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Administration de l'environnement

National Forestry Accounting Plan Luxembourg

National Forestry Accounting Plan and Reference Levels for 2021 – 2025 in accordance with Regulation (EU) 2018/841

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D'ËMWELTVERWALTUNG
Am Déngscht vu Mënsch an Ëmwelt

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1 General Introduction

1.1 General description of the forest reference level for Luxembourg

The National Forestry and Accounting Plan (NFAP) describes the approach adopted by Luxembourg to establish a Forest Reference Level (FRL) in order to comply with the 'LULUCF Regulation', *Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013*.

The FRL is *"an estimate, expressed in tons of CO_2 equivalent per year, of the average annual net emissions or removals resulting from managed forest land within the territory of a Member State in the periods from 2021 to 2025 and from 2026 to 2030, based on the criteria set out in this Regulation [2018/841]."* (Article 3(1)). In accounting terms, FRL is the counterfactual value of emissions and removals that would occur in managed forest land, in absence of any future change in management practices compared to the reference period.

For Luxembourg the following points are important to mention upfront:

+ According to the regulation the FRL has to mirror the situation and the forest practices observed between 2000 and 2009, referred to as the Reference Period (RP). Luxembourg has carried out two consecutive National Forest Inventories (NFIs) in the same period (2000 and 2010). Hence Luxembourg has a detailed and transparent dataset to carry out the required calculation.

- Yearly harvest rates are only available for forests under public ownership and not for forests under private ownership. For forests under private ownership, observed harvest rates are only available from the two NFIs. In the Green House Gas Inventory (GHGI) harvest rates for forests under private ownership are based on harvest rates for forests under public ownership (by applying a correction factor based on ratio of harvest rates from the NFIs). Hence the measured harvest rates for forests under private ownership mirrors the fluctuations of forests under public ownership and a third NFI has to be carried out to determine the real harvest.

- Due to its small forest size (~ 96 kha), annual harvest rates have strong fluctuations and make it almost impossible for a year on year benchmarking against a FRL. Furthermore, as explained here above, fluctuations are amplified in GHGI as any fluctuations in forest under pubic ownership are mirrored in forests under private ownership.

- In order to measure harvest rates in forests under private ownership Luxembourg would need to carry out another NFI. Ideally a NFI would need to be carried out in 2025 and 2030. At this moment in time there are plans to carry out another forest inventory in 2025. Alternatively, another method would need to be developed in order to measure directly harvest rates on a yearly basis.

Luxembourg has received support from the European Commission (Capacity Building Plan). Luxembourg has aimed to include all recommendations from this report in order to be in line with the Regulation. The approach adopted by Luxembourg is a harvest module based on maintaining a constant harvest to biomass ratio (alternative 2 described in Box 12 of the guidelines). The method is described in detail by Grassi and Pilli 2017 and is also often referred to as the JRC approach (Grassi & Pilli, 2017).

1.2 Consideration to the criteria as set in Annex IV of the LULUCF Regulation

> **Annex IV A (a)** the reference level shall be consistent with the goal of achieving a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, including enhancing the potential removals by ageing forest stocks that may otherwise show progressively declining sinks;

This notion links the LULUCF Regulation to the Paris Agreement and encourages Member States (MS) to reflect on the long-term development of the forest sinks, also beyond the Commitment Period (CP). This criterion can be understood to imply that a momentary change in harvest volume (because of forest age structure) can be justified, if it leads to enhancing potential removals by forest increment in the long term.

Luxembourg, as multiple other MS, has an ageing forest. An ageing forest has a high existing carbon stock but also a declining long-term sink as productivity is expected to decline in poorly managed forests. With regards to age

class structure Luxembourg aims to encourage harvest while stretching harvest over a long-time span. This is reflected in Forest Management Plans where, in general, deciduous forests, having reached their rotation age, are harvested over a 30 year period and coniferous forests over a 10 year period. This management practice protects the existing carbon stock while avoiding a reduction of the future sink, due to a reduced productivity observed in badly managed forest. Those practices are rigorously carried out in publicly owned forest and are encouraged in privately owned forests. Furthermore, harvest rates are also influenced by measures aiming to protect and improve biodiversity.

A high existing carbon stock in forests makes it however challenging to increase the annual sinks in forests. In order to achieve a balance between anthropogenic emissions by sources and removals by sink in the second half of this century all carbon sinks have to be maximised. In order to maximise carbon sinks, Luxembourg has to increase its forest areas and the production of Harvested Wood Products (HWP). Increasing the forest area will be very challenging as the pressure on land is very high. Luxembourg has a high proportion of beech forests which, unfortunately, are not very suitable to be used in construction or for the production of wood panels. Most of the wood produced is hence left in forest, exported or used as fuel wood. Luxembourg is however strongly committed to move towards a circular economy and is thriving to make best use of its wood resources. In order to achieve this, a wood cluster was set up to bring together all actors from the wood sector. Beech wood, sourced from local forests, has been used in a few experimental public construction projects. Also, the energy performance certificates in Luxembourg provide information on grey energy (and other sustainability criteria) of building materials. The results are generally more favourable for woody construction materials compared to concrete-based building materials.

Annex IV A (b) the reference level shall ensure that the mere presence of carbon stocks is excluded from accounting;

This criterion is compatible with the KP Decision 16/CMP.1. It reflects the objective that instead of only preserving existing carbon stocks, carbon stocks and the net carbon sinks are increased where possible. It is understood that a preexisting carbon stock in terrestrial vegetation such as a forest on a given area of land does not contribute towards the reduction of atmospheric carbon. Therefore, it is appropriate for the FRL to support accounting for net changes in forest carbon stocks, rather than accounting for total existing carbon stocks in forests.

Luxembourg has closely followed the guidelines commissioned by the European Commission. The FRL for Luxembourg accounts for emissions and removals that would occur in managed forest land in the absence of any future change in management. This method of net-net accounting, with reference level, excludes the mere presence of carbon stocks but considers the long time-horizon and legacy effects of past management practices associated with forestry.

2 Preamble for the forest reference level

Annex IV B (a) A general description of the determination of the forest reference level

The approach adopted by Luxembourg is a harvest module based on maintaining a constant harvest to biomass ratio (alternative 2 described in Box 12 of the guidelines). The method is described in detail by (Grassi & Pilli, 2017) and is also often referred to as the JRC approach.

Annex IV B (a) Description of how the criteria in LULUCF Regulation were taken into account.

See Annex IV A and Annex IV B description boxes throughout report.

2.1 Carbon pools and greenhouse gases included in the forest reference level

Annex IV B (b) Identification of the carbon pools and greenhouse gases which have been included in the forest reference level.

Table 2-1 *carbon pools included in the FRL*

Above-ground biomass	Yes
Belwow-ground biomass	Yes
Litter	Considered with LUC
Dead wood	Yes
Soil organic carbon	Considered with LUC
HWP	Yes

Annex IV B (b) Reasons for omitting a carbon pool from the forest reference level determination.

The choice of carbon pools considered is in line with the GHGI. A detailed description of the reasons for including or excluding different carbon pools in the GHGI are detailed throughout this report under the relevant chapters.

2.2 Demonstration of consistency between the carbon pools included in the forest reference level

The calculation of the FRL aims to guarantee a mutual consistency between actual management practices and modelled management practices. In order to achieve this consistency alternative A of Box 17 from the guidelines was chosen. The management practice for forests with public ownership has not changed during the RP. The management practice in forests under private ownership is however unknown and hence could have changed during the RP. The calculation method does not require detailed knowledge of management practices and is based exclusively on the results of the two consecutive NFI.

The consistency between historical data, as reported in GHGI, and model projected estimates for the same period is described in section 4.2.

2.3 Description of the long-term forest strategy

2.3.1 Overall description of the forests and forest management in Luxembourg and the adopted national policies

Annex IV B (c) A description of documentary information on sustainable forest management practices and intensity.

See paragraph here below

Annex IV B (c) A description of adopted national policies.

In this section policies are listed which influenced the FMP in the RP but also policies that were implemented after the RP. This should provide a good overview of the evolution of the overall forest strategy.

There are different legal obligations for forests under public ownership to establish **forest management plans** (aménagement) which have to be renewed every 10 years and the rotation age (*âge d'exploitation*) for the individual tree species to be applied:

- *Loi du 8 octobre 1920 concernant l'aménagement des bois administres*: Tous les dix ans il sera procède à une révision des plans d'aménagement. Les plans d'aménagement seront étudiés et préparés par un service spécial, rattaché à la direction de l'administration forestière conjointement avec les chefs de cantonnement
- *Instructions du 18 novembre 1952 concernant l'aménagement des forêts soumises au régime forestier*: Pour les différentes essences, l'âge d'exploitation sera fixe comme suit en tenant compte de la station:
    - Chênes 140 a 200 ans
    - Hêtres 140 a 160 ans
    - Autres feuillus 80 ans
    - Pin, melèze 80 a 120 ans
    - Epicea, douglas 70 a 100 ans
    - Sapin 100 a 140 ans
- *Règlement grand-ducal du 6 janvier 1995 concernant les règles applicables aux travaux d'exploitation, de culture et d'amélioration ainsi qu'aux ventes dans les bois administrés, modifie par Tel que modifié par la loi du 5 juin 2009 (Mem. A - 142 du 18 juin 2009, p. 1976).*
    - Sur la base des plans d'aménagement, le chef de cantonnement dresse chaque année des plans de gestion concernant les

- coupes, les cultures, la voirie, les produits accessoires et toutes les autres activités, y compris les travaux d'entretien des lignes limitatives des forets. Pour les propriétés boisées a exploitation intermittente, il est établi un plan pluriannuel.

No **clearcutting** of forest stands > 0.5 ha or clearcutting of coniferous stands < 50 years old can occur unless a relevant authorisation from the minister is acquired beforehand:

- *Loi du 18 juillet 2018 concernant la protection de la nature et des ressources naturelles - Article 13(3).*
  - Toute coupe rase dépassant 50 ares est interdite sauf autorisation du ministre.
- *Loi du 12 mai 1905 concernant le défrichement des propriétés boisées***.** Aucun défrichement ne pourra avoir lieu dans les bois de l'Etat, des communes, sections de communes ou établissements publics, qu'en vertu d'un arrêté grand-ducal.
- Loi du 30 janvier 1951 ayant pour objet la protection des bois, Tel que modifié par la loi du 5 juin **2009** (Mem. A n° 142 du 18 juin 2009, p. 1976).
  - Celui qui voudra procéder au défrichement d'un terrain boise de plus de 2 ha ou à une coupe considérée comme excessive selon les termes de l'art. 2 devra en faire la déclaration par lettre recommandée au ministre ayant dans ses attributions
  - des bois feuillus (futaies pleines ou taillis sous futaie) d'une contenance inferieure a 2 ha formant un seul tenant,
  - abstraction faite des numéros cadastraux et appartenant au même propriétaire. Le bénéfice de cette disposition ne s'étend pourtant pas aux bois qui, par l'effet d'un partage ou d'un lotissement intervenu depuis moins de dix ans, ont été détaches d'un bois feuillu qui mesurait avant le partage ou le lotissement plus de 2 ha d'un seul tenant;
  - des peuplements résineux qui ont dépassé l'âge de 50 ans;
  - des taillis simples y compris les haies a écorce ou des taillis sous futaie dans lesquels la futaie ne dépasse pas 0,25 m³ par are;
  - *des jeunes bois pendant les dix premières années après leur semis ou plantation, sauf les terrains boises ou reboises en exécution de la présente loi.*

Sustainable forest management (SFM) practices for forests under public ownership are described in:

Circulaire ministérielle du 3 juin 1999 concernant les lignes directrices d'une sylviculture proche de la nature

- In this paragraph the definition of sustainable forest management is taken from the Helsinki Resolution and hence integrated in Luxembourg.
  - « La gestion durable signifie la gérance et l'utilisation des forets et des terrains boisés d'une manière et a une intensité telles qu'elles maintiennent leur diversité biologique, leur productivité, leur capacité de régénération, leur vitalité et leur capacité a satisfaire, actuellement et pour le futur, les fonctions écologiques, économiques et sociales pertinentes aux niveaux local, national et mondial et qu'elles ne causent pas de préjudice a d'autres écosystèmes (Helsinki, Resolution H1).

