IPCC Working Group III report: The land sector and climate mitigation

April 6, 2022

This briefing summarises the IPCC Working Group III (WG3) report's main insights about the mitigation options in the Agriculture, Forestry and Other Land Uses (AFOLU) sector. The term "land sector" will be used throughout this briefing for clarity. The briefing also summarises the findings on the needs and limitations of land-based carbon dioxide removal (CDR).

Key points

- Rapid deployment of mitigation in the land sector is essential in all 1.5°C pathways. **It can provide up to 30% of the global mitigation needed for the 1.5°C and 2°C pathways.**
- The sector offers significant near-term mitigation potential at relatively low cost. **The global land-based mitigation potential is ~8–14 billion tonnes of CO_2 equivalent ($GtCO_2$-eq) each year between 2020-2050**. About 30-50% of this potential could be achieved under USD20 per tCO2-eq. Options costing USD100 per tCO_2-eq or less could reduce global GHG emissions by at least half the 2019 level by 2030 (SPM C.12). But land-based mitigation cannot compensate for delayed emissions reductions in other sectors.
- The IPCC recognises that carbon dioxide removal (CDR) is necessary to achieve net-zero GHG globally. **Modelled scenarios rely heavily on forest planting and BECCs as main options to remove emissions from the atmosphere to achieve it**.
- **But, the IPCC is not advocating for large-scale CDR.** There are many uncertainties, risks and a lack of social licence for these options. It is still uncertain whether CDR through some land-based measures can be maintained in the very long term because sinks can saturate, for example. CDR cannot be deployed arbitrarily and given the time needed to ramp-up CDR, it can only make a limited contribution to reaching net zero in the timeframe required.
- **There is a substantial investment gap in the sector.** The IPCC estimates that, to date, only USD 0.7 billion a year has been invested in land-based mitigation, well short of the more than USD 400 billion per year needed to deliver the up to 30% of global mitigation effort in deep mitigation scenarios.

The land sector is key to climate mitigation, but only within limits

The land sector is both a carbon source and a carbon sink. It accounted for ~13%-21% of global greenhouse gas (GHG) emissions between 2010-2019.[1] But the land sector is also a carbon sink, as it draws CO_2 from the atmosphere when plants grow (through the process of photosynthesis). **When the sector's sources and sinks are added up, the land sector is considered a net sink of emissions - removing about 6.6 $GtCO_2$ a year for the period of 2010-2019.**[2]

The IPCC clearly states that the land sector has huge potential for mitigation. It can both reduce emissions - for example by changing farming and livestock practices - as well as remove them from the atmosphere, via measures like planting more forests and protecting existing ones. But the sector "**cannot fully compensate for delayed action in other sectors".** (SPM C.9)

[1] Chapter 7, p.4. This is different from emissions of the entire food system, which are estimated to account for 23-42% of global GHG emissions in 2018 - Ch.12, p.4. For sinks there is also a error of aprox +/- 5.2

[2] Chapter 7, p.4. This is different from emissions of the entire food system, which are estimated to account for 23-42% of global GHG emissions in 2018 - Ch.12, p.4. For sinks there is also a error of aprox +/- 5.2. Chapter 3, p.42 : **But there are still large uncertainties on net CO_2 human emissions and its long-term trends**. Currently, national GHG inventories (NGHGI) tend to overestimate the amount of CO_2 absorbed by sinks when compared to other global models. There is a gap of ~5.5 $GtCO_2$ a year between NGHGI and Bookkeeping models and dynamic global vegetation models. The difference largely results from different definitions of what "anthropogenic" means, which leads NGHGIs to estimate that more CO_2 is taken up by sinks.

Overall, the IPCC estimates that the global land-based mitigation potential is **~8–14 billion tonnes of CO_2 equivalent ($GtCO_2$-eq) each year between 2020-2050,** at costs below USD 100/tCO_2.[3] These estimates are slightly higher than those in AR5. Considering both integrated assessment models (IAMs) and sectoral economic potential estimates, WG3 **states that "land-based mitigation could have the capacity to make the sector net-negative GHG emissions from 2036 although there are highly variable mitigation strategies for how [its] potential can be deployed for achieving climate targets"**.[4] There are many options that can help reduce and remove emissions (Box 1). Most of the options to reduce emissions are available and ready to deploy, whereas CDR needs more investment.[5]

The IPCC does not use the term 'nature-based solutions' (NbS), but 'land-based mitigation measures'. When evaluating the mitigation potential within the sector, it discusses 20 measures, both supply and demand-side (Box 1). However, when it analyses mitigation pathways, it only includes a few options because of how climate models are currently built (see the role of CDR in mitigation pathways section for more detail).

