Feasibility of the Nexus of Agricultural and Greenhouse Gas Emission targets in the case of Ireland

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Abstract

With the Food Harvest 2020 and Foodwise 2025, Ireland has published two national food strategies to chart the direction of agri-food, forestry and fisheries for what will come after the EU milk quota abolishment and to develop a strong and sustainable 'green' pillar of the Irish economy up to 2025. Next to this agricultural development strategy, Ireland has Greenhouse Gas emission targets set, which since 2009, not only contain the EU's Emission Trading Scheme sector but also the non-ETS sector.

In the absence of any mitigation, agricultural GHG emissions in Ireland are projected to increase by 9% by 2030 relative to the 2005 base year due to strong growth of the agriculture sector. Marginal Abatement Cost Curves (MACCs) estimated by the Teagasc Working Group on GHG emissions have projected the total technically feasible mitigation potential for the Irish agriculture, forestry and land use (AFOLU) sector up to 2030. Existing Irish studies on the real term realisation of mitigation measures identify, through the use of either probit or logit models, farmers' attitudes and farm structures that influence the level of adoption of abatement tools. This study adjusts the MACC abatement potential by applying the identified uptake rates of these Irish case studies. The adjusted mitigation potential for the AFOLU sector appears to lie 29% below the potential projected through the MACC approach.

From the results, it can be inferred that policy measures need to be implemented in order to increase the abatement potential of the AFOLU sector, to substantially help bring the nexus between agricultural development and GHG emission targets in Ireland closer together. One main factor influencing the uptake rate of mitigation measures is the farmers' understanding of the issues and measures available to tackle these. Therefore, the behavioural changes of farmers need to be understood and to reduce agricultural GHG emissions, polices are needed that remove the barriers to behavioural change.

Keywords: Irish Agricultural Sector, GHG emission, LULUCF, MACC approach, Abatement adoption

1 Introduction

The Irish economy continues to grow rapidly and has come a long way since exiting the EU-IMF financial assistance programme in late-2013. It is widely recognised that the Irish agri-food sector (7.7% of the total GDP in 2017) has played a key role in Ireland's export oriented economic recovery. Agri-food exports have increased by 53% since 2011 (DAFM, 2018, DAFM, 2010). The agri-food sector is the main indigenous industry in Ireland, using Irish raw materials, being predominantly in Irish ownership and widespread geographically across Ireland (DAFM, 2015). It is one of the fastest growing sectors in the Irish economy and therefore makes a significant contribution to the economic, social and environmental wellbeing of the country and rural areas (Joint Committee, 2018).

The future strategy for growth in the agri-food sector to 2020 and 2025 is outlined in the two strategy papers – Food Harvest 2020 and Food Wise 2025 respectively. These two reports have played an important role in focussing developments within the agri-food industry by setting, not only overall targets for agri-food, but also sector specific ones. These targets include an increase in the value-added in the sector, the value of exports, the milk production and the output value of the beef sector (DAFM, 2010, DAFM, 2015).

At the same time, greenhouse gas (GHG) emission reduction targets have been set for Ireland's Emission Trading Scheme (ETS) sector and also for the non-ETS sector, which includes agriculture (accounting for 52% of the non-ETS emissions). This non-ETS sector target is amongst the highest among the EU Member States (Reduction of 20% in 2020 and 30% in 2030) (EPA, 2018).

Most mitigation measures currently in place target a reduction in the emission intensity of agricultural production because the measures undertaken in the Land Use, Land Use Change and Forestry (LULUCF) sector did not count as GHG emission reduction in the agricultural sector prior to 2018. With the new EU Effort Sharing Regulation (Regulation (EU) 2018/842) in place, the potential of LULUCF in reducing agricultural GHG emissions and pursuing "carbon neutrality" for the Irish agriculture sector needs to be included as part of the national agricultural strategy as most afforestation since the 1980's takes place on private land, the majority of which is owned by farmers (DAFM, 2018b, Duesberg et al., 2014). Hence, Irish agricultural GHG emissions can in part be offset by carbon sequestration by forestry and land use change (Ryan and O'Donoghue, 2016).

