potential* but not *actual* (transformed) vegetation; and (3) do not describe diversity of disturbances which are substantially defined by regional specifics. For example, practically all DGVMs suppose an approximate equilibrium between NPP and Heterotrophic Respiration (HR) that is not a case for high latitudes with slow decomposition of accumulated dead organic matter there. As a result, DGVMs (examined an ensemble of 17 DGVMs, Cramer et al. (1999, 2001) in Northern Eurasian forests estimate well forest NPP but substantially underestimate NPP (Quegan et al. 2011).

As we discussed above, predictions by different models are not always consistent. So, simplified biogeographical SibClim3 model (Chebakova et al. xxx) predicts substantial shift of bioclimatic zone and following death of substantial areas of forests that grow at southern part of current forest zone. ORCHIDEE Model LANDIS-II supposes that major role in southern taiga of Siberia will play forest management

Thus, we could do the following conclusions

Under a business-as-usual scenario by middle of the century -

- Expected trajectories of carbon budget of the region's forests crucially depend upon reliability of climatic predictions and future social and economic developments. Uncertainties of predictions in all these fields are high. [See also notes to this Section below].
- Forests of the southern part of ECA (and particularly forests along the xeric limit zone) will be under substantial risks. It is expected that productivity and health of forests in Southeastern Europe and European South Russia will moderately decrease. This will decrease the current sink by about one fourth. However, the certainty of climate forecasts is not sufficient for these territories.
- Changes of carbon budget of forests of Central Asia and Kazakhstan are expected to be in limits of the current interannual variability. The warming impact likely will not change significantly the carbon budget of desert forests. Some decrease of productivity (and the carbon sink) is expected in mountain forests of these sub-regions due to shift of altitudinal zones and increasing impact of disturbances in lower altitudes of the mountains.
- Carbon budget of Baltic countries is expected to grow substantially. The potential productivity of the region's forest will likely increase by 30-35%. Under current regimes of natural disturbances and intensity of forest management, forests of the sub-region could increase the carbon sequestration at about one third.
- It is expected that Russian forests will remain to serve as a net sink. However, the dynamics of carbon budget in Russian territories expect to be different in different sub-regions. A number of prerequisites are very important for the entire territory which would define future carbon budget of the country. These include *inter alia*: (1) need of principal improvement of forest fire protection – this is an obligatory condition for introduction of initial elements of

sustainable forest management in the country; (2) consecutive introduction of anticipatory strategies of preparation of taiga landscapes to climate change; (3) introduction of relevant systems of adaptive forest management in the remote territories of currently unmanaged forests; and (4) implementation of ecologically acceptable legislation of industrial development of previously untouched territories which would lead to a substantial decrease of levels of air pollution and soil and water contamination.

Under a realization of the above conditions,

- Forests of European-Ural North will increase their productivity at the level of ~30%. The NECB could increase by 30-40%. A special program of forest management and protection against outbreaks of insects should be developed and implemented.
- The dynamics of carbon budget in European-Central Russia will be driven by two natural processes – increase of productivity of forests and increase of heterotrophic soil respiration. It is expected that the carbon sink will increase by 20-30% if a system of relevant forest management in secondary deciduous forests of middle and southern taiga zones will be implemented with a substantial use of forest biomass for bioenergy.
- Negative anthropogenic effects will impact carbon budget of forests in West Siberia. It will require strengthening of requirements to industrial development of the territories. The dynamics of NECB will also depend on introduction of advanced technologies of restoration of landscapes which have been destroyed by wasting extraction and elaboration of natural resources, mostly oil and gas. Likely, the NECB will slightly increase by middle of the century.
- A complicated situation is expected in Siberian and Far Eastern North. Thawing permafrost and aridization of climate will likely lead to worsening of the hydrological regime over large territories. Implementation of effective forest fire protection is difficult in these territories. It may initiate an explosive acceleration of vegetation fires which would lead to "green desertification". Overall, one could expect a decrease in forest area (the process which is already observed in far north-east of the sub-region) and decrease of the NECB by 30-50%.
- Siberian and Far Eastern South will remain a major base for increasing harvest of industrial wood. It inevitably will be accompanied by acceleration of fire and other disturbances. Forests of this sub-regions will be impacted different, often contradictory drivers. Future trajectories of the carbon budget there will be defined by the level of forest protection and efficiency of use of wood products (including use for bioenergy). One could expect that the forest carbon budget will be at the current level or slightly increase.

State of Russian forests by end of the century will crucially depend upon the level of climate change, tendencies of social and economic development and environment and forest policy of the country. Development and realization of adaptation and mitigation programs will play a substantial role.

Notes to Section 3

Two circumstances should be briefly mentioned. They deals with success and efficiency of mitigation policies at the global scale and reliability of climatic predictions.

- Taken into account the recent global dynamics of GHG emissions, it seems very likely that the peak emissions will not be reached by 2035 (Figure 3N1). It means that there is a rather high probability that the global warming will reach in the long-run ~4oC. It may generate climates in Northern Eurasia (+7-11oC of annual temperature, Figure 3N2), which are far beyond of any current understanding of impacts, responses and feedbacks of forest ecosystems to climate change. This scenario is not considered in the Report

- Absolute majority of the world climate change community believes that most advanced current knowledge on climate change are accumulated in IPCC forecasts, and probability of those are high; however, there are scientific groups which represent a substantially different point of view, particularly for Arctic. Figure 3N3 contains a forecast of the S. Petersburg Arctic and Antarctic Institute [a discussion is in Shvidenko A. et al. (2011)]. Even if probability of such a development is very low, such a scenario seems relevant to be mentioned.
- However, it is very difficult to develop an optimal (win-win?) strategy of adaptive forest management and mitigation under such inconsistency. Acceptable strategy should minimize losses if not an "expected" but an alternative forecast is realized.

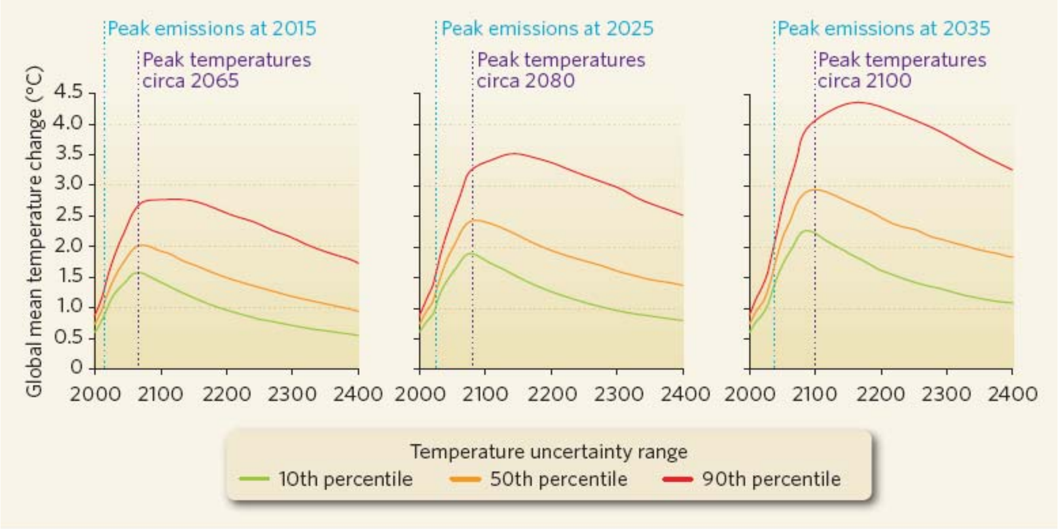

Figure 3N1. Global average surface temperature scenarios for peak emissions at three different dates with 3%-per-year reductions in greenhouse gas emissions. Source: Parry et al. Nature 458, 30 April 2009

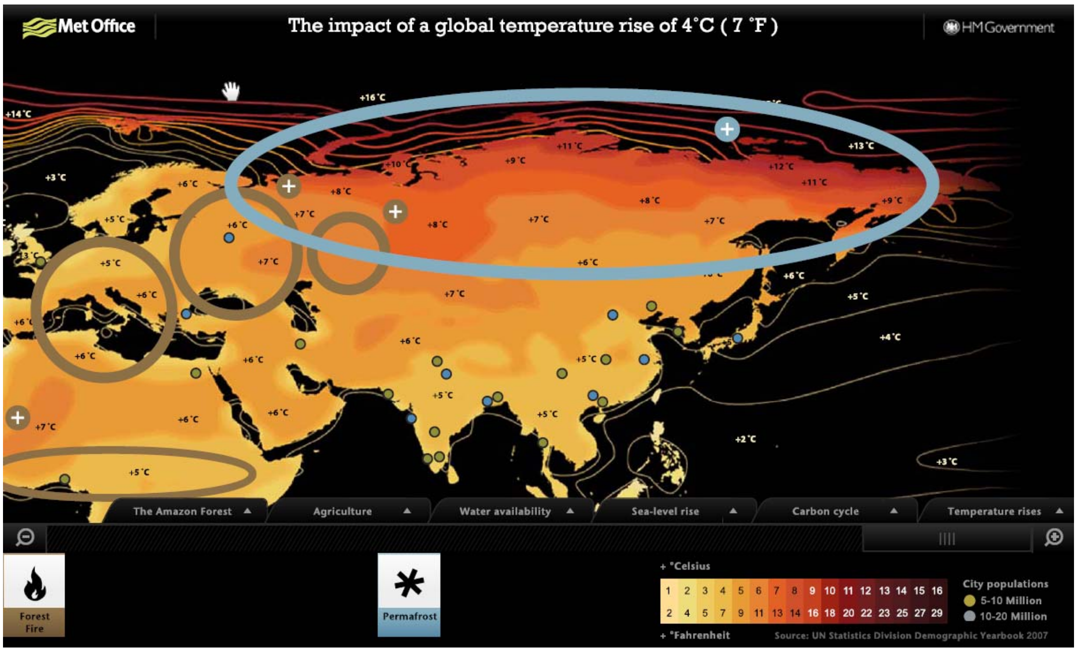

Figure 3N2. The impact of a global temperature rise of 4°C on warming in Northern Eurasia. Source

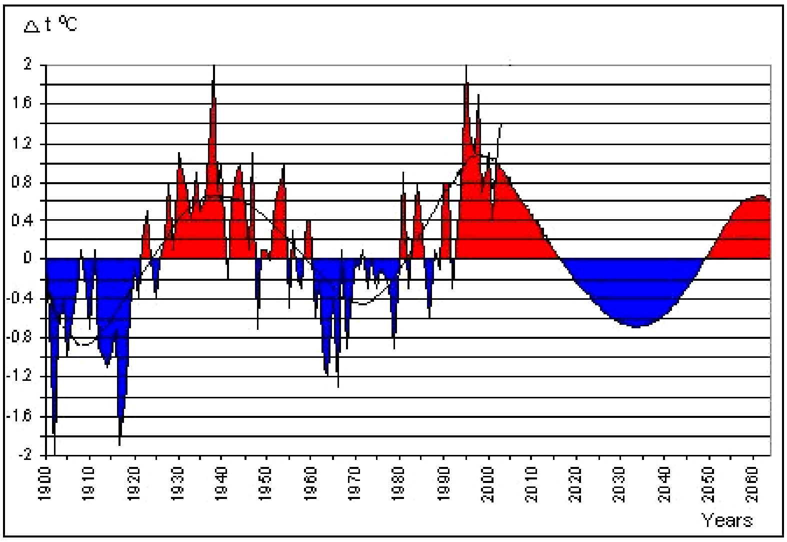

Figure 3N3. Change in anomalies of average annual temperature across 70-85° northern latitudes in the 20th – beginning of the 21st century (Eurasian Arctic) and the forecast for the 21st century according to a forecast of the Arctic and Antarctic Institute RAS (S. Petersburg). On the contrary of IPCC predictions, this forecast promises a new “small ice period during 2020-2050.

4. Climate change mitigation policy and actions

4.1. Introductory notes

The forestry activities that could be considered as an effective tool of GHG mitigation can be summarized under the following types (IPCC 2007):

- Afforestation – conversion of land to forest, usually actively promoted by planting of trees
- Reducing deforestation and degradation
- Forest management to increase stand- and landscape-level carbon density
- Inhansing off-site carbon stocks in wood products and enhancing product and fuel substitution

The policies which stimulate mitigation (afforestation, reduced deforestation, forest management) could provide a significant effect. One study reported that that global forests could sequester from 60 to 87 Pg C during 21st century (Metz *et al.*, 2001) under the cost <$187/t (Sohnen, Mendelsohn 2003). Many studies suggest that mitigation actions in forestry and forest management will increase the benefits and reduce the cost of climate policy, although the final output will strongly depend upon the level of warming. It would provide substantial effect on land use resulted in increasing the forest area by 1 billion ha within the range of carbon prices from $60 to $200 (Sohngen, Mendelson 2003, Sohngen, Sedjo 2006).

In the short run, climate change will increase the efficiency of mitigation cost. In the medium to long run, the risks associated with mitigation will also increase. Mitigation actions are likely to have substantial impacts on timber markets by affecting prices.

Economic studies show that mitigation will expand timber supply and reduce timber prices in the long run, and could increase timber prices in the short run dependently on options realized.

Evidently, afforestation increases carbon sequestration, but net effects of overall carbon sequestration depends upon how much effectively the mitigation programs are realized. For example, almost all planted forests in the Russian Far East have been killed by fire (Lyubyakin, 2003). For other side, the substitution between wood and other energy-intensive products could substantially impact mitigation effect.

Large areas of land could be converted from existing forests to support growing needs for bioenergy product based on agricultural crops, particularly taken into account new technologies for production of second generation of biofuel. Political consideration could substantially impact economic drivers. The European Union regulation that 20% of the transport fuel in the EU should be based on renewable sources in 2020 is important political driver for development of the second-generation biofuel technologies.

Carbon emission mitigation alternatives include land-use changes, forest management and bioenergy production. Land-based alternatives can contribute from 13% to 52% of the European proposed target by 2020. However, the implementation of these alternatives would concurrently required from 8 to 38% of EU agricultural land to be afforested or diverted to bioenergy crops in this period (Ovando, Caparrŏs 2009).

The basic ways in which forest can directly or indirectly contribute to GHG mitigation efforts are (1) the conversion of non-forested land to forest [in terminology of the KP and Marrakesh Accords] through planting, seeding and/or the human-induced promotion of natural seed sources; (2) preserving and increasing carbon stock in existing forest ecosystems; (3) regulating rotation periods; (4) growing biomass to substitute fossil fuel-based products and altering forestry fossil fuel usage patterns; (5) or decreasing removals, e.g., by decreasing of disturbances (Richards and Stokes 2004; Richards et al., 2006).

Agricultural land management practices that can sequester carbon in soils including organic amendments (animal manure, sewage sludge), no-tillage or reduced tillage systems, agriculture extensification, the conversion of arable lands to grasslands could compete with tendencies to convert agricultural land to forest (Freibauer *et al.*, 2004).

The potential of forest land-based carbon abatement in the region depends on areas that can be converted from non-forest to forest land. For instance, about 84% (412.6 mln ha) of the total land in Europe and 88% (339.8 Mha) in the EU-25 are classified as already “useable land”, i.e. forest and agricultural land. The GHG mitigation potential through land-use changes depend on how much land could be eventually used, i.e., depends on relative costs and climate, energy, food and rural policies, as well as on per hectare yield and technologies could be used.