The following forest practices should be applied for sustainable forest management:

- Mature tree should be present in all forests
  - présence de bois forts sur la majorité de la surface forestière;
- Harvest are usually done by individual trees or groups of trees but not by forest stands
  - récolte par arbre ou groupe d'arbres, et non pas par peuplement;
- Avoid monoculture and favour a variety of different tree species suitable for the local conditions
  - mélange d'essences d'âges multiples adaptées à la station;
- Soil protection:
  - maintien du sol dans un état optimal (durable) de conservation et de production
- No clearcutting in deciduous forests and clearcutting limited to 2 ha in coniferous forests;
  - proscrire les coupes a blanc dans les peuplements feuillus; ne sont pas considérées les coupes en bandes, par trouées et autres coupes de régénération de dimensions restreintes; limiter dans les résineux les coupes a blanc a moins de deux hectares d'un seul tenant
- Full tree logging is prohibited :
  - proscrire le full tree logging.
- Naturel regeneration with local seeds should be preferred for plantation :
  - préférer la régénération naturelle à la plantation, dans le but de conserver le potentiel génétique, et, en cas de plantation, préférer, dans le même but, des plants issus de semences récoltées sur place;
- Promote an un-even age class structure (especially in beech forests)
  - appliquer surtout en hêtraie de longues périodes de régénération permettant de créer une structure d'âge hétérogène et une diversité génétique, les semences de plusieurs années, voire de plusieurs décennies, pouvant participer à la reproduction;
- Transformation of natural forests in coniferous forests
  - proscrire la transformation de forets encore proches de la nature en plantations résineuses;
- After harvest under cover species adapted to shady location should be planted
  - introduire, après une coupe d'abri, des essences d'ombre dans les peuplements (résineux) ne se régénérant pas naturellement ou étant mal en station;
- Avoid monoculture and promote species mixes
  - créer des peuplements d'essences mixtes, non réguliers; éviter les monocultures de grandes surfaces et maintenir respectivement favoriser en mélange des espèces secondaires.
- A certain percentage of standing dead wood should be kept in place :

- Les arbres sénescents ou morts sont nécessaires au maintien des espèces inféodées. Ainsi, sur le parterre des peuplements en voie de régénération, il y a lieu de conserver des arbres sénescents au-delà de la coupe définitive, dans le but de les intégrer dans les nouveaux peuplements, d'abord en tant que arbres vieillissants, puis en tant que arbres morts. De même, il est indiqué de conserver, dans la mesure du possible, des bois morts dans tous les stades de développement. Dans ce contexte, il faut considérer comme optimum recommandable 5% des arbres dépassant 30 cm à hauteur d'homme respectivement 5% du volume sur pied.

- Maximise the amount of wood left in forest during harvest and incineration of dead wood should be prohibited:
  - laisser en forêt le plus grand volume possible de biomasse lors de la récolte des bois. L'incinération ou le ramassage intégral des bois morts et des rémanents de coupe sont à proscrire
- Pesticides should not be used, ant-heaps should be protected and bird houses should be placed on trees
  - renoncer à l'épandage de pesticides; propager des méthodes biologiques (protection des fourmilières, mise en place de nichoirs, installations de perchoirs pour les oiseaux rapaces, etc.)
- Only natural fertilisers shoud be used and liming should not occur
  - utiliser des engrais naturels (engrais verts) au moment de la plantation et renoncer a la fertilisation et au chaulage;

Additional Biodiversity enhancement measures were introduced in 2018 and affect SFM in broadleaf forests:

- *Règlement grand-ducal du 1er août 2018 établissant les biotopes protégés, les habitats d'intérêt communautaire et les habitats des espèces d'intérêt communautaire pour lesquelles l'état de conservation a été évalué non favorable, et précisant les mesures de réduction, de destruction ou de détérioration y relatives.*
  - Les mesures générales de réduction, de destruction ou de détérioration des biotopes protégés forestiers et des habitats d'intérêt communautaire forestiers, et interdites par l'article 17 de la loi précitée du 18 juillet 2018, sont :
    1. l'emploi de biocides ou de pesticides ;
    2. le pâturage ou le panage, à l'exception des bosquets composés d'au moins cinquante pour cent d'espèces indigènes;
    3. l'enlèvement de la litière forestière ;
    4. le remblayage ou le déblayage ;
    5. le travail du sol dans la couche minérale ;
    6. l'amendement, le chaulage ou la fertilisation ;
    7. le dessouchage ;
    8. le broyage surfacique de la végétation ;
    9. l'essartement à feu courant ;
    10. le changement du régime hydrique, le drainage ou le curage ;
    11. la circulation à engins lourds en dehors des chemins forestiers et des layons de débardage ;
    12. la coupe excessive supérieure à un hectare ne préservant pas, par hectare, un volume de bois d'au moins cent cinquante mètres cubes dans les futaies et d'au moins cinquante mètres cubes dans les taillis sous futaie et les taillis
    13. la récolte de l'arbre entier par l'enlèvement du tronc et des branches ;
    14. l'enlèvement d'arbres à cavité ou de vieux arbres à cavité potentielle en-dessous du seuil de deux arbres par hectare

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    15. l'enlèvement de bois mort ou d'arbres dépérissant en-dessous du seuil d'un arbre par hectare ;
    16. les mesures sylvicoles qui ont pour effet de réduire le taux de recouvrement des essences forestières feuillues adaptées à la station en-dessous du seuil de cinquante pourcent ;
    17. les plantations réalisées avec des essences résineuses sur plus de cinquante pourcent de la surface ;
    18. les plantations réalisées avec des essences résineuses par groupe ou paquet supérieur à dix ares.

  - Font partie des biotopes protégés et habitats forestiers visés par l'alinéa 1er :
  - 1° les habitats d'intérêt communautaire forestiers :
    - hêtraies du Luzulo-Fagetum
    - hêtraies de l'Asperulo-Fagetum;
    - hêtraies calcicoles médio-européennes du Cephalanthero-Fagion;
    - chênaies pédonculées ou chênaies-charmaies sub-atlantiques et médio-européennes du Carpinion betuli;
    - forêts de pentes, éboulis ou ravins du Tilio-Acerion *;
    - tourbières boisées * ;
    - forêts alluviales à Alnus glutinosa et Fraxinus excelsior (Alno-Padion, Alnion incanae, Salicion albae) *;
    - formations stables xérothermophiles à Buxus sempervirens des pentes rocheuses (Berberidion p.p.)
  - 2° les biotopes protégés forestiers :
    - peuplements d'arbres feuillus;
    - chênaies xérophiles à Campanule;
    - lisières forestières structurées;
    - bosquets composés d'au moins cinquante pour cent d'espèces indigènes

Reforestation is subsidised :

Loi du 24 juillet 2001 concernant le soutien au développement rural: Il est institué un régime d'aides au boisement de terres agricoles au profit des exploitants agricoles, des propriétaires de fonds agricoles ainsi que des collectivités publiques autres que l'Etat.
This law was subsequently replaced by: Règlement grand-ducal du 12 mai 2017 instituant un ensemble de régimes d'aides pour l'amélioration de la protection et de la gestion durable des écosystèmes forestiers. Article 6.

Implementation of the International Tropical Timber Agreement 2006 (Geneva) in Luxembourg legislation:

Loi du 18 mai 2010 portant approbation de l'Accord international de 2006 sur les bois tropicaux, fait à Genève, le 27 janvier 2006.

Implementation of the Convention on the European Forest Institute

Loi du 20 avril 2009 portant approbation de la Convention de l'Institut Forestier Européen, faite à Joensuu, le 28 août 2003.

Implementation of the FLEGT and EUTR regulations

Loi du 21 juillet 2012 concernant certaines modalités d'application et la sanction du règlement (CE) nº 2173/2005 du Conseil du 20 décembre 2005 concernant la mise en place d'un régime d'autorisation FLEGT relatif aux importations de bois dans la Communauté européenne.

Loi du 21 juillet 2012 concernant certaines modalités d'application et la sanction du règlement (UE) nº 995/2010 du Parlement européen et du Conseil du 20 octobre 2010 établissant les obligations des opérateurs qui mettent du bois et des produits dérivés sur le marché.

FSC and PEFC Luxembourg :

Most forests in Luxembourg are PEFC certified and 53% of all forests under public ownership (22.830 ha) are FSC certified. This represents about 25% of all the forests in Luxembourg.

Deforestation has to be authorised and is only allowed if it is compensated with afforestation. After a clearcut measures have to be taken to restitute the forest to an equivalent ecological and productive state:

Loi du 19 janvier 2004 concernant la protection de la nature et des ressources naturelles.

Tout changement d'affectation de fonds forestiers est interdit, à moins que le Ministre ne l'autorise, dans l'intérêt général ou en vue de l'amélioration des structures agricoles.

Le Ministre imposera des boisements compensatoires quantitativement et qualitativement au moins égaux aux forets supprimées et cela sur le territoire de la commune ou de la commune limitrophe. Il peut substituer la création d'un autre biotope ou habitat approprie au sens de l'article 17 au boisement compensatoire.

Après toute coupe rase le propriétaire ou le possesseur du fonds est tenu de prendre, dans un délai de 3 ans à compter du début des travaux d'abattage, les mesures nécessaires a la reconstitution de peuplements forestiers équivalant, du point de vue production et écologie, au peuplement exploite.

2.3.2 Description of future harvesting rates under different policy scenarios

Annex IV B (d) Information on how harvesting rates are expected to develop under different policy scenarios.

Even though the Luxembourg has an ageing forest the overall harvesting rates are expected to decline. This is mainly due to the fact that forests under public ownership are more focusing environmental criteria (with an increase in undisturbed forests). A strong increase in wood price could on the other side lead to an increase in harvest in forest under private ownership. This is especially true for coniferous forest as the remaining stock of wood in coniferous wood in forest under private ownership was still high in 2010 and hence there is a potential for increased future harvest.

3 Description of the modelling approach

3.1 Description of the general approach as applied for estimating the forest reference level

The forest age structure is a good indicator for the amount of trees available for harvest as it can forecast when trees reach their rotation age and are ready to be harvested. This is often referred to as unavoidable harvest and has been one of the main rationales behind setting up a FRL. The availability of wood that is ready to harvest does however not necessarily mean that the harvest will take place. Trees can remain in the forest for a much longer time after they have reached their rotation age and can thus act as available wood stock for years to come. With regards to forests under private ownership, harvest rates of mature forest are mainly driven by wood price and legislation. Harvest rates in forests under public ownership are also driven by wood prices but are mainly driven by harvest policy, which increasingly take into account environmental concerns. Nonetheless the age distribution will be given particular attention as it gives a good indication of the maximal potential of wood harvest.

The management practices applied in forests under public ownership are well understood, documented and mostly implemented. For forests under private ownership no information on forest management practices are known as those forests are owned by a large amount of small forest owner. The size of the forest in Luxembourg is also very small and hence a modelling approach seems not very well suited for Luxembourg.

The approach adopted by Luxembourg is the alternative 1 described in Box 12 of the guidelines. It is also referred to as the JRC approach (Grassi and Pilli 2017, Grassi et al. 2018), and is based on maintaining the ratio between the harvest and the amount of biomass available for wood supply in MFL (for both final felling and thinning) constant over time.

3.2 Documentation of data sources as applied for estimating the forest reference level

3.2.1 Documentation of stratification of the managed forest land

Table 3-1 *stratification level*

Ownership	Forest type
Private ownership	coniferous forest
	deciduous forest
Public ownership	coniferous forest
	deciduous forest

The stratification is the same as the one used in the GHGI. The data included in the NFI would allow adding further stratification levels (e.g. species, high forest/coppice, management system etc). Nevertheless, Luxembourg faces the problem that, due to a small forest area, it has only very few measurement points in its NFI. The addition of further stratification levels would lead to statistically non-significant parameters.

In Luxembourg all forest under public ownership have to submit, once every 10 year, a report providing a detailed forest inventory per forest owner (species composition, age structure, forest management) as well as the projected harvest rates for the next 10 years. One of the key aims of these reports is to generate a forest management plan including a sustainable use of wood and a balanced approach between all the different purposes that the forest fulfils. These management practices do however not reflect those practiced in forests under private ownership.

Figure 3-1 *strata description*

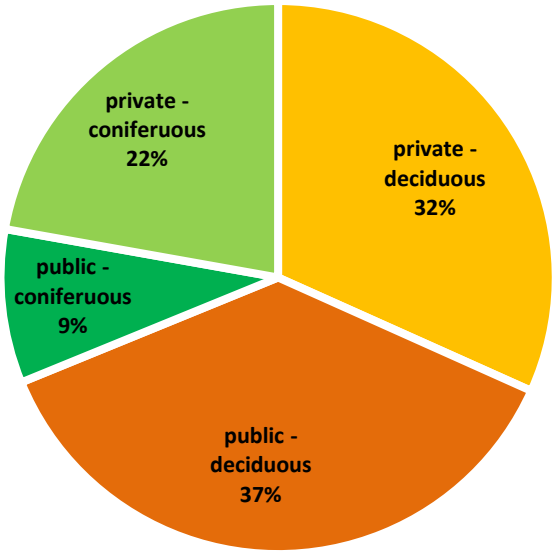


Figure 3-1 represents the forest composition according to the different stratifications. Beech (Fagus sylvatica L.) is the most important broadleaf tree species in Luxembourg and represents 25 % of the different forest types and is also commonly found in deciduous mixed forest. Oak forests are also strongly represented but a distinction has to be made between oak forests and coppice oak forests (which lower harvest rates) that can be found in the North of the country. With regards to coniferous forests in Luxembourg Norway spruce (picea abies) is the most commonly found tree.

Harvest rates are typically based on rotation age and the diameter of individual trees. The rotation age is the age of optimal harvest and depends on the type of trees and the intended use of wood. Apart from the coppice oak forests in the north of Luxembourg the majority of forest in Luxembourg have been planted in order to produce high quality wood and have thus high rotation ages. Forest produce however wood throughout their lifetime as

regularly thinning is necessary in order to produce high quality wood. The wood harvested during thinning exercised is then typically sold for heating purposes.

Once a forest has reached its rotation age the total wood stock could be harvested at once (clearfelling) and a new forest could be planted. In terms of forest management there is a clear shift away from clear-cut system to the selective felling of timber. Also, current legislation does not allow clear-felling in deciduous forests and only allows clear-felling in coniferous forest if they are older than 50 years. For Luxembourg this means that deciduous forests that have reached their rotation age are generally fell over a period of 30 years and coniferous forest over a period of 10 years.