Marginal Abatement Cost Curves (MACCs) estimated by the Teagasc Working Group on GHG emissions have projected the total technically feasible mitigation potential for the Irish agriculture, forestry and land-use (AFOLU) sector up to 2030 (Lanigan and Donnellan, 2018, Schulte et al., 2012). As a maximum linear uptake by the farmers is assumed in these studies, understanding the determining factors of farmers' decision-making processes is critical (OECD, 2012).[1] Existing Irish studies on the real term realisation of mitigation measures identify the characteristics of farmers and farms that influence the level of adoption of abatement tools through either probit or logit models. Based on these determining factors, this study will adjust the MACC abatement potential by applying the uptake rates identified through the Irish case studies.

An adjusted abatement potential for the AFOLU sector is derived, indicating the possible feasibility of achieving agricultural and GHG emission targets. Concluding, political implication regarding a possible future policy design will be depicted.

2 Irish Agriculture sector and its GHG-emissions

As the primary production sector (agriculture, fisheries and forestry) in Ireland accounts for 2.1% of total GDP, 5.6% of total employment and 6.6% of total merchandise exports in 2017, with the wider Agri-Food Sector accounting for 7.7% of total GDP, 7.7% of total employment and 11.1% of total merchandise exports, the significance of Ireland's agri-food sector becomes obvious (DAFM, 2018).[2,3]

Geographical and climate conditions in Ireland favour the production of grass over tillage crops and have led to a focus on grass-fed livestock production systems - in particular dairy and beef production (Teagasc, 2018, Dillon et al., 2018).[4] The agri-food growth targets set in the Food Harvest and Food Wise strategy papers are therefore, (DAFM, 2010, DAFM, 2015)

- Increasing the value of primary output in the agriculture, fisheries and forestry sector up to €10 billion (representing a 70% increase compared to the 2007-2009 average)
- Increasing the value-added in the agri-food, fisheries and wood products sector up to €13 billion (a 40% increase compared to the 2007-2009 average)
- Achieving a value of agri-food export target of €19 billion (increase by 85% compared to the 2007-2009 average)

[1] The maximum uptake rate reflects thereby the full biophysical potential occurring by 2030 (Lanigan and Donnellan, 2018).

[2] The agri-food sector (comprising primary production (agriculture, fisheries and forestry), food, beverages and tobacco) collectively employed 173,000 people in 2017 with 65% employed in the primary sector and 35% in the food industry (DAFM, 2018, CSO, 2018).

[3] In the EU-27 the share of agriculture in GDP is 1.2% in 2017. The agriculture sector accounts for 4.4% of the total employment (10 million jobs), the agri-food sector accounts for 6.1% of the total employment (14.24 million jobs). and 4.4% of GDP (Eurostat, 2018).

[4] Both sectors are highly grassland based with either having a high percentage of their feed covered by grass or the animals being outside for around 235 days per year (Teagasc, 2018, Dillon et al., 2018).

Those targets were further specified for the individual agricultural sectors. For the dairy sector, relative to the 2007-2009 level, an increase in milk production of 50% by 2020 after the abolition of the EU milk quota in 2015 was envisaged. For the beef, sheep and poultry sectors, a growth target in their respective output values of 20%, 20% and 10% without increasing animal numbers was set. Annual forestry planting rates were set at 7,500 ha and a target of 23,000 additional direct jobs in the agri-food sector by 2025 was set (DAFM, 2015). The development of the agri-food sector over the last years is in line with the national strategy set in the Food Harvest 2020 and Food Wise 2025 papers.

In 2017, Gross Agricultural Output (GAO) was valued at €6.92 bn with the beef and dairy sectors being the largest sectors accounting for 38.8% and 29.5% of GAO respectively. The other sectors that have a share in GAO include, pigs (7.8%), sheep (4%), cereals (3.9%), and other (16%) (Eurostat, 2018, DAFM, 2018). The vast majority of dairy products, beef and sheep meat are exported (between 80% to 90% of the total domestic production) (CSO, 2018). In 2017, Irish food and drink exports rose by about 11% to reach €13.6 bn compared to 2016. The value of Irish agri-food exports has increased by 85%, relative to the 2007-2009 level, and now account for 11.1% of total Irish merchandise exports. In value terms, agri-food exports in 2017 were mainly from the dairy (34%), the beef (18%) and the beverage sector (10%), with 40% of agri-food exports destined for the UK market and a further 32% of exports going to the rest of the EU and 28% to the rest of the world (DAFM, 2018).

