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Expected Climate Change and Options for European Silviculture

COUNTRY REPORT

BELGIUM

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[1] See Annex 1

Preambule: short description of the Belgian forests

Belgium has a temperate maritime climate, characterized by a limited temperature range, abundant and regular rainfall, and prevailing westerly winds. Altitude ranges from *ca* 0m along the coast up to 700 m in the Ardennes. Belgium belongs to two biogeographical regions: Atlantic and Continental (European Environment Agency, 2009).
Belgian forest covered *ca* 693 181 ha in 2000, corresponding to 22.7% of the total area (Vande Walle *et al*., 2005). As indicated in Table 1, the distribution of the forest cover between the three regions of the country is quite uneven.

Table 1. Distribution of the forests over the three Belgian regions[#]

Region	Total area (km^2)	Forest area (km^2)	Forest cover (%)	% of the total Belgian forest area
Brussels Capital	162	20	12.3	0.3
Flanders	13 521	1 463	10.8	21.1
Wallonia	16 845	5 448	32.3	78.6
Belgium	30 528	6 931	22.7	100.0

[#] From Vande Walle *et al*., 2005

On an area basis, the part of private ownership is about 70% and 50% (*ca* 100 000 owners for a total of 100 000 and 250 000 ha, respectively), in Flanders and Wallonia, respectively. In Flanders and Wallonia, the two main public owners are the towns (*ca* 36% and 74%, respectively) and the Region (*ca* 33% and 22%, respectively).

Forest inventories are carried out according to a similar sampling strategy in both Flanders (Waterinckx and Roelandt, 2001) and Wallonia (Rondeux *et al*., 1996). The relative importance of selected tree species in terms of area is given in Table 2 for the year 2000 (Vande Walle *et al*., 2005).

Table 2. Areas (ha) occupied by selected tree species, for the year 2000[#]

Coniferous			Deciduous		
Species	Flanders	Wallonia	Species	Flanders	Wallonia
Douglas-fir	1 280	10 800	Beech	7 790	42 200
Larch	3 060	8 200	Mixed noble	10 250	57 100
Pine	63 550	14 800	Oak	14 320	81 600
Spruce	2 860	171 700	Poplar	19 060	9 500
Other	910	19 600	Other	21 650	43 200
Total					

[#] From Vande Walle *et al*., 2005

Following the regionalization of the country, the forest policies are now defined at a regional level.
In Wallonia, forest management in public ownerships is carried out by the 'Département de la Nature et des Forêts, DNF', within the General Directorate DGO3 'Direction générale

opérationnelle de l'Agriculture, des Ressources naturelles et de l'Environnement'. From a political point of view, this matter is attached to the Walloon Ministry of Public works, Agriculture, Rural affairs, Nature, Forests and Patrimony. In its first article, the recent forest code (15 July 2008) insists on the multifunctional role of forests, saying that: 'Woods and forests are a natural, economic, social, cultural, and landscape patrimony. It is advisable to ensure their sustainable development by ensuring the harmonious coexistence of their economic, ecological, and social functions'.

In Flanders, forest management in public ownerships is carried out by the 'Agentschap voor Natuur en Bos, ANB' within the Department Leefmilieu, Natuur en Energie of the Flemish Administration. The matter is attached to the Flemish Ministry of the Environment, Nature and Culture. Already in 1990, the forest code (13 June 1990) stressed the economic, social, environmental, ecological and scientific role of forests.

The policies aimed at reducing the greenhouse gas emissions (GHGE) are elaborated at various power levels, depending on the sharing of competences between the Federal State and the Regions (Flanders, Wallonia, Brussels). In this context, the Belgian National Climate Commission (NCC) has been created to harmonize the policies across the various power levels of the country, and to create synergies between them.

1. Impacts

1.1. Observed impacts

1.1.1. Observed climatic evolution

A substantial increase in air temperature was recorded in Belgium in the 20th century. The 30-year moving average of air temperature recorded in Brussels presented two abrupt increases of about 0.5-1°C: the first during the first half of the 20th century and the second from the 1980's onwards (NCC, 2006). The average annual temperature for the period 2000-2004 (11.0°C) was 12% larger than for the period 1961-1990 (9.8°C) (NCC, 2006). The frequency of extreme temperatures also increased, *e.g.* the 11 warmest years between 1833 and 2004 all occurred since 1989 (NCC, 2006).

Observed changes for the other meteorological variables were minor. The annual average precipitation for the period 2000-2004 (812 mm) did not differ remarkably from that of the period 1961-1990 (780 mm; NCC, 2006), whereas the hours of sunshine per year for the period 2000-2004 and the period 1961-1990 were very similar (about 1555-1570 h; NCC, 2006).

1.1.2. Impacts on ecosystem dynamics and functioning

1.1.2.1. Vegetation phenology

According to monitoring data from Northern Belgium, there are indications that the growing season is starting earlier. As a result of warmer springs, for instance, the detection of birch pollen in the atmosphere shifted by 23 days earlier from 1982 to 2000 in Brussels (Emberlin *et al*., 2002). Leaf phenology of beech and pedunculate oak is followed in details since 2002 in two plots in Northern Belgium; although a relationship between budburst and temperature emerged for oak, the series is too short to derive any strong conclusion about climate change effects on this dynamics (De Bruyn *et al*., 2007).

1.1.2.2. Forest vitality and growth

At present, information about the effects of global change on tree growth trends in Belgium is still lacking. Increment data from the regional forest inventories (Wallonia, Flanders) are being available for a subsample of the plots, which will allow to make some data analysis in a near future.

The forest vitality in Belgium is monitored since 1987 (Flanders) and 1989 (Wallonia) as the proportion of trees presenting defoliation larger than 25%, according to the UNECE ICP Forests guidelines.

In Northern Belgium, 72 plots are currently monitored (Sioen *et al*., 2009). The proportion of damaged trees was relatively low till 1993 (8-17%), peaked in 1995 (33%), was stable from 1997 till 2006 (19-21%) except a smaller peak in 2000 (25%), and further decreased in 2007-2008 (14-17%) (Sioen *et al*., 2009).

In Southern Belgium, the 2008 survey concerned 1129 trees on 49 plots, on the regional 8x8 km systematic grid. At the beginning of the nineties, the proportion of damaged coniferous trees was about twice as high as that of the broadleaved; in 2005, it decreased down to *ca* 15%. The proportion of damaged broadleaved trees increased from about 10% in the 90' up to 20% in 2005. This increase was mainly explained by the status of beech trees (40% of observed broadleaved trees) which were first affected by attacks of xylophagan bark beetles following a climatic stress in the winter 1998 (see below), and then impacted by a drought episode in 2003 and a massive fructification in 2004 (Laurent and Lecomte, 2007).

Forest vitality is greatly affected by environmental conditions. The poor soil conditions of Belgian forests, due to the intrinsic soil poverty (Lambert *et al.*, 1990) as well as to the severe soil acidification that occurred in the last half century (De Schrijver *et al.*, 2006), have an overall negative effect on tree vitality. Variability of tree vitality is also largely due to disturbances/extreme events (drought, pests…), soil water balance and inappropriate silvicultural practices. They will be discussed below.