Table 3-2
rotation age by tree species (public forests)

	Rotation age (years)
Beech (Fagus sylvatica) L.)	160
Oak	200
Norway spruce (Picea abies (L.)	60
Other deciduous	80
Other coniferous	100

3.2.2 Documentation of sustainable forest management practices as applied in the estimation of the FRL

Annex IV A (f) the reference level should be consistent with the objective of contributing to the conservation of biodiversity and the sustainable use of natural resources, as set out in the EU forest strategy, Member States' national forest policies, and the EU biodiversity strategy

The FRL is based purely on observed quantitative data measured between two subsequent NFIs. Hence forest management practices have not been directly included in a modelling exercise. The forest management practices that actually occurred are however included indirectly in the calculations. The sustainability of the actual forest management practices that occurred in the RP has to be evaluated by looking at the legal framework as well as the quantitative results of the NFIs. The legal framework is described in detail in section 2.3.1 and the quantitative results are described in section 4.1.1.3. The legal framework demonstrates clearly that no forest practices were allowed during the RP that would not have been sustainable. The forest characteristics described in section 4.1.1.3 demonstrate that there is no overexploitation in forests. Hence the sustainable use of natural resources has been taken into account in the modelling of the FRL and the consistency between the modelling of the FRL and historical and evolving sustainable FMPs has been demonstrated.

4 Forest reference level

4.1 Forest reference level and detailed description of the development of the carbon pools

4.1.1 FRL modelling – harvest levels

Annex IV B (e) A description of how the following element was considered in the determination of the forest reference level:

The area under forest management

Emissions and removals from forests and harvested wood products as shown in greenhouse gas inventories and relevant historical data

Forest characteristics, including:
- dynamic age-related forest characteristics
- increments
- rotation length and
- other information on forest management activities under 'business as usual'

Historical and future harvesting rates disaggregated between energy and non-energy uses

4.1.1.1 Managed Forest Land (MFL) as estimated in GHGI

The total forest area estimated in the second forest inventory for the year 2010 was 92.150 ha and is subdivided in the following types of forests:

- deciduous forests: 58.050 ha: 63 %
- coniferous forest (spruce, pin, douglas *etc.*) 27.250 ha: 30 %
- other forested areas (shrubs, forest roads, quarries, clear cuttings, *etc.*) 6.850 ha: 7 %

The total forest area estimated in GHGI is based on remote sensing. Those areas are not identical with those estimated by the NFI. According to the data generated by the remote sensing analysis the forest area in the year 2012 was 96.107 ha compared to 92.150 ha estimated by the NFI. The difference of 3 957 ha (4%) is very small and can be explained by the two different methodologies employed.

The forest inventory is a periodic survey of permanent forest sample plots based on a randomised systematic grid sample design. Each grid has a dimension of 1 000 m * 500 m and this grid density equates to 5 200 points nationally, each representing 50 ha. If a point on the grid is considered as being a forest (use of aerial photography) the equivalent of 50 ha are added to the forest area. In Figure 4-1 the forest area is estimated at 400 ha (8 points).

Figure 4-1 *comparison of forest areas calculated via NFI and land use maps*

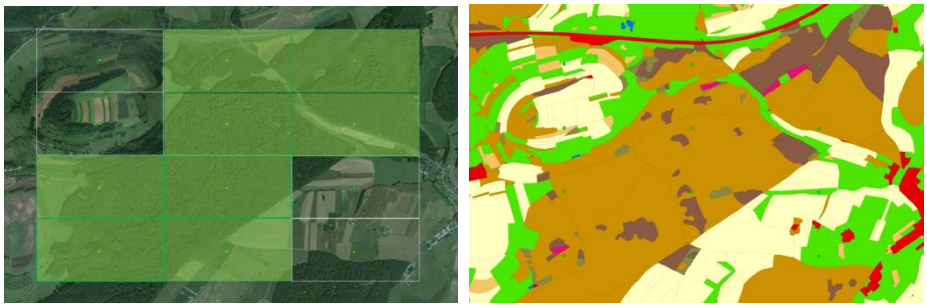
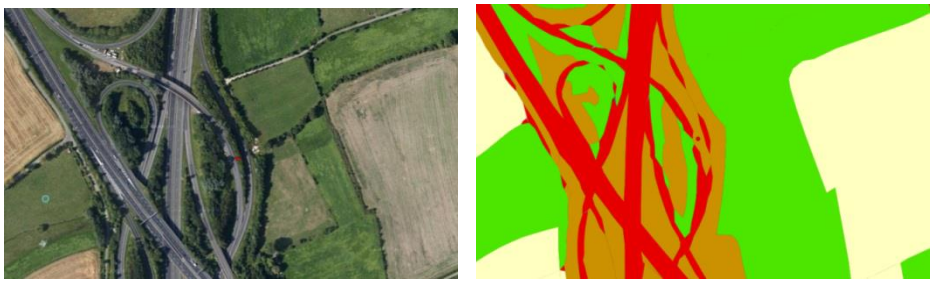


Figure 4-1 illustrates the increased level of detail employed by the land use change method which is based on occupational soil maps compared to the method employed by the NFI. The occupational soil maps often consider more types of forests compared to the NFI. For example, woody areas along motorways and roads (see Figure 4-2)

are included in the occupational soil but often left out in the NFI. During its next land use change analysis Luxembourg will critically assess those areas and its consistency with the definition of forest.

Figure 4-2
illustration of woody areas along motorways



The method employed by using land use change map methodology allows, not only to estimate forest areas, but also to have a comprehensive method to calculate areas on other land uses and more importantly on land use changes.

In order to remain consistent between the calculation of a FRL and GHGI the forest areas used for estimating the FRL will be those from GHGI.

In order to project the evolution of managed forestland (MFL) Alternative 2 of the guidelines (Box 19) was used:

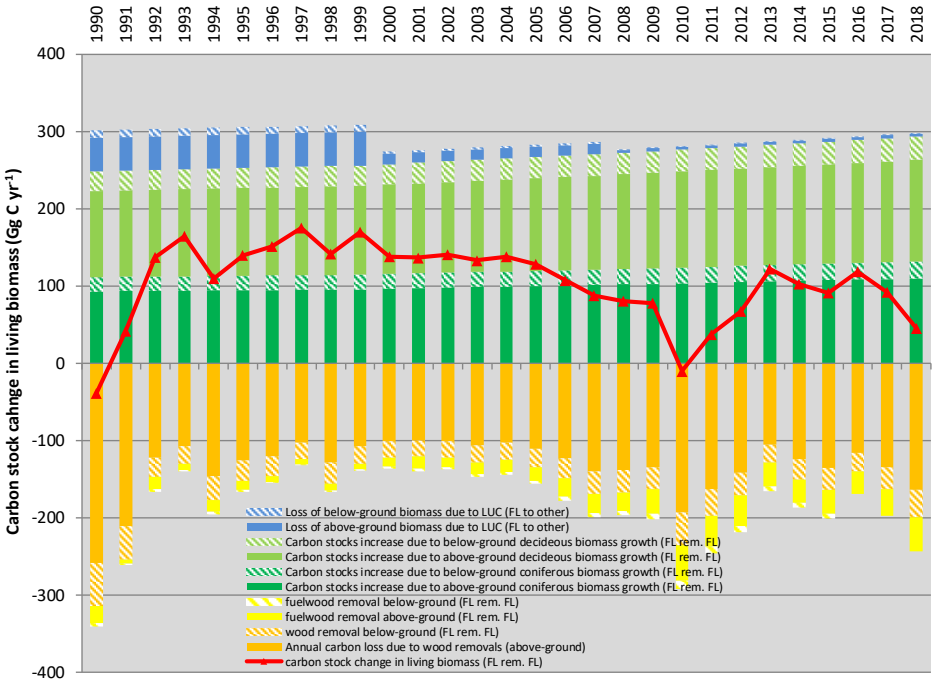
Table 4-1 *projection of MFL (ha) under the land-based approach*

	year on year land use change (ha)							*20 year moving sum (land-based approach) (ha)*						
	FL-FL	aCL-FL	pCL-FL	GL-FL	WL-FL	SL-FL	OL-FL	aCL-FL_{20}	pCL-FL_{20}	GL-FL_{20}	WL-FL_{20}	SL-FL_{20}	OL-FL_{20}	**MFL**
1971		100	48	331	19	142	61							
1972		100	48	331	19	142	61							
1973		100	48	331	19	142	61							
1974		100	48	331	19	142	61							
1975		100	48	331	19	142	61							
1976		100	48	331	19	142	61							
1977		100	48	331	19	142	61							
1978		100	48	331	19	142	61							
1979		100	48	331	19	142	61							
1980		100	48	331	19	142	61							
1981		100	48	331	19	142	61							
1982		100	48	331	19	142	61							
1983		100	48	331	19	142	61							
1984		100	48	331	19	142	61							
1985		100	48	331	19	142	61							
1986		100	48	331	19	142	61							
1987		100	48	331	19	142	61							
1988		100	48	331	19	142	61							
1989		100	48	331	19	142	61							
1990	92'617	**100**	**48**	**331**	**19**	**142**	**61**	1'994	954	6'614	375	2'844	1'223	**79'314**
1991	92'876	**100**	**48**	**331**	**19**	**142**	**61**	1'994	954	6'614	375	2'844	1'223	**79'572**
1992	93'134	**100**	**48**	**331**	**19**	**142**	**61**	1'994	954	6'614	375	2'844	1'223	**79'831**
1993	93'393	**100**	**48**	**331**	**19**	**142**	**61**	1'994	954	6'614	375	2'844	1'223	**80'089**
1994	93'652	**100**	**48**	**331**	**19**	**142**	**61**	1'994	954	6'614	375	2'844	1'223	**80'348**
1995	93'910	**100**	**48**	**331**	**19**	**142**	**61**	1'994	954	6'614	375	2'844	1'223	**80'607**
1996	94'169	**100**	**48**	**331**	**19**	**142**	**61**	1'994	954	6'614	375	2'844	1'223	**80'865**
1997	94'427	**100**	**48**	**331**	**19**	**142**	**61**	1'994	954	6'614	375	2'844	1'223	**81'124**
1998	94'686	**100**	**48**	**331**	**19**	**142**	**61**	1'994	954	6'614	375	2'844	1'223	**81'382**
1999	94'945	**100**	**48**	**331**	**19**	**142**	**61**	1'994	954	6'614	375	2'844	1'223	**81'641**
2000	95'517	**14**	**6**	**104**	**2**	**51**	**0**	1'908	912	6'388	357	2'753	1'162	**82'214**
2001	95'566	**14**	**6**	**104**	**2**	**51**	**0**	1'822	870	6'161	340	2'662	1'102	**82'786**
2002	95'616	**14**	**6**	**104**	**2**	**51**	**0**	1'736	829	5'935	323	2'571	1'041	**83'359**
2003	95'665	**14**	**6**	**104**	**2**	**51**	**0**	1'649	787	5'709	306	2'480	980	**83'931**
2004	95'714	**14**	**6**	**104**	**2**	**51**	**0**	1'563	745	5'482	289	2'389	919	**84'504**
2005	95'764	**14**	**6**	**104**	**2**	**51**	**0**	1'477	703	5'256	272	2'297	858	**85'077**
2006	95'813	**14**	**6**	**104**	**2**	**51**	**0**	1'391	662	5'029	255	2'206	798	**85'649**
2007	95'862	**14**	**6**	**104**	**2**	**51**	**0**	1'305	620	4'803	238	2'115	737	**86'222**
2008	96'000	**7**	**3**	**42**	**0**	**2**	**0**	1'212	575	4'514	219	1'975	676	**86'883**
2009	96'014	**7**	**3**	**42**	**0**	**2**	**0**	1'119	529	4'225	201	1'834	615	**87'544**
2010	96'027	7	3	42	0	2	0	1'025	484	3'936	182	1'693	554	**88'205**
2011	96'041	7	3	42	0	2	0	932	439	3'647	164	1'553	493	**88'866**
2012	96'055	7	3	42	0	2	0	839	394	3'358	145	1'412	432	**89'526**
2013	96'068	7	3	42	0	2	0	746	349	3'070	127	1'271	371	**90'187**
2014	96'082	7	3	42	0	2	0	653	303	2'781	108	1'131	311	**90'848**
2015	96'095	7	3	42	0	2	0	560	258	2'492	90	990	250	**91'509**
2016	96'109	7	3	42	0	2	0	467	213	2'203	71	849	189	**92'170**
2017	96'123	7	3	42	0	2	0	374	168	1'914	53	709	128	**92'831**
2018	96'136	7	3	42	0	2	0	281	123	1'625	34	568	67	**93'492**
2019	96'150	7	3	42	0	2	0	188	78	1'336	16	427	6	**94'153**
2020	96'163	7	3	42	0	2	0	181	74	1'273	14	378	6	**94'290**
2021	96'177	7	3	42	0	2	0	174	71	1'211	13	328	6	**94'428**
2022	96'191	7	3	42	0	2	0	167	67	1'148	11	279	6	**94'565**
2023	96'204	7	3	42	0	2	0	160	64	1'086	10	229	6	**94'703**
2024	96'218	7	3	42	0	2	0	153	60	1'023	9	180	5	**94'841**
2025	96'231	7	3	42	0	2	0	146	57	960	7	130	5	**94'978**
2026	96'245	7	3	42	0	2	0	139	54	898	6	81	5	**95'116**
2027	96'259	7	3	42	0	2	0	132	50	835	4	31	5	**95'253**
2028	96'272	7	3	42	0	2	0	132	50	835	4	31	5	**95'267**
2029	96'286	7	3	42	0	2	0	132	50	835	4	31	5	**95'281**
2030	96'299	7	3	42	0	2	0	132	50	835	4	31	5	**95'294**

Table 4-1 shows the annual land use change to forest areas as well as the forest areas remaining forest areas. Land use changes are based on land use maps which have been established in 1989, 2000, 2007 and 2012. Those land use maps have been used to determine average yearly land use changes from and to forest. In order to project the evolution of forest areas the land use changes observed between 2007 and 2012 will be extrapolated to 2030. The 20 year conversion period from land use changes to forestland into MFL is calculated by considering those yearly changes. It goes without saying an update of the land use change matrix will lead to a technical correction of the FRL.