A number of integrated studies (Sohnen, Mendelsohn 2003; Klijn et al. 2005; Tavoni et al. 2007) analyzed by Ovando and Caparrŏs (2009) predicted that from 20 to 150 Mt Cyr^{-1} can be sequestered by accumulative increasing the EU-25 forest area by 2100 between about 10 to above 60 Mha. Such a large variability follows from specifics of the scenarios used and assumptions about available land resources and their per hectare biological production.

Many diverse methodological approaches could and have been used to study the complex relationships between agriculture and forestry, GHG emissions and mitigation policies. Each method has its inherent strengths and weaknesses. Sectorally oriented studies of a “bottom-up” approach explicitly model different abatement options, their costs and effectiveness. Evidently, such an approach can provide only local optimums. Investigating welfare implications of policies, cost-benefit analysis, cost efficiency of alternative economic instruments requires a macro “top-down view”, i.e. considering intersectoral or even international interactions in form of either partial equilibrium (if e.g. only agricultural and forest sectors are considered) or (computable) general equilibrium models when agriculture and forestry are considered as a part of the whole economy (e.g., Gillig *et al.*, 2004).

There are two classes of models considering economic impacts of climate change where forests and forestry are including. One is based on general macroeconomic models including general equilibrium models. Usually forests and forestry are poorly represented in most of this class of models. Second is represented by regional and partial models. However, these models usually do not consider impacts, vulnerability, adaptation and mitigation measures (Aaheim *et al.*, 2011). Complexity of both economic and ecological systems, temporal and spatial scales, issues related to forest management and impacts of climate change

4.2. Analysis of mitigation options and relevant policies for the ECA region

4.2.1. Reducing deforestation and degradation

Reducing deforestation (human-induced conversion of forests to non-forest land uses) and forest degradation (reduction in forest biomass through non-sustainable forest management or land-use practice) are considered as the largest impacts on carbon stock (IPCC 2007).

Dynamics of land use-land cover in the ECA region are substantially different in different subregions.

Practically all countries of the former Soviet Union had increasing forest area during the period of 1960-1990s if compatible definitions of land-cover categories are used. The biggest increase has been reported for Russia which increased its forest area by 75.1 million ha (official forest inventory data). Two major reasons contributed to this process: (1) more precise forest inventory during the period; and (2) restoration of previously disturbed forest land due to improving forest protection in 1960s-1990s. After 1990s, the increase of forest area continued. Two other processes became important : (1) abandoned of agricultural land, which area by 2010 is estimated due to different sources from ~20 to ~50 million ha (Kurganova et al. 2010, Shvidenko et al. 2010) and (2) shifting of forest in previously unforested areas due to climate change.

Data on deforestation in Russia are not available because of complicated character of transfer of land to and out of the forest fund. Pan et al. (2011, Supplementary data) estimated deforestation (mostly due to transfer of forest land for industrial use) at 0.2 million ha year^{-1} in 1990-1999 and 0.15 million ha year^{-1} in 200-2007.

Other European countries of the former Soviet Union also increased their forest area in 1961-1990 (Ukraine +18.3%, Belarus +16.5%, Moldova +56.7%) due to large area of planted forests. The similar tendency (but less intensive) was observed during the last 20 years.

The three Baltic countries (current member of the EU – Estonia, Latvia, Lithuania) increased areas of their forest from+16 to +31% in 1961-1990 and from +6 to 11% in 1990s-2010)

The situation in countries of South Caucasus is different. While the areas of forests grew during 1961-1990in Armenia (+23%) and Georgia (+9%), and remain unchanged in Azerbaijan, these decreased during the last 20 years in Armenia (-8%) and Georgia (-1.3%), remained unchanged in Azerbaijan. Similar dynamics are indicated for Kazakhstan

Data for Central Asia are less reliable

4.2.2. Afforestation and reforestation

Countries which developed plans

Armenia (Gevorgyan, 2010). The 1st NC planned annual planting of 5300 ha of forests by 2050, increasing the forest area by 255.6 thousand ha and expanding forest cover from the current 11.2 to 20.1% (historical level ~35%). The SNC (2003) does not support this idea. The SNC assessed all LULUCF activities as the C source due to unsustainable forest management and agricultural land use practice. More than 17,000 ha of forests (5-5.5%) is expected to disappear due to climate change and critical growth conditions. No satisfactory accounting and monitoring system. [introduction of a relevant system of specially protected territories in order to reduce anthropogenic pressure on vulnerable ecosystems; introduction of endangered species in appropriate habitats and promotion of survival; preservation of the genetic stocks of the most vulnerable and valuable species; monitoring of vulnerable ecosystems].

Azerbaijan (Ibragimov, 2010). Forested are 989.3 th ha, PFC 11.4%, 18-43% in mountains and 0.5-2.0% in plain territories Including Karabakh -261 th ha??). Optimal PFC is estimated at18-20%. Land degradation and desertification are among the most important problems for the country. Major reasons: excessive exploitation, excessive cattle grazing, forest destruction and the use poor irrigation methods. A National Forest Restoration Program is introducing. The SNC (2002) supposed development of forest plantations at 740 x 10^3 ha with sequestration of 1.82 TgC-CO2 by 2025. The average cost of carbon sequestration was estimated at 37 USD/tone CO2 (= 135 USD/tone C). This Program is still not realized. By estimates, the potential area that is available for plantations is ~1.5 x 10^6 ha (Ibragimov, 2010).

Azerbaijan National Climate Change Action Plan (2000?) was developed but has not been financed. Mitigation measures in the forest sector include: (1) promoting improved logging practice to reduce the damage to residual trees and the soil; (2) encouraging agroforestry; (3) promoting forest expansion through improving tax policies; (4) improving legal and policy framework (control of deforestation, environmental planning, impact assessments, mitigation); encouraging the use of long-lived forest products; (5) providing financial incentives for afforestation on private lands; (6) controlling air pollution effects on forests. SNC (2006-2008).

Kazakhstan (Yesserkepova, 2010): forest fund in Kazakhstan is estimated to be 26.5 million hectares (M ha), including closed forests at 11.4Mha. FCP 4.5%, by oblast from 0.1 to 15.3%. For the last ~70 years (1936-2005) winter warming trend was, on average 0.5°C per decade, the summer one

0.2 °C per decade. In the medium climate change scenario the average annual temperature will increase by 4.6 °C with very small increase of precipitation (+5%) by 2085. The northward shift of bioclimatic zones is expected at 250-300 km, and the semi - desert arid zone will cover large areas. Vulnerability is high because of major species (pine, fir, larch and kedar) are at the southernmost edge of natural growing area of these species. The Ecological Code of the Republic of Kazakhstan (2007) – mitigation. Adaptation is not included in the basic legislation. However, the Adaptation Strategy of the Republic of Kazakhstan is part of the Plan for Action of the Ministry of Environmental Protection. According to the governmental decision (No 319 of 20 April 2007) ~145 x 10^3 ha of forests had to be planned in 2008-2010, however no scientific and resource backgrounds have been provided.

4.2.3. Management of agricultural abandoned land

Abandonment of agricultural land is a widespread phenomenon in the region due to diverse economic and social reasons. Usually marginal lands are abandoned – lands with infertile soils (too wet or too dry, stony soils, rocks, soils on steep slopes) or lands farthest from market. Social changes during transition periods , such as changes and uncertainties in ownership, demographic changes, civil wars) could also contribute to this process. One of major reason of the abandonment for substantial part of the region is the collapse of state-owned and collective farms in the early 1990s that is typical for countries in East Europe and former republics of the USSR.

Areas of abandonment land are different in different countries. Official data on the topic are imprecise and often absent due to definitial and accounting for problems. Sutton et al. (2008) reported the following extent of abandoned land as percent of agricultural land by countries (estimates for different years from 2001 to 2007): Albania 10-16, Bosnia and Herzogovina 23, Bulgaria 9, Croatia 6, Hungary 10, Kosovo 9, FYR Macedonia 11, Poland 7, Romania 10%. The following estimates are given for Baltic countries: Estonia 10% (for 2002), Lithuania 10% (1999), Latvia 21% (2002) (DLG 2005).

Data on abandoned land in Russia are not completely consistent (Kurganova et al. 2010)

There are several policy options for future developments of abandoned land that could impact completeness of use of mitigation potential of these lands. Three major options that exist for abandoned land (cf. Sutton et al. 2008):

- *Return abandoned land to agricultural use*. Land abandonment as a temporary phase of the transition is possible if new agricultural use would be profitable under new market conditions, ownership legislation, and introduction of modern technologies. There is a low probability that substantial areas of currently abandoned land will be return to agricultural use during the next two-three decades.
- *Natural revegetation.* Direction of restoration of native vegetation cover (grasses, shrubs or trees) of abandoned land depends on bioclimatic zone and site condition. As a rule, in the ECA Region this natural process could provide an environmental benefit and increase carbon sequestration. However, the lack of proper management that is usual for many countries could initiate different risks such as distribution of weeds and rodents, increase of disturbances (e.g., unregulated fires), illegal use for planting of narcotic plants, or promote processes of soil erosion. The period of restoration could be long and ineffective from a mitigation point of view.
- *Planned afforestation.* Properly implemented (species composition, optimal structure etc.), planned afforestation produces expected ecological and social benefits, and have substantial mitigation potential.
- *Use for infrastructure development or as a residential area*.

Effective implementation on national policies of effective management of abandoned land

- national inventories of abandoned land with a special identification of High Nature Value Land (HNVL)

- local and regional land use plans
- appropriate rural development policies on the landscape basis
- assessment of mitigation potential

4.2.4. Development of advanced forest protection systems

4.2.5. Implementation of sustainable forest management

Managers of forested landscapes must account for multiple, interacting ecological processes operating at broad spatial and temporal scales. These interactions can be of such complexity that predictions of future ecosystem states are beyond the analytical capability of the human mind (Gustafson *et al.*, 2011b). This requires application of different models which would allow to clarify the ability of broad silivicultural strategies to achieve multiple objectives (reduce disturbance losses, maintain the abundance of preferred species, mitigate fragmentation and sequester carbon)

Some applications showed that in Siberia there are no “best strategies” which would be able to achieve all possible forest management objectives (Gustafson *et al.*, 2011a)

4.2.5. Use of wood for bioenergy

The European Union has set a target of a 20% share of renewable energy in the energy sector, 20% greenhouse gas reduction, 20% reduced energy use through increased energy efficiency to be met by the year 2020 ***[European Commission (2008), "20 20 by 2020: Europe’s climate change opportunity, COM(2008) 30 final", European Commission, Brussels, Belgium]***. In addition to the overall 20% renewable energy target, each member state has to meet a 10% share of renewable energy in the transpor sector ***["Dir 2009/28/EC. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC" (2009)]***. The eastern countries of the European Uninon have a potential of 1,800 PJ ***[own calculations from the G4M model]*** of woody biomass from which 270 PJ is already used for pulp and paper mills and electricity and heat production ***[www.risiinfo.com]***. Eastern Europe has then the potential to decrease its fossil fuel consumption from woody biomass based energy.

This section is focusing on the potential of second generation biofuel for Eastern Europe.

Ethanol is the biofuel considered in this study. Ethanol is produced through hydroylis and fermentation and simultaneously with the following by-products: heat, electricity and biogas (biogas can further be used for power generation for example). If not consumed at the plant, heat can be sold to a district heating network and electricity to the electiricty grid. Those by-products can give to the plant high extra revenues. The production factors of those commodities are (in energy output per energy input): Ethanol: 29%, Heat: 32%, Electricity: 12%, Biogas: 8%. Those numbers are based on energy flow calculations at the plant level for very high plant capacity (Leduc et al., 2010). In practice, the conversion factor varies across technology, plant capacity... But to be economically feasible, second generation biofuel has to be produced on very large scale. Therefore only large scale production plants are considered, which means around 200 $\mathrm{MW}_{\text{biomas input}}$, and the conversion factor is assumed to be the same for each plant for every country.

The study was focused on the production of biofuel only. The competition with combined heat and power (CHP) plants was not included here. Althought the CHP production plants are cheaper, one can observe that on an environmental point of view, the production of ethanol can be more advantageous, thanks to the production of by-products. One will indeed observes less heat waste during the low heat demand period with an ethanol plant than with a CHP plant (with the following conversion factors in energy output per energy input: electricity: 35%, heat 55%) since the ethanol production plant produces les heat than a CHP plant. If one compares ethanol and CHP production, one would observe that ethanol production would be more advantageous if one would increase the carbon tax to 100-150 €/t_{CO2}. This has been done at the country level (i.e Austria (Schmidt et al., 2011) or Finland (Natarajan et al., 2011), but not yet for the present study, at the European level.

To identify the potential of biofuel in Eastern Europe on sustainable menner, a linkage between two models developed at IIASA has been studied: the Globiom model and the Bewhere model.

The Globiom model (Havlík *et al.*, 2011) is a global recursively dynamic partial equilibrium model integrating the agricultural, bioenergy and forestry sectors with the aim to give policy advice on global issues concerning land use competition between the major land-based production sectors (more information can be found at http://www.iiasa.ac.at/Research/FOR/globiom.html?sb=14). It determines the amount of resources (forest, crops, and livestock) that have to be produced in each region based on the demand and supply of each region and prices of each resource.

The Bewhere model (Leduc, 2009; Leduc *et al.*, 2010; Schmidt *et al.*, 2010) is a regional mixed integer optimization model, which determines the optimal locations of biofuel production plants based on the economy of scale, location of feedstock and biofuel demand (more information can be found at http://www.iiasa.ac.at/Research/FOR/biofuels.html?sb=13). It minimizes the cost of the supply chain from harvest of biommas to delivery of biofuel. First, the biomass needed from the already existing woody based energy plants has to be met. Then, the remaining biomass, if any, is then used in second generation biofuel production. A complete description of the model at the European level can be found in (Wetterlund, 2010).

The Globiom model generates the amount of woody biomass that can be used for energy purposes per region under sustainable conditions. Knowing the amount of woody biomass that can be produced for energy purposes in each country from the later model, this amount of woody biomass is then set as a threshold into the Bewhere model. Based on this limit and the same economical assumptions as the Globiom model, the Bewhere model determines the optimal location of production biofuel plants, if any. The potential of biofuel economically feasible is then determined for a given region.

In this study, the second generation biofuel (ethanol) potential for the eastern countries of the EU-27 has been determined. The results on the woody biomass needed and potential biofuel production are presented in the Table 9 and Figure 8.

