Teagasc note on carbon budgets

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Acronyms and Abbreviations

A	Agriculture
AFOLU	Agriculture, Forestry and Other Land Use
ANC	Areas of Natural Constraint
E	Energy System (other non-agricultural GHG emitting sectors of the economy)
BAU	Business as Usual
BVD	Bovine viral diarrhea
CAN	Calcium Ammonium Nitrate
CB1	Carbon Budget Period 1 (2021-2025)
CB2	Carbon Budget Period 2 (2026-2030)
CCAC	Climate Change Advisory Council
CCAC CBC	Climate Change Advisory Council Carbon Budgets Committee
CH_4	Methane
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
DAFM	Department of Agriculture, Food and the Marine
E70:A20	Carbon budget outcome where non-agricultural emissions (Energy) are reduced by 70% and agricultural GHG emissions reduced by 20% relative to 2018 levels.
E65:A25	Carbon budget outcome where non-agricultural GHG emissions (E) are reduced by 65% and agricultural GHG emissions reduced by 25% relative to 2018 levels.
E61:A33	Carbon budget outcome where non-agricultural GHG emissions (E) are reduced by 61% and agricultural GHG emissions reduced by 33% relative to 2018 levels.
E57:A40	Carbon budget outcome where non-agricultural GHG emissions (E) are reduced by 57% and agricultural GHG emissions (A) reduced by 40% relative to 2018 levels.
E51:A51	Carbon budget outcome where both non-agricultural GHG emissions (E) and agricultural GHG (A) emissions are reduced by 51% relative to 2018 levels.
EC	European Commission
EPA	Environmental Protection Agency
GHG	Greenhouse Gas

HNV	High Nature Value
IPCC	Intergovernmental Panel on Climate Change
kt	1000 tonnes
LESS	Low Emissions Slurry Spreading
LULUCF	Land Use, Land Use Change and Forestry
MACC	Marginal Abatement Cost Curve
MMAI	Mean Maximum Annual Increment (forestry rotation)
Mm^3	Million Cubic Metres
Mt	Million Tonnes
N_2O	Nitrous Oxide
UNFCCC	United Nations Framework Convention on Climate Change

Summary

GHG emissions from the Agriculture Sector

- Projections of GHG emissions from Irish agriculture, with and without technical abatement measures over the period to 2030 are compared with 5 different possible agriculture sector carbon budget outcomes.
- Sequestration of CO_2 from additional measures in the land use and forestry sector are also evaluated.
- Possible budgets for agriculture, forestry and other land use sector (AFOLU) are calculated based on those examined by the Climate Change Advisory Council's Carbon Budget Committee (CCAC CBC)
- In the 5 carbon budget outcomes examined by the CCAC CBC, the budget allocated to agriculture (A) and other non-agricultural sectors - the Energy system (E) - is set with reference to 2018 emissions levels.
- The 5 budgets for agriculture (A) and other sectors (E) are equivalent to emissions from the agriculture sector in 2030 being 20%, 25%, 33%, 40% and 55% lower than emissions in 2018.
- To reach the overall target of 51% lower emissions by 2030 the larger the carbon budget allocated to Agriculture (A) the smaller the budget available to non-agricultural sectors (E).
- Annual carbon budget allocations from 2021 to 2030 under each budget outcome are determined by the negative growth rate required to reduce emissions between 2021 and 2030 to the 2030 target level.
- The base level (2018) emissions from the agriculture sector is 21,965.5 kt CO_2e.
- The 2030 emissions allowed for agriculture under the 5 carbon budget outcomes range from 17,572.4 kt CO_2e under the E70:A20 budget to 10,763.1 kt CO_2e under the E51:A51 budget.
- Annual carbon budget allocations are aggregated to the 5 year budget periods set out in the Climate Action Bill 2021-2025 and 2026-2030.
- The carbon budgets for agriculture (A) and non-agricultural Energy System (E) for CB1 and CB2 under the 5 possible carbon budget outcomes are set out in Table E1.

Table E 1: Carbon Budget Allocations to the Agriculture Sector evaluated by the CCAC CBC

	Carbon Budget Period 1	Carbon Budget Period 2
	'000 t CO2e	
E70:A20	99,073.0	90,948.0
E65:A25	97,198.8	86,394.1
E61:A33	94,026.6	78,991.6
E57:A40	91,045.9	72,381.7
E51:A51	85,873.2	61,694.8

- Teagasc has evaluated the technical abatement measures assessed in the Teagasc MACC and DAFM Ag Climatise strategy, as well as abatement from additional technical measures that may be achievable over the period to 2030.

- Under a Business as Usual (BAU) agricultural activity scenario, GHG emissions from the agriculture sector, with all technical measures implemented, would exceed all of the carbon budgets in both of the budgeting periods listed in Table E1.
- If technical GHG mitigation measures cannot satisfy the carbon budget constraint, then agriculture would have to take measures to reduce agricultural activity levels.
- Under the largest carbon budget for agriculture considered (E70:A20), agricultural GHG emissions (under a BAU scenario) with all technical measures implemented, would be 3% higher than the budget allocation in period 1 (CB1) and 6% higher than the budget allocation in the second budgeting period (CB2).
- Under the smallest carbon budget considered (E51:A51), agricultural GHG emissions (under a BAU scenario) with all technical measures implemented ,would be 19% higher than the allocated budget in CB1 and 56% higher than the budget allocated for CB2.
- Table E2 shows the degree of budgetary overrun under each of the 5 carbon budget outcomes

Table E 2: Agricultural Emissions with all Technical Measures and Carbon Budget allocation: Degree of Budgetary Over run by Budgetary Outcome (budget overrun as % of allocated budget)

	Carbon Budget Period 1	Carbon Budget Period 2
E70:A20	3%	6%
E65:A25	5%	12%
E61:A33	8%	22%
E57:A40	12%	33%
E51:A51	19%	56%

- The smaller the carbon budget allocated to agriculture, the larger the reduction in agricultural activity required to allow agriculture to remain within its allocated carbon budget.
- Earlier papers by Teagasc submitted to the CCAC have shown the negative economic consequences of reductions in agricultural activity, as well as the negative impact of lower agricultural activity scenarios on employment within the Irish economy.

GHG sequestration from Land Use, Land Use Change and Forestry sector

- Teagasc has also evaluated the impact of additional land use and forestry measures on sequestration in the land use, land use change and forestry sectors.
- The GHG accounting approach used to measure emissions and removals of GHG by the land use, land use change and forestry (LULUCF) sector has important ramifications.
- Decisions relating to the GHG accounting process determine whether or not agriculture, land use, land use change and forestry sectors are considered as an integrated sector (AFOLU).
- Such GHG accounting decisions either relax or harden the constraints placed on levels of agricultural activity by carbon budget allocations for agriculture.
- There are two GHG accounting conventions, Net-Net and Gross-Net, that are used to assess GHG removals and emissions by the land use, land use change and forestry sectors.

- For the land use and forestry measures evaluated by Teagasc, if a **Net-Net approach** accounting approach to emissions and removals from the Land Use, Land Use Change and Forestry sector is chosen, this **would allow the AFOLU sector to remain within most of the budgets** implied by the 5 budget outcomes evaluate by the CCAC CBC for both CB1 and CB2.
- However, if the **Gross Net** approach to accounting for net sequestration by the Land Use, Land Use Change and Forestry sector is chosen, then we find that the AFOLU sector would not remain within the carbon budget allocations considered by the CCAC.
- In its (July 2021) proposals for a revision to EU Regulation 2018/841, the European Commission has proposed that a Net-Net accounting of emissions and removals in the AFOLU sector be used for the period 2021-2025, with a Gross Net approach to be adopted for the AFOLU sector for the period 2026-2030 and onwards.
- Our analysis shows that the approach proposed by the European Commission may allow the Agriculture, Forestry and other Land Use (AFOLU) sector to remain within some of the possible budget allocations implied the 5 budget sets examined by the CCAC for the first budgeting period (2021-2025).
- However our analysis finds that in the second budgetary period (2026-2030) emissions from the AFOLU sector, with all technical measures accounted for, would exceed the carbon budget, if the reduction in emissions from the AFOLU sector required is greater than 20%.

Carbon Budget Outcomes and Agricultural Activity Levels

- Where **agriculture as a sector is considered in isolation** from the land use, land use change, and forestry sectors **none of the budget targets** outlined in Table E1 **are likely to be achieved** under a Business as Usual activity scenario.
- To remain within all of the budgets considered, action would be required that would reduce agricultural activity levels.
- As shown by Teagasc analysis, reducing agricultural activity to comply with GHG budgetary targets, this would lead to lower agricultural output value and lower agricultural sector income, as well as knock on negative consequences for value added and employment in the wider economy.
- If emissions from the land use, land use change and forestry and agriculture sectors are considered together, using the **Net-Net approach** to the accounting for land use, land use change and forestry emissions for both carbon budget periods, this relaxes the constraints on agricultural activity likely to be posed by the carbon budgets considered by the CCAC.
- If either a **Gross-Net approach** or the **European Commission's proposed approach** (where Gross-Net approach utilised from 2026 onwards), **action would have to be taken to reduce agricultural activity** to allow AFOLU the sector to remain within budget, particularly in the CB2 budget period.

Introduction

In this note we set out our assessment of Irish agriculture sector emissions of GHG with and without measures (technical abatement measures in agriculture and agricultural land use measures) over the period to 2030 and compare these with 5 different possible agriculture sector carbon budgets outcomes.

We provide detail on the nature of the absolute agriculture GHG mitigation measures considered. The set of technical agricultural measures is expanded relative to that considered in the 2018 Teagasc GHG MACC (Lanigan and Donnellan, 2018) and Ag Climatise (DAFM, 2020).

Credit for Land Use and Forestry Measures will be important in achieving likely reduction commitments at a sectoral level. We present estimates of net sequestration from the Land Use, Land Use Change and Forestry sector and highlight the importance of the accounting rules that are used.

We use Business as Usual projections of agricultural activity levels provided to the EPA in December 2020 to illustrate how the agriculture sector GHG emissions, with and without measures, would compare with the possible carbon budget allocations to the sector. Two other scenarios are also examined. The first alternative agricultural activity scenario is where the Irish dairy herd by 2030 is effectively unchanged in size as compared to 2020 (Teagasc Scenario B). The second of the alternative agricultural activity scenarios is a “high agricultural activity” scenario provided by Teagasc to the EPA in December 2020 (Teagasc Scenario A+).

Readers should note that many of the mitigation measures analysed are likely to be very challenging to implement at the farm level. Policy action will almost certainly be required to incentivize the adoption of many of the measures considered. The incorporation of the mitigation measures within the national GHG inventory will also be necessary and for some measures this may prove challenging.