4.1.1.2 *Emissions and removals from forests as shown in greenhouse gas inventories and relevant historical data*

Figure 4-3 *emissions and removals from forests as calculated in GHGI*



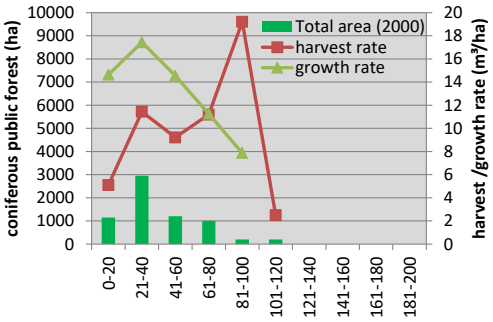
With regards to ***Figure 4-3*** the following points can be observed:

- The two main drivers behind carbon emissions and losses are harvest (responsible for the year on year fluctuation) and reduced land use changes over time. Reduced land use changes mean that an increase amount of land enters the MFL (from afforestation) compared to a reduced amount of land leaving forest (deforestation).
- The carbon losses due to land use changes from forestland are reported under the land use that the forests are changed into. In order to avoid double counting the associated loss of biomass has to be subtracted from the total wood removals in the forest remaining forest category. For illustrative purposes they have been reported as sinks in this chart (blue bars).
- Growth rate in forests are easy to predict and are more or less constant over the years. The harvest rate, on the other hand, has strong year on year fluctuations and is the strongest contributor to changes in emissions.
- Wood removals are split between wood and fuelwood. This ratio is used in order to estimate the future production of HWP.

4.1.1.3 Forest characteristics

Figure 4-4 *forest area, harvest rate and growth by age-structure , and ownership for coniferous forests*

Coniferous forest – public ownership



Coniferous forest – private ownership

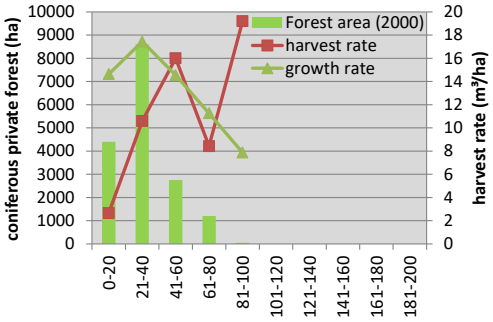
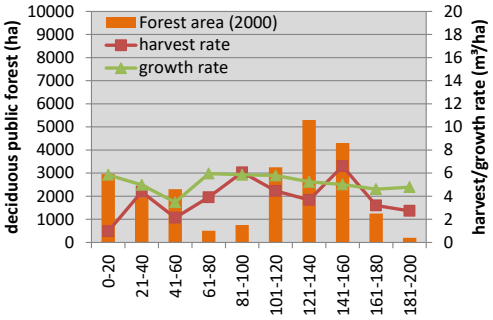


Figure 4-5 *forest area, harvest rate and growth by age-structure , and ownership for deciduous forests*

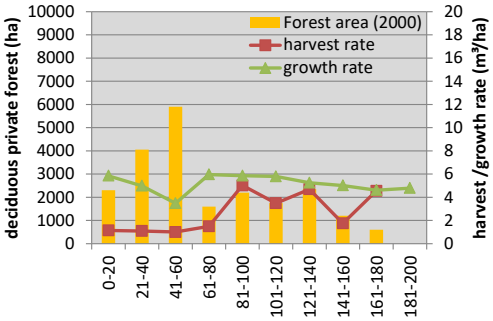
deciduous forest – public ownership

20 year age classes



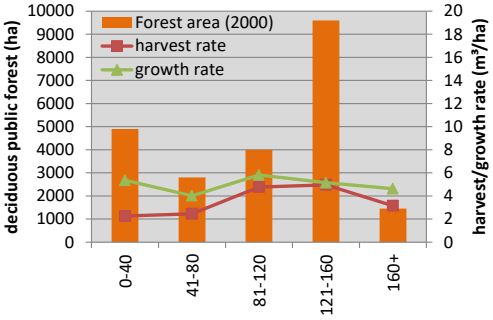
deciduous forest – private ownership

20 year age classes



deciduous forest – public ownership

40 year age classes



deciduous forest – private ownership

40 year age classes

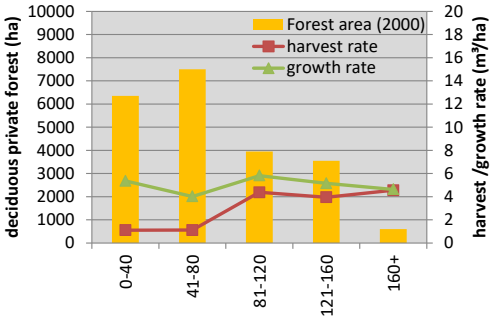
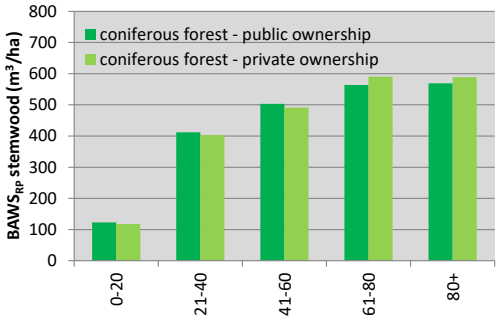
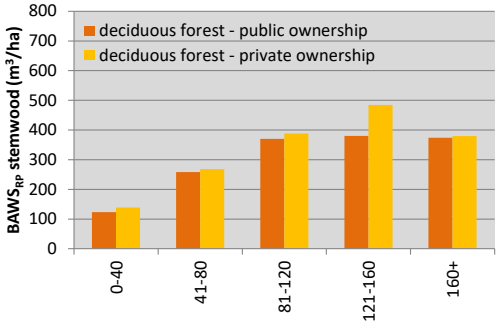


Figure 4-6 **B**iomass **A**vailable for **W**ood **S**upply (m^3 stemwood) by age class, ownership and forest type

Stemwood (m^3/ha) - coniferous forest



Stemwood (m^3/ha) - deciduous forest



A few trends can be identified when analysing those charts:

- Strong variations of harvest rates can be observed in each strata (age class, type of forest and ownership). This can be explained by the small size of the forest in Luxembourg. Some strata are only described by very few sample plots. The age class 81-100, for coniferous forests under private ownership, is, for example, only described by 4 sample plots (200 ha). The addition of more strata would increase the uncertainty due to the small amount of sample plots. For coniferous forest the rotation age is typically very low and hence the age distribution is not as wide spread as for deciduous forests. The 20 year age class stratification for coniferous forests can hence be maintained. In order to reduce the current uncertainty, the age classes for deciduous forests, the age classes will be combined into fewer age classes for deciduous forests.
- The forest age structure is typical for an ageing, and underexploited forest. Especially deciduous forests have been underexploited in the last years which can mainly be attributed to a depressed wood price. In most cases exploiting and maintaining those forests comes at a higher cost compared to the revenue that the harvest could generate.
- Public deciduous forests are highly marked by an ageing forest structure but also show a higher overall harvest rate compared to privately owned forests. In order to revert the trend of ageing forest and to maintain a sustainable harvest in the future the Forest Agency has, over the last years, pursued an active policy of maintaining forests.
- Coniferous forests are better exploited and the observed age class structure seems to be more in line with well exploited forests. This can particularly be observed in private forests where a high harvest rate can be seen in the age class 41-60. Indeed, in the beginning of 2000, a policy was introduced to allow clearfelling of coniferous forest older than 50 years. In publicly owned forests a higher proportion of older trees can be found. Nevertheless, a fairly high harvest rate can also be seen here.

4.1.1.4 Historical harvesting rates

The biggest constraint in Luxembourg is that **no annual data on harvest in forest under private ownership is available**. It is believed that privately owned forest belong to some 14.000 owners and most owners have no more than 50-100 ha (often these 50 ha are not continuous, but splitted). The collection of data seems an extremely difficult or even impossible task.

Data on total wood harvest is published on an annual basis by the forest agency - ANF (Administration de la Nature et des Forêts) and is based on annual wood harvest from public forest. In order to estimate wood harvest in privately owned forest the ratio between harvest in privately owned and publicly owned forest from the NFIs is used according to the method illustrated in ***Figure 4-7***:

Figure 4-7 *official calculation method for estimating harvest rates in* privately owned forest

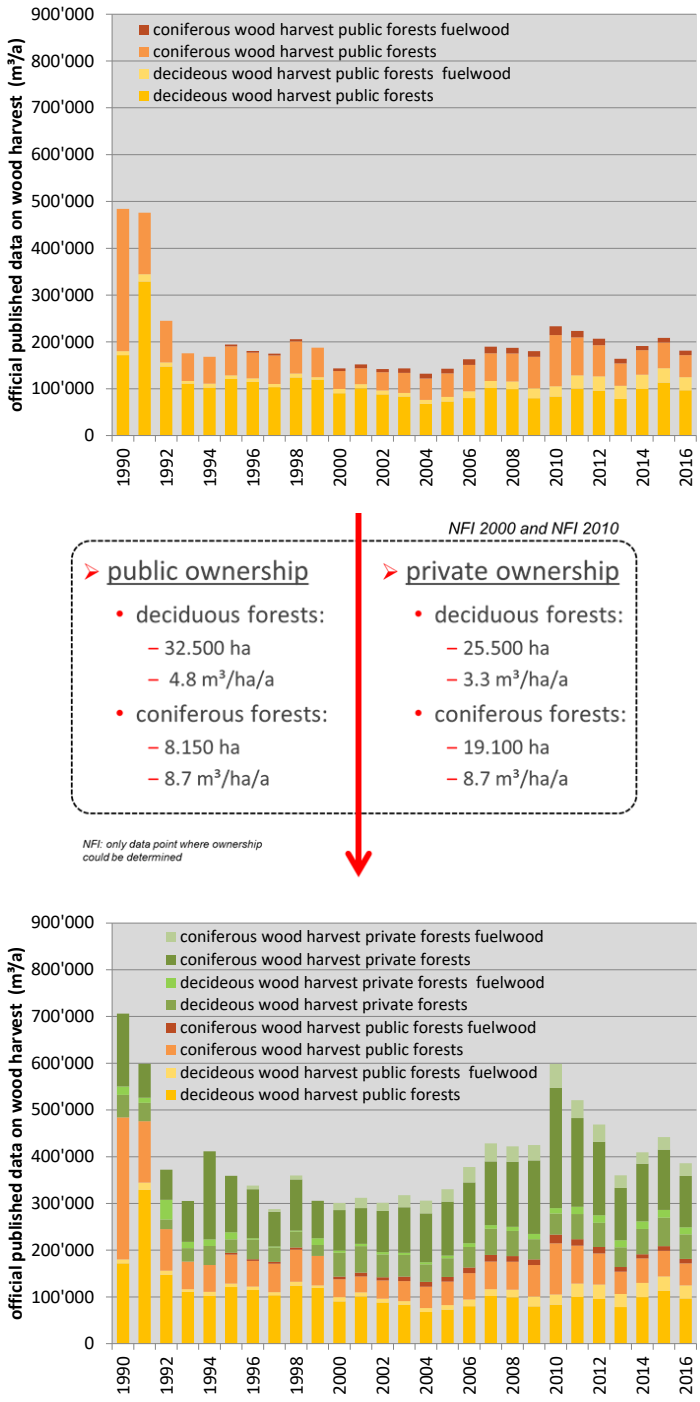
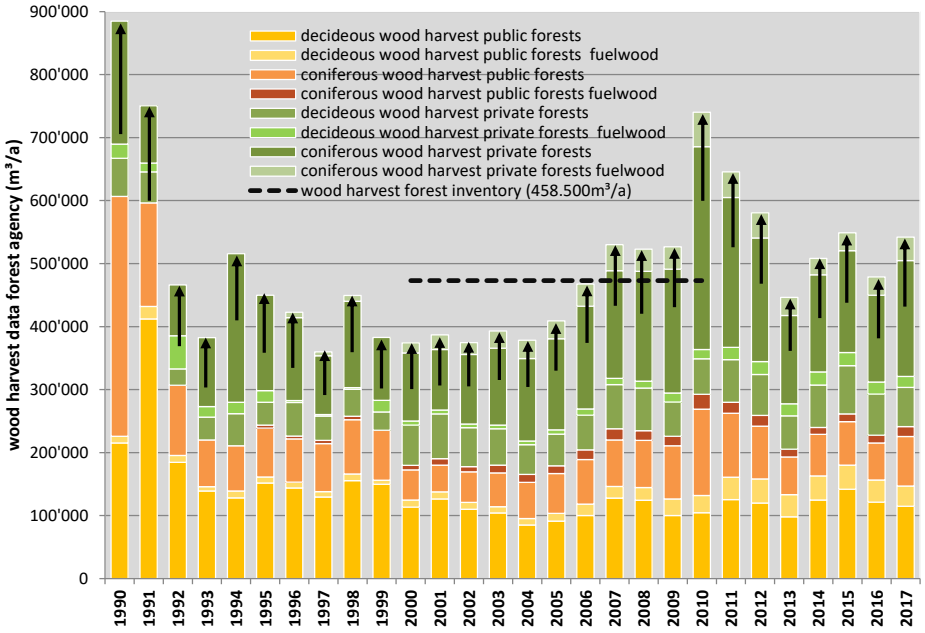


Figure 4-7 shows the yearly harvest from public forests (orange/yellow/pink/red bars) as collected by the ANF. The green bars show the estimated harvest from private forests. Harvest from forest under private ownership is estimated by applying the specific harvest ratios and forest distribution as collected by the NFI. The main weakness of this method is that any fluctuations in harvest from forests under public ownership are directly transferred to the estimated harvest from privately owned forest. This inflates he overall fluctuations in harvest that are reported.