Table 9. Bio-Gasoline second generation. Linkage Globiom-Bewhere

Year	Country	Biomass input		Biofuel	
		PJ	Mt	M m3	PJ out
2020	Estonia	0.00	0.00	0.00	0.00
2020	Latvia	29.56	1.60	0.41	8.64
2020	Lithuania	14.78	0.80	0.20	4.32
2020	Slovenia	14.78	0.80	0.20	4.32
2020	Bulgaria	0.00	0.00	0.00	0.00
2020	Romania	0.00	0.00	0.00	0.00
2020	Czech Republic	0.00	0.00	0.00	0.00
2020	Hungary	0.00	0.00	0.00	0.00
2020	Poland	0.00	0.00	0.00	0.00
2020	Slovakia	0.00	0.00	0.00	0.00
2030	Estonia	0.00	0.00	0.00	0.00
2030	Latvia	14.78	0.80	0.20	4.32
2030	Lithuania	14.78	0.80	0.20	4.32
2030	Slovenia	14.78	0.80	0.20	4.32
2030	Bulgaria	0.00	0.00	0.00	0.00
2030	Romania	0.00	0.00	0.00	0.00
2030	Czech Republic	0.00	0.00	0.00	0.00
2030	Hungary	24.45	1.32	0.34	7.15
2030	Poland	0.00	0.00	0.00	0.00
2030	Slovakia	14.78	0.80	0.20	4.32
2040	Estonia	0.00	0.00	0.00	0.00
2040	Latvia	14.78	0.80	0.20	4.32
2040	Lithuania	14.78	0.80	0.20	4.32
2040	Slovenia	14.78	0.80	0.20	4.32
2040	Bulgaria	0.00	0.00	0.00	0.00
2040	Romania	0.00	0.00	0.00	0.00
2040	Czech Republic	0.00	0.00	0.00	0.00
2040	Hungary	0.00	0.00	0.00	0.00
2040	Poland	0.00	0.00	0.00	0.00
2040	Slovakia	14.78	0.80	0.20	4.32
2050	Estonia	0.00	0.00	0.00	0.00
2050	Latvia	29.56	1.60	0.41	8.64
2050	Lithuania	14.78	0.80	0.20	4.32
2050	Slovenia	14.78	0.80	0.20	4.32
2050	Bulgaria	0.00	0.00	0.00	0.00
2050	Romania	0.00	0.00	0.00	0.00
2050	Czech Republic	0.00	0.00	0.00	0.00
2050	Hungary	0.00	0.00	0.00	0.00
2050	Poland	0.00	0.00	0.00	0.00
2050	Slovakia	44.34	2.40	0.61	12.96

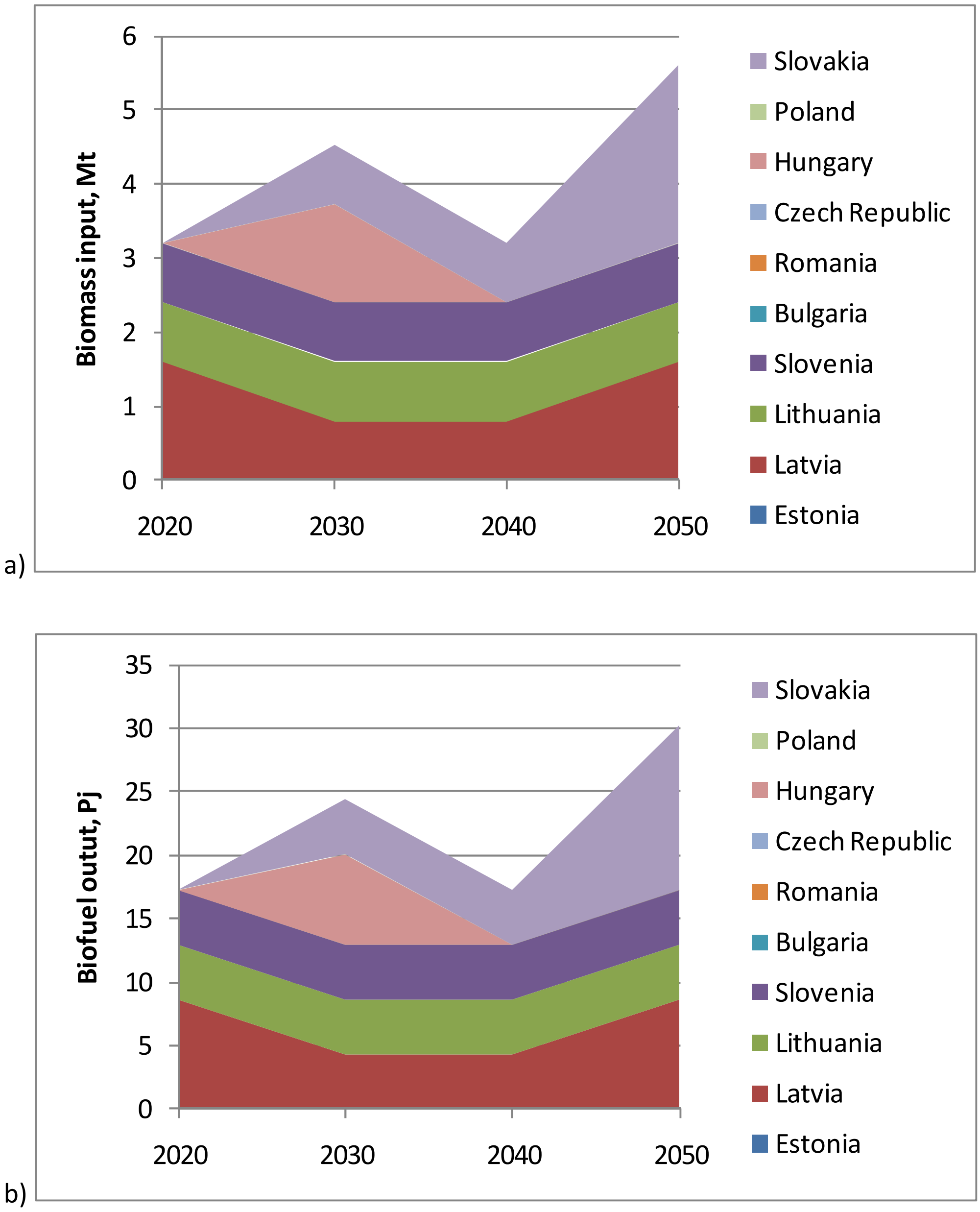

Figure 8. Biomass potential for biofuel in selected countries

Case study: Analysis of relevant mitigation options for the xeric belt

Case study: Analysis of relevant mitigation options for north of Siberia

Case Study: Analysis of relevant mitigation options for the Ukraine

Forests and forestry in the Ukraine have a number of specific features which should be taken into account in solution of current and future problems which hinder transition to sustainable forest management and introduction of integrated land management on landscape basis:

- low average level of forest cover percentage in major part of the country, substantial different growth conditions in different bioclimatic zones that defines regional specifics of forest management, different vitality and vulnerability of forests, as well as different impacts of expected climate change;

- dominance of ecological services of forest and high share of forests (~ 50%) with limited industrial use; over the last three decades, the area of protective forests of the country has about doubled, mainly at the expense of forests which were formerly under industrial exploitation;
- a special role of forests and trees outside of forests in protection of agricultural land;
- significant areas of specially protected forests (13.7%) with a stable rate of their increase;
- historically formed situation when the forests are allotted to numerous permanent users (more than 50 Ministries, agencies and institutions have forests in permanent use); while the governance of forests managed by the states is more or less sufficient, the management of forests of other stakeholders (almost one-third of the total area) is not satisfactory;
- a significant area of forests are situated in zones of radioactive contamination;
- artificial (planted) forests require intensive management;
- about 0.5 million ha of forests on land of the state reserve are in a clearly unsatisfactory condition (suffer from illegal harvest, are not protected against fire and outbreaks of insects and diseases etc.).
- availability of about 2.5 million ha for afforestation;
- unclear legislative state of above 400 thousand ha of shelter belts which protect about 13 million ha of arable lands, and overall unsatisfactory situation with protection of existing and development of new protective forests;
- a vital needs of restoration and revitalization of degraded and abandoned lands and implementation of effective management on such territories.

Mitigation measures in forestry and forest management of Ukraine

Increase of the area of forests

The existing area of forests in Ukraine is not sufficient for environment protection. During 1990-2004, forests have been planted at 383 thousand ha, 71 thousand ha of unproductive land were afforested and 9 thousand ha field protective shelter belts have been developed. Recommendations on critical/ optimal forest cover vary (Mikhovich, 1972; Pasternak *et al.*, 1987 etc.) A long-period recommendation for afforestation (Kopiy, 1999; Pilipenko and Yukhnovsky, 1998, 2003) suggested that 2.0 million ha of currently treeless land should be planted the first 5 years, 2.8 million haduring the next 10 years, and 2.837 million ha during the following 10 years. It would increase the forest cover percent (FCP) for the country at 25%. Recent governmental decisions and programs support the above opinion and estimates. The State Program "Forests of the Ukraine" for 2002-2015 stated that the minimal area of increasing forests is at 2-2.5 million ha. The Draft State Program "Use and protection of land" (2005) indicates that during 2005-2015 about 2.5 million ha of agricultural land should be removed out agricultural land and transferred in natural vegetation (forests, grasslands).

While validity of the above estimates seems solid, still the rates of afforestation in the Ukraine is far from the recognized needs. The decision of the Cabinet of Ministers of the Ukraine No 189 dated on 28.02.2002 "About the immediate measures on development of protective forests on destroyed lands and in river basins" has planned only development of 79.0 thousand ha of protective forests including 8.4 thousand ha of field protective and runoff regulating shelterbelts during 2001-2015.

Development of protective forests on agricultural land

Agroforestry is a crucial tool for improvement the structure of agro-landscapes. The scientific basis of such strategy is well developed and recognized. One hectare of forest shelterbelts protects

25-40 ha of arable lands and productivity of such lands increases for up to 15-20% as compared with shelterless fields, as well as protect land from dust storms, water and wind erosion. The Ukraine has a long and productive experience in use of agroforestry measures for protection of agricultural land from erosion. During the period of 1960-1990s, there were planted: about 750 thousand ha of anti-erosion plantations on lands which are not suitable for agriculture (sands, steep banks etc.); 440 thousand ha of forest shelterbelts which protect above 13 million ha of arable land. However, after 1990s, anthropogenic pressure, decreased governance in agriculture and negative socio-ecological condition of the country resulted in decreasing the field protective forest cover from 1.5% to 1.3% under the optimal value of 3-3.5% (Yukhnovsky 2003).

A detailed analysis of areas of forest protective plantations which have to protect unstable and degraded elements of agricultural landscapes (like sands, banks of rivers and water reservoirs etc.) has been done in a Draft National Program on Land Protection for 1997-2010 and several decisions of the Ukrainian government. The Program and decision have not been implemented, but it contains appropriate information for the estimation of the areas required protection by agroforestry measures. These decision indicated the needs to develop field-protective and runoff-regulated shelter belts at the area of 297.8 thousand ha; to plant protective forest on unstable elements of landscapes at 375.7 thousand ha and to create protection forests on eroded lands of 538 thousand ha. Advanced scenario developed in (Shvidenko et al. 2008), which refers to most urgent needs, supposed planting of protective forests on 837 thousand ha, 1640 thousands ha and 2632 thousand ha by 2015, 2020, and 2030, respectively. In addition, this scenario supposes development of shelterbels on agriculture land of 102, 206 and 335 thousand ha by 2015, 2020 and 2030, respectively.

Increase of productivity of existing forests.

In spite of a rather high level of the current productivity of Ukrainian forests, possibilities for its increasing exist. Practically all measures aiming at increasing forest productivity are coherent with the carbon management paradigm and maintain environmental services of forests. They include (1) use of genetically improved seeds and seedlings; (2) introduction of tree species of high productivity and vitality in conditions of changing environment; (3) optimization of species composition of planted forests; (4) development of special carbon sequestering plantations with a short rotation period; (5) improvement of forest management regimes aiming at optimization of stand structure; (6) use of mineral fertilizers; (7) optimization of major technical indicators regulating sustainable forest harvest (e.g., age of final felling); (8) introduction of ecologically safely technologies of final felling (particularly, use of relevant combination of clear, gradual and selective cutting) in forest of different regions, species and functional destination.

Improvement of protection of forests.

Substantial areas of forests are affected by pests and diseases (e.g., 753 thousand ha in 2004). Changing climate decreases resilience and vitality of forests in many large regions. For instance, the process of drying spruce stands in Carpathian is accelerated, particularly in secondary forests which were developed outside indigenous sites. Planted forest developed in specific conditions (e.g., on bare sands) require specific anticipatory protection measures. Forest fire becomes more dangerous taking into account increasing aridity of climate. An absolute majority of ignitions is provided by population what is evidenced about insufficient level of ecological education of population. Forest protection monitoring needs substantial improvements.

Improvement, scientific and information support of forest management.

Measures on increasing productivity and vitality of forests require relevant improvements of forest management regimes, manuals and instructions (e.g., regulation of age of harvest; regulation of age distribution of forests; requirements to optimal relative stocking of stands; rules of forest protection; availability forests for recreation; etc.). Research and information support should be oriented to perspective fields of selection, development of plantations, new methods of forest protection against pests and diseases; etc.

Management of forests and landscapes contaminated by radionuclides.

As a result of the accident at the Chernobyl Nuclear Power, almost 300 thousand ha of forests were excluded from the use, and substantial part of Polyssja has a restricted regime of forest use. The contaminated area of agricultural land of 11 *oblast'* by Cesium-137 accounts for 8.4 million ha of which 35.6 thousand ha outside of the abandonment zone and 54.9 thousand ha in the abandonment zone has the level of contamination more than 15 Cu/km2 that excludes any possibility for population to live there and provide any use of these land by available technologies. Sanitary state of these territories is not sufficient. Dead stands are source of a high fire threat. Ill weeds on agricultural lands are also the source of secondary contamination. Natural forest regeneration during the last years is insufficient. Afforestation is only the way for improving the environmental condition here. Implementation of a plan to plant 35.6 thousand hectare of forests on land contaminated by radionuclides inside the abandonment zone (so-called “30 km zone”) will require development special technologies. Major goals of adaptation & mitigation measures here includes (1) fixation of radioactive substances in forest ecosystems; (2) regulation of run-off, decreasing wash-out of radionuclides, (3) decreasing wind and water erosion; and (4) transformation of contaminated agricultural lands in forests and natural grasslands. Continuity of forests and avoiding forest fire are major tasks there.

Development of legislative base of adaptation and mitigation.

A proper legislative base and institutional structure are crucially important. This includes a need of many actions at different levels including finances and taxation, legislation and proper administration.

5. Forestry Emissions Projections and Abatement Cost for the ECA Region

5.1. General approach

To produce consistent projections of CO_2 emissions from forestry activities at country level until 2050, two different models, an economic land use model (GLOBIOM) and a detailed forestry model (G4M) communicate as shown in the Figure 9 below. The economic land use model GLOBIOM is located in the centre of the framework. The model uses recent baseline projections by WEO (2010) for future bioenergy demand and related assumptions on population growth, economic development (GDP), and technical progress rates as macro-economic drivers. GLOBIOM represents the forestry, agriculture, bioenergy and livestock sectors for in total 28 world regions.

For baseline and policy scenarios, the economic land use model projects domestic production and consumption, net exports and prices of wood and agricultural products. The sector specific information from the economic model is used by the forest model to project GHG emissions and removals for detailed land management options. The forestry model is applied to estimate emissions and removals from forest management and afforestation/reforestation activities. Based on a baseline projection it also provides abatement cost curves for the selected land use activities.