1.1.2.3. Water cycle

Different aspects of the water balance have been investigated for Belgian forests in various studies (e.g. Misson *et al.*, 2002; Meiresonne *et al.*, 2003; Verstraeten *et al.* 2005; Vincke *et al.*, 2005a; Vincke and Delvaux, 2005; Vincke *et al.*, 2005b; Nadezhdina *et al.* 2007; Vincke and Thiry, 2008). Verstraeten *et al.* (2005) reported seasonal and annual values of evapotranspiration (ET), rainfall, transpiration (T), soil evaporation (E) and canopy interception evaporation (INT) for 14 stands in Northern Belgium between 1971-2000 (modeled data) and 2000-2001 (experimental data). They found an average ratio of actual *vs.* potential ET of 78-99%, T of 315 mm y^{-1}, E of 47 mm y^{-1} and INT of 126 mm y^{-1}, with larger water use for poplar than for pine stands. In Southern Belgium, the role of soil water constraints in the decline of pedunculate oak has been highlighted, but no direct link with climate change could be ascertained. Despite many investigations, analyses about the effect of climate change on water balance in Belgian forest ecosystems are still lacking.

1.1.2.4. Carbon cycle

Belgian forests present different C balances. Between 1997 and 2001, a typical mixed beech – Douglas fir stand was a C sink (390-790 g C m^{-2} y^{-1}) and was mostly affected by radiation and air humidity (Aubinet *et al.*, 2002). For the same period, a typical Scots pine – pedunculate oak stand was largely a C source (average of 111 g C m^{-2} y^{-1}) and most affected by temperature and management (Carrara *et al.*, 2003). However, there is evidence that C stocks in forest biomass and forest soil are increasing in the last decades. In Belgium, forest biomass increased from 8400 to 10100 g C m^{-2} between 1990-2000 (Vande Walle, 2007), whereas soil organic matter increased from 6400 to 9100 g C m^{-2} between 1960-2000 (Lettens *et al.*, 2005).

Despite information about C balance and the rich datasets collected about the different component of the forest C cycle (Aubinet *et al.*, 2002; Janssens *et al.*, 2002; Carrara *et al.*, 2003; Curiel Yuste *et al.*, 2005a; Curiel Yuste *et al.*, 2005b; Sampson *et al.*, 2006, Vande Walle, 2007), no clear relationships between C dynamics and climate change can be drawn because C cycle assessment started recently (late 90s) and lacked regularity. Datasets about long-term differences in forest C stocks exist (e.g. soil C stocks variation between 1960 till 2000; Lettens *et al.*, 2005). However, effect of forest aging (many forests were planted after World War II) and management practices (Lettens *et al.*, 2005) hinder the elucidation of climate change impacts on C sequestration dynamics.

1.1.2.5. Nitrogen cycle

At the global scale, N is the nutrient which commonly limits tree growth due to climate-induced limitations on N mineralization. In Belgium, the relationships between the variability of the N cycle and climate change are difficult to identify because of the overwhelming effect of air pollution (Weissen *et al.*, 1990). For example, atmospheric N deposition in Northern Belgium increased from 1950 onwards reaching values among the highest in Europe (35-45 kg N ha^{-1} y^{-1}; Neirynck *et al.*, 2004) and substantially started to decline only after 2000 (Neirynck *et al.*, 2008). The situation appears somewhat different in Wallonia, where total N deposition on forest ecosystems (*ca* 24 kg ha^{-1} y^{-1}) appears to be stable since the 90' (Blin and Brahy, 2007). Overall, many Belgian forests are supposed to be N saturated.

A long-term monitoring (1992-2007) on a representative pine forest revealed that the atmospheric input far exceeds the N requirement of the forest and that large N losses occur through nitrate leaching and NO_x emissions (Neirynck *et al*., 2008). Nevertheless, the forest is not at steady state and still accumulates about 50% of the total N deposition, especially in the forest floor. Recent trends in emission reduction resulted in reduced nitrate leaching from forest soils, but did not change NO_x losses or biomass N content (Neirynck *et al*., 2008).

1.1.2.6. Biodiversity

Most of the changes in forest biodiversity that occurred in the last decades in Northern Belgium were induced by deposition of sulphur and nitrogenous compounds. In fact, understory plant species typical of acid soils and nutrient-rich habitats increased, whereas neutrophilous/basidophilous species and species from poor-nutrients habitats declined (Lameire *et al*., 2000; Van der Veken *et al*., 2004; Hermy *et al*., 2008). Changes of hydrology are also of importance, as losses of wet habitat species have been associated with a lowering of the water table (Lameire *et al*., 2000; Hermy *et al*., 2008). Biodiversity in forest birds increased, whereas that of mammals was stable (Dumortier *et al*., 2005; Hermy *et al*. 2008). However, changes in birds and mammals population are mostly due to management practices and habitat changes, rather than climate change, although exceptions do exist as *e.g.* the reduction in the pied flycatcher (Dumortier *et al*., 2005; Hermy, 2008).

1.1.3. Disturbances and extreme events

There were several disturbances and extreme events in Belgium, in particular in the Southern part, during the last thirty years: severe droughts in 1976 and 2003 (coupled with a heat wave), windstorms in 1990, pest attacks on beech between 1999 and 2001 (*Trypodendron* sp.). But so far no direct link with climate change was proven, even though some global climate change projections predict an increase in the frequency and intensity of climate hazards (Bréda and Badeau, 2008).

1.1.3.1. Drought

Drought was found to have some significant effects on tree vitality and growth (*e.g.* enhanced leaf and fine root mortality) and C cycle (*e.g.* reduced soil respiration) of Belgian forests, but such effects did not substantially affected forest dynamics, except in some specific decline and dieback, such as that of oak. In most cases, the effect of drought can not be easily isolated, especially for stands that were weakened by silviculture and/or unfavourable site conditions. Yet, when drought intensity and duration renders this stress critical (extreme events), direct and after-effects during the recovery phase are commonly observed. Measurements from the hot and dry summer 2003 performed at an extensively investigated pine-oak mixed forest (Janssens *et al*., 2002; Carrara *et al*., 2003; Curiel Yuste *et al*., 2005a; Curiel Yuste *et al*., 2005b; Konôpka *et al*., 2005; Sampson *et al*., 2006) can be used as case study. In 2003, annual temperature (11.7°C) and precipitation (686 mm) at the site were well above and below, respectively, than the long-term means (9.8 °C and 750 mm). Similarly, the temperature of July-August 2003 was about 10-20% higher than summer temperature for previous years, whereas precipitation was about 35-50% lower. In 2003, periods with soil water content (SWC) below the water holding capacity were observed from mid June till early October. A particularly severe water stress was recorded between late July and late August, with SWC occasionally close to the wilting point and relative extractable water often below 0.2. Such drought event was the most relevant occurring in the last decade. In fact, the site conditions (*i.e.* precipitation well distributed along the year and sandy soil with a clay layer at 1.5-2 m depth) normally secure moist conditions with trees rarely suffering of water limitation. The important drought of 2003 did not have a large effect on wood growth in that case. The width of the 2003 ring was slightly lower than the width of the 2002 ring for both pine and oak (5-15%), but very similar to the average annual width for the last 10 years (3-4% difference, Vansteenkiste unpublished). The absence of large effect of drought on growth was confirmed by preliminary simulations of photosynthesis which showed for both pine and oak no reduction in gross primary production between 2003 and the previous wetter years 2001 and 2002. On the other hand, drought affected mortality of leaves and fine roots: in the period between late July and late August reduction in LAI was observed for both species (about 10-20%), whereas fine root mortality far exceeded fine root production (Konôpka *et al*., 2005). Although significant, such effects were however relatively small with no major effect at the stand level, confirmed by the growth and assimilation estimations reported above.