In the discussion in this note we concentrate on the Business as Usual (BAU), no policy change agricultural activity projections. An appendix to this note (Appendix B) provides equivalent information on the two alternative agricultural activity scenarios (Teagasc Scenario B and Teagasc Scenario A+). This Appendix illustrates the importance of the outlook with respect to agricultural activity for our analysis. Differences in the agricultural activity levels (and associated emissions of GHGs) across the three scenarios analysed are driven primarily by differing developments in the two key bovine breeding inventories: Dairy cows and Other (suckler) cows.

Under the BAU scenario, growth in the Irish dairy cow inventory continues over the medium term in response to market signals (strong real prices). The projected rate of growth in the Irish dairy cow inventory slows in the second half of the current decade, as the costs of further expansion in cow numbers increase. In the BAU scenario the inventory of suckler cows in Ireland contracts steadily over the period to 2030, as the already low margins from farming suckler cows contracts further in the face of growth in the costs of production that is projected over the medium term to exceed the growth in nominal beef output prices.

Under the Stable Dairy Herd Scenario (B) dairy cow inventories by 2030 are constrained to be no higher than in 2020. Associated with this outcome is slower negative growth in Irish suckler cow inventories. These two bovine breeding inventories compete at the margin for grassland resources, and reduced demand (relative to the BAU scenario) for grassland due to lower dairy cow numbers allows for a somewhat higher level of other (suckler) cows. Overall cattle inventories under the Stable Dairy Herd

Scenario (B) are lower than those projected under BAU scenario. This is due to a) the lower number of calves produced per other (suckler) cow as compared to the average for Irish dairy cows and b) to the lower number of total breeding cows (dairy and suckler) under the Stable Dairy Scenario.

Under the third scenario, the Higher Agricultural Activity Scenario (A+), growth in dairy cow inventories is higher than projected under the BAU and the contraction in the suckler cow inventory in Ireland is lower than under the BAU. In aggregate bovine breeding inventories are considerably higher than under the BAU scenarios. The higher levels of agricultural activity (relative to our BAU Scenario) are driven by a higher level of real prices (and subsidies) that are assumed to be received by farmers in Ireland under this scenario. Under the High Agricultural Activity Scenario (A+) both the total bovine breeding inventory (dairy plus other cows) and the total cattle inventory are higher than under the BAU.

Our analysis concludes that with the level of agricultural activity projected under the BAU scenario, the expanded set of absolute agriculture mitigation measures, by themselves, are insufficient to leave agriculture operating within budget for all of the carbon budget allocation outcomes considered. This finding also holds for the other two agricultural activity scenarios considered (Scenario B and Scenario A+).

The more demanding (viz. the smaller) the carbon budget allocated to agriculture, the greater the distance between the projected agricultural GHG emissions and the carbon budget targets. Our analysis highlights the large contribution that technical mitigation measures can make to reducing emissions of GHG from agriculture. However, by themselves these technical mitigation measures alone will not allow agriculture to “live” within most of the carbon budgets considered by the CCAC CBC.

Three alternative approaches to accounting for net sequestration from Land Use, Land Use Change and Forestry (LULUCF) sector are considered in this note. These are

- the gross-net accounting approach
- the net-net accounting approach, and
- the approach proposed within the recent European Commission proposal for a revised regulation with respect to emissions and removals of GHG from land use, forestry and agriculture sectors (EC, 2021) wherein a net-net approach is used for the period 2021-2026 and a gross-net approach thereafter.

Under **Gross-Net accounting rules**, our analysis shows that for both the CB1 and CB2 periods, total emissions in agriculture and land use, land use change and forestry sectors would exceed all considered budgets. The inclusion and exclusion of credits for sequestration by forestry does not alter the outcome with respect to total emissions from the AFOLU sector falling within the budgetary limits considered.

Our analysis shows how under a BAU scenario with **Net-Net accounting rules** used, with the expanded set of absolute agriculture measures and with full credit for LULUCF measures allocated to agriculture, that emissions from agriculture , forestry and other land use sector would be within its budget for CB1 under all budgetary scenarios. With Net-Net accounting rules emissions from agriculture, forestry and other land use would only exceed its budget in CB2 in the most ambitious budget allocation wherein the budget for agriculture, forestry and other land use sectors is reduced by an amount consistent with a 51% relative to the levels of net emissions in 2018.

Under the revised rules as proposed in the European Commission's recent proposal (EC 2021) where Net-Net accounting is used for CB1 and Gross Net accounting is used for CB2 (and subsequent budgetary periods), net emissions from the agriculture and land use, land use change and forestry sectors (with all agriculture and land use and forestry measures) would be within budget for CB1 for all budgetary scenarios. However, with Gross-Net accounting used for CB2 agriculture, land use, land use change and forestry emissions would be in excess of the carbon budget for all carbon budget outcomes considered with the exception the least ambitious budget scenario (E70:A20).

When agriculture is evaluated on a stand-alone basis (that is not integrated with other land using and forestry sectors) technical abatement actions considerably reduce the level of agricultural emissions. However, under a Business as Usual agricultural activity scenario emissions are in excess of all carbon budgets considered for the sector. To stay within the carbon budgets assessed significant reductions in the level of agricultural activity would be required.

Depending on the carbon budget allocated to the agriculture and land use, land use change and forestry sector significant reductions in the level of agricultural activity, large increases in rates of afforestation and significant changes in the rate of forestry harvest will be required if a Gross-Net accounting approach is adopted or if the European Commissions proposed hybrid approach is adopted.

It is only with the use of a Net-Net accounting approach to land use and forestry emissions and significantly increased afforestation and changes in forestry management practices (increasing forestry rotations lengths by effectively delaying forestry harvesting activities) that emissions from the AFOLU sector are assessed as likely to remain within carbon budgets under a Business as Usual scenario.

All of the additional measures and the associated mitigation projected as achievable is predicated on assumptions regarding uptake of mitigation measures by farmers and the full incorporation of all of these measures within national inventories. Where the marginal abatement costs associated with these measures are positive (that is where these measures are costly to implement for the farmer) policy actions are likely to be required to incentivize these measures. The reflection in due course of the mitigation of GHG emissions by these additional measures in national GHG inventories is also not guaranteed. The measures outlined in this note and earlier Teagasc MACC report (Lanigan and Donnellan, 2018) will be the subject of the normal scientific peer review process used for updating the national GHG inventories.

The structure of the paper is as follows. In the next section we outline how we have calculated the agriculture budget equivalents for the first two carbon budgetary period (CB1 and CB2) associated with the 5 Energy - Agriculture budgets considered by the CCAC CBC. This is followed by a discussion of the set of agricultural mitigation measures considered and then by a discussion of the role of LULUCF measures.

Emissions of GHG under the BAU scenarios are then compared with the possible carbon budgets for agriculture, forestry and other land use sectors. T

Carbon Budgets (CB1 and CB2)

Five different carbon budgets have been considered by the CCAC CBC. These 5 budget outcomes are defined by the different combinations of emissions reductions from the Agriculture and Energy sector that together yield reductions in total GHG emissions of 51% by 2030 relative to a base period of 2018. The smaller the budget allocated to agriculture (energy) the larger the budget allocation for energy (agriculture). The budget nomenclature indicates the reduction allocated to the "energy sector" (E) and the agriculture sector (A), so e.g. the carbon budget outcome denoted by E70:A20 is where the budget for agriculture is that associated with a level of emissions from agriculture in 2030 that is 20% lower than the level of emissions in 2018. The energy sector represents all of the non-agriculture parts of the GHG inventory.

To calculate the two carbon budgets CB1 (2021-2025) and CB2 (2026-2030) the 2030 emissions associated with each of the 5 carbon budget allocations are calculated. To do this, the level of GHG emissions in 2030 consistent with the reductions in GHG emissions associated with the 5 carbon budgets considered by the CCAC CBC is calculated. These five budget outcomes envisage a carbon budget allocation to agriculture consistent with a 20%, 25%, 33%, 40% and 55% reduction in agricultural GHG emissions by 2030 relative to emissions in 2018.

Having calculated the level of agricultural GHG emissions in 2030 for each of the five budgets, the annualised percentage reduction required between 2021 and 2030 to move from the reported level of GHG emissions in 2020 and the target level in 2030 is calculated. This annualised % reduction (R_Ag) is calculated as

R_Ag = [(Ag_2030/Ag_2020)^(1/(2030-2020)-1]*100

Where Ag_2020 is the observed level of agricultural GHG emissions in 2020 and Ag_2030 is the target level of emissions from agriculture that varies across the 5 carbon budget scenarios.

Given the observed level of emissions from agriculture in 2020 (20,852.4 MT CO_2e) the set of 5 annualised percentage reduction (R_Ag) are used to calculate five sets of ten year annual agricultural GHG emission totals for the period 2021-2030. These annual budgets for agriculture are then aggregated to 5 year totals CB1_Ag and CB2_Ag corresponding to the two carbon budgeting period CB1 (2021-2025) and CB2 (2026-2030).

As is clear from Table 1, the carbon budgets for the period 2026-2030 (CB2) are smaller than those for the first budget period CB1 (2021-2025) and the larger the required reduction in agricultural emissions, the smaller the carbon budget allocation to agriculture.

Table 1: Carbon Budgets for Agriculture implied by CCAC CBC Carbon Budgets

	2018 Agricultural GHG emissions (Ag_2020)	Implied 2030 Agricultural GHG emissions (Ag_2030)	Annualised % reduction 2021-2030 to reach 2030 Target level (R_Ag)	Agriculture Carbon Budget 2021-2025 (CB1_Ag)	Agriculture Carbon Budget 2026-2030 (CB2_Ag)
E70:A20	21,965.5	17,572.4	-1.70%	99,073.0	90,948.0
E65:A25	21,965.5	16,474.1	-2.33%	97,198.8	86,394.1
E61:A33	21,965.5	14,716.9	-3.42%	94,026.6	78,991.6
E57:A40	21,965.5	13,179.3	-4.48%	91,045.9	72,381.7
E51:A51	21,965.5	10,763.1	-6.40%	85,873.2	61,694.8

An equivalent process is used to create carbon budgets for the land use, land use change and forestry sector (LULUCF) in Table 2 and these can be used to create budgets for agriculture and LULUCF and for agriculture and land use and land use change only. The budgets implied are presented in Table 3 and Table 4.