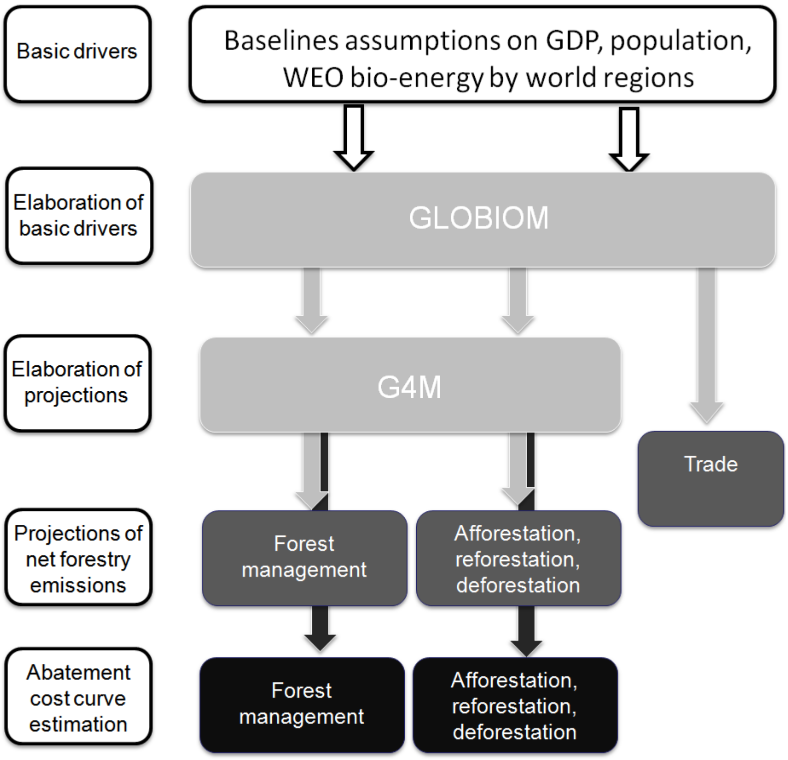

Figure 9: Overview of general modelling approach.

The models use several sources of input data some available for each grid, some by country aggregates and others are global. The data supporting the values in Table 10 are known for each grid. Some of the values are also available for time series.

Table 10: List of data sources used by the models

Data	Year	Source
Grid level data		
Land area	2000	JRC, 2000
Forest area	2010	FAO (2010)
Forest NPP	-	Cramer *et al.*, 1999
Build up land	2010-2050	Tubiello and Fischer (2007)
Biomass map	2005	Kindermann et al. (2008)
Population density	1990-2050	CIESIN, 2005
Population density	1990-2050	Grübler *et al.*, 2007
Country level data		
PPP	2005	World Bank (2005)
Discount rates	2004	Benitez et al. (2004)
Corruption factor	2005	Kaufmann *et al.*, 2005
Fraction of long living products	2000–2010	FAO (2010)
Scenarios/Region level data		
POLES bioenergy scenario	2010	POLES model result

5.1.1. GLOBIOM description

General description

The Global Biosphere Management Model (GLOBIOM)[1] has been developed and is used at the International Institute for Applied Systems Analysis (IIASA). GLOBIOM is a global recursive dynamic partial equilibrium model integrating the agricultural, bioenergy and forestry sectors with the aim to provide policy analysis on global issues concerning land use competition between the major land-based production sectors. It is *global* in the sense that it encompasses all world regions aggregated in a way that can be altered. GLOBIOM covers 28 (or 50) world regions.[2] *Partial* denotes that the model does not include the whole range of economic sectors in a country or region but specialises on agricultural and forestry production as well as bioenergy production. These sectors are, however, modelled in a detailed way accounting for about 20 globally most important crops, a range of livestock production activities, forestry commodities as well as different energy transformation pathways.

GLOBIOM disaggregates available land into several land cover/use classes that deliver raw materials for wood processing, bioenergy processing and livestock feeding. Figure 10 illustrates this structure of different land uses and commodities. Forest land is made up of two categories (unmanaged forest and managed forest); the other categories include cropland, short rotation tree plantations, grassland (managed grassland) and ‘other natural vegetation’ (includes unused grassland).

The detailed modelling of land based activities means that the GLOBIOM model relies on a detailed database containing geo-spatial information. This information is made up of different layers: geo-spatial characteristics that do not change over time (due to climate change and/or management practices) such as altitude, slope, and soil are used to form geographical clusters or ‘Homogenous Response Units’ (HRU). On top of this layer containing time invariant characteristics come country boundaries and a 0.5° x 0.5° grid layer that contains more detailed information such as data on climate, land use/cover, etc. This information forms Simulation Units (SimU) that are the

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[1] Documentation of the GLOBIOM model can be found at www.globiom.org.

[2] The disaggregation of the EU into 27 individual countries has been performed only recently, originally five European region are defined and used for this project (http://www.iiasa.ac.at/Research/FOR/globiom/regions.html).

basic geographical unit for the analysis. For each SimU, different management systems are distinguished. For the bulk of global crop production four management systems are available in GLOBIOM; these are irrigated, high input – rainfed, low input – rainfed and subsistence management.

The global agricultural and forest market equilibrium is computed by choosing land use and processing activities to maximize welfare (i.e. the sum of producer and consumer surplus) subject to resource, technological, and policy constraints. These constraints ensure that demand and supply for *inter alia* irrigation water and land meet but also impose exogenous demand constraints so as to reach, for instance, a certain biofuel target. Prices and international trade flows are endogenously determined for respective aggregated world regions (i.e. in this context for the 28 regions mentioned above). Imported and domestic goods are assumed to be identical (homogenous), but the modelling of trade does take into account transportation costs and tariffs. GLOBIOM includes accounting for greenhouse gas emissions and sinks from agricultural and forestry activities. This includes among others accounting for N_2O emissions from fertiliser use whose intensity in turn depends on the management system.[3]

It is possible within the model to convert one land cover/use to another; the total land area spanning all the categories included remains fixed, however (this forms part of the constraints mentioned earlier). The arrows on the left-hand side of Figure 10 indicate the initial land category and therefore show the way in which land cover/use can change (i.e. unmanaged forest can be converted into managed forest or cropland). The greenhouse gas consequences from land use change are derived from the carbon content of above- and below-ground living biomass of the respective land cover classes.

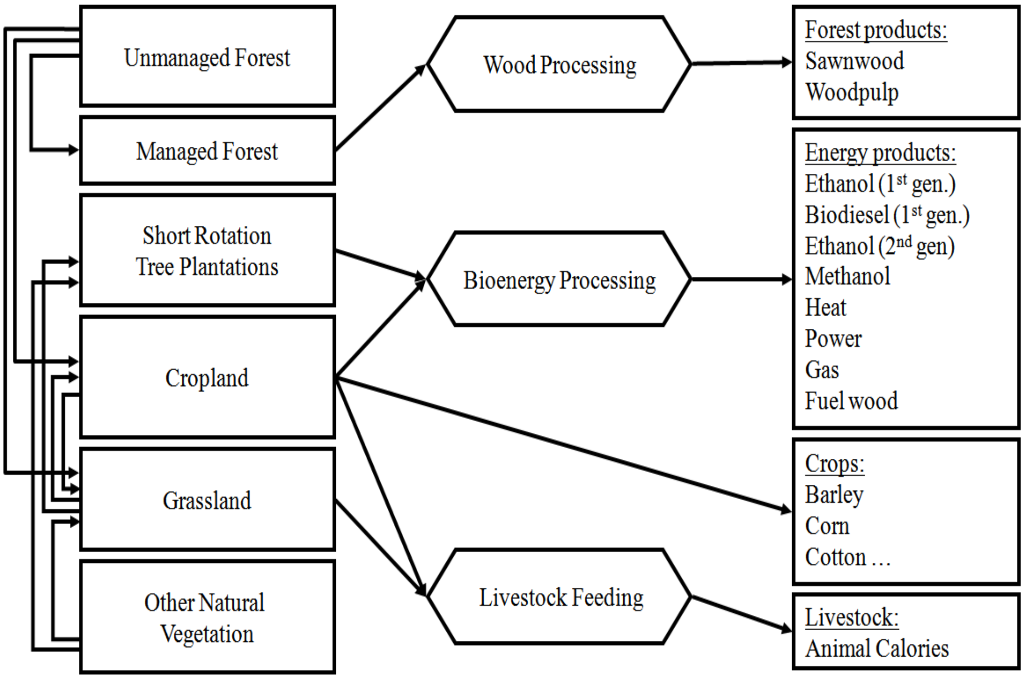

Figure 10. GLOBIOM land use and product structures (Havlík *et al*, in press). Note: The arrows on the left represent the direction where a given land use/cover type can expand given the current constraints in the model.

The model is *recursive dynamic* in the sense that changes in land use made in one period alter the land availability in the different categories in the next period. Land use change is thus

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[3] The calculation of N_2O emissions is in accordance with IPCC 1996, which does not take detailed soil characteristics into account (such as soil carbon content) that can have important implications for the amount of emissions.

transmitted from one period to the next. As GLOBIOM is a partial equilibrium model, not all economic sectors are modelled explicitly. Instead, several parameters enter the model exogenously, or are pre-determined in other words, including wood and food demand which in turn are derived from changes over time in gross domestic product (GDP), population (same projections as used in PRIMES) and food (calorie) consumption per capita (projections according to FAO, 2006). Assumptions on GDP, population growth and calorie consumption per capita are the underlying driver of the model dynamics. The base year for the model is the year 2000, the model horizon is 2050. The exogenous drivers population and GDP growth have been updated to take recent economic downturns into account by relying on 2009 data. In relation to yield development, GLOBIOM typically assumes 0.5 % autonomous technological progress in crop improvement[4]; in addition, the possibility to shift between management systems as well as the relocation of crops to more productive areas also provides for regional average yield changes. When it comes to 'bioenergy dynamics', projections on regional biomass demand in heat and power (BIOINEL), direct biomass use i.e. for cooking (BIOINBIOD) and liquid transport fuel use (BFP1 and BFP2 or first and second generation biofuels, respectively) over the next two decades are implemented in GLOBIOM as target demands or minimum demand constraints.

Resources for the different types of bioenergy products can be sourced from agricultural and (existing) forestry activities but also from newly planted short rotation tree plantations. First generation biofuels include ethanol made from sugarcane, corn and wheat, and biodiesel made from rapeseed, palm oil and soybeans. Biomass for second generation biofuels is either sourced from existing forests/wood processing or from short rotation tree plantations. Havlík *et al* (in press) define different scenarios for the sourcing of second generation biofuels. They also conducted an analysis to establish the scale of land available for short rotation tree plantations. Summarised in a few words, they arrive at available area by excluding areas unsuitable for their level of aridity, temperatures, elevation and population density from total arable land area (grassland, cropland, 'other natural vegetation').

Recent applications of GLOBIOM have analysed the impacts of different development scenarios in terms of population growth, economic development and technical change on global food production and consumption (Schneider *et al*, 2011) as well as the global land-use implications of first and second generation biofuel targets (Havlík *et al,* in press). The explicit inclusion of water as a resource (along with land and irrigated land) makes GLOBIOM a strong tool for analysing water related impacts of different development scenarios (Sauer *et al*, 2010).

The main drivers of results and crucial underlying assumptions are the following:

- Yield assumption: 0.5 % autonomous yield increase per year due to technical progress typically assumed.5 This assumption can be easily altered in GLOBIOM to reflect latest available yield projections or to run sensitivity scenarios;
- Calorie consumption per capita derived from projections according to FAO (2006);
- Available land reserve and availability to convert grassland and 'other natural vegetation': 5 per cent of area per period (10-year periods) allowed to be converted to short rotation plantings

The following variables are sent to G4M for the forest sector model runs:

- Prices of commodities relevant for G4M (wood, land etc.)
- Wood production

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[4] Note that Havlík *et al* (in press) work with a different, ie zero per cent, yield assumption.

[5] Note that autonomous yield increase is only one of three components of the yield change in GLOBIOM. The other two components are management system change (intensification) and shift of the production to more or less yielding zones (re-allocation). It was found that the 0.5 value enables best to reproduce recent total yield changes according to FAOSTAT. Disaggregated data which would enable to define the autonomous yield growth in a less arbitrary and more differentiated way (by region and crop) is not available.

- Per GLOBIOM region

5.1.2. G4M description

General description

The Global Forest Model (G4M) is applied and developed by IIASA and estimates the impact of forestry activities (afforestation, deforestation and forest management) on biomass and carbon stocks. By comparing the income of managed forest (difference of wood price and harvesting costs, income by storing carbon in forests) with income by alternative land use on the same place, a decision of afforestation or deforestation is made. As G4M is spatially explicit (currently on a 0.5° x 0.5°resolution) the different deforestation pressure at the forest frontier can also be handled. The model can use external information (like wood prices, prescribed land-use change from GLOBIOM) from other models or data bases, which guarantee food security and land for urban development or account for disturbances. As outputs, G4M produces estimates forest area change, carbon sequestration and emissions in forests, impacts of carbon incentives (e.g. avoided deforestation) and supply of biomass for bio-energy and timber.

For Europe the initial forest growing stock (aboveground biomass) per grid cell was taken from the European forest biomass map from Gallaun et al. (2010) and scaled to total biomass using the biomass map of Kindermann et al. (2008). For countries outside Europe the original forest biomass map compiled by Kindermann et al. (2008) was used.

The model handles age classes with one year width. Afforestation and disturbances cause an uneven age-class distribution over a forest landscape. The model performs final cuts in a manner, that all age classes have the same area after one rotation period. During this age class harmonization time the standing biomass, increment and amount of harvest is fluctuating due to changes in age-class distribution and afterwards stabilizing.

The main forest management options considered by G4M are species selection, variation of thinning and choice of rotation length. G4M does not model species explicitly but a change of species can be emulated by adapting NPP, wood price and harvesting costs. The rotation length can be individually chosen but the model can estimate optimal rotation lengths to maximize increment, maximize stocking biomass or maximize harvestable biomass.

To initialise forest biomass the forest biomass map compiled by Kindermann et al. (2008) was used. Increment is determined by a potential Net Primary Productivity (NPP) map (Cramer *et al.*, 1999) and translated into net annual increment (NAI). At present this increment map is static but can be changed to a dynamic growth model which reacts to changes of temperature, precipitation or CO_2 concentration. Age structure and stocking degree are used for adjusting NAI. If stocking degree of forest modelled with a given age structure (country average) in a cell is greater than 1.05 age structure of the modelled forest is shifted iteratively by a few age classes towards older forest. If stocking degree of forest modelled in a cell is smaller than 0.5 age structure of the modelled forest is shifted iteratively by a few age classes towards younger forest. It is required that the shifts are symmetrical to keep country average age structure close to statistical value. If the age structure shift distribution within a country is skewed towards older forest, the country's average NAI is increased iteratively. If the age structure shift distribution within a country is skewed towards younger forest country NAI is decreased iteratively.

The model uses external projections of wood demand per country (estimated by GLOBIOM) to calculate total harvest iteratively. The potential harvest amount per country under a scenario of rotation lengths that maintain current biomass stocks is estimated. If total harvest is smaller than wood demand the model changes grid per grid (starting from the most productive forest) management to a rotation length that optimizes forest increment and thus allows for more harvest. This mimics the typical observation that managed forests (in some regions) are currently not managed optimally with respect to yield. The rotation length is changed at maximum by five years per time step. If harvest is still too small and unmanaged forest is available the status of the unmanaged forest will change to managed. If total harvest greater than demand the model changes management to maximum biomass rotation length, i.e. manages forests for carbon sequestration. If wood demand is still lower than potential harvest managed forest can be transferred into unmanaged forest. Thinning is applied to all managed forests. The stands are thinned to maintain a stocking degree specified. The default value is 1 where thinning mimics natural mortality along the self-thinning line. The model can consider the use of harvest residues e.g. for bioenergy purposes.

Introducing a carbon price incentive to generate carbon abatement cost curves means that the forest owner is paid for the carbon stored in forest living biomass above a baseline or pays a tax, if the carbon in forest living biomass is below the baseline. The baseline is estimated assuming forest management without the carbon price incentive.