Similarly, the forest vitality assessment performed annually at the regional level in the framework of the plot level I assessment revealed that during the dry summer of 2003 none of the most common species presented abnormal level of tree defoliation (Sioen and Roskams, 2004). Finally, simulations for oak revealed that the C balance in 2003 did not change substantially compared to the previous wetter years because the amount of C taken up did not change (see above) and because an increase in autotrophic respiration was counterbalanced by a reduction in heterotrophic respiration (Curiel Yuste *et al*., 2005b; Konôpka *et al*. 2005). No evident post-drought effects were observed in the subsequent years, both at stand and regional levels. The recorded increase in defoliation in 2004 for beech is supposed to be dependent on the mast reproduction (2004 was a mast-year for beech) rather than resulting from drought damage (Sioen *et al*., 2009).

In Southern Belgium, transpiration was analyzed in pure and mixed stands of oak (*Quercus petraea* LIEBL.) and beech (*Fagus sylvatica* L.) at the tree and stand levels in 2003 (Jonard *et al*., submitted). Mean annual rainfall is about 1044 mm with 411 mm falling between May and September and mean annual temperature is around 8°C. However, in 2003, rainfall was 836 mm and mean annual temperature was 9.8 °C. The pure beech stand experienced some drought stress with relative extractable water reaching 0.2, inducing some stomatal regulation. Besides those direct effects, no persistent after-effects have been observed so far.

The Vielsalm site of the Carboeurope network (which is a mixed stand of beech, Douglas fir, Abies and spruce), was submitted to a moderate drought intensity in 2003, that did not reduce stomatal conductance to a large extent. At Vielsalm, water stress lasted for only 1-2 months. The effect on the total ecosystem respiration (TER) variation was not significant, as for the effect on gross primary production (GPP) variation (Granier *et al*., 2007). The water use efficiency (average GPP versus evapotranspiration) was reduced from 6 to 4 gC $kg^{-1}H_2O$ (Reichstein *et al*., 2007). In some sites of Southern Belgium, post-drought effects were observed in the crown conditions of the subsequent years. In the European beech and Norway spruce plots of forest monitoring (level II) located in the Ardennes, a marked increase in defoliation was observed after 2003 (on average 5% per year). European beech trees were already recovering a better crown condition in 2006 while Norway spruce trees were still deteriorating in 2008.

1.1.3.2. Pests

A rich dataset about the impact of pests on tree vitality has been recorded in Northern Belgium since 1995, in the framework of the ICP Forests plot level I assessment (www.inbo.be); a similar pest observation network will soon be set up in Wallonia. There are some indications that (i) the numbers of tree attacked by insects species thriving at warmer temperature (*e.g* the oak processionary caterpillar and the oak splendour beetle) increased since the beginning of the inventory (Dumortier *et al*., 2005) and that (ii) pests are less active during dry summer (Sioen and Roskams, 2004). Furthermore, studies on beech forests in Southern Belgium revealed that pests booming can be favoured by early and severe frost events of particularly harsh winter (Henin *et al*., 2003). Indeed, the most probable cause of the beech decline observed in 1999-2000, that concerned about 19% of the beech standing volume, was the mild winter of 1998 followed by late frosts which favoured attacks of xylophagan bark beetles (*Trypodendron* sp.; Nageleisen and Huart, 2005). A master thesis is currently studying the impact of a period of drought followed by early frost on the susceptibility of beech to be attacked by bark beetles (S. La Spina, Université Libre de Bruxelles - ULB). However, detailed analyses of the relationship between pest damage and climate change are still lacking.

1.1.3.3. Windstorms

The windstorms in 1990 concerned about 11 million m^3 in Wallonia, mainly in spruce stands, followed by 500.000 m^3 lost due to attacks by *Ips typographus* in 1991-92. So far however, no direct link with climate change could be established.

1.2. Expected impacts

1.2.1. Expected Climatic evolution

Most of the projections of climate change impact on Belgian forests in the 21st century have been performed using the climate scenario described in Rasse *et al.*, (2001), Vande Walle and Lemeur, (2001), Misson *et al*., (2002) and Van Cleemput *et al*., (2006). Site-specific meteorological datasets were constructed at a half-hourly basis for the 21st century from (i) 2-4 years of measured meteorological variables and (ii) outputs of the general circulation model CGCM1 (McFarlane et *al*., 1992; Flato et *al*., 2000). The atmospheric CO_2 concentration was assumed to increase exponentially between 355 ppm in 1990 and 700 ppm in 2100, following the IS92a (“business as usual”) IPCC scenario. According to CGCM1, temperature appears to be the only climatic variable that will be substantially modified in the course of the 21st century in Belgium, with a predicted temperature increase of about 3°C (Van Cleemput *et al.*, 2006). However other projections foreseen that winter precipitations should be increasing by 6 to 23% by the end of this century and summer precipitations could decrease by 50% in some regions (van Ypersele and Marbaix, 2004) or, following the SRES A1B scenario for climate change, that summer precipitations in Southern Belgium would decrease by 15% in average (calculations based upon climatic data from www.meteo.be). All these projections must be interpreted with caution, being highly scenario-dependent as well as affected by the inherent uncertainties resulting from modelling the climate at the regional rather than at the global scale.

1.2.2. Impacts on ecosystem dynamics and functioning

1.2.2.1. Phenology

Manipulative experiments revealed that the phenology of coniferous species might be significantly modified with an increase in air CO_2 concentration. Saplings of Scots pine growing in Northern Belgium at elevated CO_2 concentration showed in comparison with ambient saplings an increased growth in early season and decreased growth later on. This was evident both for leaves, with hastened budburst (6-9 days) and earlier needle fall, and for stemwood, with relatively higher growth rate in spring and lower in the summer (Jach and Ceulemans, 1999).

1.2.2.2. Biodiversity

No specific info for Belgium till now.

1.2.2.3. Forest vitality and growth

Future projections of C assimilation and biomass production have been performed in Belgium for pine and beech forests (Rasse *et al*., 2001; Vande Walle and Lemeur, 2001; Van Cleemput et *al*., 2006). In the 21st century the gross primary production (GPP) is predicted to substantially increase (about 40%), mostly because of the increase in atmospheric CO_2 concentration. As a consequence of the increased assimilation, net biomass production (NPP) is also expected to increase. However, its increment would be less pronounced (15-30%) because of the increased respiration due to higher temperature and larger standing biomass. Such modeling results are supported by experiments on pine saplings subjected to elevated CO_2 concentration. Despite the larger belowground respiration and changes in C allocation pattern, saplings subjected to three years of CO_2 treatment in Belgium showed in fact a strong increase in biomass (Janssens *et al*., 1998; Jach and Ceulemans, 2000).

Management appears to have significant effect on forest growth. Simulations performed for a Scots pine stand assumed to be planted in 2000, thinned intensively in the juvenile phase and at about 50 years (Rasse *et al*., 2001) revealed that GPP will be substantially larger (30%) than for a similar stand growing in the 20th century conditions; however, the difference in NPP will be substantially larger up to the thinning at 50 years but less marked afterwards because of the changes in photosynthetic capacity and respiration (Rasse *et al*., 2001).