Box 1. What are the main ways the land sector reduces and removes emissions between 2020-2050?

Forests and other ecosystems have the highest potential for carbon mitigation, according to global sectoral models. Protecting, managing and restoring these ecosystems is likely to reduce and/or sequester up to 7.4 billion tonnes of CO_2 equivalent each year between 2020 and 2050.[6] Crucially, the IPCC finds that protecting ecosystems has the highest potential. The report also stresses that halting deforestation and restoring peatlands is vital to keeping temperature rises below 2C.

Agriculture and demand-side measures provide the second and third highest potential for mitigation, potentially reducing and/or sequestering up to 4.1 and 3.6 billion tonnes of CO_2 equivalent a year respectively between 2020 and 2050.[7] For agriculture, the measures that have the greatest potential are soil carbon management in croplands and grasslands, agroforestry, biochar and rice cultivation, as well as livestock and nutrient management. On the demand-side, it's shifting to healthy diets and reducing food waste and loss.

Land sector mitigation measures can have important co-benefits, but only if done properly. For example, "reforestation and forest conservation, avoided deforestation and restoration and conservation of natural ecosystems and biodiversity, improved sustainable forest management, agroforestry, soil carbon management and options that reduce CH_4 and N_2O emissions in agriculture from livestock and soil, can have multiple synergies with the sustainable development goals."[8]

But there are many risks and trade-offs. Large-scale or poorly planned deployment of bioenergy, biochar, and afforestation of naturally unforested land. (high confidence) for instance, can compete with scarce resources, such as agricultural land. [9] This can threaten food production and security and reduce adaptive capacity. The use of non-native species and monocultures (e.g. planting one type of tree) in forest projects can also lead to biodiversity loss, and negatively impact ecosystems.[10] There are also risks in relation to land's ability to continue to act as a carbon sink in the future, which can reduce land sector measures' capacity to mitigate emissions.[11]

Joint and rapid effort is key to achieving high levels of mitigation in the sector, the IPCC says. But there has been a lack of funds to support these efforts. The IPCC estimates that, to date, only USD 0.7 billion a year has been invested in the sector, well short of the more than USD 400 billion per year needed to deliver the up to 30% of global mitigation effort envisaged in deep mitigation scenarios.[12]

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[3]Chapter 7, p.41. The bottom end represents the mean from IAMs and the upper end the mean estimate from global sectoral studies. The economic potential is about half of the technical potential from AFOLU, and about 30-50% could be achieved under USD20 tCO2-eq-1. Note that the IPCC uses a different methodology for individual AFOLU options than for the total sector potential.
[4]Chapter 7, p.42. "Economic mitigation potential is the mitigation estimated to be possible at an annual cost of up to USD100 tCO2 -1 mitigated. This cost is the price at which society is willing to pay for mitigation and is used as a proxy to estimate the proportion of technical mitigation potential that could realistically be implemented."
[5]Chapter 7. 42
[6]SPM, p.43
[7]SPM, p.43
[8]SPM, p. 53
[9]SPM, p. 55
[10]Chapter 7 of WGIII provides an overview of 20 mitigation measures, evaluating the co-benefits and risks from land-based mitigation measures, estimated global and regional mitigation potential and associated costs according to literature published over the last decade.
[11]Chapter 7.4
[12]Chapter 7, p.6. This is based on land-based carbon offsets (i.e. money from the Clean Development Mechanism, voluntary carbon standards, compliance markets and reduced deforestation).

What does the IPCC say about the scale of land-based CDR?