The peaks in 1990 and 1991 and the subsequent fall in harvest can be explained through the salvage logging after the windstorm of 1990. The peak in 2010 has been traced back to the change of forest practice in one northern

commune and also because of salvage logging after the windstorm Xinthia. Considering that this increase happened in coniferous forests the estimated wood harvest of privately owned forests was strongly affected as the area of private coniferous forest is twice as high as public coniferous forests and the average harvest rate out of coniferous forests is very high (8.7 m³/h/a).

Figure 4-8 *historical harvesting rates GHGI*



The black dotted line shown in *Figure* 4-4 is the total average harvest in stemwood as estimated by comparing the two NFIs. The average harvest (377 000 m³/a) between 2000 and 2010, published by the ANF, is 25 % lower than the average measured during the forest inventory (473 000 m³/a). One of the reasons is that the potential stemwood measured in the NFI does not consider removal losses (and bark fraction) which are estimated at 10%. The other reason is the difference in total forest area between forest inventory (86.050 ha) and forest area measured from GHGI (96.000 ha) which inflates the total harvest from the forest inventory. Furthermore a high proportion of dead wood remains in public forest after harvest.

For the purpose of the GHGI the whole time series of official statistics on wood harvest data (1990-2017) was amended (+25%) to match the wood harvest rate of the forest inventory. The reasons to align the data collected from the ANF to the one from the forest inventory are the following:

- It's a conservative approach.
- The data collected from the inventory is more reliable as it is based on a more systematic approach
- The calculation of the total biomass removed is based on country specific biomass expansion and conversion factors (described here above) which are based on the definition of stemwood as measured during the forest inventory.

It is also important to note that the measured wood harvest shown **Figure 4-8** also includes the biomass removed during conversion of forestland in other land use. According to IPCC Guidelines 2006 Chapter 4.2.1.3 the definition of wood removals and fuelwood removals state clearly that "wood removal from Forest Land Remaining Forest Land and wood removal coming from Forest Land conversion to other uses should be separated". In order to avoid double counting in the GHGI the data of carbon loss due to biomass loss from forest land conversion to other land use is subtracted from the carbon loss due to wood removal. ***Figure 4-3*** this harvest is shown as a carbon gain in order to make it visible in the chart.

4.1.1.5 Modelling harvest rates

As mentioned, beforehand forest management practices in forest under private ownership are unknown. For forests under public ownership forest management practices are known but are not necessarily consistently applied (they often diverge for even and uneven age stands). Rotation ages are for example available for public

forests (see **Table 3-2**) and are used to establish forest management plans. For private forests no rotation ages could be identified.

For this reason the modelling approach, based on maintaining a constant harvest to biomass ratio (alternative 2 described in Box 12 of the guidelines), was chosen. This method does not require a modelling approach based on forest management practices and is in line with the GHGI as it is based on the result of the GHGI.

In order to maintain consistency with GHGI the modelling of the harvest rates are carried out in volume (m^3 stemwood) and not in weight of biomass. In GHGI a biomass conversion (Table 4-10) is applied to the measured harvest rate. The same method is applied to the calculation of the FRL.

Alternative 2: Maintain the 'harvest to biomass' ratio

This is a more general alternative based on the previous Alternative 1. It uses the same step-by-step method but replaces the biomass available for wood supply (BAWSRP and BAWSCP) by the total biomass (TBARP and TBACP) 20. The steps for this alternative then become:

- Step a: Calculate the total biomass in the RP (TBA_{RP}).
  The results of this step are described in *Figure 4-6*

- Step b: Document the harvest amount during the RP (H_{RP}).
  The results of this step are described in *Figure* 4-6 and *Figure 4-5*.

- Step c: Estimate the Harvest Fraction of Management (HFM_{RP}) during RP as: $HFM_{RP}= H_{RP} / TBA_{RP}$. HFM_{RP} is a proxy that expresses the impact of all constraints on the harvest during RP.
  The results are provided in Table 4-2, Table 4-3, Table 4-4 and Table 4-5

- Step d: Estimate the future biomass available for wood supply (TBA_{CP}) by applying the same FMP of the RP to the expected age-related evolution of forest characteristics (e.g.,biomass and increment).
  Results described in *Figure 4-9*

- Step e: Set future harvest (HCP) as: HFM_{RP} x TBA_{CP}.
  Results described in *Figure 4-9*

Table 4-2 *calculation parameters for deciduous forests under public ownership*

age class	TBA_{RP} (m^3/ha/a)	H_{RP} (m^3/ha/a)	HFM_{RP}	$increment_{RP}$ (m^3/ha/a)
0-40	123	2.25	1.83%	5.36
41-80	258	2.46	0.95%	4.02
81-120	370	4.77	1.29%	5.82
121-160	380	4.96	1.31%	5.15
160+	374	3.15	0.84%	4.63

Table 4-3 *calculation parameters for deciduous forests under private ownership*

age class	TBA_{RP} (m^3/ha/a)	H_{RP} (m^3/ha/a)	IM_{RP}	$Growth_{RP}$ (m^3/ha/a)
0-40	139	1.11	0.80%	5.36
41-80	268	1.11	0.41%	4.02
81-120	388	4.37	1.13%	5.82
121-160	485	3.95	0.82%	5.15
160+	379	4.55	1.20%	4.63

Table 4-4 *calculation parameters for coniferous forests under public ownership*

age class	TBA_{RP} (m^3/ha/a)	H_{RP} (m^3/ha/a)	IM_{RP}	$Growth_{RP}$ (m^3/ha/a)
0-20	123	5.10	4.14%	14.63
21-40	412	11.44	2.78%	17.44
41-60	503	9.21	1.83%	14.55
61-80	564	11.19	1.98%	11.26
80+	569	8.05	1.41%	7.87

Table 4-5 *calculation parameters for coniferous forests under private ownership*

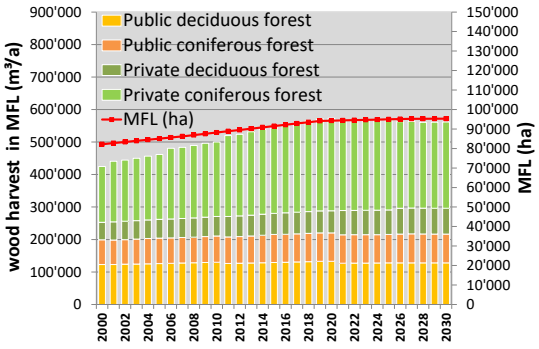
age class	TBA_{RP} (m^3/ha/a)	H_{RP} (m^3/ha/a)	IM_{RP}	$Growth_{RP}$ (m^3/ha/a)
0-20	118	2.66	2.25%	14.63
21-40	403	10.59	2.63%	17.44
41-60	492	16.00	3.25%	14.55
61-80	590	8.43	1.43%	11.26
80+	589	14.33	2.43%	7.87

The assumption is taken that the growth rates are the same in forest under public and private ownership. The reason behind this assumption is to reduce the uncertainty due to a lack of samples. The assumption also seems justified as it is not suspected that growth rates are largely affected by ownership.

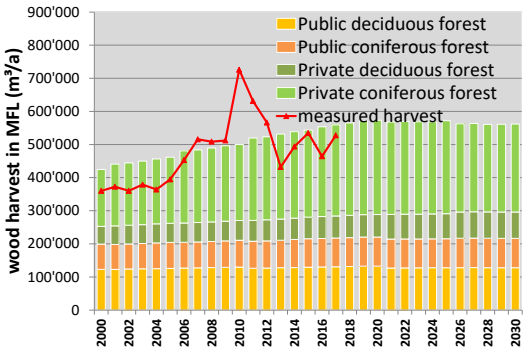
The conservative approach is taken that no final harvest is realised. The management intensity does include final harvest for the RP. Considering the evolution of the age class distribution (especially for coniferous forest) there is a strong chance that the proportion of final harvest will be higher in the future.

Figure 4-9 *projected harvest*

projected harvest and MFL



projected harvest and measured harvest



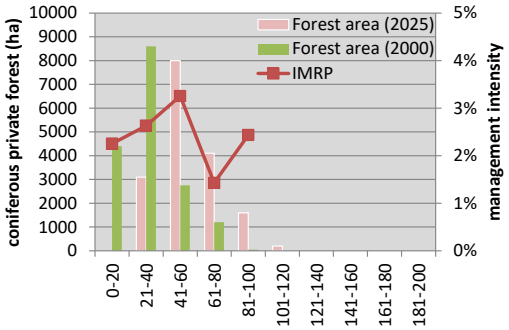
The following observations can be drawn from the projection of harvest

- The results from the calculations of harvest are expressed as specific harvest (m^3/ha) and are multiplied by the area of MFL. As the area of MFL is set to increase in the future (**Table 4-1**) so will the harvest in this category. This is the main driver in the evolution of projected harvest.
- The projected harvest has peaked in 2020 (as has the evolution of MFL). The harvest is expected to remain fairly constant for the duration of the CP.
- In order to compare the measured harvest of historic data and the projected harvest the harvest linked to land use change from forest has been subtracted from the measured harvest.

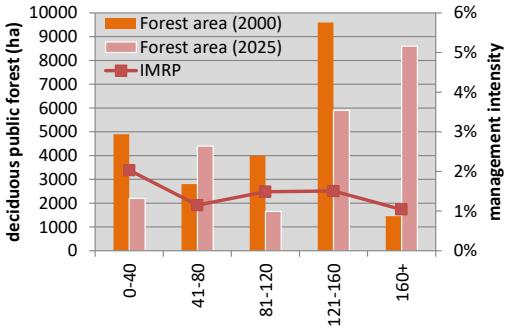
- As already mentioned multiple times the measured harvest has strong yearly fluctuations which cannot be simulated as they can be the result of windfall, deferred harvest between years etc. Over a long term average the projected harvest seems however to follow the measured harvest.

Figure 4-10 *age class evolution and management intensity*

Private ownership/coniferous forest



Public ownership/deciduous forest



- For the period after 2010 the measured harvest is lower than the projected harvest. This is due to the fact that the harvest in forests under private ownership is purely based on measured harvest in forests under public ownership. Between 2000 and 2010 forests under private ownership had a high proportion of forests under the age of 40. Clearcutting in coniferous forest above 50 years is allowed and it can be reasonably assumed that harvest will have increased in those forests. The measured harvest is however only based on forest under public ownership and the harvest in those forests. An increase in harvest in coniferous forests under private ownership due to a change in age class structure can only be picked up if a third NFI is conducted. Hence it is very likely that the measured harvest in coniferous forests under private ownership is underestimated. It is hence essential that a third NFI is conducted in order to validate harvest levels in privately owned forests.

4.1.2 FRL modelling – dead wood

Table 4-6 *values for dead wood by inventory year (tonnes d.m. ha^{-1} yr^{-1})*

	2000	2010
Dead wood on floor	6.3	7.0
Dead wood standing	3.8	5.0

In the 2017 GHGI a stock-difference approach was used to account for changes in dead wood. In the 2018 GHGI the results of the dead wood calculations from the FRL have been used instead. This means that the evolution of the carbon stock in dead wood is the same in GHGI and the FRL.

Data on dead wood stocks is available at two points in time (NFI 1 – year 2000 and NFI 2 – year 2010). Dead wood with a diameter greater than 7 cm and older than 3 years (unlikely to be harvested) was considered. In order to estimate the biomass for dead wood the biomass expansion factor were not applied which means that small branches of dead wood are not considered. Even though the degree of decomposition influences the quantity of biomass it is not considered in this study as no data on decomposition was collected. Over the last years the forest agency has pursued an active policy to increase the dead wood in public forest. This has led to an increase in dead wood in the forest as can be seen in **Table 4-6**.

The calculation for the FRL estimates an evolution of the dead carbon stock by considering dynamic age-related characteristics. For the calculation of the FRL a carbon pool variation module (Box. 13 in the guidance) is used to estimate the evolution of this carbon pool. Carbon stock change factors (CSCF) were established according to the same stratification as applied for the calculation of harvest rate. CSCF factors were established according to forest type, ownership and age classes. The stratification according to age class allows taking into account of the age class evolution.