As far as forest vitality (or decline) is concerned, it is highly probable that some persistent after-effects of hot and/or dry summers generate some damages to forest ecosystems, in particular those with less resistant species and/or those which suffered from insect damages as well (defoliation is known to induce significant decrease in growth during the subsequent years). Pedunculate oak, European beech and Norway spruce are among the species most concerned in Belgium (see 1.1.3.1).

1.2.2.4. Carbon cycle

As a result of increased NPP (see above), models generally predict for Belgian forest an increase in C accumulation (10-25%) in the 21st century (Vande Walle and Lemeur, 2001). However, some exceptions do exist with slightly projected increases in C release (4%; Van Cleemput *et al*., 2006). Differences in model simulations are likely due to differences in the simulation of soil respiration which is an important process in the forest C balance but difficult to model accurately (Verbeeck *et al*., 2006).

Coniferous forests growing under the 21st century climatic conditions are expected to accumulate more C than at the current climatic conditions if thinned in the juvenile phase (< 20 years). On the other hand, C accumulation is substantially reduced for those forests that are thinned at mature age (50 years; Rasse *et al*. 2001).

1.2.2.5. Water cycle

Misson *et al*. (2002) predicted that the combined effect of increase in air temperature and atmospheric CO_2 concentration over the next century would not result in major changes in the transpiration of two typical deciduous forests in Southern Belgium (common beech and pedunculate oak) with no change in water stress. This is because the increased transpiration rate due to increasing evaporative demand will be compensated for by reductions in stomatal conductance due to increasing CO_2 concentration and temperature. Similarly, in a recent study, Gielen *et al*. (unpublished) have predicted no increase in drought stress for a pine stand in Northern Belgium by the end of the next century. Still, aside from gradual climate change, the effect of extreme events such as heat waves and drought could affect forest ecosystems (see below).

Leaf area index and soil extractable water, both species and site specific variables, have a strong impact on forest eco-hydrology. As forest management is urged to adopt new management techniques in order to mitigate the impacts of climate change on forests, leaf area indices might be quite different than the actual ones, which could in turn have a strong impact on water partitioning.

1.2.2.6. Nitrogen cycle

Simulations performed for a Belgian beech forest with a relatively moderate atmospheric N input (28 kg N ha^{-1} y^{-1}; in Belgium atmospheric N deposition are up to about 45 kg N ha^{-1} y^{-1} - see 1.1.2.5) showed for the 21st century a slight reduction in NPP (3%) and C accumulation (6%) in case of a 25% reduction in N deposition and more pronounced reductions (13% in NPP and 24% in C accumulation) in case of 50% reduction in N deposition (Vande Walle and Lemeur, 2001). Therefore, growth and C sequestration potential of Belgian forests with low-moderate N deposition might be reduced because of N shortage in case atmospheric N depositions will be substantially reduced in future.

1.2.3. Disturbances and extreme events

1.2.3.1. Drought

As mentioned above, drought stress is not expected to increase in Belgian forests which will likely continue to experience only low water shortage in summer. It should be noted that in the scenarios used in the existing simulation studies the variability and frequency of extreme events were not considered (Misson *et al.*, 2002). A substantial increase in extreme drought events might change the current forest dynamics and increase their vulnerability to water shortage.

A research promoted by Prof. J-C. Grégoire (ULB) is currently studying the impact of a period of drought followed by early frost on the susceptibility of beech to be attacked by bark beetles. The drought experiment (coordinated by Prof. Ch. De Cannière, ULB, and Prof. C. Vincke, Université catholique de Louvain - UCL) is in progress. No results are available yet.

1.2.3.2. Insect

There is no specific information for Belgium till now. Battisti *et al*. (2005), report a recent latitudinal and altitudinal expansion of the pine processionary moth, *Thaumetopoea pityocampa*, whose larvae build silk nests and feed on pine foliage in the winter. In north-central France (Paris Basin), its range boundary has shifted by 87 km northwards between 1972 and 2004. Given that the present distribution of the oligophagous *T. pityocampa* is not constrained by the distribution of its actual or potential hosts, and that warmer winters will cause the number of hours of feeding to increase and the probability of the lower lethal temperature to decrease, these authors expect the trend of improved survival in previously prohibitive environments to continue, causing further latitudinal and altitudinal expansion in other regions. One of the expected consequences of phytophagous insect attacks is massive defoliation, which among others, results in an immediate reduction in latewood, a significant decrease in radial growth in the subsequent year and eventually mortality. This kind of stress can increase the susceptibility of forest stands to drought disturbance (Bréda and Badeau, 2008).

1.3.Impact monitoring

1.3.1. Usual monitoring system/network

No special monitoring networks have been established to monitor the impact of climate change on forests in Belgium. On the other hand, trends in ecosystem dynamics and

functioning or disturbances might be derived from the datasets collected in the framework of the ICP Forests plot level I and level II assessments.
In Northern Belgium, Plot level I assessment started in 1987. The grid is denser than the European guidelines (16 × 16 km): it was 8 × 8 km between 1987 and 1994 and 4 × 4 km from 1995 onwards, for a total of 72 plots. Crown conditions are followed as well as the causes of damage (discoloration, insect, fungi, masting, crown mortality, outflow of resin or slime, exploitation) (Verstraeten *et al*., 2007). Plot level II assessment is running in Northern Belgium since 1989 in 11 plots. Foliar nutrient status, increment, meteorological condition, ground vegetation, deposition of air pollution, soil and soil solution chemistry are measured in 5 plots (two coniferous stands and three broadleaved stands), whereas concentration of air pollutants is measured in one coniferous stand (Verstraeten *et al*., 2007). In addition, the phenology of beech and pedunculate oak is followed in detail since 2002 in two plots. Flowering, leaf development, leaf coloring and leaf fall are followed weekly for the same trees and forest plots each year (Verstraeten *et al*., 2007). Leaf phenology represents one (but still in test phase) of the two main indicators that are used to study the impact of climate change on forests in Northern Belgium. The other indicator is the start date for record of birch pollen in air (data available from 1974; see 1.1.2.1) (De Bruyn *et al*., 2007).
In Southern Belgium, crown condition is observed in 49 level I plots since 1989 (grid: 8 × 8 km). Plot level II assessment is running in Southern Belgium since 1995 in 8 plots. Crown condition, foliar nutrient status, litterfall, increment, ground vegetation, soil chemical properties are monitored in all plots, whereas deposition of air pollution and meteorological conditions are measured in four plots and soil solution chemistry in two plots.

In both regions, forest inventories are being carried out on a 1000m * 500m grid (Rondeux *et al*., 1996; Waterinckx and Roelandt, 2001). In addition to tree and stand attributes, ecological variables related to soil and plant communities are also available for parts of the plots. The whole inventory cycle extends over a 10 year-period, that is one tenth of the total sample is inventoried each year; this allows, among other things, calculation of tree increment and stand productivity. In Wallonia, a study is currently carried out to determine the best way data or plots from both level I and forest inventory networks could be combined to increase the monitoring efficiency, and resulting interpretation.

The CarboEurope-IP network (Brasschaat and Vielsalm sites) has been providing data for the last 10 years. Those data are very useful information as they consist in CO_2, water vapour and energy fluxes monitoring, coupled with biological and physiological information upon the concerned forests.