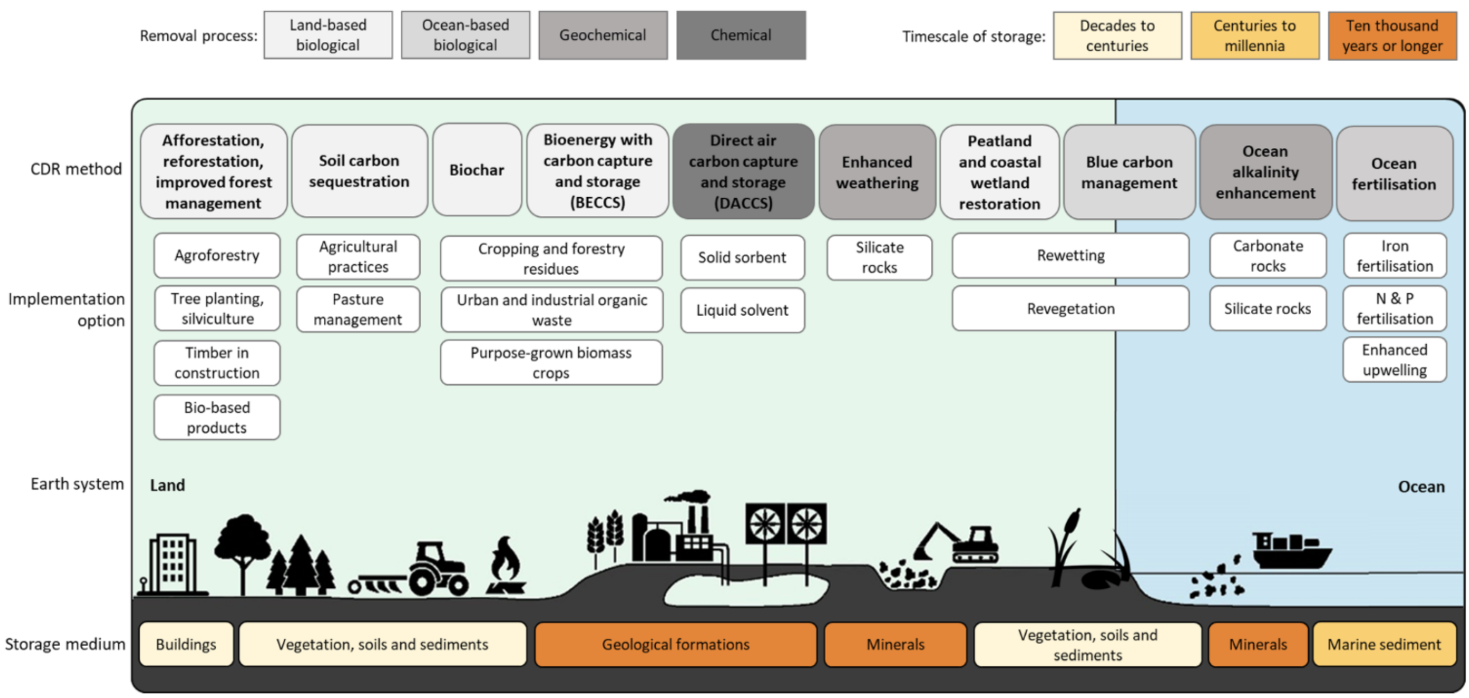
Mitigation potential of different CDR options

CDR is defined by the IPCC **as "human activities that remove emissions from the atmosphere and durably store it".** Thus, CDR excludes uptake of emissions not directly caused by humans. CDR can help in several phases of mitigation:

1. Reducing net CO_2 or GHG emission levels in the near-term
2. Counterbalancing residual emissions from hard-to-transition sectors like industry and agriculture to help reach net-zero CO_2 or GHG emissions targets in the mid-term
3. Achieving and sustaining net-negative CO_2 or GHG emissions in the long-term if deployed at levels exceeding annual residual emissions.[13] Therefore, offsets are discussed in the report as a way to counterbalance residual emissions, highlighting that hard-to-abate sectors could have more social licence to rely on CDR.[14]

Currently, the only widely practised CDR methods include afforestation, reforestation, improved forest management, agroforestry and soil carbon sequestration.[15] Figure 1 presents the options that can be deployed on land as well as in the oceans. The IPCC discusses these options, presenting a summary of their mitigation potential, risks, co-benefits and costs. (Table 1 in the appendix) However, the IPCC does not go into detail on all options. For example, it mentions that the choice of feedstock for BECCS could lead to positive or negative impacts, but does not explore all feedstock options and their related consequences.