Table 2: Carbon Budgets for Land Use, Land Use Change and Forestry implied by CCAC CBC Carbon Budgets

	2018 LULUCF GHG emissions (LULUCF_2020)	Implied 2030 LULUCF GHG emissions (LULUCF_2030)	Annualised % reduction 2021-2030 to reach 2030 Target level (R_LULUCF)	Agriculture Carbon Budget 2021-2025 (CB1_LULUCF)	Agriculture Carbon Budget 2026-2030 (CB2_LULUCF)
E70:A20	6,060.0	4,848.0	-2.21%	29,760.4	26,618.5
E65:A25	6,060.0	4,545.0	-2.84%	29,199.3	25,287.4
E61:A33	6,060.0	4,060.2	-3.93%	28,249.7	23,123.4
E57:A40	6,060.0	3,636.0	-4.98%	27,357.3	21,190.9
E51:A51	6,060.0	2,969.4	-6.89%	25,808.4	18,065.9

Table 3: Carbon Budgets for Agriculture, Forestry and Other Land Use (AFOLU) implied by CCAC CBC Carbon Budgets

	2018 AFOLU GHG emissions (AFOLU_2020)	Implied 2030 AFOLU GHG emissions (AFOLU_2030)	Annualised % reduction 2021-2030 to reach 2030 Target level (R_AFOLU)	Agriculture Carbon Budget 2021-2025 (CB1_AFOLU)	Agriculture Carbon Budget 2026-2030 (CB2_AFOLU)
E70:A20	28,025.5	22,420.4	-2.21%	128,833.4	117,566.5
E65:A25	28,025.5	21,019.1	-2.84%	126,398.1	111,681.5
E61:A33	28,025.5	18,777.1	-3.93%	122,276.4	102,115.0
E57:A40	28,025.5	16,815.3	-4.98%	118,403.2	93,572.6
E51:A51	28,025.5	13,732.5	-6.89%	111,681.7	79,760.7

Table 4: Carbon Budgets for Agriculture, Land Use and Land Use Change excluding Forestry implied by CCAC CBC Carbon Budget Scenarios

	2018 AFOLU GHG emissions (Ag+LULUC_2020)	Implied 2030 AFOLU GHG emissions (Ag+LULUC _2030)	Annualised % reduction 2021-2030 to reach 2030 Target level (R_ Ag+LULUC)	Agriculture Carbon Budget 2021-2025 (CB1_ Ag+LULUC)	Agriculture Carbon Budget 2026-2030 (CB2_ Ag+LULUC)
E70:A20	30,938.5	24,750.8	-2.21%	145,793.2	132,735.8
E65:A25	30,938.5	23,203.9	-2.84%	143,038.2	126,092.2
E61:A33	30,938.5	20,728.8	-3.93%	138,375.3	115,292.6
E57:A40	30,938.5	18,563.1	-4.98%	133,993.6	105,648.8
E51:A51	30,938.5	15,159.9	-6.89%	126,389.4	90,056.1

Agriculture measures

The activity levels generated under the business as usual (BAU) scenario (Teagasc Scenario A), stabilized emissions scenario (Teagasc Scenario B), and increased activity scenario (Teagasc Scenario A+) were inputted into the agricultural GHG flow model previously used to generate GHG emission reduction estimates published as part of the Marginal Abatement Cost Curve (MACC) analysis (Lanigan et al. 2018). The model structure is based on the UNFCCC Common Reporting Format and utilises IPCC methodologies to generate GHG emissions for various categories of agricultural activity (IPCC 2006).

Measures included in this analysis are as per the 2018 Teagasc GHG MACC in terms of uptake rate and absolute mitigation per unit of agricultural activity. The uptake level and rate of uptake for a given measure was based on Ag Climatise targets (DAFM 2020) see Table 5 below. The adoption of Low Emission Slurry Spreading (LESS), for example, has explicit targets, with 60% of all slurry to be spread by LESS by 2022; 80% by 2025; and 90% by 2027. Where no Ag Climatise target was specified, adoption rates were based on the Teagasc MACC (Lanigan et al. 2018) and linear uptake was assumed. This allows the mean mitigation potential across the entire reporting period (2021- 2030) to be calculated, as well as the maximum abatement potential in 2030. Agricultural mitigation strategies were also sub-categorised between measures that have an impact on the **GHG emissions intensity** and those measures that affect **absolute GHG emission levels** (via either a reduction in input levels or changes in emission factors).

There are a number of projects currently underway or in development both in Teagasc and in partner institutions that have the potential to further reduce emissions of methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). However, it must be stated that while the methane measures (additives, reduced age of slaughter) are currently being researched, no peer reviewed paper relating to the use of these technologies and management practice changes within the context of Irish production systems has yet been published. In terms of N_2O and carbon measures, the research basis for understanding the future potential of these measures are subject to funding and are currently the subject of new DAFM research proposals. National research has not yet been performed.

Table 5: Teagasc MACC & Ag Climatise measures and targets

Measure	Target
Nitrogen use	Limit mineral N to 350,000 tonnes by 2025; 325,000 tonnes N by 2030. Reduce N_2O by 50% by 2030
Liming	2 million tonnes annual usage by 2030
Protected Urea	Prohibit the use of urea, replacing with a urease inhibitor treated urea product by end of 2023. Replace 65% of CAN with protected urea by 2030
LESS	Achieve a target of 60% of all slurry spread by low emissions slurry spreading by 2022; 80% by 2025; and 90% by 2027.
Covered stores	From 2022 all newly constructed external slurry stores to be covered. All existing external slurry stores to be covered by December 2027
Clover	Require incorporation and maintenance of clover (and mixed species) in all grass reseeds by 2022
Dairy and Beef genetics	Genotype the entire national herd by 2030 to underpin the development of enhanced dairy and beef breeding programs
Animal Health	Complete BVD eradication by 2023
	Significantly reduce the prevalence of Bovine Tuberculosis in the national herd.
	Increase the level of participation in the Irish Johnes Control Programme (IJCP) by expanding this beyond dairy herds.
Bovine and porcine crude protein	Reduce the average levels of crude protein in pig feeds to 16% Reduce the levels of crude protein in feeds for grazing ruminants to a maximum of 15%.

The attainment of any projected reductions projected in this note is dependent on a) the research being funded and b) peer reviewed publications being produced and c) the measures being capable of being fully reflected/captured in the national GHG inventories. As a result of ongoing research, the peer review processes and revisions to national inventories, total mitigation potentials are subject to change.

The new measures which may be implemented into a future marginal abatement cost curve analysis are listed in Table 6. The new measures are categorised into measures that could flow from ongoing or proposed Methane, Nitrous Oxide and Carbon sequestration research programmes described below. The details of the measures listed in Table 6 can be found in Appendix A of this paper. Again readers should note that the process of establishing the efficacy of these possible additional measures is inherently uncertain. The accounting for projected mitigation achieved is also contingent on the incorporation of measures within national inventories.

Table 6: Potential new agricultural measures to reduce greenhouse gas emissions from agriculture

Measure	Emission factor reduction	Potential mean reduction kt CO_2e	Maximum reduction kt CO_2e
Reduced finishing times	1 month reduction	174	323
3NOP	30% reduction in methane from indoor-finished steers and autumn milkers	31* (only comes on-stream in second period)	103.5
Compound Fertiliser	40% reduction	109	206
Slurry spreading	Disaggregation of EF's	Reduction of 233 kt is on baseline only	unknown
Lime CO2 EF reduction	EF reduced from 12% to 4.7% 53% of lime sequestered	158	296
Enhanced weathering	0.3 tC sequestered per 1 tonne applied	4.5	15
Agro forestry	1.43 tC ha-1 n above, below ground biomass and extra SOC	5.4	26
Hedgerows	0.85 tCO_2e per km (New hedge) 0.65 85 tCO_2e per km (better management)	6.6	15
Digestate from AD/biogas	17% C sequestered	96	179
Pig slurry on arable	12% of applied slurry is sequestered	14	28

Results: Agriculture only

Our estimates of the annual mitigation potential of the measures listed in Table 5 and Table 6 under the Business as Usual agricultural activity scenario are presented in Table 7. These annual mitigation potentials are also aggregated to carbon budget period 1 (2021-2025) and carbon budget period 2 (2026-2030) totals.

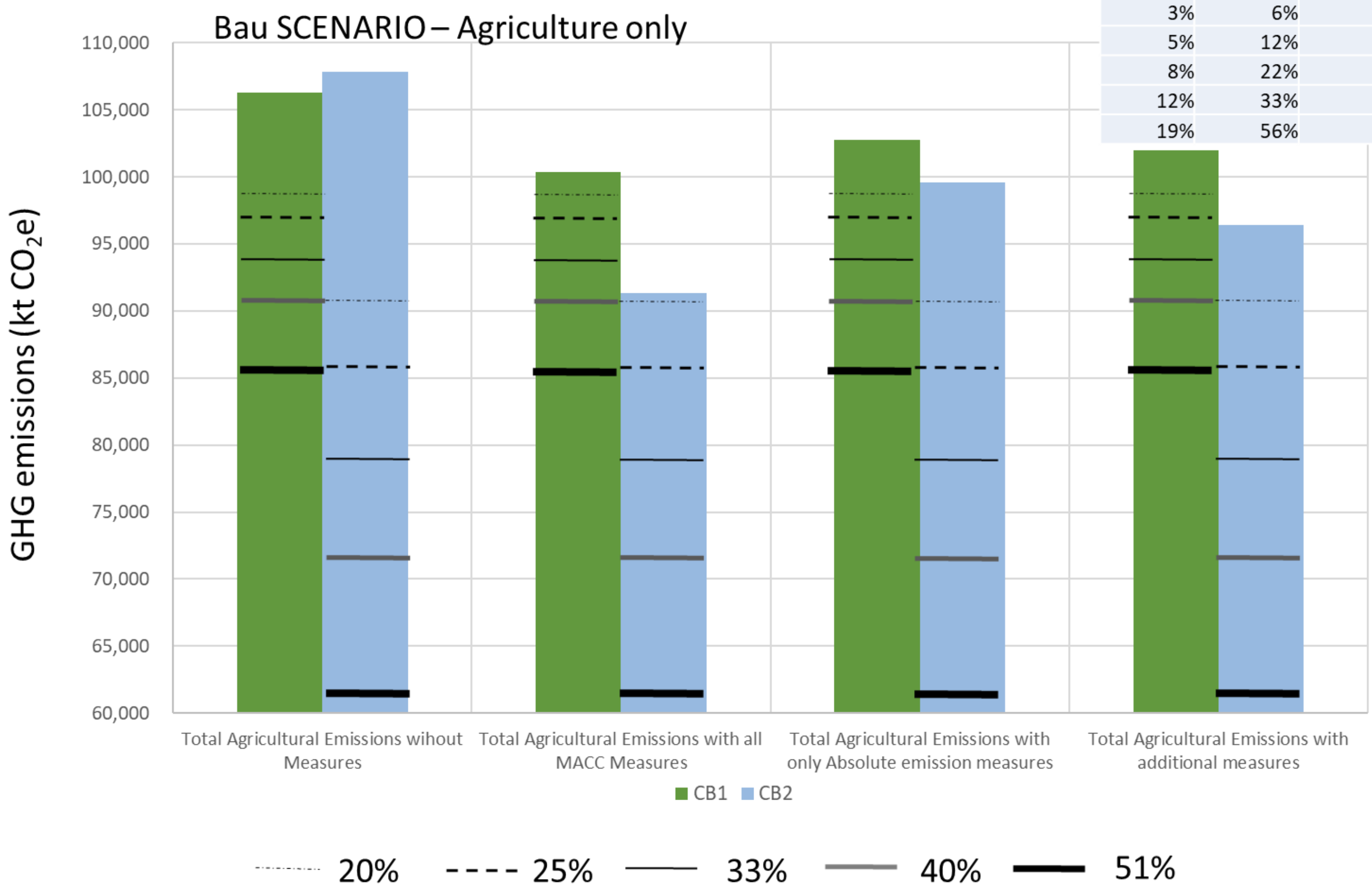
Figure 1 presents the total agricultural GHG emissions relative to the carbon budgets implied by the five carbon budgets considered by the CCAC CBC (E70:A20, E65:A25, E61:A33, E57:A40 and E51:A51). Agricultural emissions without measures, with all of the measures considered in the Teagasc MACC Analysis (Lanigan et al. 2018), with only the absolute measures considered in the Teagasc 2018 MACC analysis (Table 5) and with the MACC absolute measures plus the additional measures listed in Table 6.