The measures considered as mitigation measures in forestry in G4M are:

- Reduction of deforestation area
- Increase of afforestation area
- Change of rotation length of existing managed forests in different locations
- Change of the ratio of thinning versus final fellings
- Change of harvest intensity (amount of biomass extracted in thinning and final felling activity

These activities are not adopted independently by the forest owner. The model is managing land dynamically and one activity affects the other. The model is calculating the optimal combination of measures. The introduction of a CO_2 price gives an additional value to the forest through the carbon stored and accumulated in it. The increased value of forests in a regime with a CO_2 price changes the balance of land use change through the net present value (NPV) generated by land use activities towards forestry. In general, it is therefore assumed that an introduction of CO_2 price leads to a decrease of deforestation and an increase of afforestation. This might not happen at the same intensity though. Less deforestation increases land scarcity and might therefore decrease afforestation relative to a baseline.

The existing forest under a CO_2 price is managed with longer rotations of productive forests, and shifting harvest to less productive forest (see Box 1). Where possible the model increases the area of forests used for wood production, meaning a relatively larger area is managed relatively less intensively. This model paradigm implies also changes of the thinning versus final felling ratio towards more thinnings (which affect the carbon balance less than final fellings). Forest management activities can have a feedback on emissions from deforestation because they might increase or decrease the average biomass in forests being deforested. It also influences biomass accumulation in newly planted forests depending on whether these forests are used for production or not.

Box 1: Abatement cost curves for forest management activities – detailed algorithm.

For the generation of cost curves for forest management a two step approach is used:

STEP 1. Every year, starting from the onset of mitigation measures, forest management in each cell is changed towards a state that maximises the forest biomass. For the forest used for wood production, where NPV estimated for the maximum biomass rotation length (NPV_{wc}) is greater than the BAU NPV (NPV_{bau}, $NPV_{bau}>=0$), current rotation length is increased proportionally to the $(NPV_{wc}-NPV_{bau})/NPV_{bau}$. If the NPV condition is not satisfied, the current rotation length is increased by five years. In all cases the maximum rotation length is not allowed to be higher than the rotation length maximising biomass. NPV for the new rotation length is estimated (NPV_c) and kept in memory. NPV in all cases is estimated for the next 50 years.

STEP 2. The production of wood to satisfy wood demand has higher priority than the carbon accumulation. After Step 1 the forest management of forests within each country is adjusted to harvest as much as the country wood production prescribed (by GLOBIOM). A precondition of the adjustment is that the new NPV multiplied by an adjustment hurdle coefficient to be greater or equal to NPV_c estimated in Step 1. The adjustment hurdle varies from 1 to 2500 and to -1. The forest management adjustment for the cells within each country starts with the hurdle=1. If the total harvest does not satisfy prescribed wood production, the hurdle is increased by 0.3 and the forest management adjustment is repeated for the forests within the country again. The last hurdle tried is minus one, allowing forest management leading to negative NPV in order to satisfy wood production.

Baseline definition

- Drivers are WEO 2010/POLES 2011 data on
  - Population
  - Prices from GLOBIOM
  - Wood production from GLOBIOM
- Calibration to area information of latest dataset from the FAO's Global Forest Resources Assessment 2010
- Specification of how much wood is burned after deforestation
  - Latin America - 90% slash burn and 10% selling
  - Africa - 50% slash burned and 50% selling
  - The remaining area - 10% slash burned and 90% selling
- Wood products
  - Two categories, long and short living
    - Decay rate long ln(2)/20
    - Decay rate short 0.5

MACCs

- Annual MAC curves for 2030 and 2050
- The MAC curves are based on the assumption that a carbon price is introduced in 2010 that increases linearly until 2015 to five specified levels (10, 20, 30, 50, 100 USD per t CO2) and remain constant after 2015 until 2050.

Output

- Annual projection for AR, D and FM from 1990 until 2050
- Output variables per country
  - Forest area
  - Afforestation area
  - Deforestation area
  - Afforestation total biomass emissions
  - Deforestation total biomass emissions

    - Forest management total biomass emissions
- Smoothing with running 5-year mean and fixing of initial year bumps

5.2.Results

5.2.1. Baseline development

Figure 11 introduces the baseline development projected by G4M calibrated to FRA 2010 forest area change data for afforestation, deforestation and forest management emissions. While deforestation emissions are expected to drop from about 50-60 Mt CO2 annually in 2005 to about 16 Mt CO_2 in 2030, afforestation (initiated after 1990) removals amount about 80 Mt in 2030, constantly increasing thereafter. Emissions in the forestry sector for ECA countries, however, are dominated by a large sink from existing forests. G4M projects a decrease of the sink from about 1400 Mt CO_2 annually in 205 to about the half in 2050. In total forestry is expected still to be a net sink in ECA countries in 2050.

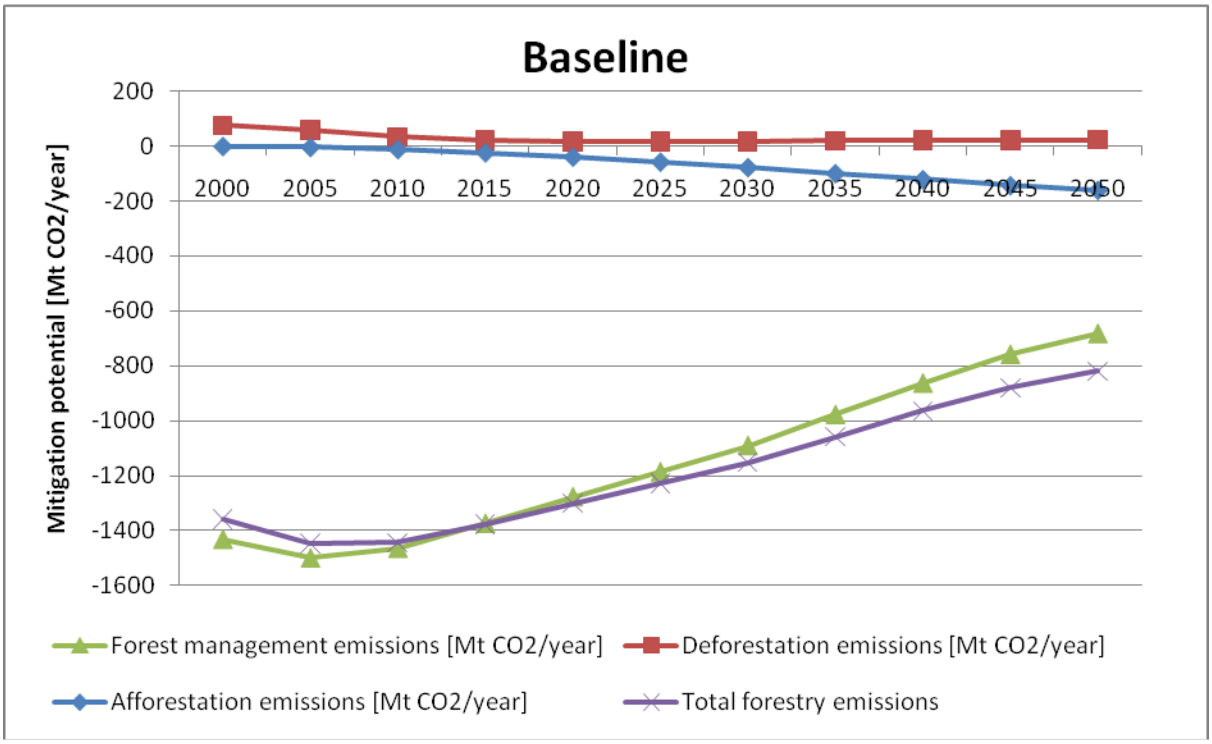

Figure 11: Baseline development projected by G4M calibrated to FRA 2010 forest area change data for afforestation, deforestation and forest management emissions.

The emissions projections by components and individual countries are presented on Figure 12-Figure 18.

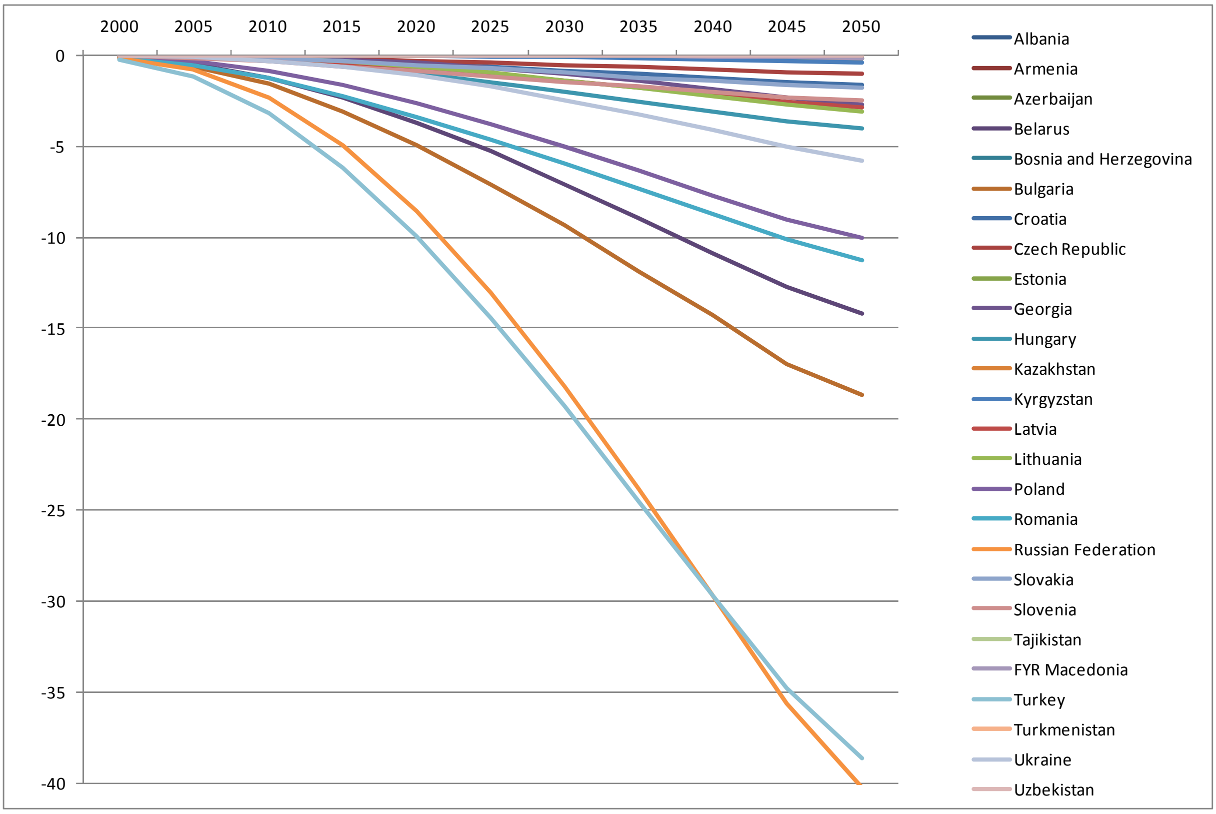

Figure 12. Afforestation emissions [Mt CO2/year]

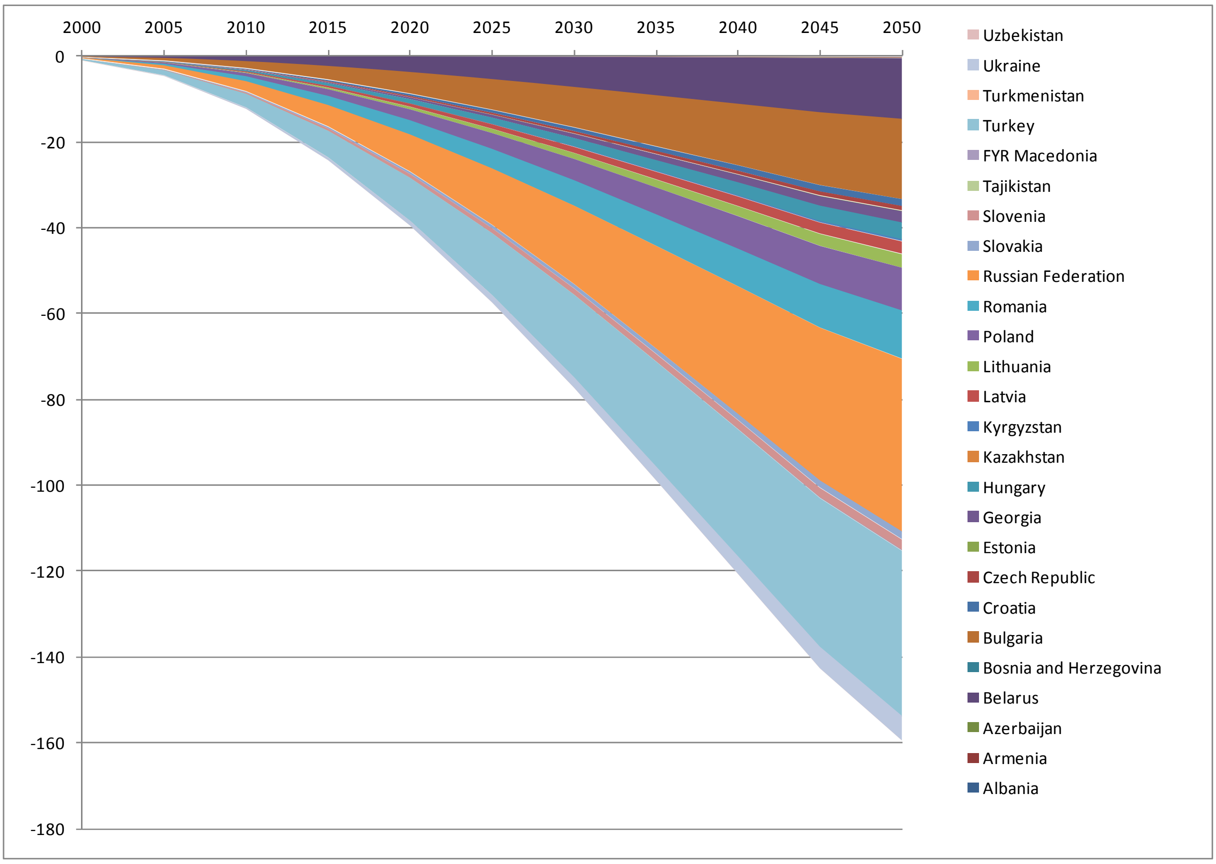

Figure 13. Afforestation emissions accumulated [Mt CO2/year]