Over the last 10 years, the average family farm income for dairy enterprises have been 5 times the average income from beef farms. After the abolition of the EU milk quota system, a shift in the decision-making process of livestock farmers was therefore witnessed, with mixed dairy farm production systems looking to specialise in becoming pure dairy farms. Furthermore, the potential for higher returns in dairy production compared with other enterprises has led to some larger scale beef and cereal farms converting to dairy production, with this trend more commonplace amongst the younger generation of farmers (DCCAE, 2017, DAFM, 2018).

This development is also reflected in changes in the number of livestock. The total cattle herd (including dairy cows) was 6.6% higher in 2017, relative to the 2007-2009 level. The presence of the milk quota system up to 2015, effectively capped the number of dairy cows, with the percentage of dairy cows within the national cattle herd remaining relatively stable at around 16-17%. Since 2015, this ratio has changed, leading to a 31% increase in the number of dairy cows and the dairy cow herd now accounts for approximately 20% of the total cattle number (CSO, 2018). This has led to a stocking rate for dairy farms in Ireland of 2 lu/ha, which is one of the highest in Europe (e.g. German dairy stocking rate is 1.47 lu/ha) (Dillon et al., 2018).

These trends have led to an increase in milk production since 2014 of nearly 28%, to 7.5 Mt in 2017. This expansion in the Irish dairy sector between 2015 and 2017 has been achieved through a combination of increased cow numbers (+19.1%) with increased specialisation through the substitution of non-dairy activities (primarily beef) with dairy cows and increased average milk yield per cow (+8.2%) (Eurostat, 2018). This sharp increase in Irish milk production post quota abolition is in strong contrast to many of the EU’s largest milk producers where the change in production has been relatively modest.[5]

Even though the focus of development has shifted slightly from the beef sector towards the dairy sector, Ireland is still the fifth largest net exporter of beef in the world with exports valued at €2.4 bn in 2017, a 6% increase on the previous year, making beef the most valuable sector of the Irish meat industry. Relative to the 2007-2009 level, beef meat production had increased by 13.4% by 2017. Approximately 90% of domestic production is exported (CSO, 2018). The output value of the cattle sector has increased

[5] For example, Germany, the largest milk producer in the European Union with a production of 31.9 Mt in 2017, or 20.6% of European milk production, only increased its total milk production since 2014 by 1.7% (average EU growth rate 4.7%) (Eurostat, 2018).

by more than 30% relative to the 2007-2009 level (DAFM, 2018). This development results from a strong rise in beef prices in the same period (CSO, 2018).

Furthermore, the National Farm Survey in 2017, indicates that the specialised beef production sector was the most prevalent farm type with 72,400 (55%) farms, recording an average farm size of 26.5 ha, followed by 23,421 (18%) dairy farms with an average farm size of 58.6 ha (CSO, 2018). Despite the widespread nature of beef production in Ireland, the sector is characterised by low incomes and a high reliance on farm payments (DAFM, 2018).

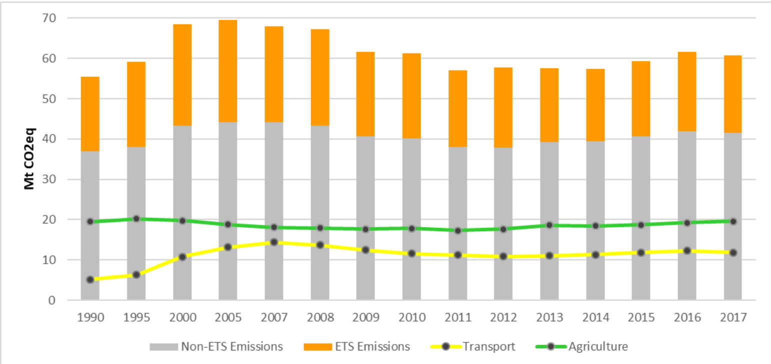
This recent growth in the Irish agricultural sector has on the other hand, had a strong impact on the agricultural GHG emissions. The main sources of GHG emissions in Ireland in 2016 are energy (31%), agriculture (32.2%) and transport (19.5%) (Duffy et al., 2019). This figure highlights agriculture's sizeable contribution to Irish GHG emissions but also the importance of agriculture in trying to limit overall Irish GHG emissions (DCCAE, 2017, Duffy et al., 2019).[6]