Figure 1 show that there is no carbon budget outcome where agricultural emissions, even with the expanded set of absolute emissions measures, falls within any of the five budgets considered by the CCAC CBC under the BAU Scenario. The introduction of Carbon Budgets that are consistent with reducing national GHG emissions by 51% by 2030 clearly represent a *change* from business as usual. Regardless of the budget scenario considered by the CCAC CBC, changes to agricultural activities over and above the additional measures analysed by Teagasc will be required. This analysis suggests that reductions in the level of agricultural activity would be required to live within any of the carbon budgets considered by the CCAC CBC.

The magnitude of the negative adjustment to agricultural activity, output value, gross value added and employment in the agriculture and food processing industries is found to increase with the severity of the implied reduction in agricultural activity required by the different carbon budget scenarios. Estimates of the negative economic impact of reduced agricultural activities was presented to the CCAC CBC in an earlier note (Donnellan and Hanrahan, 2021).

Table 7: Mitigation potential by year & total abatement potential for Carbon Budget 1 (2021-2025) & Carbon Budget 2 (2026-2030).

Emissions Intensity Measures	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	CB1	CB2
Dairy EBI	55.1	91.2	134.7	195.0	255.0	365.5	473.3	578.3	675.3	789.7	731.0	2882.2
Animal Health	27.6	55.2	82.8	110.4	138.0	165.6	193.2	220.8	248.4	276.0	414.0	1104.0
Beef Genomics (Terminal traits)	22.4	35.1	63.4	81.9	99.2	115.1	129.8	143.5	156.8	167.8	302.0	713.0
Beef Genomics (Maternal traits)	0.0	11.3	15.3	19.5	23.8	28.3	33.0	37.9	42.9	48.2	70.0	190.3
Use of sexed semen	4.3	8.6	12.9	17.2	21.5	25.8	30.1	34.3	38.6	42.9	64.4	171.7
Absolute emission measures												
Fertiliser type	158.4	203.2	242.6	277.0	306.8	333.3	356.7	376.2	392.2	405.1	1188.0	1863.5
Drainage (mineral soils)	44.0	85.1	123.7	160.1	193.6	224.2	252.2	277.2	299.3	318.9	606.5	1371.8
Nitrogen Use Efficiency	3.5	23.9	61.0	98.2	135.3	172.5	209.6	246.8	284.0	321.1	322.0	1234.0
Low-emission slurry spread	24.5	42.3	62.7	76.3	88.4	93.7	99.2	100.0	100.7	100.7	294.2	494.2
Clover in grass swards	20.3	61.0	101.7	142.4	183.0	223.7	264.4	305.0	345.7	386.4	508.4	1525.2
Crude protein in pigs & bovines	5.8	10.8	16.0	21.2	26.4	31.5	36.5	41.5	46.3	50.4	80.2	206.2
Lipids	2.0	3.7	6.4	12.2	20.7	32.3	46.7	64.1	79.7	96.8	45.1	319.6
Slurry acidification	16.7	33.4	50.2	67.1	83.8	100.3	116.8	133.1	149.3	165.4	251.1	665.0
Cover slurry stores	0.4	0.7	1.1	1.5	1.8	2.2	2.6	2.9	3.3	3.7	5.5	14.7
Reduced N2O from org soils	7.9	15.7	23.6	31.5	39.3	47.2	55.1	62.9	70.8	78.7	118.0	314.7
Extended Grazing	15.0	22.5	29.1	35.8	42.3	48.6	54.7	60.6	66.2	71.7	144.8	301.9
Additional measures												
3NOP	0.0	0.0	0.0	0.0	0.0	20.7	41.4	62.1	82.8	103.5	0.0	310.5
Earlier Slaughter of Beef cattle	0.0	64.5	96.8	129.0	161.3	193.6	225.8	258.1	290.3	322.6	290.3	1290.4
Compound Fertiliser	0.0	0.0	27.4	54.7	82.1	109.5	136.9	164.2	191.6	219.0	164.2	821.2
Enhanced weathering (Basalt)	0.0	0.0	0.0	0.0	0.0	0.0	5.5	11.1	16.6	22.1	0.0	55.3
Digestate from AD/biogas (Slurry)	0.0	17.9	35.8	53.7	71.6	89.5	107.4	125.3	143.2	179.0	179.0	644.4



CB1	CB2		CB1&CB2
3%	6%		4%
5%	12%		8%
8%	22%		15%
12%	33%		21%
19%	56%		34%

Figure 1: Business as usual scenario with all MACC agriculture measures, with ‘absolute only’ agriculture measures and with absolute and ‘new’ additional measures. Lines indicate 5 year 1st and 2nd carbon budgets.

A. Land Use, Land Use Change and Forestry Measures

A.1. Current Rules

The Agriculture and LULUCF sectors are currently treated separately in the emissions accounting system. Agriculture reports on a gross-net basis, whilst LULUCF reports total gross-net emissions for completeness purposes, but these do not count towards reduction targets. The LULUCF Regulation 2018/841 governs the methodology by which CO_2 emissions and removals are accounted from the land-use (LULUCF) sectors. It currently contains three different ways of accounting for emissions or removals associated with different land uses

1. Afforested and deforested land (Article 6) is accounted for using a gross-net approach: total emissions and removals for the periods 2021-2025 and 2026-2030.
2. Managed cropland, grassland and wetland (Article 7) are currently accounted for using a net-net approach: emissions and removals for the two periods minus five times the value of average annual emissions in the base period (2005-7).
3. Managed forest land (Article 8) is accounted for as the emissions and removals for the two periods minus five times the Member State's Forest Management Reference Level (FMRL).

A.2. Future EU LULUCF Rules

The 2021 amended EU LULUCF regulation proposed by the European Commission (EC, 2021), signals a *fundamental shift* in accounting principles from a "no debit rule" forest reference level (in the case of forestry) or a net-net system (from grasslands, croplands and wetlands) to a gross net system, with a shared LULUCF target for the whole EU. There will be no impacts on the already assessed period 2021-2025. However, the gross-net target approach means that all member states have to reduce emissions or increase removals based on a set LULUCF removal target of -310 $MtCO_2$ across the EU by 2030.

The proposed allocation of the EU27 target to member states is based on the proportion of managed land and a reference level for the LULUCF sector in 2016-2018. The projected net-net accounting of LULUCF using ***current EPA projections*** of removals and emissions as prescribed under EU LULUCF Regulation (EU) 2018/841 are shown in Table 8.

Under a BAU scenario, gross-net accounted LULUCF is a source of 29.5 $MtCO_2$ and 32.3 $MtCO_2$ for Carbon Budget 1 and Budget 2 respectively. This compares to a SINK of -17.5 $MtCO_2$ and -11.85 $MtCO_2$.using net-net accounting conventions. The reason for this large discrepancy is due to the fact that net-net emissions are expressed relative to a baseline, while gross-net accounting encompasses the full suite of emissions associated with a given category. Therefore moving from net-net accounting to gross-net accounting has significant implications in terms of carbon budgeting. Moving to modified EU LULUCF rules as proposed by the European Commission (2021) would result in a sink of -17.5 $MtCO_2e$ in Budget 1 but a source of 32.3 $MtCO_2e$ in Budget 2 (Table 8).

A.3. Changes to Inventory Projections

Since the publication of the Teagasc MACC and the EPA GHG projections for 2020-2040, a number of factors have confounded the size of the national Forestry sink. First planting rates are much lower than previously projected (circa 3 kha has actually been planted as opposed to a projection of 8 kha per annum). In addition, new emission factors for forestry based on drained organic soils have increased emissions from managed Forest Land on histosols from 0.45tC ha^{-1} to 1.68 tC ha^{-1}, a four-fold increase (Jovani-Sancho et al. 2021). When in due course these changes are reflected in the national inventory projections, there will be substantial implications for LULUCF emissions. With the inclusion of revised emission factors, forestry will become a gross-net source of emissions by 2024 and would be a net source of 0.68 Mt CO_2 across the entire 2021-2030 commitment period.

Forestry planting trends are expected to diverge from the required trajectory, meaning that the LULUCF source will increase in the absence of corrective measures (Table 9). In terms of additional forestry contributions for this commitment period, reduced deforestation and/or delayed/decreased levels of harvest of managed forest lands would be required. This is because an increase in the afforestation rate in the period to 2030 will have little net impact during the first two Carbon Budgeting periods. However, increased afforestation rates beyond the 8 kha per annum target set out in the Teagasc MACC *will* be essential in order for the AFOLU sector to attain climate neutrality by 2050 (Duffy et al. 2021).

In the absence of additional LULUCF measures, gross-net forestry emissions under revised projections (incorporating higher emissions factors for forestry on histosols) would result in a small C sink for Carbon Budget 1 of -4.2 $MtCO_2e$ in Carbon Budget 1 and a ***Carbon source*** of +4.9 $MtCO_2e$ in Carbon Budget 2. This would result in the whole LULUCF sector becoming a strong C source (45.6 Mt CO_2e and 52.6 Mt CO_2e for Carbon Budgets 1 and 2 respectively). This would represent a huge increase in sectoral (LULUCF) emissions compared to those arising when using the net-net accounting approach (**Table 9**)**.** Even with the additional measures described above, gross-net LULUCF emissions would be a net GHG source of 28.6 Mt CO_2e and 22.5 Mt CO_2e for CB1 and CB2 respectively (**Table 10**).