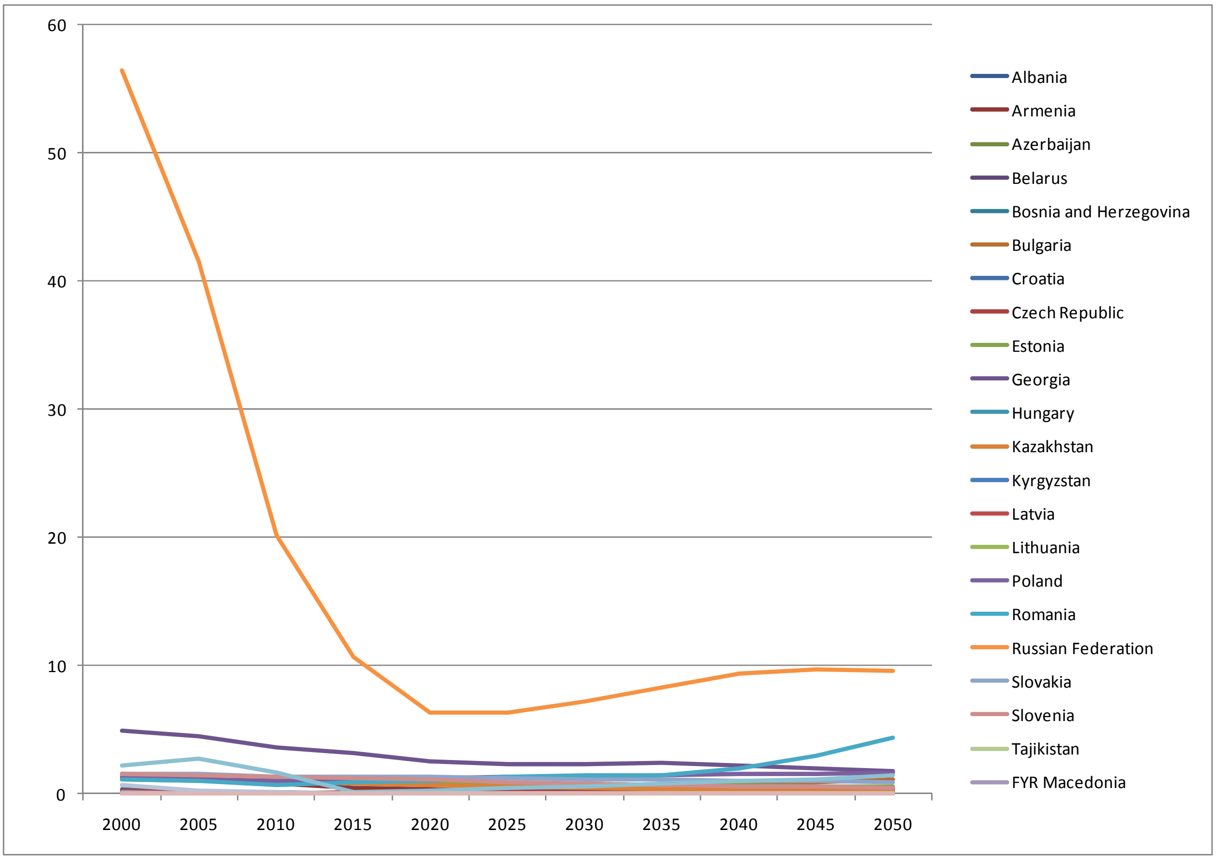

Figure 14. Deforestation emissions [Mt CO2/year]

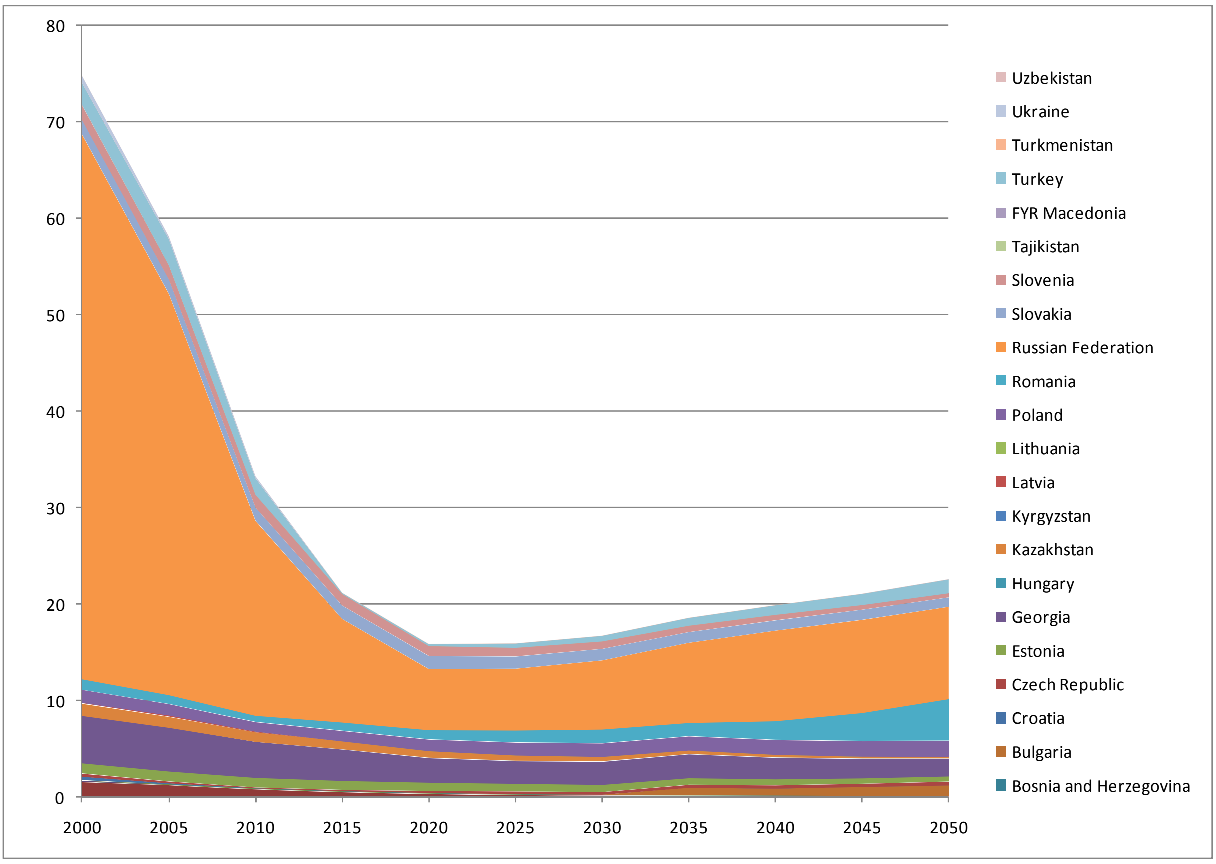

Figure 15. Deforestation emissions accumulated [Mt CO2/year]

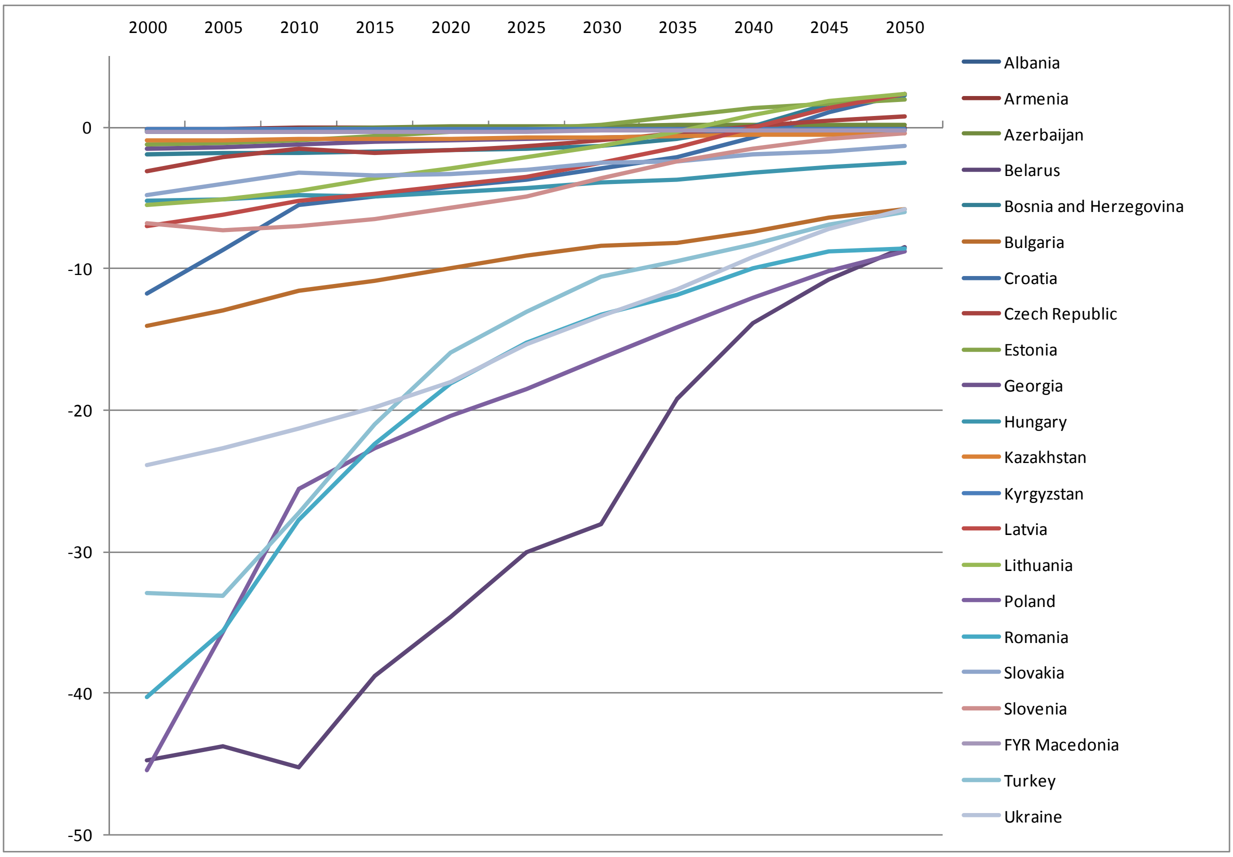

Figure 16. Forest management emissions [Mt CO2/year]

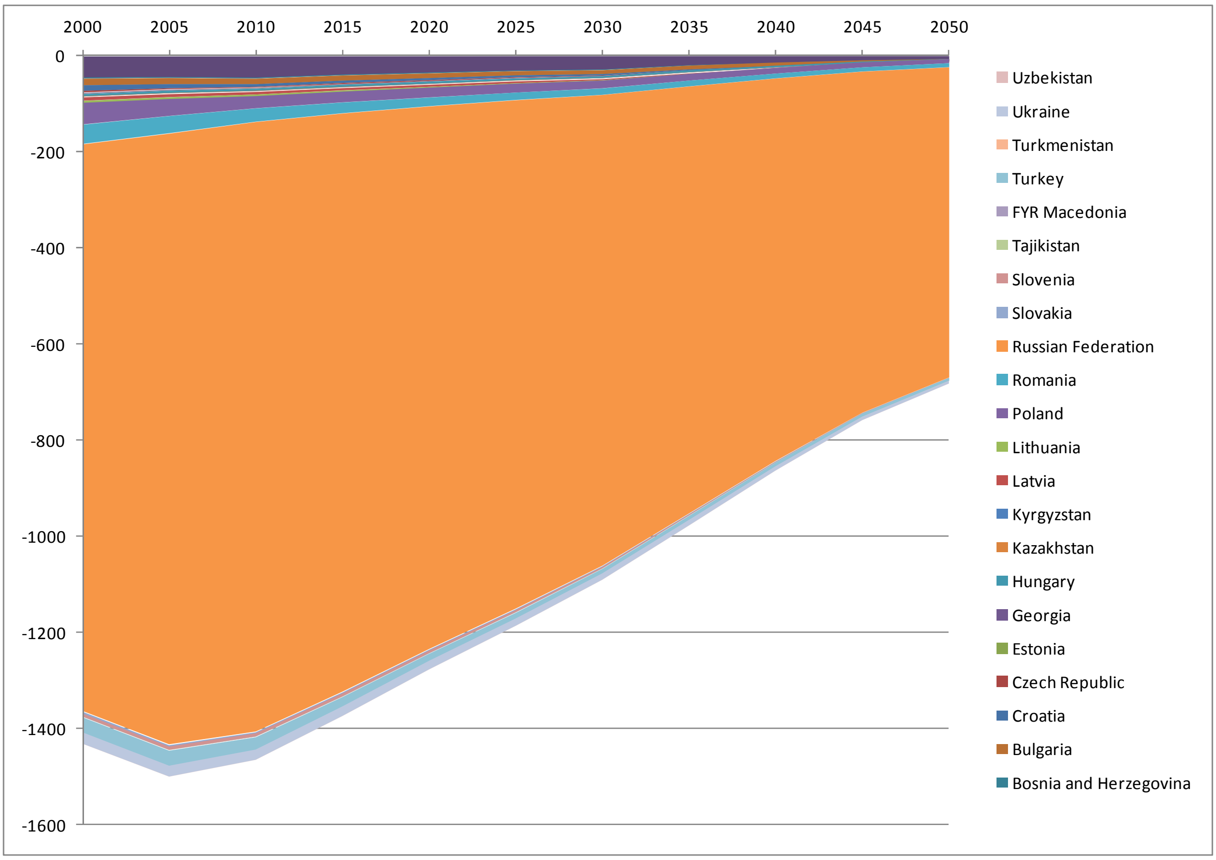

Figure 17. Forest management emissions accumulated [Mt CO2/year]

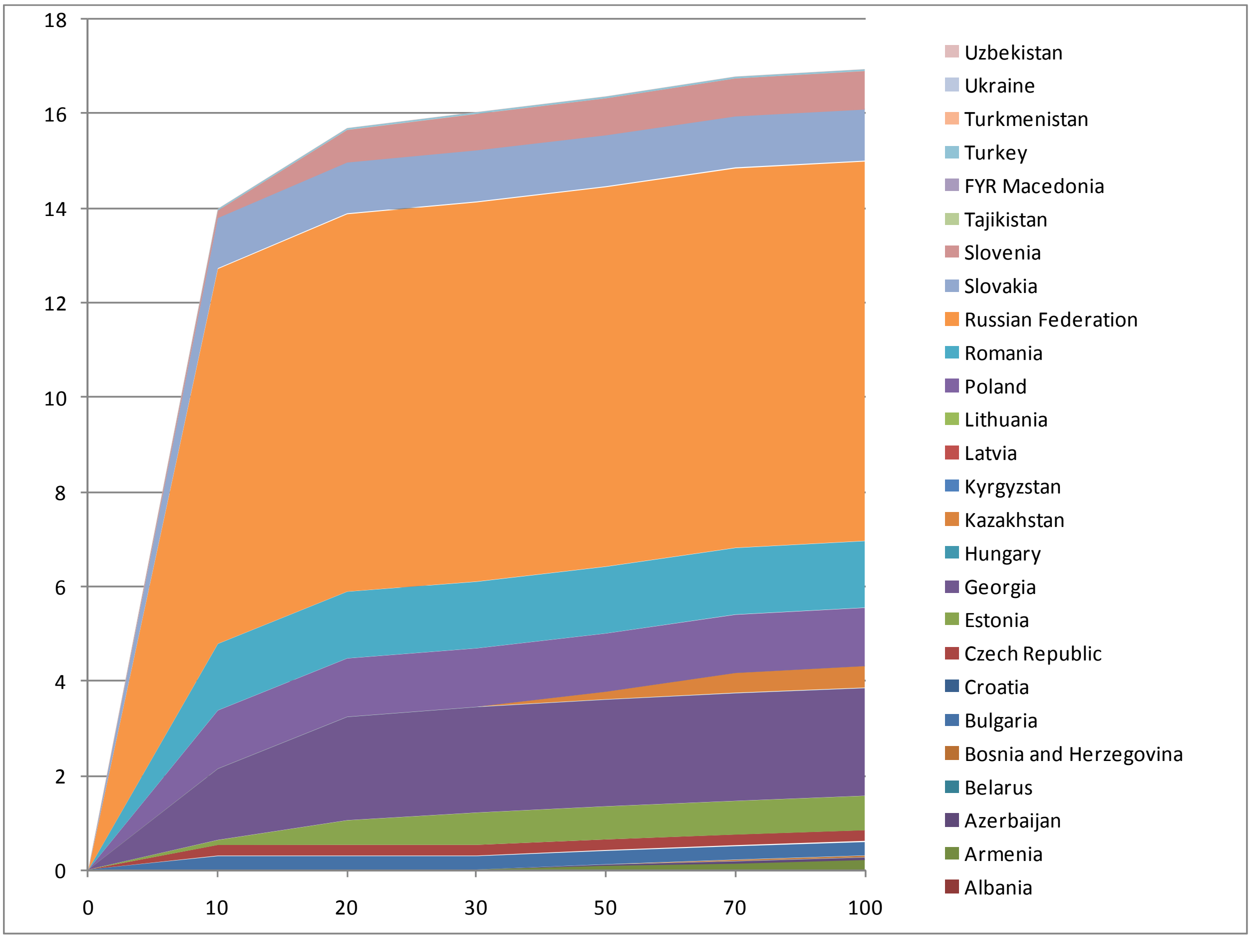

Figure 18. Accumulated mitigation over period 2010-2050, averaged. Deforestation MACC 2050 [Mt CO2/year]

5.2.2. Mitigation cost curves

When introducing a carbon price, a value is given to the existing forest carbon stock, in the sense that increases of the carbon stock are rewarded, for decreases the forest owner receives a penalty. This leads to considerable reductions of deforestation area and associated emissions in ECA countries, an enhancement of forest area through afforestation and changes in forest management towards higher forest carbon stocks. Lower carbon prices lead to relatively higher mitigation potentials compared to higher carbon prices, following the typical shape of a mitigation cost curve (see Figure 19). The potential for additional carbon storage through afforestation is rather limited (< 1 Mt CO2 per year). This is mainly due to a relatively high baseline. Afforestation rates in the baseline are already at high levels, e.g. triggered by policies already in place. This trend of high recent afforestation rates is picked up by the model and also maintained in the future (resulting in 33 Mt CO2 in 2030 and 71 Mt CO2 in 2050, annually). Additional afforestation is therefore rather expensive. In addition, many regions of ECA are facing growth constraints. Newly established forests grow therefore rather slowly.