Figure 1. CDR methods across Land sector and Oceans (IPCC- WG3 Chapter 12, p.37)



The role of CDR in mitigation pathways

The WG3 report looks at what the science says about mitigating the climate crisis. As established in most scientific literature, achieving net zero by mid-century is the safest way to stay Paris aligned. There are, however, many different routes to net zero. Thus, the scope of this report is to chart the options, limits,

[13]SPM, p. 48
[14] The IPCC evaluates previous offsets measures, such as REDD+, offsets within emissions trading systems, among others in chapter 7;Chapter 3, p. 14-15
[15]SPM, p. 47

benefits and trade-offs of pursuing a net-zero emissions society. To do this, the IPCC reviewed more than 3000 pathways, including over 1200 scenarios, to develop five "Illustrative Mitigation Pathways" (IMPs) and two high-emissions pathways for reference.

The report finds that "CDR is a necessary element to achieve net-zero CO_2 and GHG emissions, and counterbalance residual emissions from hard-to abate sectors".[16] It is also a key element in scenarios that are likely to limit warming to 2°C or lower by 2100".[17] All of its IMPs use land-based CDR, which is dominated by BECCS, afforestation and reforestation.[18]

In most scenarios that limit temperatures to 2°C or lower, the IPCC predicts cumulative volumes of CO_2 removed between 2020-2100 could reach (all median values)[19]:

- BECCS - 328 $GtCO_2$
- Net CO_2 removal on managed land (including afforestation and reforestation) - 252 $GtCO_2$
- Direct Air Capture Capture and Storage (DACCS) - 29 $GtCO_2$.

To put this into perspective, the remaining carbon budget assessed by WG1 from the beginning of 2020 onwards is 500 $GtCO_2$ for limiting warming to 1.5°C with a 50% chance of success.[20] The IPCC also predicts that mitigation measures in 2°C or below pathways can significantly transform land all around the world. These pathways are "projected to reach net-zero CO_2 emissions in the land sector between the 2020s and 2070, with an increase in forest cover of about 322 million hectares (-67 to 890 million ha) [an area almost as big as the US and India combined] in 2050 in pathways limiting warming to 1.5°C with no or limited overshoot". [21]

Delaying action will result in larger and more rapid deployment of CDR later, especially if there is a temperature overshoot. Then, large-scale deployment of CDR will be needed to bring temperatures back.[22] Since IAM pathways rely on afforestation, reforestation and BECCS, delayed mitigation can lead to a lot of changes in land use, with negative impacts for sustainable development.[23] The IPCC points out that "strong near-term mitigation to limit overshoot, and deployment of other CDR methods than afforestation / reforestation and BECCS may significantly reduce the contribution of these CDR methods in scenarios limiting warming to 1.5 or 2C".[24] "Stronger focus on demand-side mitigation implies less dependence on CDR and, consequently reduces pressure on land and biodiversity**".[25]** It adds that: **"Within ambitious mitigation strategies…, CDR cannot serve as a substitute for deep emissions reductions"**.[26] To put this into perspective, the market for carbon offsets today, which include these CDR measures, reduce global emissions by about 0.1%, according to the Energy Transitions Commission.

But while most scenarios in WG3 still rely on CDR to achieve net-zero, the IPCC is not advocating for large amounts of it. Instead, the reliance on CDR reflects the state of climate modelling and research (see box 2 in appendix). The IPCC discusses the uncertainty, risks and lack of social licence for CDR, such as concerns that large-scale CDR could obstruct near-term emission reduction efforts or lead to an over-reliance on technologies that are still in their infancy.[27] **It stresses that there is uncertainty about how much CDR will be deployed in the future and the amount of CO_2 it can remove permanently from the atmosphere.**[28] This is because some measures in the land sector cannot be maintained indefinitely as these sinks will ultimately saturate, while trees can also be cut down, burnt or die prematurely.[29]

[16]Chapter 12, p. 35
[17]Chapter 12, p. 35
[18]Chapter 12, p.4 and p. 55
[19]Chapter 12, p. 5
[20]Summary for policymakers, p. 6
[21]Chapter 3, p. 6
[22]Smith et al. 2019; Hasegawa et al. 2021
[23]IPCC 2019, Hasegawa et al. 2021
[24]Chapter 12, p. 56
[25]Chapter 3, p. 7
[26]Chapter 12, p. 38
[27]Chapter 12, p. 39
[28]Chapter 12, p. 39
[29]Chapter 3, p.7