The assumptions underlying additional land use measures in Table 10 are as follows:

- Increased afforestation, decreased deforestation and extension of the age of rotation. Forestry planting at 3,500 ha in 2008 rising to 8,000ha per annum by 2030.

Projected deforestation rates are primarily driven by requirements for new wind-power sites and restoration of peatland ecosystems. However, deforestation to grassland is projected to contribute 0.74 Mt CO_2 over the period from 2021 to 2030 and this represents a 'preventable' source of deforestation. Afforestation will have little impact during this commitment period (Carbon Budget periods 1 and 2), but a large increase in the afforestation rate over the period to 2030 and beyond will be required in order to preserve the forest sink into the future (post 2030).

In **Table 10** forestry is increased by 500 ha per annum up to a rate of 8,000 ha by 2030. The extension of rotation age pathway would see an increase in clear fell age to the maximum mean annual increment (MMAI) and this would result in a reversal from a small emissions source of 0.68 $MtCO_2$ for 2021-2030 to a net removal of -34.7 $MtCO_2e$ over the same period (**Table 10**). The drawback of this measure is that the short-term level of harvest is reduced from 2.5 Mm^3 to 1 to 2 Mm^3 over the period to 2030.

A.1. Ireland's LULUCF Target under Revised Regulations

Based on Member State allocated targets outlined in Annex 2 of the revised Regulation (EC, 2021), Ireland has been allocated an emission target of 3.7Mt per annum for the entire LULUCF sector by 2030. Ireland's current LULUCF reference net emission value for 2016-2018 is 4.33Mt CO_2. However, this reference level will change to 6.06 Mt CO_2 in the 2022 Inventory due to methodological alterations, resulting in an adjusted target of 5.47 Mt CO_2. While this may not seem to be a challenging target, the business as usual (BAU) forest contribution noted earlier is projected to be declining from a sink of 4 Mt CO_2 in 2018 to a net emission source by 2024 due to age class and afforestation rate legacy effects (Table 9). This dynamic will have a large impact on the LULUCF profile in the second and subsequent budgetary periods beyond 2030 because the distance to Ireland's LULUCF net emissions target will increase year on year due to high emissions from peat-based grassland soils and increased forest land emissions up to 2037.

Table 8: Business as usual LULUCF emissions using CURRENT LULUCF Projections and accounted on a gross-net†, net-net†† and proposed EU LULUCF Regulation proposal basis ‡

BAU	Gross Net		Net-Net		New LULUCF Regs	
	CB1	CB2	CB1	CB2	CB1	CB2
	2021-2025	2026-2030	2021-2025	2026-2030	2021-2025	2026-2030
Forest land (Current Inventory)	-11.40	-2.35	-20.02	-12.32	-20.02	-2.35
HWP (Current Inventory)	-8.86	-13.06	1.07	1.04	1.07	-13.06
Total forest land Including (HWP)	**-20.26**	**-15.40**	**-20.02**	**-12.32**	**-20.02**	**-15.40**
Deforestation to settlement and other	1.77	1.77	1.77	1.77	1.77	1.77
Cropland (CL)**	0.05	-0.04	-0.40	-0.50	-0.40	-0.04
Grassland (GL)**	35.82	35.95	1.75	1.88	1.75	35.95
Wetlands (WL)**	10.79	8.73	-0.60	-2.67	-0.60	8.73
Settlements	1.12	1.06	-	-	-	1.06
Other	0.25	0.25	-	-	-	0.25
Total LULUCF	**29.53**	**32.30**	**-17.50**	**-11.85**	**-17.50**	**32.30**
Total LULUCF minus Forestry	49.79	47.71	2.52	0.48	2.52	47.71

** Based on the formula used for the option 1.2 target (p 85 of the EC Impact Assessment Report accompanying the proposed EU LULUCF regulation (EC 2021)) and the 2020 LULUCF inventory submissions from Ireland and the EU.

Table 9: BAU LULUCF emissions using NEW FORESTRY projections accounted for under gross-net†, net-net†† and proposed EU LULUCF Regulation proposal basis‡

BAU	Gross Net		Net-Net		New LULUCF Regs	
	CB1	CB2	CB1	CB2	CB1	CB2
	2021-25	2026-2030	2021-25	2026-2030	2021-25	2026-2030
Afforestation (New BAU projections)	-9.80	-9.29	-9.80	-9.29	-9.80	-9.29
Forest land (FL-FL) incl. HWP (New BAU Projections)	5.58	14.19	1.07	1.04	1.07	14.19
Total forest land Incl (HWP)	**-4.22**	**4.90**	**-8.72**	**-8.25**	**-8.72**	**4.90**
Deforestation to settlement and other	1.77	1.77	1.77	1.77	1.77	1.77
Cropland (CL)**	0.05	-0.04	-0.40	-0.50	-0.40	-0.04
Grassland (GL)**	35.82	35.95	1.75	1.88	1.75	35.95
Wetlands (WL)**	10.79	8.73	-0.60	-2.67	-0.60	8.73
Settlements	1.12	1.06	1.11	1.06	1.11	1.06
Other	0.25	0.25	0.25	0.15	0.25	0.25
Total LULUCF	**45.57**	**52.61**	**-4.85**	**-6.55**	**-4.85**	**52.61**
Total LULUCF minus Forestry	49.79	47.71	3.87	1.70	3.87	47.71

* See paragraph 6 (p 15) of the recital of the proposed EU regulation (EC 2021).

** Based on the formula used for the option 1.2 target (p 85 of the EC Impact Assessment Report accompanying the proposed EU LULUCF regulation (EC 2021)) and the 2020 LULUCF inventory submissions from Ireland and the EU.

Table 10: BAU New LULUCF emissions Projections as accounted for under gross-net†, net-net†† and proposed EU LULUCF Regulation proposal basis‡ with additional Grassland, Cropland and Forestry measures (WAM) included.

WAM	Gross Net		Net-Net		New LULUCF Regs	
	CB1	CB2	CB1	CB2	CB1	CB2
	2021-25	2026-2030	2021-25	2026-2030	2021-25	2026-2030
Forest (L-FL) +500 ha p.a. to 8000 ha	-9.77	-9.50	-9.77	-9.50	-9.77	-9.50
Forest land (FL-FL) extended MMAI	-8.80	-6.63	1.074	1.039	1.07	-6.63
Total forest land incl. (HWP)	**-18.58**	**-16.12**	**-8.70**	**-8.46**	**-8.70**	**-16.12**
Deforestation to settlement and other	1.40	1.40	1.40	1.40	1.40	1.40
Cropland (CL)**	-0.22	-0.77	-0.67	-1.23	-0.67	-0.77
Grassland (GL)**	33.84	27.93	-0.23	-6.14	-0.23	27.93
Wetlands (WL)**	10.79	8.73	-0.60	-2.67	-0.60	8.73
Settlements	1.12	1.06	-	-	-	1.06
Other	0.25	0.25	-	-	-	0.25
Total LULUCF	**28.60**	**22.47**	**-8.80**	**-17.09**	**-8.80**	**22.47**
Total LULUCF minus Forestry	47.17	38.59	-0.10	-8.63	-0.10	38.59

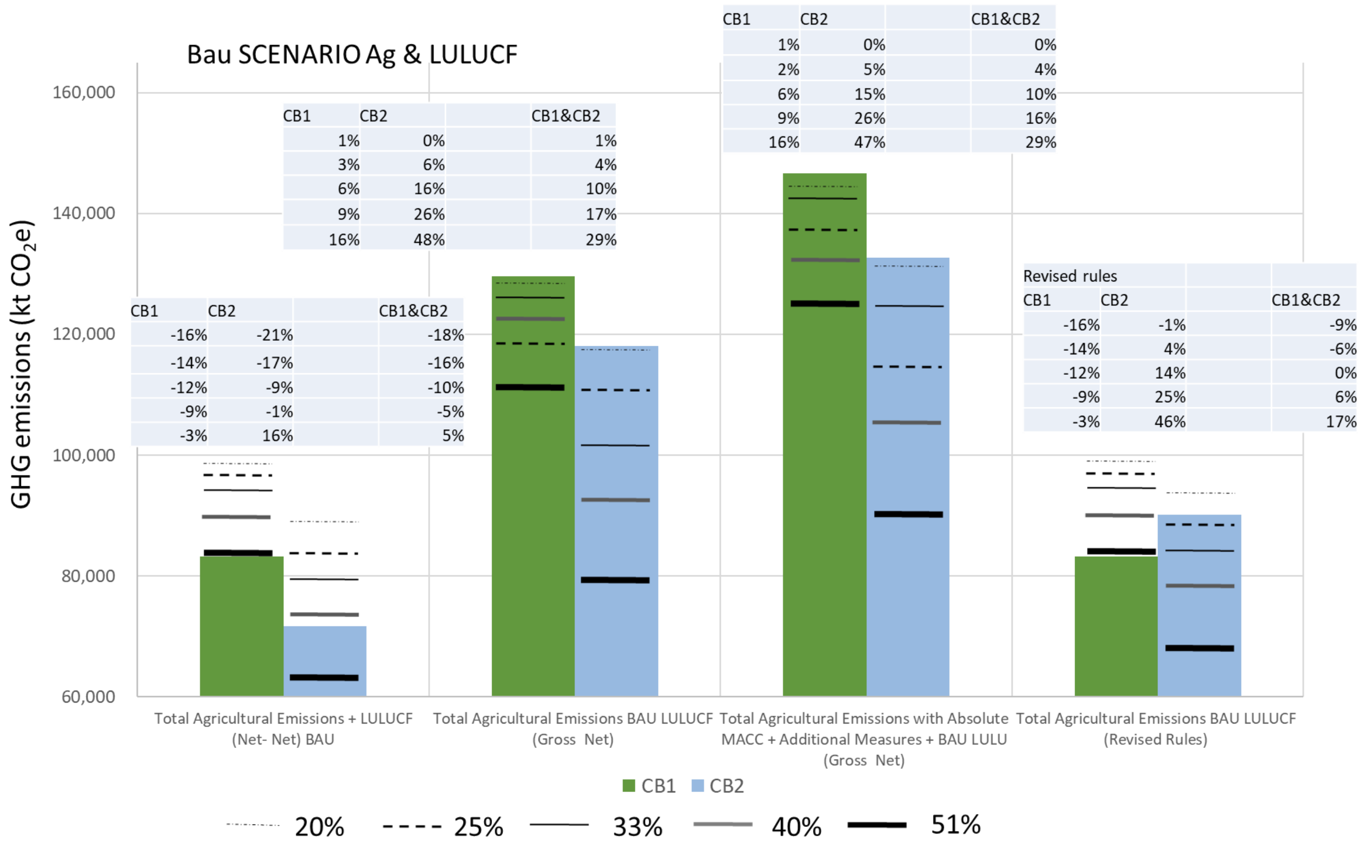


Figure 2: Business as usual scenario with absolute and 'new' additional measures and including LULUCF measures on a net-net, gross-net, gross-net excluding forestry and Revised LULUCF Regulations basis. Lines indicate 5 year 1st and 2nd carbon budgets.