More potential for mitigation can be achieved through avoiding deforestation. Deforestation emissions are expected to drop significantly (largest share of deforestation and deforestation reduction can be observed in Russia). Still, in 2030 and 2050 about 20 Mt CO2 will be emitted annually according to the model. Up to 15 (2030) and 16 (2050) Mt CO2 could be avoided annually at a price of 20-30 USD per t CO2. At higher prices this potential cannot be increased further. This study looked at the potential of avoiding deforestation in 2030 and 2050. A shorter time horizon, e.g.

addressing the year 2020 would result in a higher potential, simply due to the fact that the baseline deforestation that can potentially be avoided in 2020 is still higher compared to later in the century.

The highest potential in both years, 2030 and 2050 can be expected from forest management change. This is due to the vast amount of forest area in ECA countries. Not all forests are managed and some might be not available for wood supply. Measures in forest management that were considered in the MACCs include changes from final cut to longer rotations and more thinnings and geographical shifts of forest management. However, only the forest contributing to wood supply is considered and not remote forests that might sink or source but out of reach for management. Forest management potential is increasing over time. The measures are assumed to be started in 2010. They, however, need time to show effects on the carbon balance.

In total, afforestation, avoided deforestation and forest management could yield emission reductions/sink enhancements of about 80 Mt CO2 annually in 2030, and 110 Mt CO2 in 2050. About 80% of the potential is achieved in Russia (Table 14, Table 15).

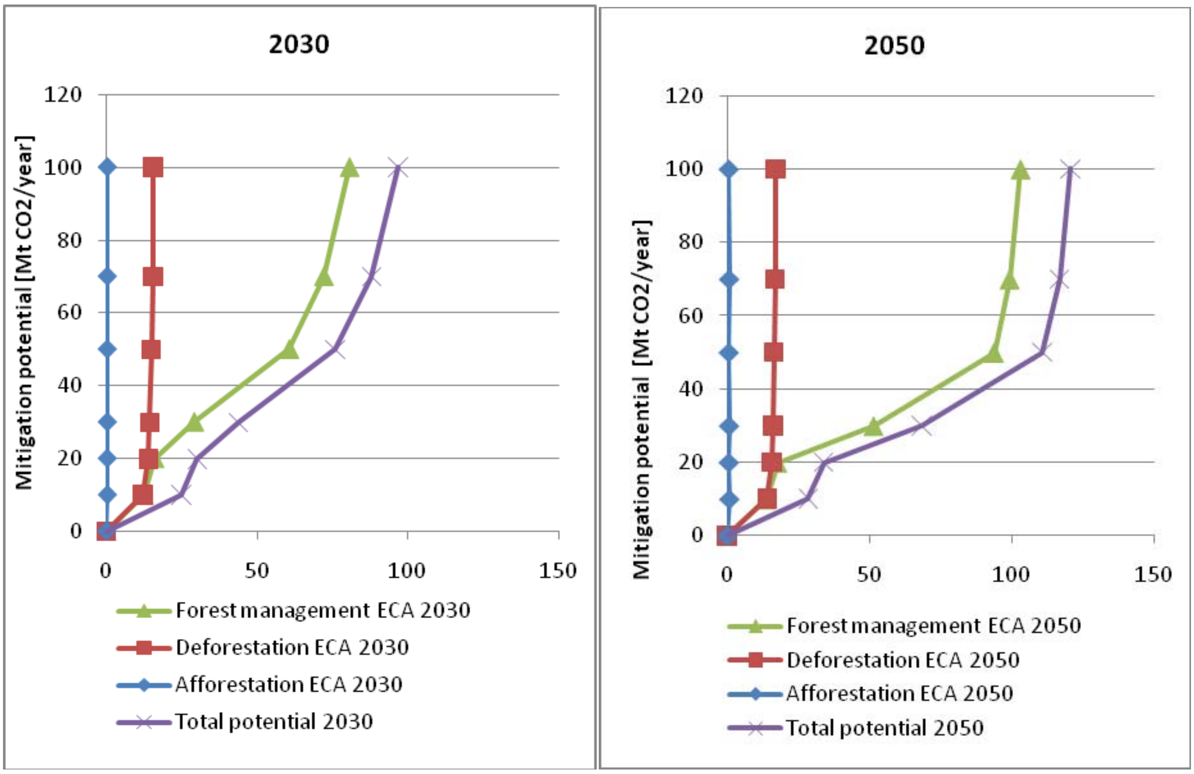

Figure 19: Cost curves for all considered ECA countries for afforestation, avoided deforestation and forest management (Annex1 countries only) for the years 2030 and 2050.

Conclusions

This report provides an overview of mitigation potential of the ECA forests in the short, medium and long run. Practically in all parts of the region forests are estimated as a major mitigation tool

Our review suggests that climate change will have substantial impacts on the region's forests by end of this century. If the global warming would exceed 3.5-4^{o}C by 2100s (what seems very probably taking into account the current tendencies of the dynamics of GHG emissions), the situation in vast territories of the region could be classified as catastrophic. Under such conditions, the increase of precipitation will not compensate the expected level of warming that will generate different risks for forest ecosystems. Explosive increase of wildfires and insect outbreaks are very likely. The short-term impacts will be relatively small; however, already increasing instability of climate will likely introduce regional weather patterns which could provide clearly negative

Particularly, the potential threat is high in continental Asia of high latitudes where thawing permafrost could cause large scale change of northern landscapes and explosive increase of carbon emissions mostly in form of methane. In the south

Very likely, climate change impacts will accelerate in the medium and long term if mitigation and abatement efforts are not undertaken

As it follows from economic studies that timber prices will fall (increase) if forest productivity increases (decreases). Large disturbances

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Appendixes

Baseline country tables

Table 11: Afforestation emissions [Mt CO2/year]. Negative values show sink, positive values source to the atmosphere.

Countries	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Albania	0.00	0.00	0.00	-0.01	-0.02	-0.04	-0.05	-0.08	-0.10	-0.13	-0.16
Armenia	0.00	0.00	0.00	0.00	-0.01	-0.02	-0.04	-0.07	-0.10	-0.14	-0.18
Azerbaijan	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.02	-0.03	-0.04	-0.06	-0.07
Belarus	-0.10	-0.46	-1.21	-2.33	-3.71	-5.27	-7.10	-8.98	-10.88	-12.75	-14.22
Bosnia and Herzegovina	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulgaria	-0.13	-0.60	-1.58	-3.10	-4.97	-7.13	-9.37	-11.86	-14.29	-16.95	-18.68
Croatia	-0.01	-0.06	-0.15	-0.29	-0.45	-0.63	-0.83	-1.05	-1.27	-1.48	-1.62
Czech Republic	-0.01	-0.05	-0.11	-0.20	-0.30	-0.42	-0.54	-0.67	-0.79	-0.92	-1.01
Estonia	0.00	0.00	-0.01	-0.02	-0.03	-0.05	-0.06	-0.09	-0.11	-0.13	-0.15
Georgia	-0.01	-0.04	-0.11	-0.24	-0.44	-0.69	-1.02	-1.40	-1.83	-2.31	-2.72
Hungary	-0.03	-0.12	-0.33	-0.65	-1.05	-1.51	-1.99	-2.54	-3.08	-3.61	-4.02
Kazakhstan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kyrgyzstan	0.00	0.00	0.00	-0.02	-0.04	-0.07	-0.11	-0.17	-0.25	-0.34	-0.41
Latvia	-0.01	-0.07	-0.21	-0.42	-0.70	-1.03	-1.39	-1.78	-2.18	-2.56	-2.85
Lithuania	-0.01	-0.05	-0.16	-0.35	-0.62	-0.97	-1.37	-1.81	-2.27	-2.75	-3.12
Poland	-0.07	-0.32	-0.84	-1.63	-2.62	-3.78	-5.03	-6.35	-7.70	-9.03	-10.07
Romania	-0.14	-0.53	-1.26	-2.25	-3.39	-4.64	-5.97	-7.37	-8.76	-10.12	-11.25
Russian Federation	-0.14	-0.76	-2.30	-4.95	-8.57	-13.06	-18.23	-23.85	-29.70	-35.60	-40.24
Slovakia	-0.02	-0.08	-0.19	-0.35	-0.54	-0.75	-0.97	-1.22	-1.44	-1.66	-1.78
Slovenia	-0.05	-0.17	-0.36	-0.60	-0.87	-1.16	-1.45	-1.74	-2.02	-2.29	-2.49
Tajikistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FYR Macedonia	0.00	0.00	0.00	0.00	-0.01	-0.02	-0.03	-0.05	-0.08	-0.11	-0.14
Turkey	-0.26	-1.18	-3.15	-6.17	-10.00	-14.42	-19.27	-24.50	-29.70	-34.76	-38.61
Turkmenistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ukraine	-0.02	-0.10	-0.30	-0.64	-1.12	-1.73	-2.45	-3.25	-4.12	-5.03	-5.76
Uzbekistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grand Total	-1.01	-4.60	-12.28	-24.24	-39.47	-57.39	-77.29	-98.86	-120.71	-142.71	-159.56

Table 12: Deforestation emissions [Mt CO2/year]. Negative values show sink, positive values source to the atmosphere.

Countries	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Albania	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Armenia	1.54	1.22	0.80	0.52	0.35	0.25	0.19	0.16	0.13	0.11	0.10
Azerbaijan	0.10	0.10	0.09	0.09	0.08	0.08	0.07	0.06	0.05	0.05	0.04
Belarus	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bosnia and Herzegovina	0.06	0.06	0.06	0.05	0.05	0.04	0.04	0.03	0.02	0.02	0.02
Bulgaria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.71	0.90	1.09
Croatia	0.34	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Czech Republic	0.31	0.18	0.08	0.12	0.19	0.25	0.27	0.30	0.32	0.32	0.38
Estonia	1.08	1.06	1.02	0.96	0.90	0.83	0.77	0.72	0.66	0.61	0.56
Georgia	4.91	4.49	3.66	3.19	2.49	2.28	2.34	2.43	2.18	1.95	1.79
Hungary	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kazakhstan	1.27	1.14	1.00	0.85	0.73	0.61	0.51	0.40	0.31	0.25	0.21
Kyrgyzstan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Latvia	0.05	0.14	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lithuania	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poland	1.34	1.16	0.98	1.07	1.19	1.31	1.38	1.45	1.52	1.59	1.64
Romania	1.15	0.96	0.68	0.90	1.00	1.29	1.47	1.41	1.97	2.94	4.35
Russian Federation	56.42	41.57	20.20	10.73	6.32	6.39	7.16	8.31	9.39	9.66	9.56
Slovakia	1.53	1.51	1.34	1.36	1.33	1.25	1.17	1.09	1.05	1.02	0.96
Slovenia	1.52	1.48	1.40	1.24	1.08	0.94	0.82	0.71	0.62	0.54	0.48
Tajikistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FYR Macedonia	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Turkey	2.22	2.71	1.71	0.12	0.20	0.46	0.58	0.80	0.99	1.15	1.44
Turkmenistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ukraine	0.72	0.26	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Uzbekistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grand Total	74.76	58.13	33.29	21.21	15.91	15.97	16.77	18.62	19.93	21.11	22.62

Table 13: Forest management emissions [Mt CO2/year]. Negative values show sink, positive values source to the atmosphere.

Countries	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Albania	-0.31	-0.31	-0.30	-0.29	-0.28	-0.27	-0.25	-0.22	-0.20	-0.17	-0.15
Armenia	-0.14	-0.12	-0.08	-0.07	-0.06	-0.05	-0.05	-0.04	-0.03	-0.03	-0.02
Azerbaijan	-0.27	-0.23	-0.09	-0.01	0.05	0.07	0.08	0.12	0.13	0.14	0.14
Belarus	-44.76	-43.73	-45.27	-38.81	-34.59	-30.08	-28.10	-19.23	-13.88	-10.77	-8.46
Bosnia and Herzegovina	-1.92	-1.80	-1.79	-1.72	-1.62	-1.51	-1.36	-0.86	0.05	1.61	2.22
Bulgaria	-14.08	-12.93	-11.58	-10.85	-9.96	-9.09	-8.37	-8.18	-7.42	-6.36	-5.81
Croatia	-11.76	-8.66	-5.48	-4.91	-4.19	-3.71	-2.94	-2.10	-0.68	1.04	2.37
Czech Republic	-3.14	-2.15	-1.56	-1.85	-1.65	-1.35	-0.97	-0.46	0.05	0.48	0.76
Estonia	-1.22	-1.12	-0.88	-0.65	-0.36	-0.16	0.14	0.73	1.32	1.69	1.96
Georgia	-1.50	-1.40	-1.19	-1.02	-0.89	-0.80	-0.70	-0.58	-0.44	-0.35	-0.28
Hungary	-5.21	-5.08	-4.81	-4.91	-4.65	-4.29	-3.89	-3.67	-3.24	-2.83	-2.53
Kazakhstan	-0.92	-0.90	-0.88	-0.84	-0.79	-0.75	-0.70	-0.64	-0.58	-0.51	-0.46
Kyrgyzstan	-0.13	-0.13	-0.14	-0.14	-0.14	-0.14	-0.14	-0.13	-0.13	-0.12	-0.10
Latvia	-6.99	-6.15	-5.19	-4.72	-4.12	-3.54	-2.55	-1.41	-0.05	1.33	2.38
Lithuania	-5.48	-5.15	-4.50	-3.58	-2.89	-2.08	-1.33	-0.31	0.86	1.84	2.34
Poland	-45.48	-35.68	-25.55	-22.67	-20.44	-18.56	-16.36	-14.13	-12.09	-10.20	-8.77
Romania	-40.31	-35.59	-27.78	-22.36	-18.07	-15.28	-13.23	-11.8	-10.0	-8.77	-8.56
Russian Federation	-1179.4	-1271.5	-1268.9	-1203.6	-1129.4	-1058.4	-979.8	-888.9	-796.0	-709.8	-645.8
Slovakia	-4.80	-4.05	-3.23	-3.39	-3.26	-3.01	-2.56	-2.39	-1.93	-1.68	-1.33
Slovenia	-6.84	-7.33	-7.03	-6.49	-5.72	-4.89	-3.61	-2.38	-1.53	-0.86	-0.39
Tajikistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FYR Macedonia	-0.31	-0.31	-0.30	-0.30	-0.29	-0.29	-0.27	-0.26	-0.24	-0.22	-0.21
Turkey	-32.90	-33.11	-27.29	-20.99	-15.88	-13.04	-10.52	-9.49	-8.32	-6.87	-6.03
Turkmenistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ukraine	-23.87	-22.65	-21.27	-19.83	-17.98	-15.33	-13.32	-11.47	-9.16	-7.16	-5.82
Uzbekistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grand Total	-1431.7	-1500.1	-1465.1	-1374.0	-1277.2	-1186.5	-1090.8	-977.8	-863.5	-758.6	-682.6

MACC country tables

Table 14: Total forestry MACC 2030 [Mt CO2/year].