Table 4-7 *dead wood calculation parameters for coniferous forests under public ownership*

age class	NFI 2000 (td.m. ha^{-1})	NFI 2010 (td.m. ha^{-1})	CSCF (td.m. $ha^{-1}yr^{-1}$)
0-20	2.5	6.1	0.36
21-40	10.1	10.3	0.02
41-60	11.3	14.6	0.33
61-80	19.6	12.9	-0.67
80+	0.4	13.1	1.26

Table 4-8 *dead wood calculation parameters for coniferous forests under private ownership*

age class	NFI 2000 (td.m. ha^{-1})	NFI 2010 (td.m. ha^{-1})	CSCF (td.m. $ha^{-1}yr^{-1}$)
0-20	2.6	4.0	0.14
21-40	10.2	17.2	0.71
41-60	21.8	21.6	-0.02
61-80	10.6	10.6	0.00
80+	21.5	40.6	1.91

Table 4-9 dead wood *calculation parameters for deciduous forests under private ownership*

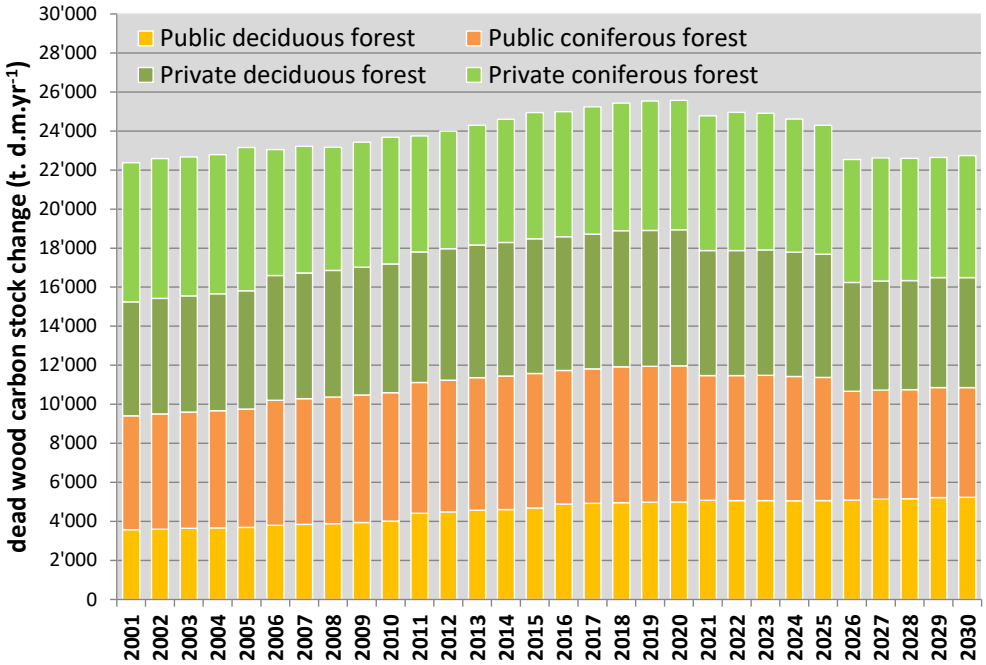
age class	NFI 2000 (td.m. ha^{-1})	NFI 2010 (td.m. ha^{-1})	CSCF (td.m. $ha^{-1}yr^{-1}$)
0-40	5.9	7.5	0.16
41-80	11.0	16.0	0.50
81-120	18.8	14.8	-0.40
121-160	12.8	15.0	0.22
160+	3.9	6.3	0.24

Table 4-10 dead wood *calculation parameters for deciduous forests under public ownership*

age class	NFI 2000 (td.m. ha^{-1})	NFI 2010 (td.m. ha^{-1})	CSCF (td.m. $ha^{-1}yr^{-1}$)
0-40	5.7	6.2	0.05
41-80	7.0	9.9	0.30
81-120	13.0	11.0	-0.20
121-160	11.8	13.2	0.14
160+	1.4	3.0	0.15

In order to project the dead wood stock the projected forest areas for each stratum were calculated using the age-structure module. Those projected areas were then multiplied by the respective CSCFs for each stratum calculated here above.

Figure 4-11 *projected dead wood stock change*



Here as well a continuous increase can be observed in the first years due to an increase until 2020 of MFL. An abrupt change can be observed in 2020. This is can be explained that the age of a lot of trees was estimated at round figures (e.g. 50 years.) For deciduous forest this meant that in 2021 trees that were estimated at 60 years all transited in the category 81-120 years. This had a strong influence in deciduous under private ownership as those forests have a younger age structure. For deciduous forest under public ownership this effect is not as strong as the age structure of those forests is much older. For coniferous forests under private ownership the dead wood accumulation rate (see Table 4-8) in the categories 21-40 and 41-60 are almost zero and hence no major difference is observed. For coniferous forests under public ownership the opposite is true.

It is important to highlight the importance of carrying out a third forest inventory in order to measure the dead wood stock before 2025. If this is not the case than any real increase of dead wood will not be accounted for in the GHGI.

4.1.3 FRL modelling – litter

For the changes in carbon stock in litter the IPCC GPG Tier 1 approach is used assuming that no changes in the litter carbon stock occur. Unfortunately, no data on litter C stock changes has so far been collected in Luxembourg so that this hypothesis could not be verified. The same approach is being used for the calculation of the FRL.

4.1.4 FRL modelling – HWP

LU does unfortunately not have very reliable available for calculating HWP and has in the past not provided estimates on this carbon pool. This can be partly explained by the small size of the country with high import and export of wood products. Article 5(4) requires the Member States to include in their accounts any change in the carbon stock of above-ground biomass, below-ground biomass, litter, dead wood, soil organic carbon, and HWP.

LU has taken the decision to include HWP in its accounting for FRL and the GHGI 2018. LU has addressed certain issues regarding incomplete and inconsistent datasets by using a different range of conservative hypothesis and simplifications.

Annex IV A (c) the reference level should ensure a robust and credible accounting system that ensures that emissions and removals resulting from biomass use are properly accounted for;

Emissions from the use and disposal of harvested wood products are estimated using the model described in (Hirashi, et al., 2014). The basis of this model is the first order decay function which simulates total stock volumes depending on the life expectancy of products. The life expectancy of HWP is described by using half-life values. The half-life is the number of years it takes for the quantity of carbon stored in a harvested wood products category to decrease to one half of its initial value. The evolution of stock volumes are calculated using the following equations:

$$C(i+1) = e^{-k} \cdot C(i) + \left[\frac{1-e^{-k}}{k}\right] \cdot Inflow\ (i) \qquad \textit{(Equation 4-1)}$$

$$\Delta C(i) = C(i+1) - C(i) \qquad \textit{(Equation 4-2)}$$

where :

i = year

C(i) = the carbon stock in the particular HWP category at the beginning of the year i, (GgC)

k = decay constant of first order decay function for each HWP category given in units yr^{-1} (k=ln(2)/HL, where HL is the half-life of the HWP pool in years

Inflow(i) = the inflow to the particular HWP category during the year i (GgC/a)

ΔC(i) = carbon stock change of the HWP category during year i (GgC/a)

The evolution of stock volumes is carried for two different types of products: sawnwood (which has a half-life of 35 years) and wood-based panels (which have a half-life of 25 years).

According to Annex V imported HWP shall not be accounted for by the importing Member State. This is realised by using the production approach which estimates the net change of the proportion of the HWP carbon pool that originates from wood harvested in the producer country. In order to achieve this the share of industrial roundwood for the domestic production of HWP originating from domestic forests is calculated for each year with the following equation (Hirashi, et al., 2014):

$$f_{IRW}(i) = \frac{IRW_P(i) - IRW_{EX}(i)}{IRW_P(i) + IRW_{IM}(i) - IRW_{EX}(i)} \qquad \textit{(Equation 4-3)}$$

4.1.4.1 Data available in the FAO database

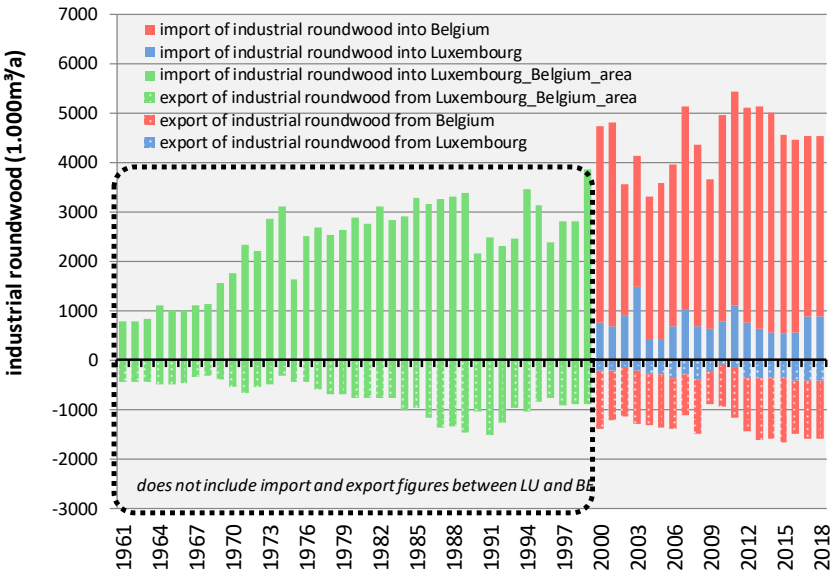
FAOSTAT-Forestry provides annual production and trade estimates for numerous forest products, primarily wood products such as roundwood, sawnwood, wood panels, pulp and paper. For most countries, historical data are available from 1961 onwards. These estimates are provided by countries through an annual survey conducted by FAO (JFSQ questionnaire). In cases where countries have not provided information through the questionnaire, FAO estimates annual production. The LU forest agency is responsible for submitting this questionnaire. For LU the JFSQ questionnaire is often prefilled with import and export data from Eurostat (comex). The comex database does however only include import and export data but not production of HWP. The forest agency only submits data on production data on roundwood (industrial roundwood, sawlogs, and pulpwood). Production data on wood-based panels, sawnwood, wood pulp, paper etc have only submitted occasionally and were based on basic production capacity figures of individual factories rather than actual production figures.

4.1.4.2 Data available on production, imports and exports of industrial roundwood

In order to use the production approach, the share of industrial roundwood, originating from domestic forests, for the domestic production of HWP needs to be calculated. Furthermore, data for the main HWP categories need to

date back, ideally, to 1960. For most countries data on HWP categories in the FAO database date back to 1960. For Luxembourg this is unfortunately not the case as all the data on HWP categories only date back to the year 2000. From 1961 until 2000 data is combined for Luxembourg and Belgium who are jointly considered as one region. *Figure 4-12* is showing import and export of industrial roundwood retrieved from the FAO database for Luxembourg, Belgium and the Luxembourg-Belgium area.

***Figure 4-12** import and export of industrial roundwood in Luxembourg and Belgium (source: FAO)*



As Luxembourg and Belgium are considered as one region between 1961 and 2000, fluxes of roundwood between both countries are not available. This is visible in *Figure 4-12* as there is a clear jump in combined export and import figures between both countries after 2000. Import and export figures between Luxembourg and Belgium are however considerable in relation to the total production of roundwood in LU. Luxembourg exports a high amount of beech wood to a paper mill in Belgium. This paper mill has been in operation since the seventies. On the other hand, Luxembourg has one of the biggest wood-panel producers in Europe. It is however estimated that only 10% of the wood, needed for the production, originates from Luxembourg. Hence it can be assumed that a vast majority of this wood is imported from Belgium. One reason for the high volume of wood import is that the production of wood-panels requires coniferous wood which is very abundant in Belgium.

Figure 4-13 *amended import and export of industrial roundwood in Luxembourg and Belgium (source: FAO)*

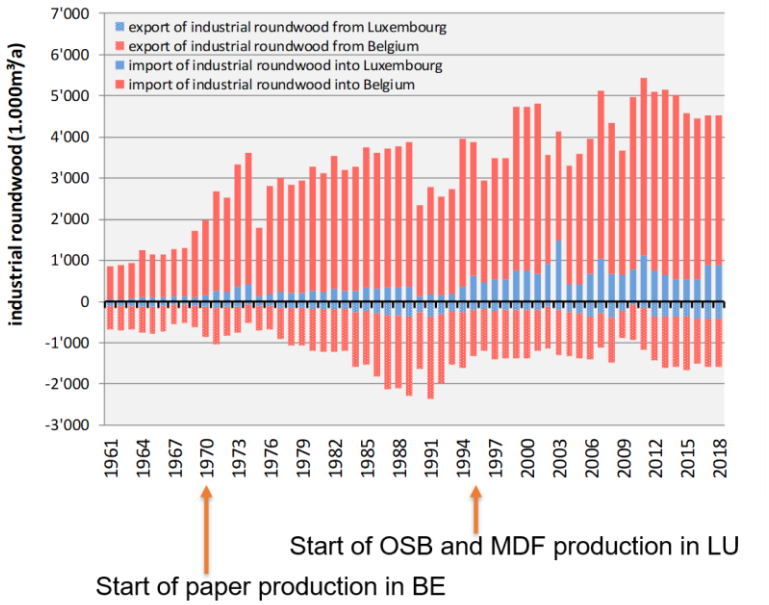
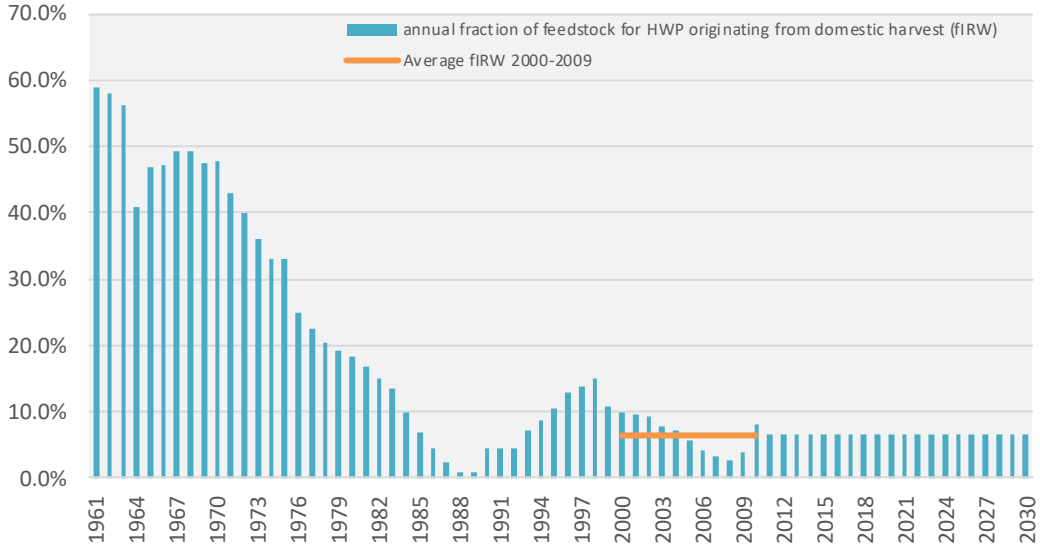


Figure 4-13 illustrates how the import and export of industrial roundwood was amended to take into account import and export figures between LU and BE:

- Increase of combined export of roundwood from Luxembourg and Belgium in order to take into account the export and import figures between those two countries. This was realised by comparing total import and export between 2000 and 1999
- A decrease of industrial roundwood into Luxembourg before the start of the wood-panel production in 1995.