1.3.2. Specific monitoring system/network

There is presently no specific monitoring system dedicated to climate change. In a near future, however, a Forest Health Monitoring will be launched in Southern Belgium, in order to monitor biotic and abiotic disturbances/extreme events occurrence.

1.4.Impact management

In the governmental Statement of July 2009, the new Regional government (Wallonia) committed itself to give the forest administration the responsibility of monitoring forest health, as well as of developing strategies to fight against crises resulting from large scale diseases or windthrow (http://gov.wallonie.be/IMG/pdf/projet_de_declaration_de_politique_regionale_wallonne.pdf).

2. **Adaptation**

Following a demand from the Walloon Ministry of Public works, Agriculture, Rural affairs, Nature, Forests and Patrimony, a group of experts was constituted in July 2007 with the aim to make a state of the art about the impacts of climate change on forests, as well as to propose relevant measures related to both adaptation and mitigation. This resulted in a report entitled 'Climate change and its impacts on the Walloon forests. Recommendations to decision-makers, and to forest owners and managers', dated January 2009 (Laurent and Perrin, 2009). In the governmental Statement of July 2009, the new Regional government (Wallonia) committed itself to execute the recommendations of this report (http://gov.wallonie.be/IMG/pdf/projet_de_declaration_de_politique_regionale_wallonne.pdf). The content of this section mostly originates from the abovementioned document.

2.1. Vulnerability of forests and forestry

It is quite difficult to assess the vulnerability of both forests and forestry because the impacts of climate change are affected by uncertainties (e.g. in defining the effective trends and extremes of climate change and the interactions between positive and negative feedbacks), because of the difficulties to assess the stability (resistance and resilience) of forest ecosystems and to evaluate the effectiveness of management practices. Climate change represents both a threat and an opportunity for the sector. In Wallonia, a preliminary ranking of some major commercial tree species (*Fagus sylvatica* L., *Quercus petraea* Liebl., *Quercus robur* L., *Picea abies* Karst., *Pseudotsuga menziesii* Franco, *Pinus sylvestris* L. / *Pinus nigra* Arn.) according to their sensitivity to selected climate change- induced conditions (heat wave, air dryness, windstorm, pests, soil water regime), has been proposed. The overall results suggest a high and very high sensitivity of *Fagus sylvatica* (*ca* 14% of the forested area in Wallonia) and *Picea abies* (*ca* 36% of the forested area in Wallonia), respectively. Whereas some expected change (*e.g.* increase in mean air temperature, in CO_2 concentrations and in the length of vegetation period) would result in contrasting effects on productivity and vitality, depending on the site, most would negatively impact the forests. On the opportunity side, climate change leads to a renewed interest in forests and wood products because of their potential role in mitigating the effects. Much of this mitigation, however, will depend on how and to what extent forest ecosystems will be impacted by climate change (see 1.1 and 1.2).

2.2. General adaptation strategy or policy

As explained in details in Section 3.1, 11 strategic axes have been defined in the frame of the National Climate Plan (NCP, 2008) to fight climate change and fulfil the requirement of the Kyoto Protocol.
Among these, one (axis 5) is specifically directed towards forests, as it contains measures aimed at increasing or maintaining the carbon sink effectiveness of forest ecosystems, as well as at adapting them to climate change; three others will have indirect effects on forests. All these are further discussed in section 3.1.

2.3. Forest adaptation measures

Given the limited size of the region, as well as the numerous uncertainties associated with climate change effects, most adaptation measures listed below are however neither species, stand, nor site specific. As research progresses, this is however likely to change.

Four main recommendations have been proposed by the above mentioned working group (Laurent and Perrin, 2009): (1) to maintain and improve the adaptability of ecosystems to climate change; (2) to reduce any foreseeable risks at both tree and ecosystem levels, and (3) to forecast the risks and manage the crises.

(1) To improve adaptability, it is proposed to increase species biodiversity at all levels, as well as diversity of habitats and structures at various scales. This will be achieved by: (i) using a wider range of tree species and provenances, in particular those supposed to be more robust to climate change, either indigenous or exotic, in pure and mixed species stands; (ii) implementing more complex structures, including old growth stages; taking special consideration to the management of edges, and (iii) using natural regeneration whenever feasible and appropriate.

(2) With regards the reduction of additional stress at the tree level, the following measures are advocated: (i) to ensure species suitability for the site conditions; (ii) to adapt the silvicultural systems and the treatments to the target species; (iii) to maintain or improve the physical soil properties through efficient harvesting methods; (iv) to limit the browsing and game pressure. At the ecosystem level, the stability will be improved by optimizing the use efficiency of resources (nutrient, water). For water, it will be necessary to reduce water consumption through the selection of appropriate tree species and through density management, as well as to promote soil and water table recharge. For nutrients, special attention will be given to the functioning of nutrient cycles while controlling both external inputs as well as nutrient export through harvesting.
Another suggestion is to decrease rotation length to reduce the risk of exposure, while decreasing the costs. Finally, identification of susceptible stands, like those located in unsuitable sites, as well as their transformation into more resilient structures, will be given special consideration.

(3) As concerns risk management, it will be necessary to increase our present understanding of processes acting on both sites and communities, and to develop appropriate predictive tools. In order to improve predictability at various spatial and temporal scales, efforts will be made to adapt or develop functional-based models. A special effort will be given to the following: (i) biogeochemistry (nutrients, carbon, water) and energy fluxes; (ii) growth and sensitivity of trees and stands to various stress factors, acting either alone or in combination; (iii) site characterization and functioning.
The integrated monitoring of forests (health, pests, abiotic factors, …) will be reinforced to increase early detection of change, identify trends and patterns, and contribute to increased understanding.
Information to forest owners and managers will be improved, as their present choices are expected to have long-term impacts.
Finally, crisis plans will be established to face the expected increase in disturbance frequency associated with pests and/or windthrow.

The ‘translation’ of these recommendations into specific management measures depends on the corresponding specific zone of the ecological network (Branquart and Liégeois, 2005), which may be either multifunctional management zones, biodiversity development zones, or central conservation zones.

2.4.Research studies on forest adaptation

At the Federal state level, the programme ‘Science for a Sustainable Development’ (Section 3) gives funding opportunities to support research on forest adaptation. For instance, a project entitled ‘FORBIO – Effects of tree species diversity on forest ecosystem functioning’ (http://www.belspo.be/belspo/ssd/science/projects/FORBIO_EN.pdf) is currently running. In both regions, several research programmes deal with forest adaptation.
In Wallonia, the regional working group identified 4 key issues for research regarding climate change: biogeochemistry and heat fluxes; growth and sensitivity of trees and stands to constraints; improvement of risk assessment; modelling tools for ecosystem functioning. These will be partly addressed in the new 5-year forest research programme called ‘Accord-cadre de recherche et de vulgarisation forestières’ for the period 2009-2014.

3. **Mitigation**

3.1. Processes, instruments and strategies

In Belgium, the policies aimed at reducing the greenhouse gas emissions (GHGE) are elaborated at various power levels, depending on the sharing of competences between the Federal State and the Regions (Flanders, Wallonia, Brussels). Each power level determines its priorities concerning climatic and environmental policies. In this context, the Belgian National Climate Commission (NCC) has been created to harmonize the policies across the various power levels of the country, and to create synergies between them. In November 2002, the Federal State and the three Regions of the country have concluded an Agreement concerning the elaboration, the fulfilment, and the follow up of a National Climate Plan. This Plan synthesizes the whole set of measures that have already been elaborated at the various power levels, so as to comply with the obligations of the Kyoto Protocol.