Countries	baseline	Carbon price [USD/t CO2]					
		10	20	30	50	70	100
Albania	-0.26	0.00	0.00	0.00	0.00	0.00	0.00
Armenia	0.43	0.00	0.00	0.00	0.13	0.20	0.30
Azerbaijan	0.22	-0.02	0.01	0.01	0.05	0.08	0.09
Belarus	-31.23	0.23	0.99	1.48	1.72	1.72	1.71
Bosnia and Herzegovina	-1.24	0.17	0.20	0.20	0.20	0.23	0.24
Bulgaria	-13.49	-0.43	-0.57	-0.37	-0.34	-0.30	-0.36
Croatia	-3.03	1.06	1.58	1.82	2.04	2.26	2.31
Czech Republic	-2.00	0.05	0.44	0.46	0.15	0.47	0.39
Estonia	1.17	0.36	0.73	0.92	0.76	0.84	0.80
Georgia	1.93	1.53	2.22	2.31	2.39	2.44	2.46
Hungary	-4.84	-0.09	-0.11	-0.09	0.02	-0.02	0.14
Kazakhstan	0.10	0.00	0.00	0.00	0.27	0.53	0.59
Kyrgyzstan	-0.17	0.00	0.00	0.00	0.00	0.00	0.00
Latvia	-2.37	0.77	0.80	0.83	0.57	1.20	1.10
Lithuania	-0.46	0.34	0.23	0.22	0.26	0.27	0.26
Poland	-18.29	0.41	0.72	0.39	1.25	1.90	1.94
Romania	-15.38	0.91	1.32	1.28	1.23	1.22	1.18
Russian Federation	-963.85	18.02	18.99	31.82	62.76	72.43	80.97
Slovakia	-1.76	0.86	1.25	1.28	1.29	1.23	1.23
Slovenia	-3.22	0.28	0.88	0.76	0.74	0.72	0.79
Tajikistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FYR Macedonia	-0.28	0.00	0.00	0.00	0.00	0.00	0.00
Turkey	-17.21	0.41	0.39	0.41	0.31	0.33	0.33
Turkmenistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ukraine	-14.16	0.03	0.05	0.06	0.12	0.14	0.18
Uzbekistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total potential 2030	-1089.41	24.88	30.11	43.81	75.92	87.88	96.63
Annex1	-1090.13	23.21	27.69	41.28	72.88	84.40	92.96

Table 15: Total forestry MACC 2050 [Mt CO2/year].

Countries	baseline	Carbon price [USD/t CO2]					
		10	20	30	50	70	100
Albania	-0.21	0.00	0.00	0.00	0.00	0.00	0.00
Armenia	0.25	0.00	0.00	0.00	0.09	0.14	0.22
Azerbaijan	0.22	-0.01	0.00	0.01	0.05	0.07	0.08
Belarus	-15.02	1.19	2.11	1.96	1.60	1.59	1.55
Bosnia and Herzegovina	-0.62	0.20	0.23	0.23	0.23	0.26	0.26
Bulgaria	-13.84	0.67	-0.50	0.56	-0.11	-0.02	-0.03
Croatia	-2.14	0.96	1.40	1.65	1.81	1.73	1.70
Czech Republic	0.25	0.22	0.33	0.37	0.17	-0.05	0.04
Estonia	2.56	0.14	0.64	0.67	0.75	0.84	0.92
Georgia	1.30	1.48	2.20	2.26	2.30	2.33	2.35
Hungary	-4.52	-0.18	-0.18	-0.08	0.00	-0.03	-0.03
Kazakhstan	0.12	0.00	0.00	0.00	0.17	0.45	0.50
Kyrgyzstan	-0.22	0.00	0.00	0.00	0.00	0.00	0.00
Latvia	0.66	0.31	0.36	0.76	0.78	0.83	1.14
Lithuania	0.87	0.05	0.15	0.10	0.10	0.29	0.09
Poland	-10.72	1.04	0.92	0.53	1.55	1.49	1.48
Romania	-13.48	0.02	-0.02	-0.15	0.37	0.36	-0.18
Russian Federation	-645.00	20.89	24.52	56.81	98.18	103.37	107.81
Slovakia	-0.23	1.53	1.46	1.49	1.49	1.48	1.49
Slovenia	-0.78	0.26	0.62	1.20	1.11	1.26	1.15
Tajikistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FYR Macedonia	-0.24	0.00	0.00	0.00	0.00	0.00	0.00
Turkey	-5.28	-0.42	-0.36	-0.27	-0.17	0.12	-0.15
Turkmenistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ukraine	-8.07	0.02	0.05	0.08	0.15	0.18	0.20
Uzbekistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total potential 2030	-714.16	28.37	33.92	68.17	110.61	116.68	120.57
Annex1	-714.75	26.70	31.49	65.68	107.79	113.44	117.17

Table 16. Gross domestic product, population and land area by country

Region	NN	Country	GDP 2009, billions US$	GNI, PPP US$	Population, millions	Land area, 1000 ha
1	1	Albania	12.02	4,000	3.17	2,740
4	2	Armenia	8.71	3,100	3.08	2,820
4	3	Azerbaijan	43.02	4,840	8.78	8,263
3	4	Belarus	49.04	5,560	9.66	20,748
1	5	Bosnia & Herzegovina	17.04	4,700	3.77	5,120
1	6	Bulgaria	48.72	6,060	7.59	10,864
1	7	Croatia	63.03	13,770	4.43	5,592
2	8	Czech Republic	190.27	17,310	10.49	7,726
3	9	Estonia	19.08	14,060	1.34	4,239
4	10	Georgia	10.74	2,530	4.26	6,949
2	11	Hungary	128.96	12,980	10.02	8,961
6	12	Kazakhstan	115.31	6,920	15.89	269,970
1	13	Kosovo, Republic of	5.39	3,240	1.81	1,089
5	14	Kyrgyz Republic	4.58	870	5.32	19,180
3	15	Latvia	26.20	12,390	2.26	6,229
3	16	Lithuania	37.21	11,410	3.34	6,268
1	17	Macedonia, FYR	9.22	4,400	2.04	2,543
2	18	Moldova	5.40	1,560	3.60	3,287
1	19	Montenegro	4.14	6,650	0.62	1,345
3	20	Poland	430.08	12,260	38.15	30,633
2	21	Romania	161.11	8,330	21.48	22,998
7	22	Russian Federation	1,231.89	9,340	141.85	1,638,139
1	23	Serbia	42.98	6,000	7.32	8,746
2	24	Slovak Republic	87.64	16,130	5.42	4,810
1	25	Slovenia	48.48	23,520	2.04	2,014
5	26	Tajikistan	4.98	700	6.95	13,996
1	27	Turkey	614.60	8,720	74.82	76,963
5	28	Turkmenistan	19.95	3,904	5.11	46,993
2	29	Ukraine	113.55	2,800	46.01	57,938
5	30	Uzbekistan	32.10	1,100	27.77	42,540
		Total	**3,585.44**	**229,154**	478.39	**2,339,703**

World Bank Country Statistics: http://data.worldbank.org/country)

Table 17. Forest area and growing stock

NN	Country	Forest area		OWL area	Growing stock	
		1000 ha	%	1000 ha	mln m3	m3/ha
1	Albania	776	28.3	255		
2	Armenia	262	9.2	45		
3	Azerbaijan	936	11.3	54		
4	Belarus	8,630	42.5	520		
5	Bosnia & Herzegovina	2,185	42.7	549		
6	Bulgaria	3,927	36.2	0		
7	Croatia	1,920	34.3	554		
8	Czech Republic	2,657	34.4	0		
9	Estonia	2,217	52.3	133		
10	Georgia	2,742	39.5	51		
11	Hungary	2,029	22.6	0		
12	Kazakhstan	3,309	1.2	16,479		
13	Kosovo, Republic of					
14	Kyrgyz Republic	954	5	390		
15	Latvia	3,354	53.9	113		
16	Lithuania	2,160	34.5	80		
17	Macedonia, FYR	998	39.6	143		
18	Moldova	386	11.7	70		
19	Montenegro	543	40.4	175		
20	Poland	9,337	30.7	0		
21	Romania	6,573	28.6	160		
22	Russian Federation	845,600	49.4	73,220		
23	Serbia	2,713	30.7	410		
24	Slovak Republic	1,933	40.2	0		
25	Slovenia	1,253	62.2	21		
26	Tajikistan	410	2.9	142		
27	Turkey	11,334	14.7	10,368		
28	Turkmenistan	4,127	8.8	0		
29	Ukraine	9,705	16.8	41		
30	Uzbekistan	3,276	7.7	874		
	Total	**936,246**	**38.8**	**104,847**		

Sources: State of Europe's Forest 2011; FRA, 2010; Author's estimation for Russia

Table 18. Forest area and carbon stock dynamics

NN	Country	Forest area 1000 ha				Carbon stock in living forest biomass				
						mln tons				t/ha
		1990	2000	2005	2010	1990	2000	2005	2010	2010
1	Albania	789	769	782	776	49	49	48	49	63.1
2	Armenia	347	304	283	262	17	15	14	13	49.6
3	Azerbaijan	936	936	936	936	54	54	54	54	57.7
4	Belarus	7,780	8,273	8,436	8,630	386	482	540	611	70.8
5	Bosnia & Herzegovina	2,210	2,185	2,185	2,185	96	118	118	118	54.0
6	Bulgaria	3,327	3,375	3,651	3,927	127	161	182	202	51.4
7	Croatia	1,850	1,885	1,903	1,920	190	221	237	253	131.8
8	Czech Republic	2,629	2,637	2,647	2,657	287	322	339	356	134.0
9	Estonia	2,090	2,243	2,252	2,217	168	168	167	165	74.4
10	Georgia	2,779	2,768	2,755	2,742	192	203	207	212	77.3
11	Hungary	1,801	1,907	1,983	2,029	117	130	136	142	70.0
12	Kazakhstan	3,422	3,365	3,337	3,309	137	137	137	137	41.4
13	Kosovo, Republic of									
14	Kyrgyz Republic	836	858	869	954	27	34	37	56	58.7
15	Latvia	3,173	3,241	3,297	3,354	193	234	244	272	81.1
16	Lithuania	1,945	2,020	2,121	2,160	134	146	151	153	70.8
17	Macedonia, FYR	912	958	975	998	60	62	60	60	60.1
18	Moldova	319	324	363	386	22	26	28	29	75.1
19	Montenegro	543	543	543	543	33	33	33	33	60.8
20	Poland	8,881	9,059	9,200	9,337	691	807	887	968	103.7
21	Romania	6,371	6,366	6,391	6,573	600	599	601	618	94.0
22	Russian Federation	814,300	821,800	833,700	845,600	34,900	36,055	36,602	37,500	44.3
23	Serbia	2,313	2,460	2,476	2,713	122	138	147	240	88.5
24	Slovak Republic	1,922	1,921	1,932	1,933	163	190	202	211	109.2
25	Slovenia	1,188	1,233	1,243	1,253	116	141	159	178	142.1
26	Tajikistan	408	410	410	410	3	3	3	3	7.3
27	Turkey	9,680	10,146	10,740	11,334	686	743	782	822	72.5
28	Turkmenistan	4,127	4,127	4,127	4,127	11	11	12	12	2.9
29	Ukraine	9,274	9,510	9,575	9,705	499	662	712	761	78.4
30	Uzbekistan	3,045	3,212	3,295	3,276	8	14	18	19	5.8
	Total	**899,197**	**908,835**	**922,407**	**936,246**	**40,088**	**41,958**	**42,857**	**44,247**	**47.3**

Sources: State of Europe's Forests 2011; FRA, 2010; Author’s estimation for Russia

Table 19. Forest harvest dynamics

NN	Region	Industrial roundwood, 1000 m3			Woodfuel, 1000 m3		
		1990	2000	2005	1990	2000	2005
1	Albania	244	43	27	561	167	164
2	Armenia	9	8	11	79	66	76
3	Azerbaijan	31	31	4	31	31	4
4	Belarus	5,479	4,876	6,571	822	951	1,074
5	Bosnia & Herzegovina	3,791	3,259	3,006	982	1,067	1,337
6	Bulgaria	2,457	2,799	3,772	943	979	1,938
7	Croatia	2,646	2,646	3,077	961	961	1,181
8	Czech Republic	11,874	14,836	16,786	1,156	1,023	1,487
9	Estonia	8,975	8,975	4,565	2,194	2,194	1,590
10	Georgia	103	91	111	248	299	666
11	Hungary	4,129	3,860	3,452	2,615	2,322	2,943
12	Kazakhstan	2,024	189	535	577	483	231
13	Kosovo, Republic of						
14	Kyrgyz Republic	7	13	9	32	32	16
15	Latvia	2,781	12,288	13,129	2,165	2,194	3,230
16	Lithuania	2,779	4,665	5,446	872	1,506	1,452
17	Macedonia, FYR	129	129	132	520	520	480
18	Moldova	43	38	41	270	277	299
19	Montenegro	221	221	221	305	305	305
20	Poland	22,783	29,598	35,572	4,338	3,382	4,635
21	Romania	14,917	12,919	14,293	1,883	1,509	1,464
22	Russian Federation	268,396	104,546	134,870	68,131	47,770	50,905
23	Serbia	1,149	946	1,002	1,761	1,189	1,306
24	Slovak Republic	5,073	5,819	8,260	472	331	406
25	Slovenia	2,701	2,058	2,368	277	489	868
26	Tajikistan	0	0	0	6	7	7
27	Turkey	9,946	11,514	11,905	15,680	11,116	9,722
28	Turkmenistan	0	0	0	10	10	10
29	Ukraine	8,577	7,814	11,387	5,013	4,417	5,290
30	Uzbekistan	3	5	9	46	24	21
	Total	**381,267**	**234,186**	**280,561**	**112,950**	**85,621**	**93,107**

Source: FRA, 2010. Red numbers missed in source and added from the next reported period to keep consistency.