B. Summary, Commentary on EC proposed regulation amending (EU) 2018/841 and implications for Research and Inventories

The Carbon Budget process will allocate a carbon budget to the agriculture sector for the budget period 2021-2025 (CB1) and the period 2026 to 2030 (CB2). The analysis presented in this note shows that even with the achievement of the additional agriculture measures outlined in this note and their complete reflection within national GHG inventories that agricultural emissions under a BAU agricultural activity will exceed the budgets that might be set for both CB1 and CB2.

The analysis presented in this note shows that the accounting rules used will be critical in determining if the agriculture sector and the land use, land use change and forestry sectors combined would be able to remain with a carbon budgets as framed by the energy/agriculture framework used to evaluate potential carbon budgets by the CCAC CBC. The use of a Gross Net accounting approach for both budgeting periods would not allow the agriculture, land use and forestry sectors to remain within any of the budgets being considered by the CCAC.

The European Commission's recent proposal for a revised regulation dealing with emissions and removals of GHG from land use, forestry and agriculture sectors proposes a hybrid approach with the land use and forestry sector considered on a net-net accosting basis for the period 2021 to 2025 and on a gross net basis thereafter. Our analysis shows that the AFOLU sector would fall within all carbon budget considered for the first carbon budgeting period, but that in the second period emissions from the agriculture and land use, land use change and forestry sectors would fail to remain within all carbon budgetary scenario budgets – with the exception of the budget under the E70:A20 scenario.

The use of a net-net accounting approach and the allocation to agriculture of credits from land use and forestry measures would allow the AFOLU sector to remain within budget under most of the carbon budget scenarios considered.

B.1. Proposals for regulation amending (EU) 2018/841

The European Commission recent proposals for how emissions and removals of GHG in the LULUCF and agriculture sectors are treated presents important challenges for the Irish agriculture and land use sectors. The proposals change both the accounting rules and Member State obligations in terms of achieving net LULUCF removals from those set out in the current LULUCF regulation in the following ways.

- Compliance with allocated national targets will be verified on the basis of *reported greenhouse gas emissions and removals*.
- For the period 2026-2030, *binding annual* targets of net greenhouse gas removals will be set for each Member State and will result in a target of 310 million tonnes CO_2 equivalent for the European Union as a whole.
- Furthermore, the Commission proposes to combine the agriculture non-CO2 greenhouse gas emissions with the land use, land use change and forestry sector, thereby creating a newly regulated AFOLU sector.
- The Commission's proposals ultimately set a target for an EU-wide **Net-Zero AFOLU sector by 2035**.

- The Annex to the EC Proposal seeks the enhancement of monitoring requirements using digital technologies; aligns the objectives with related policy initiatives addressing biodiversity and bioenergy; determines the European Union target of climate neutrality for 2035 in the land sector (which combines the LULUCF sector and the non-CO_2 agricultural sector); and commits the Commission to make proposals for national contributions to the 2035 target by 2025.

National LULUCF targets are set out in Article 2 of the EC proposal (EC, 2021). This states that '*The scope for the period 2026-2030, is based directly upon reported emissions and removals for the greenhouse gas inventory pursuant to Regulation (EU) 2018/1999.*' In simple terms this means **full, gross-net accounting** of all sectoral emissions and removals post 2026. The Commission justifies this approach as the simplest and most transparent method and that it is required in order to provide methodological consistency with the ESR (Regulation (EU) 2018/842).

In addition the Commission claims that it will *'reflect the current mitigation performance of the LULUCF sector, and each Member State's share of the Union managed land area, reflecting the capacity of that Member State to improve its performance in the sector'.*

The Proposals thus envisage setting a LULUCF target for each Member State analogous to the ESR targets no later than 31 December 2025. The proposed regulation clearly sets the ambition for net-zero emissions from AFOLU by 2035 and negative AFOLU emissions thereafter. Article 4.4 of the amended Regulation states that

> *'The Union-wide greenhouse gas emissions and removals in the sector set out in Article 2(3) of this Regulation shall be balanced within the Union at the latest by 2035, thus reducing emissions to net zero by that date and the Union shall achieve negative emissions thereafter.'*

There is a large variation in LULUCF net removals and emissions among Member States (Figure 3). However, the majority of Member States will either benefit marginally or not lose out to any great degree from the changes proposed by the Commission. The countries that are set to lose out the most under these proposals are Denmark, Ireland and Germany. While Germany still possesses a large sink under full reporting, it had a very generous allowance under the Forest Management Reference Level. By contrast, Ireland and Denmark are both relatively de-forested territories and are set to see their LULUCF sectors switch from being a net sink to a source under the Commission proposals.

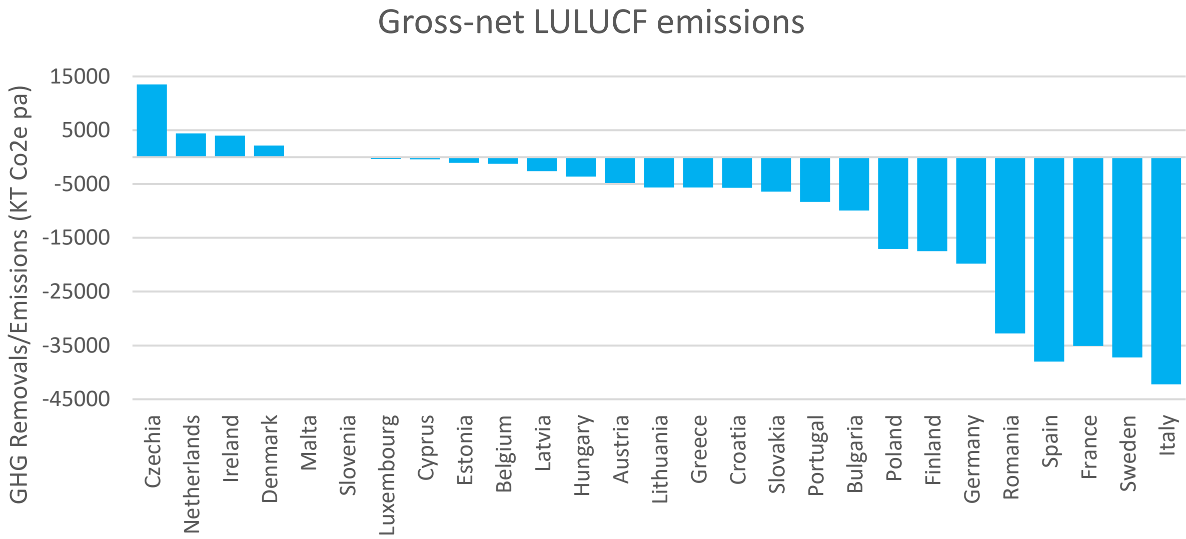


Figure 3: Gross-Net LULUCF emissions/removals from all Member States in 2019

The revised EC proposals will impact on Ireland as a whole and on the AFOLU sectors in particular. It will particularly impact on the ability to achieve current Effort Sharing Regulation targets, much less any revised target. Under a Business as Usual (BAU) scenario, in the absence of mitigation, LULUCF is projected to report a net source of between +20.45 Mt CO2e (current projections, Table 8) and +47.76 Mt CO2e (new projections Table 9) over the combined Carbon Budget period 1 and 2 from 2021-2030. Under the LULUCF revisions, the shift to a gross-net accounting methodology in the second reporting period (2026-2030), will result in a switch to being a net source of 32.3 Mt CO2e – 52.61 Mt CO2e in the absence of remedial measures.

The modalities of the target under the EC regulation proposal (2021) will be similar to the ESR in that the limit assumes a linear trajectory between 2026 and 2030. The start point will be the mean emissions for the period 2021-2023 with the linear trajectory commencing in 2022 and over the 2026-2030 commitment period, annual LULUCF emissions/removals should not exceed this limit. The start point is the mean of 2021-2023 emissions and this start point begins in 2022, linearly decreasing to 2030. In the absence of mitigation, BAU emissions in 2030 are projected to increase by 30.5% relative to 2021-2023 mean emissions.

In 2031, under the EC proposals, agricultural emissions will be combined with BAU LULUCF emissions, and projections of net AFOLU emissions are estimated at 28.6 Mt CO_2e.

If the additional measures as described in Teagasc MACC and Ag Climatise are implemented, a net sink of -8.8 Mt CO2e is projected for the 2021-2025 Carbon Budget period. In the second period (2026-2030), under the revised rules proposed by the Commission and with additional measures implemented, a net source of 22.5Mt CO2e is estimated. By 2030, LULUCF emissions with additional measures would have decreased by 27% relative to 2021-2023.

In terms of increasing removals or decreasing emissions from the sector (LULUCF), the options are limited over the commitment period. In the medium term, accelerated forestry planting will ensure that post-2030 AFOLU emissions are mitigated to a much greater extent, but will do little for the current commitment period (to 2030). Nevertheless, increased afforestation will be required in order to obtain significant reductions in AFOLU emissions in the 2030-2050 period. There is only limited scope to increase cropland measures. The main options for enhancing net LULUCF balance from agricultural soils for the period (2021-2030) will be in terms of a) reducing emissions from wetland soils and b) increasing the mineral grassland C sink.

B.2. Implications for Research and Inventories

Due to the change to reporting-based targets (gross-net accounting), the greenhouse gas emissions and removals from the LULUCF sector will need to be estimated with a higher level of accuracy. While Tier 1 reporting will be acceptable for the 2021-2025 period, Tier 2 methodologies will be required for grassland and Tier 3 methodologies will be required for wetlands and grasslands under histic soils in the second Carbon Budgeting period (2026-2030). Development of Tier 3 methodologies is also required for areas identified as being at high future climate risk.

The European Commission Proposal also obliges Member States to develop 'Geographically-explicit land-use conversion data'. Furthermore *'The GHG inventory shall comprise a system for monitoring land-use units with high carbon stock land'* as well as requiring monitoring of special areas of conservation (SAC) and high nature value (HNV) areas.