The following four main objectives have been set up in the National Climate Plan (NCP, 2008): (i) to define the major strategic axes so as to fulfil the obligations of the Kyoto Protocol; (ii) to establish a coordinated monitoring system for the various policies and measures, based on both modelling and indicators collection; (iii) to elaborate a national strategy to adapt to climate change and (iv) to prepare a long-term strategy to fight against climate change.
Briefly, the following six strategic axes have been defined: (1) to optimize energy production; (2) to make a rational use of energy within the buildings; (3) to act on industrial processes; (4) to develop sustainable forms of transport; (5) to promote sustainable management of agricultural and forest ecosystems; (6) to increase efforts in waste management. Five additional strategic axes have been established across sectors: (7) to increase support to research related to climate change; (8) to heighten public awareness on the problem of climate change and how to fight against it; (9) to increase the involvement of public authorities in further reducing GHGE; (10) to carry out flexible mechanisms; (11) to introduce a climate component in all policies dedicated to development.

Strategic axis (5) contains measures aimed at increasing or maintaining the carbon sink effectiveness of forest ecosystems, as well as at adapting them to climate change.
Under Cluster AG-C ‘Maintaining the carbon sequestration potential of forests’, two objectives are further defined: (i) to limit deforestation and promote afforestation and (ii) to ensure ecologic stability of forests.
(i) Through its forest policy, the Flemish region intends to increase its permanent forested area, as well as to increase non-permanent afforestation in agricultural zones. In Wallonia, forest area is protected through various legislations. The Walloon law for land management, town planning, heritage, and energy (Code Wallon de l’Aménagement du Territoire, de l’Urbanisme, du Patrimoine et de l’Energie – CWATUPE) prohibits, among others, any permanent land use change within forested areas unless due revision of the land management plan. The new forest code (15 July 2008) introduced a series of constraints in order to protect biodiversity and wood stocking in both public and private forests.
(ii) The ecologic stability of forests is improved through certification schemes (FSC in Flanders and Brussels, PEFC in Wallonia), as well as through the inclusion of an important part of the forest area in the Natura2000 network (*e.g. ca* 30% of the forest area in Wallonia is

under Natura2000 status). In Flanders and Brussels, about 10000 ha are FSC-certified, whereas in Wallonia *ca* 50% of the forest area (281052 ha) was PEFC-certified in August 2009.
Under Cluster AG-D 'Biomass production for energy', a plan entitled 'Wood-Energy' intends to develop the use of wood as energy by towns and local communities in Wallonia, with or without heat network.

Three others will have indirect effects on forests.
Under axis 1 ('Optimizing energy production'), Cluster EP-A 'Promotion of a more environmentally friendly energy production' contains a series of measures leading to an increase in biomass use as an energy source, and that could thus have an effect on fuelwood fluxes (see Section 3 for more details).
Under axis 2 ('Making a rational use of energy within the buildings'), several measures of the Cluster EC-B 'Measures in the residential sector' could affect forestry through urbanistic prescriptions affecting wood construction (EC-B06), quality control of biofuels (certification) for use in boilers and stoves (EC-B02), as well as promotion of biomass boilers (EC-B01).
Finally, axis 7 ('Increasing support to research related to climate change') could also have indirect effects on forests. It is implemented differently, depending on the power level. At the Federal level, the research programme 'Science for a Sustainable Development' (2005-2009) - SSD consists of 8 priority research areas (energy, transport and mobility, agriculture and food, health and environment, climate, biodiversity, atmosphere and terrestrial and marine ecosystems and transversal research); several of them are directly or indirectly related to climate. At present, 71 research networks are financed.
The Flemish government gives high priority to research in the field of energy. In Wallonia, special support is given to the development of new technologies to optimize energy use; some of these research are part of the so-called Walloon Mashall plan.

As reported below, Belgian forests are estimated to sequester about 1.1 M ton C y^{-1} and will likely continue to accumulate C for the next century (Vande Walle, 2007). An amount of C equivalent to 15% of the actual C sequestration in forest ecosystems can be accounted for under Article 3.4 of the Kyoto Protocol. For Belgium, this is about 170 k ton C y^{-1}. However, each country has a cap (*i.e.* the maximum amount allowed) of C removal with activities under Article 3.4. For Belgium, the cap is only 30 k ton C y^{-1} (0.1% of the 1990' GHGE). Because of the low potential of this measure, the high costs to verify and prove the C sequestration by forests, as well at its sensitivity to disturbance impacts, the Belgian government decided therefore to not use this possibility of C mitigation (see Vande Walle, 2007 for a review).
Where possible, the establishment of new multifunctional forests represents an economically more attractive mitigation strategy than the establishment of bio-energy crops (Garcia-Quijano *et al.*, 2005). The establishment of a new plantation in the tropics has also higher costs than for a domestic new multifunctional forest (Garcia-Quijano *et al.*, 2005). Although conservation of tropical forest is not a CDM project under the Kyoto Protocol, it would be economically attractive for Belgian institutions to take into consideration this mitigation option because its costs are competitive for voluntary market and, likely, future commitment periods of the Kyoto Protocol (Garcia-Quijano *et al.*, 2005).

3.2.Carbon accounts

Within the scheme for GHGE trading within the European Union established in agreement with the Kyoto Protocol, Belgium has globally to decrease its emissions by 7.5% compared to 1990. The sharing between the three Regions of the country has been determined by the Consultation Committee of 8th March 2004; it amounted to -7.5%, -5.2%, and +3.475% for Wallonia, Flanders and Brussels, respectively. Estimations of GHGE showed that a reduction of 5% was reached in 2006 (www.unfccc.int). To further reduce the GHGE, the Belgian government allocated between 2005 and 2009 a total of 82 million euro for JI/CDM projects for the period 2008-2012. In 2007, the contributions of the main sectors to Belgium GHGE were as follows (NRI, 2008): energy industries (21%), industries (manufacturing - combustion: 20%; processes: 10%), transport (20%), residential (14%), agriculture (9%) and commercial (4%).

Each Region is responsible for its own emission inventory, using concomitant methodologies in agreement with IPCC guidelines; these regional inventories are then combined to make the national GHGE inventory. In Flanders, the GHGE inventory is carried out by the Department Air, Environment and Communication of the Flemish Environmental Agency (VMM); in Wallonia, the inventory is compiled by the Walloon Agency for Air and Climate (AWAC), using mostly the IPCC methodology; the GHGE inventory for the Brussels region is carried out by the Institute for Environmental Management (IBGE-BIM), using the IPCC and EMEP/CORINAIR methodologies. Recently, important efforts have been made to harmonize these methodologies across the regions.

As regards carbon accounting in forests, Belgium adopted the following definition of forests: minimum tree crown cover of 20%; minimum land area of 0.5ha; minimum height at maturity of 5m. This is in full agreement with the official FAO definition used in the Forest Resource Assessment (FRA). Belgium follows the methodology described in the Good Practice Guidance for Land Use, Land-Use Change and Forestry (GPG 2000) to establish the LULUCF inventory, and forest inventory in particular.