The high annual fluctuations of roundwood import into Luxembourg is probably due to stock fluctuations of roundwood purchased by the HWP producers.

Figure 4-14 *annual fraction of feedstock for HWP originating from domestic harvest (before 2000, RP and CP)*



Import and export of industrial roundwood are very high and show strong yearly fluctuations. Those fluctuations can partly be explained by stock changes and bulk purchases by the wood processing industry. Unfortunately, yearly fluctuations of import and export can, on an annual basis, lead to inconsistent results. For this reason, a 10-year moving average was used in order to calculate the annual fraction of feedstock for HWP originating from domestic harvest (f_{IRW}). In the RP the average value for f_{IRW} is 6,4 % and the same value was used for modelling HPW in the CP (see *Figure 4-12*).

4.1.4.3 *Harvesting rates disaggregated between energy and non-energy uses.*

Data on harvest rates, disaggregated between energy and non-energy use, is only available for public forests. In the reference period this ratio was 15%. For modelling HWP this ratio remained constant throughout the commitment period and was also applied to wood harvested in private forests.

4.1.4.4 *Production of wood-based panels and sawnwood*

As mentioned in the previous chapters LU has a major wood-panel (mainly OSB and MDF) producer. Unfortunately, no production data is collected in LU. Data on export of wood-based panels is however based on the comex database and are very reliable. Hence the assumption is taken that the production of wood-based panels is equal to the export of wood-based panels. This assumption seems justified as it is a conservative approach and the market for wood-based panels is LU is small compared to the production.

For the production of sawnwood and wood-based panels before 2000 the combined production between LU and BE was split onto both countries by considering the production ratio of both countries for the period between 2000 and 2005 (5-year average). As the production of wood-based panels only started in 1995 the calculation for wood-based panels was considered to be zero before that year.

Annex IV A (e) a constant ratio between solid and energy use of forest biomass as documented in the period from 2000 to 2009 shall be assumed

The projection of HWP production in the CP is linked to the projected harvest rate, the ratio between energy and non-energy use as well as the average production of HWP in the RP. An increase of projected harvest would hence lead to an increase of production of HWP. This approach is in line with Annex IV A (e) but does not consider that production of HWP is linked to production capacity rather than wood availability.

Figure 4-15 *projection of wood-based panel production and sawnwood in Luxembourg*

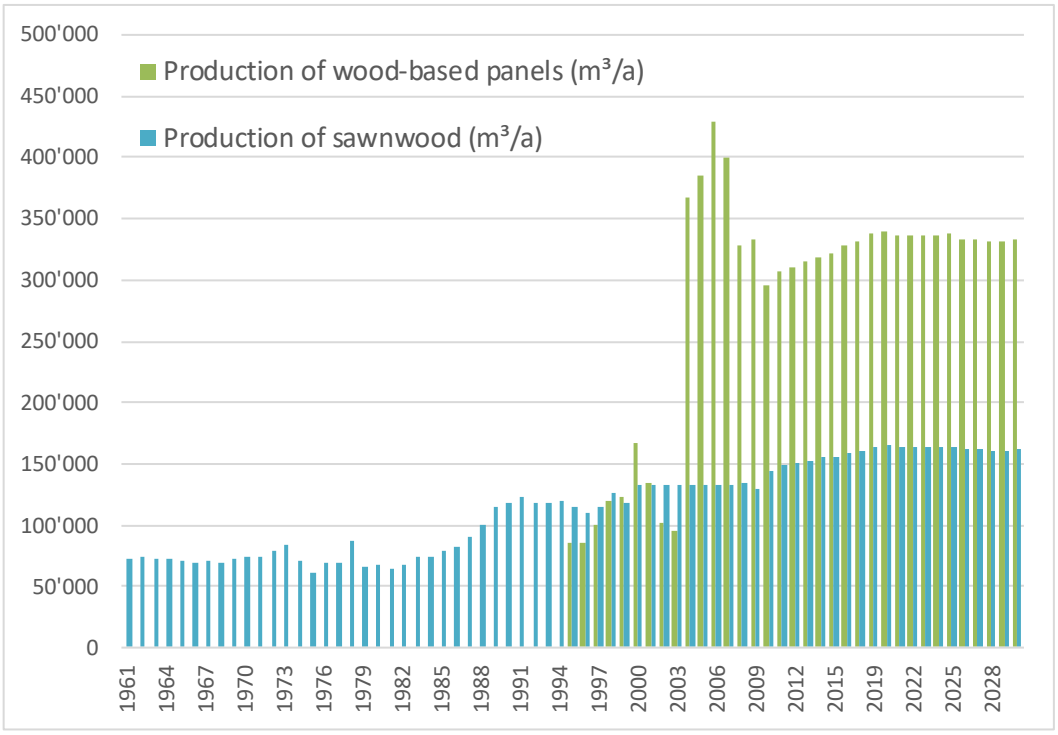


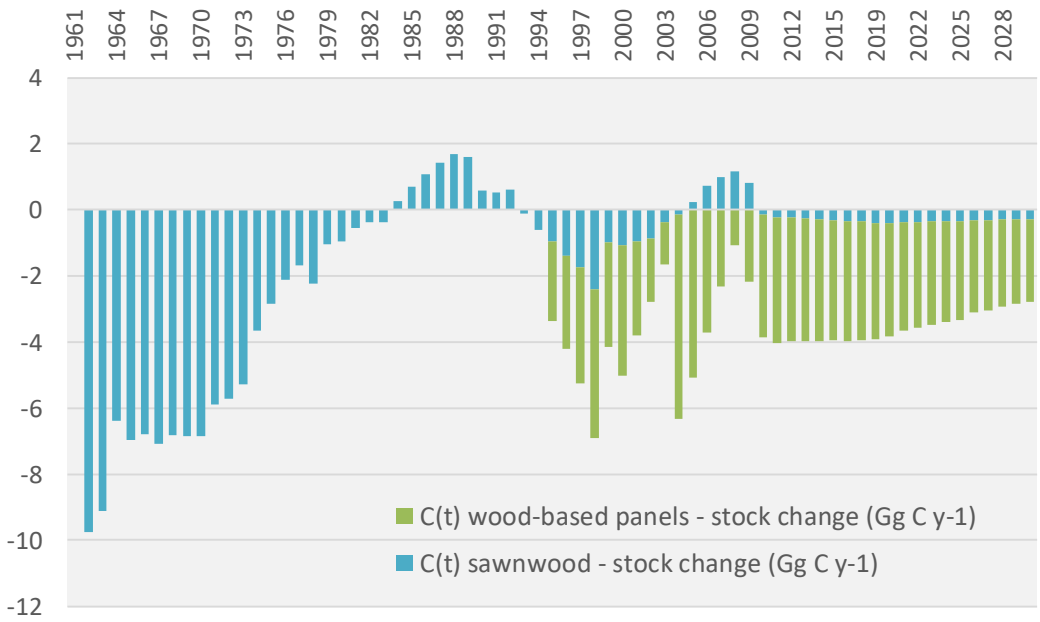
Figure 4-12 shows measured data on production of wood-based panels and sawnwood from 1961-2009. From 2010 onwards production data have been estimated with regards to the production in the RP as well as projected harvest rates.

4.1.4.5 *Data available on production, imports and exports of pulpwood*

There is no production of paper and paperboard in Luxembourg using pulpwood originating from LU forests.

4.1.4.6 *Projected emissions and removals in the HWP pool.*

Figure 4-16 *historical and projected carbon emission and removals in HWP*



By 1985 the balance for sawnwood in terms of inflow and outflow has been reached. For wood-panels the production only started in 1995 and hence a balance has not been reached yet. This leads to projected sink for this carbon pool.

Annex IV A (d) the reference level shall include the carbon pool of harvested wood products, thereby providing a comparison between assuming instantaneous oxidation and applying the first-order decay function and half-life values;

The carbon pool of harvested wood products has been included. The previous version of the NFAP assumed instantaneous oxidation and hence an analysis between the two versions allows a comparison between assuming instantaneous oxidation and applying the first-order decay function and half-life values. The difference between instantaneous oxidation and applying the first order decay function is an increase of the FRL by +/- 3 (Gg C yr^{-1}) or only 2,6 %.

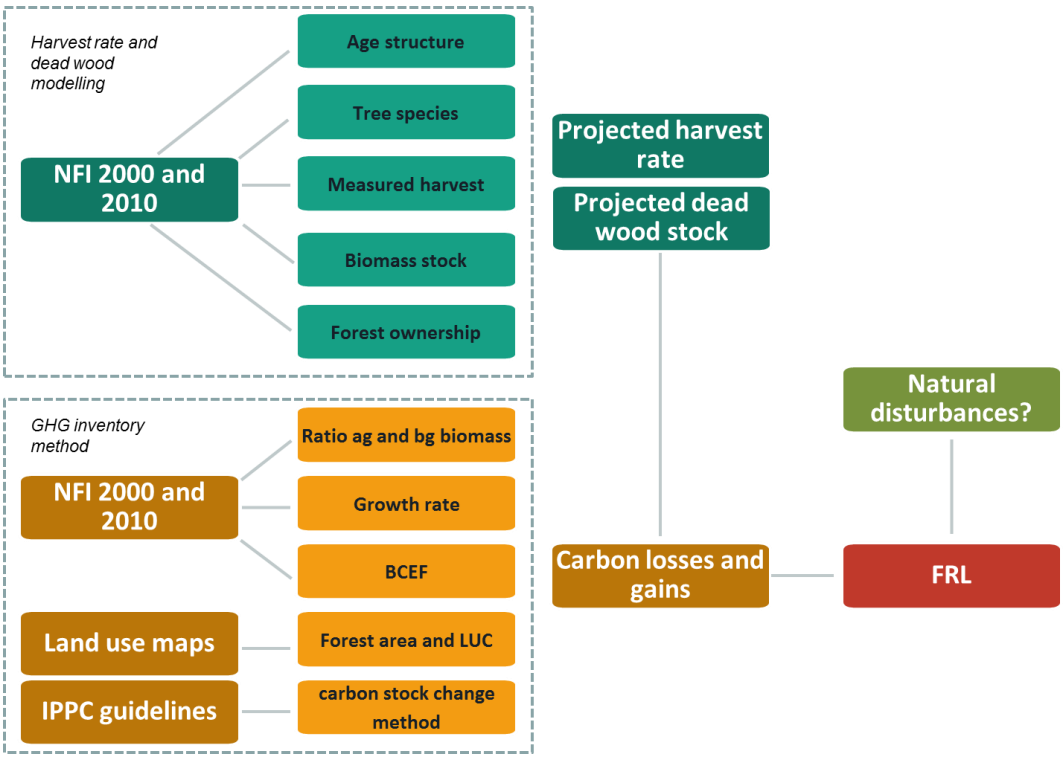
4.2 Consistency between the forest reference level and the latest national inventory report

Annex IV A (g) the reference level shall be consistent with the national projections of anthropogenic greenhouse gas emissions by sources and removals by sinks reported under Regulation (EU) No 525/2013;

National projections reported under Regulation (EU) No 525/2013 have been revised and published on 15th march 2019. Those figures reflect the changes this study apart from the calculations of HWP which were only introduced after this date.

Annex IV B (c) A description of approaches, methods and models, including quantitative information, used in the determination of the forest reference level, consistent with the most recently submitted national inventory report.

Figure 4-17 *FRL calculation method.*



In order to guarantee consistency between the GHGI and the calculation of the FRL Luxembourg decided to use the same calculation method for carbon pool. ***Figure 4-17*** illustrates how the FRL is calculated compared to the GHGI.

The calculation of the FRL can be split in two parts:

1. In a first step (green part of ***Figure 4-17***), the projected harvest rate is calculated according to the method described in section 4.1.1.5. Strata specific values for growth, harvest, biomass etc have been extracted from the NFIs in order to determine total harvest. As the measured harvest from GHGI is corrected in order to be in line with the results of the NFI the consistency and comparability of both harvest rates is guaranteed. Also no assumption on climate change was made to determine harvest rates.
2. In the second step (brown/orange part) the calculation method of the GHGI is used to calculate carbon losses and gains. A detailed description of these calculations can be found in the latest National Inventory Report (NFI) from Luxembourg. In those calculations country specific biomass conversion and expansion factors (extracted from NFIs) are used to convert harvest and growth from m^3 in tonnes of biomass. Those factors were estimated by taking into account the proportion and types of trees (NFI) found in coniferous forests as well as deciduous forest (Alderweireld, 2015). The same applies to growth factors which are based on NFI but are aggregated according to forest type (and not ownership or age structure).