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Appendix A: New Agriculture, Land Use and Forestry Measures

A. Agriculture Measures

A.1. New Methane Research

Feed Additives

The DAFM funded project Meth-Abate and the SFI centre 'VistaMilk' are currently investigating the methane mitigating effects of a range of feed additives.

Preliminary data from 'Meth-Abate' shows some promising effects of a range of feed additives from in vitro studies. A range of halides generated by NUIG in collaboration with GlasPort Bio show significant methane reductions (up to 50%) in vitro and in treating manure and slurry. These additives are currently being evaluated in trials with sheep and later trials will evaluate effects in cattle.

3-NOP (Bovaer) is a synthetic non-toxic compound, 3-nitrooxypropanol, produced by the company DSM. It is a promising methane inhibitor in that its supplementation results in a consistent methane yield decrease of ~30% in many trials across the world (Martinez-Fernandez et al., 2014; Haisan et al., 2017; Romero-Perez et al., 2014; Jayanegara et al., 2018). However, 3-NOP has not yet being tested under Irish production systems. Teagasc will be conducting a methane mitigation trial in growing beef cattle on 3-NOP in June 2021 as part of their EFSA approval process for registration of the additive for use under Irish production systems. It is likely that 3-NOP will be registered in 2022 and available for use in Ireland.

3-NOP in its current form can only be applied in in-door systems. A slow release prototype is currently being developed for grazing cattle and is being tested in New Zealand. This 3-NOP variant should become available in 2023/24. This 3-NOP technology for grassland production system will be tested later in the Meth-Abate project on dairy pasture based systems.

Reduced Age of slaughter

Over the period 2010 to 2020 there has been substantial progress made in the age at which bovine animals are slaughtered in Ireland. For example in 2010 the average age at which dairy-sired steers were slaughtered was 908 days, while in 2020 the corresponding age was 857 days. As a result, enteric and manure methane emissions have reduced by 158 kt CO_2e over that period. For most animal categories there has been substantial reduction in the age at which animals are slaughtered. Over the period 2010 to 2030 Irish cattle carcass weights remained static. Looking towards 2030 it is possible that such reductions in age at slaughter could continue. However, further reductions in age at slaughter will likely be associated with a reduction in carcass weights. Without incentives and directly selecting genetically for animals that have a pre-disposition for a reduction in age at slaughter, the progress over the next decade is expected to be less that achieved between 2010 and 2020. Mitigation potential is still however substantial.

Estimates are currently being developed to determine the national mitigation potential. In this note we assume that over the period 2021 to 2030 a further one month reduction in average age at slaughter can be achieved that would yield a mean reduction in emissions of 174 kt CO_2e over the period 2021-2030.

A.2. New Nitrous Oxide Research

Compound fertilisers

The current MACC (Lanigan et al. 2018) focuses on switching from straight nitrogen use from CAN to protected urea as the national emission factor is reduced by 1.09 percentage points or an average emissions reduction of 0.35MTCO$_2$ and maximum reduction of 0.55 MTCO$_2$e by 2030 (Lanigan et al 2018). The reason for this reduction in the emission factor is that avoiding applying high nitrate containing fertilisers to wet soils reduces the potential for N_2O emissions from denitrification. Compound fertiliser sales account for circa 50% of the total nitrogen fertiliser sales in Ireland and currently the default IPCC emission factor of 1% is used for these fertilisers. Different compound fertilisers have different nitrate to ammonium ratios, ranging 0.05 for 10:10:20, 0.53 for 18:6:12 and 0.8 for 27:2.5:5. We hypothesise that, similar to the protected urea research, N_2O emissions will be higher from these high nitrate containing compound fertilisers. A preliminary field trial in 2020 showed a significant (40%) reduction in N_2O emissions from the lower nitrate to ammonium ratio in compound fertilisers compared to CAN. There is currently a project proposal under review with the DAFM Research Stimulus Fund. This research and associated fertiliser use changes could represent a mean reduction in emissions of 109 kTCO$_2$eq yr-1, rising to a maximum of 206 kt CO$_2$e yr-1 if 50% if high N compounds were switched to low N compounds.

Slurry spreading

The spreading of slurry on soils results in direct and indirect N_2O emissions. This is captured in the national GHG inventory and currently accounts for 846.32 kT CO$_2$e, which represents 16% of N_2O emissions from agricultural soils. Currently Ireland uses the default emission factor of 1% for manure, which is the same default value for any fertiliser, regardless of its source and nitrogen form. Recent work by Krol et al. (2016) produced new emission factors of 1.2% and 0.31% for dung and urine excreted at pasture, highlighting that Irish emission factors were lower than those applicable under the default Tier 1 approach. In fact, the combined excreta emission factor calculated after the partitioning of dung and urine in the ruminant diet was 0.86%. It is expected that the slurry N_2O emission factor should be more closely aligned with that of animal excreta than with that of synthetic fertiliser due to the large portion of nitrogen in slurry in the organic form. Indeed, the literature indicates that N_2O emission factors for manure are generally less than 1%, with UK disaggregated values of 0.37% and 0.72% for solid manure and slurry respectively (Bell et al., 2016; Misselbrook et al., 2014; Thorman et al., 2020) with potential differences due to slurry spreading methods and timing of application. This research has the potential to reduce manure emissions by 30-60% or 313 ktCO$_2$e yr-1. This would represent a reduction in baseline emissions if new national emission factors confirm the reductions in N2O emissions for manure spread using low emissions methods.

A.3. Carbon Sequestration Research

Use of digestate to increase carbon sequestration

The total carbon content of digestates varies between 28 % and 47 % of the dry matter (Tambone et al. 2010). During anaerobic digestion, lignin is not degraded, whereas volatile fatty acids (>90 %), cellulose (>50 %), hemicellulose (>80 %), and raw protein are degraded (Tambone et al. 2010). Digestate is enriched in thermostable compounds due to increased aromaticity (e.g., aromatic lignin increases by 30–60 %), and an accumulation of long-chain aliphatic components. This results in a relative increase of the biological recalcitrance in the digestates compared to the raw feedstock.

Mineralisation of digestate organic matter upon application to soils is therefore substantially lower compared to raw cattle or pig slurry (Egene et al. 2021). Sequestration rates have been estimated at between 0.17% and 0.37 % of C applied.

Gaseous N losses from digestate or the solid fraction of digestate (if separated) during storage represent the main challenge regarding digestate management after anaerobic digestion. This is due to the increased ammonium content and increased pH compared to feedstocks. Techniques dedicated to prevent N losses when storing manures are equally valid when storing digestates. Similar to solid farmyard manures, solid digestates should be, whenever possible, applied directly to land, thus bypassing the storage phase (Petersen and Sørensen 2008; Thorman et al. 2007). Alternatively, acidifying chemicals such as alum can be added to reduce volatilisation. If the levels of biogas and biomethane production projected in the Teagasc MACC were to be realised, this would yield over 7 million tonnes of digestate per annum by 2030 (Lanigan et al. 2018). This would deliver a mean C sequestration increase of 96 ktCO_2e per annum rising to 179 ktCO_2e yr-1 by 2030. Again, the research needs to be done in order to deliver this expected mitigation.

Carbonation and Enhanced weathering

Carbonation and enhanced weathering are processes where the formation of carbonate minerals in soils is promoted artificially, mimicking natural pedogenic carbonate formation to produce a measurable permanent sink for atmospheric CO_2. Basic rocks, such as basalt, occur widely and show great potential for enhanced weathering (0.3t CO_2e/t for basalt, Beerling et al. 2018). The addition of basalt rock dust to soils can reduce pH, condition soils and enhance CO_2 sequestration (Beerling et al. 2018). The addition of ground silicate minerals to soils can enhance CO_2 removal by release of base cations (e.g.,Ca2+, Mg2+), which neutralize by reacting with carbonic acid and forming dissolved bicarbonate/ carbonate minerals in soil water solutions, which either precipitate in soils or ultimately deposit on the oceanic floor via runoff waters (Lefebvre et al. 2019). Also rock particle addition to soils may provide 'extra' mineral surfaces where organic carbon can accumulate and stabilize. This could represent a reduction in emissions of 15 2 ktCO_2e yr-1 if 5,000 ha had 10 t basalt added per hectare.

Multispecies Swards

There is growing evidence that multispecies swards can significantly reduce nitrogen fertiliser requirements by over 150 kg N ha-1 and also out-perform high nitrogen fertiliser perennial ryegrass monocultures, even under drought conditions (Finn et al. 2018). Multispecies swards with Plantain have been found to reduce yield scaled nitrous oxide emissions by 58-63 % (Cummins et al. In Review) through a number of effects, such as biological nitrification inhibition (Bracken et al. 2020). If 50,000 ha of Nitrate Derogation pasture was converted to multispecies swards, this would reduce N_2O emissions by up to 69 Kt CO_2e yr-1, comprising 49 ktCO_2e from fertiliser displacement and 19 ktCO_2e from reduced N_2O emissions. There are suggestions that multispecies swards can increase soil carbon sequestration (Lange et al. 2015) and reduce enteric methane emissions, however, results are uncertain and national research is urgently required to confirm both C sequestration and methane benefits. Further research is also needed to fine tune the optimal agronomic management of swards under grazing and to quantify the benefits of multispecies swards on greenhouse gas emissions and carbon sequestration.

Pig slurry on arable

Increasing application of pig slurry onto cropland will enhance the input of organic carbon into low soil organic carbon systems. If 50% of pig slurry is spread on tillage land, this would increase C input by 15,000 tC per year. If 12% is assumed to be incorporated into Soil Organic Carbon (SOC), this will result in 11.2kt CO_2e per year abated. In addition, 2.5 kt of mineral N would be displaced resulting in a reduction in N_2O emissions of up to 35.8 ktCO_2e per year.

Agroforestry

Agroforestry, the growing of trees combined with animal or crop agriculture, has the potential to increase carbon removal in wood products and soil carbon sequestration. Mean above-ground sequestration has been estimated at 0.6 tC ha-1 yr-1 and SOC increase at 0.83 tC ha-1 for temperate regions (Feliciano et al. 2018). Given that agroforestry is classified as forestry and requires a re-classification of land and mandatory re-planting, it is unlikely that more than 5,000 ha would be established prior to the end of the decade. This would accrue up to 26 kt CO_2e per annum sequestration by 2030.

Hedgerows

Hedgerows can sequester C in both above/below ground biomass and via increased soil organic carbon. Previous estimates have indicated that hawthorn-dominated hedgerows sequester between 0.6 and 3.3 t C ha-1 yr-1 (Black et al. 2014, Green et al. 2019). Planting 10,000km of new hedgerows would increase C sequestration by approximately 9.5 ktCO_2e yr-1, while increasing height and/or width and allowing a tree to develop every 6-10 m could increase sequestration by circa 0.65 tCO_2 km-1. If 10% of the hedgerow area (65,000km) was improved, this would yield an extra 6.5 ktCO_2 yr-1.