Appendix

Mitigation potential of different CDR measures

Table 1. Summary of status, costs, potentials, risk and impacts, co-benefits, trade-offs and spillover effects and the role in mitigation pathways for CDR methods. TRL = Technology Readiness Level. (ch 12.p.58-61)

CDR option	Status (TRL)	Cost (USD tCO2 -1)	Mitigation Potential (GtCO2 yr)	Risk & Impacts	Co-benefits	Trade-offs and spill-over effects	Role in modelled mitigation pathways
DACCS	6	100–300 (84–386)	5–40	Increased energy and water use.	Water produced (solid sorbent DAC designs only).	Potentially increased emissions from water supply and energy generation.	In a few IAMs: DACCS complements other CDR methods.
Enhanced weathering (EW)	3–4	50–200 (24–578)	2–4 (<1–95)	Mining impacts. Air quality impacts of rock dust when spreading on soil.	Enhanced plant growth, reduced erosion, enhanced soil carbon, reduced pH, soil water retention.	Potentially increased emissions from water supply and energy generation.	In a few IAMs: EW complements other CDR methods.
Ocean alkalinity enhancement	1–2	40–260	1–100	Increased seawater pH and saturation that may impact marine life, possible release of nutritive or toxic elements and compounds, mining impacts.	Limiting ocean acidification.	Potentially increased emissions of CO2 and dust from mining, transport and deployment operations.	No data.
Ocean fertilisation	1–2	50–500	1-3	Nutrient redistribution, restructuring of the ecosystem, enhanced oxygen consumption and acidification in deeper waters, potential for decadal-to-millennial-scale return to the atmosphere of nearly all the extra carbon removed, risks of unintended side effects.	Increased productivity and fisheries, reduced upper ocean acidification.	Subsurface ocean acidification, deoxygenation, altered meridional supply of macronutrients as they are utilised in the iron-fertilised region and become unavailable for transport and utilisation in other regions, fundamental alteration of food Webs and biodiversity.	No data.
Blue carbon management in coastal wetlands	2–3	Insufficient data, estimates range from ~ 100 to ~ 10000	<1	If degraded or lost, coastal blue carbon ecosystems are likely to release most of their carbon back to the atmosphere, potential for sediment contaminants, toxicity, bioaccumulation and biomagnification in organisms, issues	Provide many non-climatic benefits and can contribute to ecosystem based adaptation, coastal protection, increased biodiversity, reduced upper ocean acidification, could potentially benefit	If degraded or lost, coastal blue carbon ecosystems are likely to release most of their carbon back to the atmosphere. The full delivery of the benefits at their maximum global capacity will require years to decades to be achieved	Not incorporated in IAMs, but in some bottom-up studies: Small contribution

				related to altering degradability of coastal plants, use of subtidal areas for tidal wetland carbon removal, effect of shoreline modifications on sediment redeposition and natural marsh accretion, abusive use of coastal blue carbon as means to reclaim land for purposes that degrade capacity for carbon removal.	human nutrition or produce fertiliser for terrestrial agriculture, anti-methanogenic feed additive, or as an industrial or materials feedstock.		
BECCS	5–6	15–400	0.5–11	Competition for land and water resources to grow biomass feedstock, biodiversity and carbon stock loss if from unsustainable biomass harvest.	Reduction of air pollutants, fuel security, optimal use of residues, additional income, health benefits and, if implemented well, can enhance biodiversity, soil health and land carbon	Competition for land with biodiversity conservation and food production	Substantial contribution in IAMs and bottom-up sectoral studies
Afforestation/ Reforestation	8–9	0–240	0.5–10	Reversal of carbon removal through wildfire, disease, pests may occur. Reduced catchment water yield and lower groundwater level if species and biome are inappropriate.	Enhanced employment and local livelihoods, improved biodiversity, improved renewable wood products provision, soil carbon and nutrient cycling. Possibly less pressure on primary forests	Inappropriate deployment at large scale can lead to competition for land with biodiversity conservation and food production.	Substantial contribution in IAMs and also in bottom-up sectoral studies.
Biochar		10–345	0.3–6.6	Particulate and GHG emissions from production, biodiversity and carbon stock loss from unsustainable biomass harvest.	Increased crop yields and reduced non-CO2 emissions from soil, and resilience to drought.	Environmental impacts associated particulate matter, competition for biomass resource.	In development - not yet in global mitigation pathways simulated by IAMs.
Soil carbon sequestration in croplands and grasslands	8–9	45–100	0.6–9.3	Risk of increased nitrous oxide emissions due to higher levels of organic nitrogen in the soil, risk of reversal of carbon sequestration.	Improved soil quality, resilience and agricultural productivity.	Attempts to increase carbon sequestration potential at the expense of production, net addition per hectare is very small, hard to monitor.	In development - not yet in global mitigation pathways simulated by IAMs. In bottom-up studies: Medium contribution.
Peatland and coastal wetland restoration	8–9	Insufficient data	0.5–2.1	Reversal of carbon removal in drought or future disturbance, risk of increased methane emissions.	Enhanced employment and local livelihoods, increased productivity of fisheries, improved biodiversity, soil carbon and nutrient cycling.	Competition for land for food production on some peatlands used for food production.	Not in IAMs but some bottom-up studies with medium contribution.