Using the same calculation method for FRL and GHGI guarantees consistency but also requires a technical correction if the calculation method of the GHGI is changed.

Annex IV A (h) the reference level shall be consistent with greenhouse gas inventories and relevant historical data and shall be based on transparent, complete, consistent, comparable and accurate information. In particular, the model used to construct the reference level shall be able to reproduce historical data from the National Greenhouse Gas Inventory

Annex IV B (b) Demonstration of the consistency between the carbon pools included in the forest reference level.

Figure 4-18 *historical and projected carbon emission and removals in MFL*

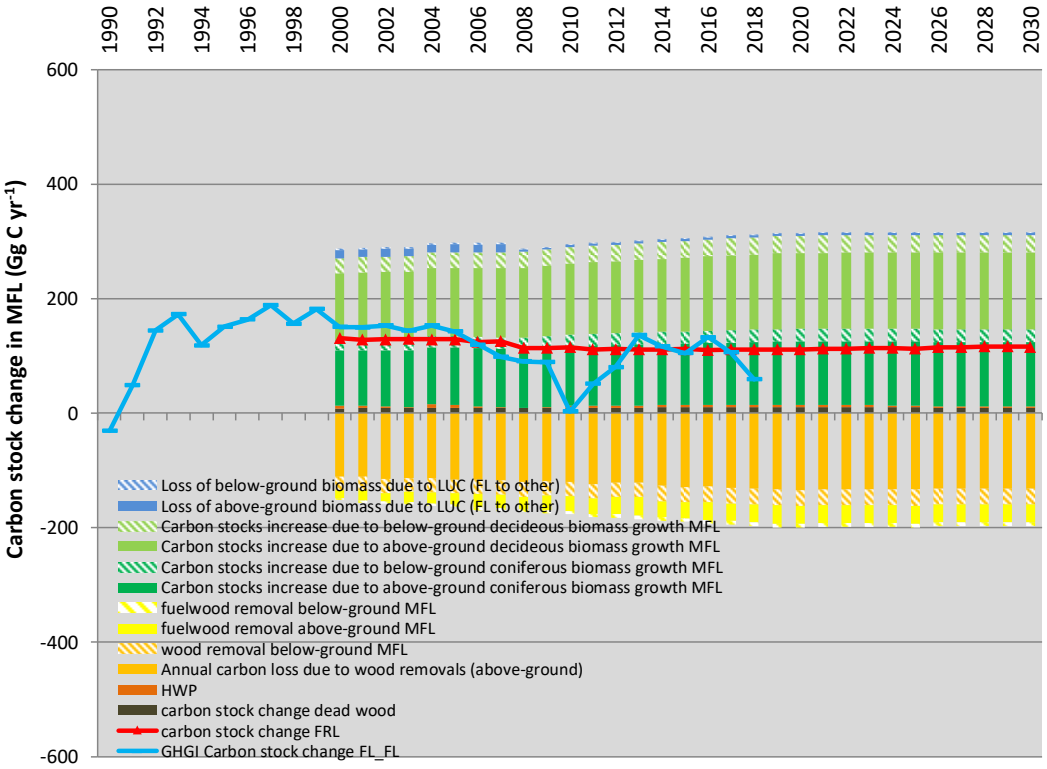
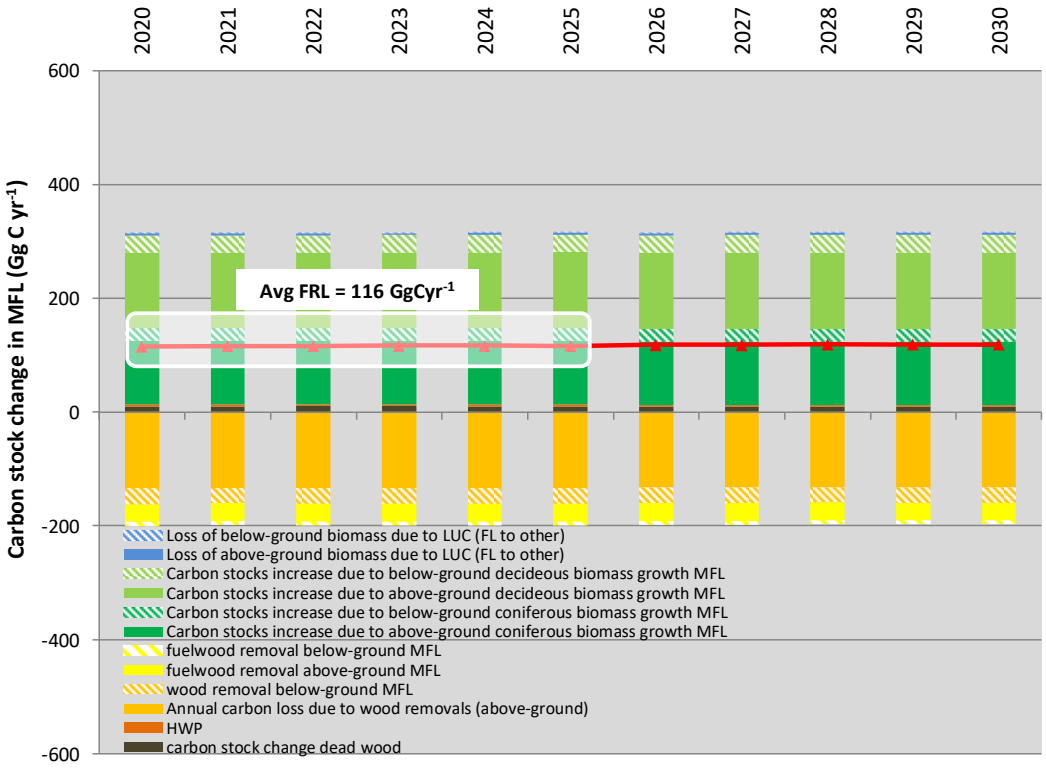


Figure 4-18 compares the projected carbon stock gains and losses from FRL with the historical carbon stock change in GHGI (blue line). The year on year variations of the total carbon stock change in GHGI is driven by fluctuations in harvest rates. The reasons of those yearly variations in harvest have been explained in great detail in section 4.1.1.4 and it is impossible for the calculations of FRL to reproduce those annual changes. Taking into account the fact that the fluctuations cannot be reproduced there seems, nevertheless, to be a good match between historical and projected carbon losses and gains.

4.3 Calculated carbon pools and greenhouse gases for the forest reference level

Figure 4-19 *projected carbon emission and removals in MFL for the CP*



For the CP, from 2020 to 2025, the FRL to be considered is 116 $GgCyr^{-1}$ or **- 426 (Gg CO_2 yr^{-1}).**

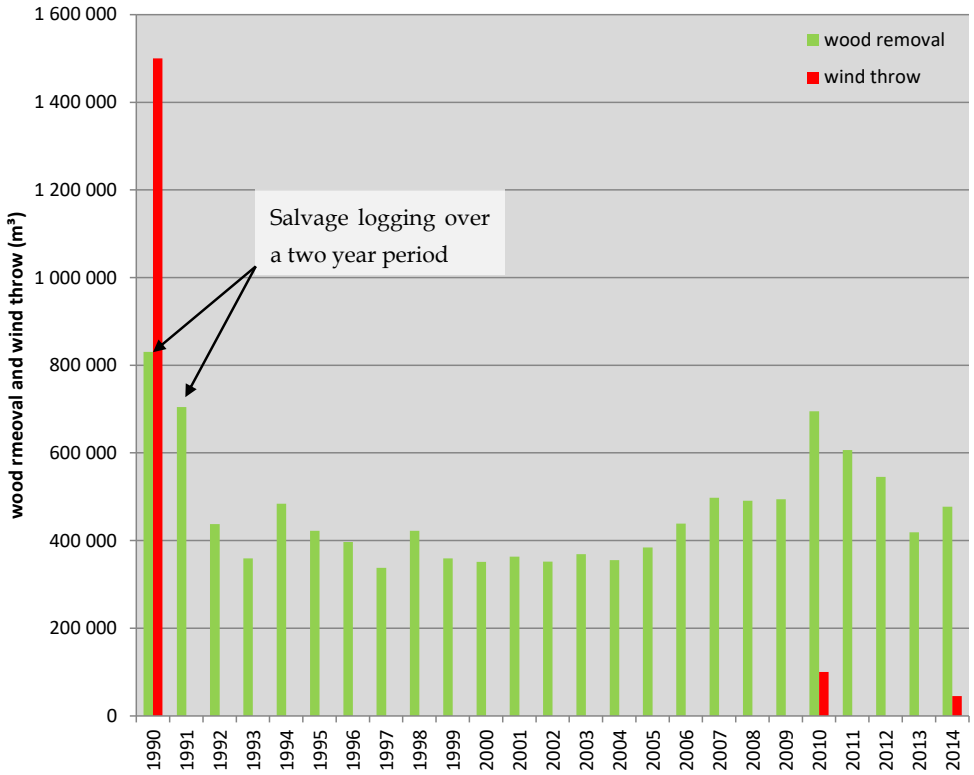
4.4 Background level of natural disturbances

Luxembourg has decided to elect the provision for the treatment of natural disturbance emissions for FRL

Wildfires have occurred on some occasions but are very rare and the extent has always been very limited. Insect attacks (eg bark beetle) do occur in Luxembourg but forest owners have an obligation to remove infected trees (salvage logging) in order to stem its propagation. The same principle applies to disease infestations (mainly fungal infestation like Fomes fomentarius and ash tree infestation). Ash tree infestation with Hymenoscyphus fraxineus is, as in many European countries, widespread in Luxembourg. Luxembourg does, however, not have a big ash tree population (+/- 1,3 %) and infestations are generally acted on by removing trees (salvage logging).

Extreme weather events, like wind storm, on the other hand, can have wide reaching consequences for Luxembourg. Due to the small size of the country one major storm can have a severe impact on the total forest population in Luxembourg.

Figure 4-20 *data on wood loss through windfall*



Data on wood loss due to wind storms are available for following storms: Viven, Wiebke (1990), Klaus (2009) and Xynthia (2010) and have been collected by the forest agency. *Figure 4-20* is showing wood loss due to wind throw (red bars) as well as wood removal due to forest management (green bars). Wind storms do not occur on an annual basis and hence a number of years show zero emissions due to windstorms. The most severe windstorm was windstorm Viven, Wiebke in 1990. The following wood losses due to the wind storms in 2010 and 2014 were only minor. The data on wood removal highlights how, after the wind storm of 1990, salvage logging has been taking place over two years. In Luxembourg wood lost through the wind storms is in general salvaged. Emissions from and associated with salvage logging cannot be excluded from accounting during the commitment period and consequently historical emissions from natural disturbances should exclude emissions from salvage logging.

Due to the small number of natural disturbances over the course the analysed time series the default method cannot be used as the standard deviation is always greater than the mean average over the remaining values (and this by excluding one, two or all three values). In the past, most wood lost has been recovered through salvage logging and hence the provision for natural disturbances could not have been applied. It seems also unlikely that Luxembourg will apply the provision in the future. The provision has to be regarded more as a safeguard in case of major storm events might hit Luxembourg in the future and affect most of the forest areas.

5 Conclusion

The National Forestry and Accounting Plan (NFAP) describes the approach adopted by Luxembourg to establish a Forest Reference Level (FRL) in order to comply with the 'LULUCF Regulation'. Luxembourg has received technical support from the European Commission during the preparation of the NFAP and FRL. In order to be in line with the Regulation Luxembourg has implemented all recommendations of this report.

Two consecutive national forest inventories (NFIs) were carried out during the reference period (2000 and 2010) and the FRL is based exclusively on the results from these two NFIs. In order to make best use to this data Luxembourg used a harvest module developed by the Joint Research Centre. This model is based on maintaining a constant harvest to biomass ratio and is described as alternative 2 (Box 12) of the guidance document developed by the European Commission).

Due to its small forest size (~ 96 kha) the results of the NFI (only 1.200 sample plots) have to be aggregated as much as possible in order to maintain the results statistical significant. Hence the stratification was limited to ownership (private or public), forest type (deciduous or coniferous) and age classes.

The comparison of the FRL with historical results from the Green House Gas Inventory (GHGI) is very difficult because annual measured harvest rates have very strong fluctuations. Windfall events or simultaneous harvest in different areas are not always balanced out in other forest areas and create strong year on year fluctuations. Those fluctuations are not a consequence of the evolution of age-class structure or change in forest management practices and are impossible to reproduce through simulations. The comparison of the results from the GHGI and the FRL can only be realised over a long time period.

Luxembourg has included the HWP carbon pool in its calculation for the FRL as well as the 2018 GHGI.

For the calculation of the dead wood pool a variation module (Box. 13 in the guidance document) is used to estimate the evolution of this carbon pool.

As a result of these calculations the FRL chosen for Luxembourg is 116 $GgCyr^{-1}$ or **- 426 (Gg CO_2 yr^{-1})..**

The harvest in forests under private ownership is based on the harvest measured in forests under public ownership. In order to have meaningful result in the GHGI and be able to compare the results to the FRL it is imperative to realise another NFI in 2025 and/or 2030. A further NFI would also allow measuring the change in the carbon stock in dead wood. Alternatively, another method would need to be developed in order to measure directly harvest rates in forest under private ownership on a yearly basis.

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