B. Land Use Measures

The assumptions underlying our additional land use measures are as follows:

Forestry

Increased afforestation, decreased deforestation and extension of the age of rotation. Forestry planting at 3,500 ha in 2008 rising to 8,000ha per annum by 2030 (See Table 10). The extension of rotation age pathway would see an increase in clear-fell age to the maximum mean annual increment and this will result in a reversal from a net emission of 16.3 MtCO_2 for 2021-2030 to a net removal of -14.1 MtCO_2 over the same period. The drawback is that the short-term level of harvest is reduced from 2.5 Mm3 to 1 to 2 Mm3 over the period to 2030.

Deforestation to grassland is projected to contribute 0.74 Mt CO_2 over the period from 2021 to 2030. This should be halted as a priority. Afforestation will have little impact during this commitment period (CB1 and CB2), but should be maximised in order to preserve the forest sink into the future (post 2030).

Straw incorporation and cover crops

Straw incorporation on 55,000 ha of principally oaten straw and cover crops on 90,000 ha by 2030.

Pig slurry on arable

Increasing application of pig slurry onto cropland will enhance the input of organic carbon into low soil organic carbon systems. If 50% of pig slurry is spread on tillage land, this would increase C input by 15,000 tC per year. If 12% is assumed to be incorporated into SOC, this will result in 11.2kt CO_2e per year abated. In addition, 2.5 kt of mineral N would be displaced resulting in a reduction in N2O emissions by up to 35.8 ktCO_2e per year.

Improved grassland sequestration

Better management of 450,000 ha of grassland (increased time to reseeding, increase in legumes, less frequent use of heavy machinery, long term pasture management plans. This measures is expected to result in reduced emissions of 2.06 Mt CO_2e by 2030.

Rewetting of histosols

Rewetting on 80,000 ha of grassland on mineral soils. Emissions reduced by a net 20.2 tCO_2 per hectare.

Appendix B: Emissions under Alternative Agricultural Activity Scenarios & Carbon Budget Outcomes

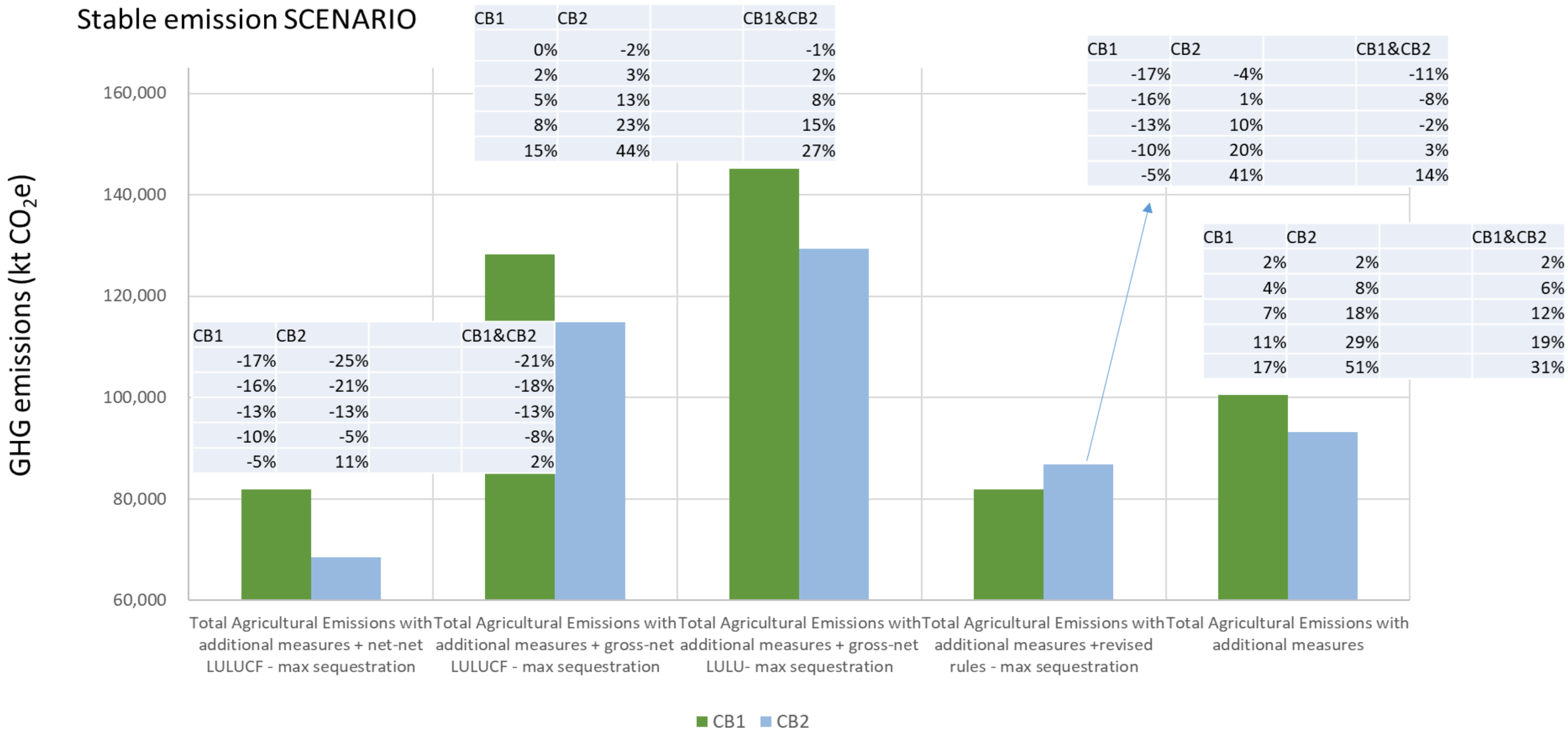
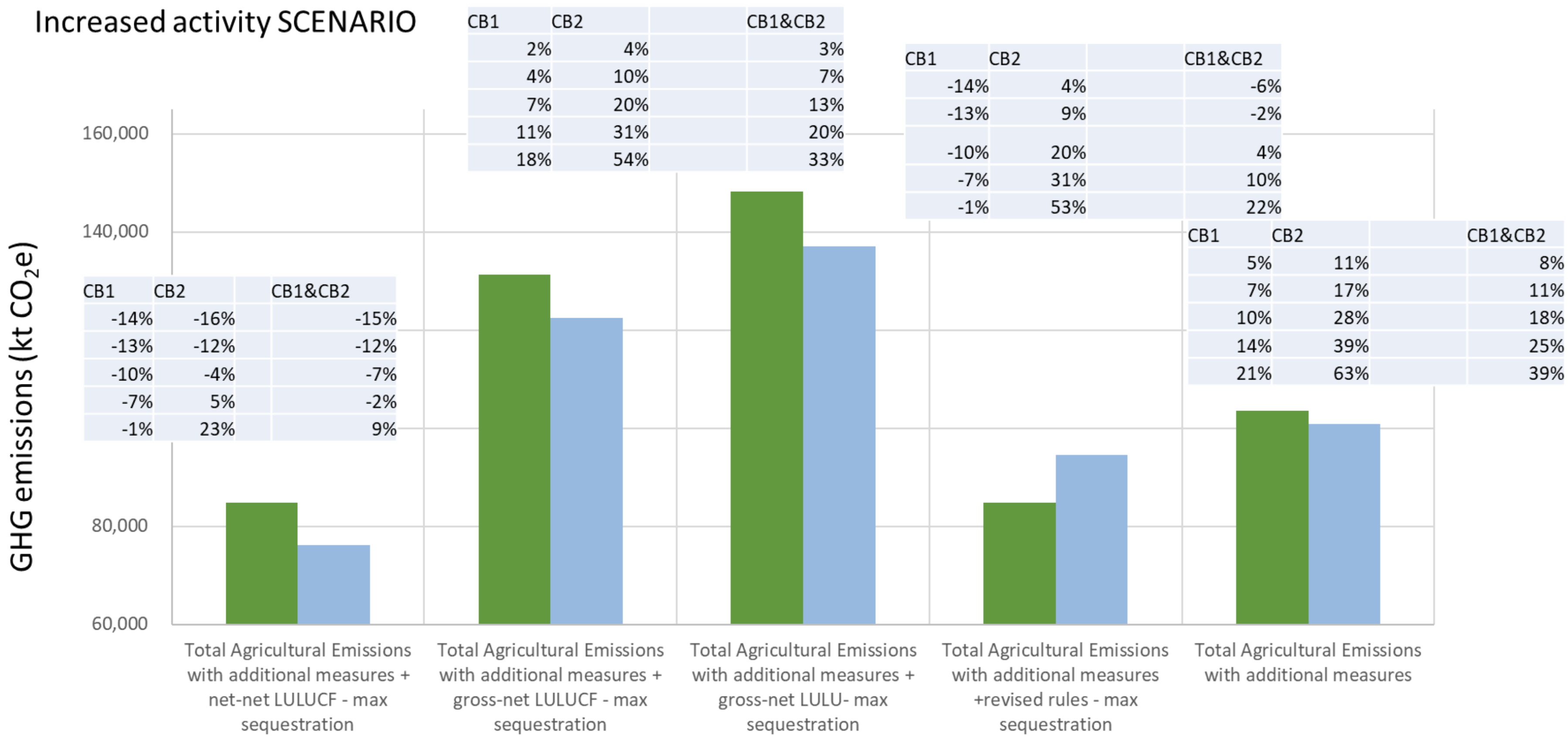


Figure A 1: Stable emissions scenario with absolute and 'new' additional measures and including LULUCF measures on a net-net, gross-net, gross-net excluding forestry and Revised LULUCF Regulation (Fit for 55) basis.



CB1	CB2	CB1&CB2
-14%	-16%	-15%
-13%	-12%	-12%
-10%	-4%	-7%
-7%	5%	-2%
-1%	23%	9%

CB1	CB2	CB1&CB2
2%	4%	3%
4%	10%	7%
7%	20%	13%
11%	31%	20%
18%	54%	33%

CB1	CB2	CB1&CB2
-14%	4%	-6%
-13%	9%	-2%
-10%	20%	4%
-7%	31%	10%
-1%	53%	22%

CB1	CB2	CB1&CB2
5%	11%	8%
7%	17%	11%
10%	28%	18%
14%	39%	25%
21%	63%	39%

Figure A 2: Increased Activity scenario (A+) with absolute and 'new' additional measures and including LULUCF measures on a net-net, gross-net, gross-net excluding forestry and Revised LULUCF Regulation (Fit for 55) basis.