The standing carbon stocks in living biomass were computed from the *ca* 13000 inventory plots of the two regional (Flanders and Wallonia) forest inventories (as a result of its limited contribution to the total forested area i.e. 0.3%, no inventory in the Brussels region has been performed so far). Briefly, the total solid wood volumes of each dominant species were first converted into total dry mass by the infra-densities; these were in turn converted to dry biomass using expansion factors, and then to carbon quantities using species-specific carbon concentrations. According to these calculations, the carbon stock in the biomass averaged 59.8 M ton C in 2000. The carbon in dead organic matter is defined as all standing dead trees and fallen logs and branches (deadwood), as well as carbon in litter; the actual stocks were estimated to be 1.38 Mt C and 13.73 Mt C, respectively. For both components, it was assumed that the annual stock remained constant (NRI, 2008).

In 1990, the LULUCF sector in Belgium was a net sink of 1422.19 Gg CO_2 y^{-1} (NIR, 2008). The evolution of biomass carbon stock used two different methodologies, depending on the reference period: a linear interpolation for the 1990-2000 period, and a mechanistic model for the 2001-2004 period. In the period 1990-2000, Belgian forests are estimated to have taken up on average 2.8 ton C ha^{-1} y^{-1} or 1.1 M ton C y^{-1} (Vande Walle, 2007). Such amount is about 3% of the GHGE in Belgium in 1990. After 2003, the results of the model indicated net annual carbon removals of 1.3-1.5 M ton C y^{-1} (NRI, 2008). This methodology will be revised in the next years.

For Wallonia, the net annual C storage in forests amounted to *ca* 0.41 M ton C y^{-1} during the period 2000-2005, whereas the standing organic carbon stock in 2005 was 101,5 M ton C (living biomass: 51.5; deadwood+litter:11.0; 0-20 cm soil: 39.0) (Laitat *et al*., 2004).

3.3.Forestry as a source of bioenergy

3.3.1. Context and policies

Use of bioenergy is promoted at all power levels of the country, for transport as well as for electricity and heat production. By 2010, the contribution of renewable electricity to gross electricity consumption has been targeted to 6% (Van Stappen *et al*., 2007). Following the EU Directive 2009/28/EC[2], the objective for 2020 is ambitious for Belgium since the share of energy from renewables in final consumption of energy is targeted to 13%. It's therefore essential to develop and improve certification systems to insure sustainable production of biomass (Marchal *et al*., 2009).
Renewables in Wallonia represented 2770 GWh (primary production) and 10091 GWh in 1991 and 2007, respectively. For the year 2007, solid biomass accounted for 65% of renewables (the share of total biomass was 93%). In 2007, the share of biomass was 4.0% and 8.2% in electricity and heat consumption, respectively; wood and wood-derived products represented by far the largest part of biomass used for heat production (forest by-products + fire wood = 74.6%) (Goor *et al*., 2007; ICEDD, 2008).

A large range of solid rough woody products are potential candidates to be used for energy: logs, chips, sawdust, pellets, grinded industrial waste, and barks. The potential sources of biomass targeted for use in energy systems include: forests (tops and branches of trees left after timber harvests, poor quality trees in managed forests, trees removed during land clearing operations); solid or liquid (*e.g.* black liquor) wood residues from wood-processing industries; waste from urban areas, including construction wood; wood from agricultural lands (hedges and short rotation coppice), as well as from gardens, parks and road sides (Ponette *et al*., 2007). Because of market opportunities, a series of techniques have been developed to optimize the collection and further transportation of residues from the forest. In Wallonia, however, this tendency could be limited by legislation guidelines that forbids the exportation of residues in some zones (biodiversity development zones and central conservation zones, see section 2) of the regional-owned forests, and recommends to limit them elsewhere (Branquart and Liégeois, 2005). Although not excluded, the use of potential sawn logs for energy will not be encouraged because various policies promote the highest possible valorisation level of wood. For example, a series of measures have been set up to increase the use of wood as a construction material (storage as well as substitution effect). Wood from short rotation coppice in agricultural land will probably be limited by the development of non perennial energetic crops. On the other hand, wood collected from hedges will mainly be used for self-consumption. Because wood industries can use their by-products within their own installations and are encouraged to do so through green certificates, only that part which cannot be used in-house can be further sold either for other wood

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[2] 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.

processing industries or as fuelwood. Globally, the contribution of the remaining wood sources (wastes, and wood residues from gardens, parks and road sides) to fuelwood will be low, due to their limited amounts.

Several policies have been developed to promote the use of renewable energies such as biomass, targeting specific groups of end-users: (i) private individuals, (ii) towns and local communities and (iii) industrial sector. (i) Subsidies to private individuals mainly concern heating, notably from fuelwood. Because these subsidies are directed towards the use of more efficient heating systems, its effect on overall wood consumption is probably low. Note, however, that the effective individual fuelwood consumption is very difficult to assess, as a significant part escapes from market rules. (ii) The plan entitled ‘Wood-Energy’ intends to develop the use of wood as energy by towns and local communities in Wallonia, with or without district heating system. (iii) At the industrial level (Marchal *et al*., 2006), two mechanisms may influence the use of wood for energy, although not specific to wood: green certificates together with co-generation (combined heat and power systems) for the production of green electricity, and emission trading [3]. For green certificates, it is useful to distinguish between three types of actors of the industrial sector: the traditional (non green) electricity producers, the integrated industries, and the non integrated industries (Ponette *et al*., 2007). For the electricity producers, the green certificates alone don’t appear to be sufficient to increase the demand in local fuelwood. The combination with emission trading, as well as the evolution of market conditions (certificates, pellets) could however change this situation. For the integrated industries using cogeneration, the green certificates leads to a reduction of energy costs. As these actors already used such products, this policy would have no major effect on the supply of wood to other wood-processing industries in the short-term; in the mid- to long-terms, the total number of cogeneration projects could however increase, leading to a possible decrease in wood supply. In most cases, the principle of a non-integrated project is to use solid by-products from wood-processing industries in a cogeneration installation so as to produce electricity and heat, which will then be used for the production of pellets. It appears that for these projects, green certificates are essential.
As concern emission trading, each industry that is registered could be interested to lower its emissions so as to sell their excess allowances. One way to do so would be to substitute its actual energy source for biomass, including wood, which is considered to be CO_2-neutral.

In Wallonia, it is rather difficult to estimate which additional part of the local wood resource – if any – will be mobilized as a result of this increased demand; this is particularly true for products such as pellets whose transportation costs are relatively low compared to their potential returns. Another major question concerns the impacts these policies could have on those wood-processing industries such as fibreboard, particleboard and wood pulp industries, which use the same input material.