Agroforestry	8–9	Insufficient data	0.3–9.4	Risk that some land area lost from food production; requires high skills	Enhanced employment and local livelihoods, variety of products improved soil quality, more resilient systems.	Some trade-off with agricultural crop production, but enhanced biodiversity and resilience of the system.	No data from IAMs, but in bottom-up sectoral studies: Medium contribution
Improved Forest management	8–9	Insufficient data	0.1–2.1	If improved management is understood as merely intensification involving increased fertiliser use and introduced species, then it could reduce biodiversity and Increase eutrophication.	In case of sustainable forest management, leads to enhanced employment and local livelihoods, enhanced biodiversity, improved productivity.	If it involves increased fertiliser use and introduced species, it could reduce biodiversity and increase eutrophication and upstream GHG emissions.	No data from IAMs, but in bottom-up sectoral studies: Medium contribution.

Source: IPCC- WG3 Chapter 12

Box 2. A word about climate models and the potential and limitations of land sector mitigation

Since the last IPCC reports, there have been more assessments of the total mitigation potential of the land sector.[30] These can be split into:

- **Sectoral models:** These estimate the potential of the sectors and/or individual measures. But they rarely capture cross-sector interactions, making it difficult for them to account for land competition and trade-offs. This could lead to double counting when aggregating sectoral estimates across different studies and methods.[31] They usually show higher mitigation potential as they include more land-based mitigation options than IAMs.[32]
- **IAMs and integrative land-use models (ILMs):** IAMs assess multiple and interlinked practices across sectors, and thus account for interactions and trade-offs (i.e. land competition). IMLs combine different land-based mitigation options, which are only partially included in IAMs. Both have extended their coverage, but the modelling and analysis of land-based mitigation options is new compared to sectoral models. Consequently, "[Land sector] options are only partially included in these models, which mostly rely on afforestation, reforestation and BECCS".[33]
- Currently, most models do not consider, or have limited consideration of, the impact of future climate change on land.[34] And there is still uncertainty about land's ability to act as a sink in the future and how this will impact mitigation efforts.[35] Bottom-up and non-IAM studies show significant potential for demand-side mitigation.[36] (see Table 2 in the Appendix)

When evaluating the potential of different land-based mitigation measures, AR6 uses mainly sectoral models and compares to IAM's, when available. But, AR6 still relies on IAMs/ILMs to devise mitigation pathways. This can be problematic in two main ways:

- **Climate change impacts on land and future mitigation potential:** Given the [IPCC WG1](#) finding that land sink efficiency is decreasing with climate change, relying too much on land to remove CO_2 from the atmosphere could be problematic. This could create a false sense of security and allow for land mitigation to be used as an excuse for not making deep emissions cuts. This is key as many corporations are relying on offsetting emissions in the land sector instead of reducing them.
- **Unrealistic CDR projections (over-reliance on BECCS and afforestation and reforestation)**: The volumes of future global CDR deployment assumed in IAM scenarios are large compared to current volumes of deployment. This is a challenge for scaling up. Similarly, the lack of representation of other options makes it difficult to compare [different measures](#) and envisage a different future that alters the contribution of land in terms of timing, potential and sustainability.

[30] Chapter 7, p.40
[31] Chapter 7, p.40-42
[32] Chapter 3, p. 64
[33] Annex III- p.29; Chapter 7, p.86
[34] Chapter 7. 42
[35] Chapter 7. 116
[36] Chapter 3, p. 7