3.3.2. Selected research results

In the last decades, extensive investigation on bio-energy has been carried out in Belgium (Ceulemans and Deraedt, 1999; Laureysens *et al*., 2000; Laureysens *et al*., 2005; Lettens *et al*., 2003; Deckmyn *et al*., 2004; Garcia-Quijano *et al*., 2005; Vande Walle, 2007). Here, we’ll mostly consider conventional bio-energy crops as short rotation coppice (SRC) with

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[3] In Belgium, three issuing bodies (VREG: de Vlaamse Reguleringsinstantie voor de Elektriciteits- en Gasmarkt; CWaPE: Commission Wallonne Pour l’Energie; BRUGEL: Commission de regulation pour l’énergie en Région de Bruxelles Capitale) are responsible for the certification of the generating units as well as the grant of the Green Certificates, respectively in Flanders, Wallonia and Brussels, resulting in a total of 5 on-going Green Certificates mechanisms: 2 different in Flanders (1 Green, 1 Cogen), 1 in Wallonia, 1 in Brussels and 1 at the Federal level (Van Stappen *et al*., 2007).

typically 3-year rotation for the above-ground biomass and 25-year rotation for the belowground biomass (Ceulemans and Deraedt, 1999). Poplars and willows are the most common species used in SRC in Belgium (Ceulemans and Deraedt, 1999; Laureysens *et al.*, 2000; Laureysens *et al.*, 2005) but trials with other species as birch and maple have been performed (Vande Walle *et al.*, 2007). Below, the main findings about applicability, benefits and drawbacks of SRC with a particular emphasis for the northern part of the country (Flanders) are reported in four sections: (1) C sequestration in the ecosystem, (2) fossil fuel and CO_2 emission reduction, (3) environmental impact and (4) costs. In these analyses SRC will be compared with multifunctional forest (MUFOR), *i.e.* long-rotation forests managed with a 10 year thinning and regenerated with a group selection system where wood production is combined with ecological and recreational functions (Garcia-Quijano *et al.*, 2005) and low-input bio-energy crops *i.e.* mixed indigenous coppice (MIC) with longer rotations and little management (Lettens *et al.*, 2003).

(1) As far as C sequestration in the ecosystems is concerned, MUFOR are more advantageous than bio-energy crops because they store larger amount of C in both standing biomass and soil (Deckmyn *et al.*, 2004; Garcia-Quijano *et al.*, 2005). Furthermore, C stored in wood of MUFOR can be sequestered from the atmosphere for long-time because it can be used as primary materials for goods and construction. In Flanders, average C stocks in poplar SRC and beech/oak MUFOR for a period of 150 years are about 160 and 250 ton C ha^{-1}, respectively, which increased to 180 and 330 ton C ha^{-1}, respectively, in a climate change scenario (Deckmyn *et al.*, 2004).

(2) Use of SRC implies high reduction of fossil fuel and CO_2 emissions because of the direct substitution for fossil fuel. Such reductions are larger than the reduction obtained from MUFOR and MIC (Lettens *et al.*, 2003; Garcia-Quijano *et al.* 2005). For instance, poplar SRC provides in 150 years an average CO_2 emission reduction of 7-9 ton C ha^{-1} y^{-1}, whereas beech/oak MUFOR of 1.7-2.0 ton C ha^{-1} y^{-1} (Deckmyn *et al.*, 2004). In any case, potential reduction in fossil fuel and CO_2 emission attainable through bio-energy crops are likely to be of less importance in Belgium at regional and national level, because of the scarcity of the land. For instance, the maximum area that will likely be available for bio-energy crops in Flanders is expected to be 10 000 ha (Vande Walle *et al.*, 2007). The establishment of bio-energy crops for such land extension is expected to reduce the regional fossil fuel use and CO_2 emission of only 0.2-0.3% (Vande Walle *et al.*, 2007). Therefore, the use of bio-energy in Belgium seems to be interesting only locally, with the establishment of small-scale plantations linked to a local combined heat and power plant (Vande Walle *et al.*, 2007).

(3) The environmental impact of SRC is high because it negatively effects vegetation and biodiversity and because, especially for poplars, it requires large amount of water (Garcia-Quijano *et al.*, 2005). The impact of MUFOR and of MIC, which require less fertilizers, herbicides and management, is lower (Lettens *et al.*, 2003; Garcia-Quijano *et al.*, 2005). On the other hand, because of the high CO_2 emission reduction and the very little land occupation (*i.e.* high area-use efficiency), the environmental impact of SRC per ton CO_2 emission reduction is relatively small (Garcia-Quijano *et al.*, 2005). This fact (and the secondary positive effects that SRC might have on soil properties; Vande Walle *et al.*, 2007) could mitigate the negative effects of SRC reported above or even render SRC more environmental friendly than MUFOR and MIC (Lettens *et al.*, 2003; Garcia-Quijano *et al.*, 2005).

(4) In Belgium, SRC has high costs (*e.g.* costs for growing, transporting and using bio-fuel in specialized power stations). This makes SRC-alternatives more economically attractive. For instance, to reduce CO_2 emissions in Flanders, the establishment of new MUFOR is less costly than SRC. MUFORs provide particularly higher benefits in case (i) they are established in contaminated sites or replace loss making agriculture and (ii) they offer high environmental and recreational potentials (Garcia-Quijano *et al.*, 2005).

3.4. Research studies on mitigation

Mitigation possibilities are currently investigated in the following Belgian research projects:
(1) POPFULL. System analysis of a bio-energy plantation: full greenhouse gas balance and energy accounting (project coordinator: Prof. Ceulemans, University of Antwerp - UA; duration 01/03/2009 - 28/02/2014)
The objectives of this project are: (i) to make a full Life Cycle Analysis (LCA) balance of the most important greenhouse gases (CO_2, CH_4, N_2O, H_2O and O_3) and of the volatile organic compounds (VOC's), and (ii) to make a full energy accounting of a SRC plantation with fast-growing trees. The project involves both an experimental approach at a representative field site in Belgium and a modelling part. For the experimental approach a poplar SRC is monitored during the course of 1+3 years, harvested and transformed into bio-energy using two alternative techniques, i.e. a small-scale gasification and co-combustion in a large-scale electricity plant. Eddy covariance techniques are used to monitor net fluxes of all greenhouse gases and VOC's, in combination with common assessments of biomass pools (incl. soil) and fluxes. For the energy accounting LCA and energy efficiency assessments are used over the entire life cycle of the SRC plantation until the production of electricity and heat. A significant process based modeling component will integrate the collected knowledge on the greenhouse gas and energy balances toward predictions and simulations of the net reduction of fossil fuel greenhouse gas emissions (avoided emissions) of SRC over different rotation cycles.
(2) SimForTree: A decision support tool for sustainable forest management based on eco physiological analysis and simulation of the variability in tree development (project coordinator: Prof. Ceulemans, UA; co-principal investigators: Prof. Van Acker, Ghent University, UGent, and Prof. Muys, Catholic University of Leuven, KULeuven; duration: 01/01/2007 - 31/12/2010).
The strategic objective of the consortium is to develop a physiological forest-wood chain model (SimForTree) which is able to compare and evaluate different sustainable forest management strategies with respect to their impact on wood quality, ecosystem functioning and forest structural development. The work of the consortium is developed along three main lines: (i) an observational line that investigates the tree and forest variability under different site and management regimes; (ii) a model development line that integrates/links both existing knowledge and the new information from the experimental work into a validated and operational model, and (iii) a simulation line that applies the capacities and power of the model as a decision-support system for different end-users. In fact, as the physiological forest-wood chain model SimForTree is conceived as an integrating tool, it has potential applications within the forestry sector in its broadest sense. An important use of the SimForTree model is for solving environmental assessment questions. For instance, the model will be an excellent tool for long-term scenario analyses on effect of forest management and climate change on the C balance and the amount of C sequestered by forest ecosystem for different spatial and temporal scales.

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