The Irish GHG emission targets for the non-ETS sector, set by the EU, are (EPA, 2018)

- For 2020 a reduction of non-ETS emissions by 20% on 2005 levels including a linear reduction pathway between 2013 and 2020.
- For 2030 a 30% reduction of non-ETS emissions compared to 2005 levels with binding annual limits over the 2021-2030 period to meet that target.

Agricultural and transport GHG emissions as non-ETS emissions account for 75% of the total Irish non-ETS emissions. (Figure 1) Hence, it needs to be assumed that the agricultural sector will be targeted with a similar reduction (Lanigan and Donnellan, 2018).

Figure 1 Trends in Irish Greenhouse Gas Emissions 1990-2017 (Mt CO_2eq)



Source: Duffy et al. (2019).

Emissions of GHG from the agricultural sector amounted to 19.6 Mt CO_2eq in 1990 and 19.5 Mt CO_2eq in 2017, a reduction of only 0.2%. Methane (CH_4) and Nitrous Oxide (N_2O) are the most significant GHGs emitted from agricultural activities in Ireland due to the dominance of dairy and beef cattle and, to a lesser extent, sheep production (DCCAE, 2017). Cattle account for 90.4% of CH_4 emissions in Irish agriculture in 2016 (Duffy et al., 2019). Enteric fermentation accounts for 51% of total agricultural emissions (DCCAE, 2017). The emissions of N_2O from the agricultural sector follow similar trends to those of CH_4, as the number of cattle also largely determine the amount of nitrogen inputs to agricultural soils from synthetic fertiliser and animal manures, which combined produce the bulk of N_2O emissions (92.5% of total N_2O emissions in 2017) (Duffy et al., 2019).

[6] Irish agricultural GHG emissions' contribution to the overall emissions is quite outstanding compared to other European Member States. The sector is and has been over time the largest single contributor to the overall emissions. In Germany the agricultural GHG emissions contribute to 7.1% of the overall emissions, in Italy 7.1%, in France 16.7%, in the Netherlands 9.8% and in Spain 10.5% (Eurostat, 2018).

Between 2005 and 2011, GHG emissions from agriculture continued on a downward trajectory, from the peak of 1998 (21 Mt CO_2eq) (Annex 1). During this period a decline in livestock numbers as well as a reduction in the use of synthetic nitrogen fertiliser due to reforms of the Common Agricultural Policy, higher prices for synthetic fertilisers, a better understanding by farmers of the importance of efficient nitrogen use and the wider economic crises, contributed to GHG emissions reaching their lowest level of 17.3 Mt CO_2eq in 2011 (Duffy et al., 2019, DCCAE, 2017).

From 2011 on, the GHG emissions in the agricultural sector began to increase gradually and by 2017 were 13.4% higher than their 2011 level (Annex 1). This has been primarily driven by a strong increase in livestock numbers (mainly dairy cows and their resulting offspring) and increased use of synthetic nitrogen fertiliser due to the abolition of the EU milk quota system and a drive to achieve the national agriculture policy strategy outlined in the Food Harvest 2020 report (Duffy et al., 2019).

The initially observed reduction has therefore been fully negated, resulting in an increase in agricultural GHG emissions to a level in 2017 that is 4.4% higher than 2005, nearly reaching the 1990 level (Duffy et al., 2019, CSO, 2018, FAO and GDP, 2019). The increase in livestock numbers has therefore outpaced the reduction in emission intensity and as a result, total agricultural GHG emissions continue to increase. Hence, increasing emissions of GHG from agriculture will present great challenges for Ireland to meet its 2020/2030 targets under the EU Effort Sharing Regulation (Regulation (EU) 2018/842) (European Council, 2018).

3 Irish LULUCF sector

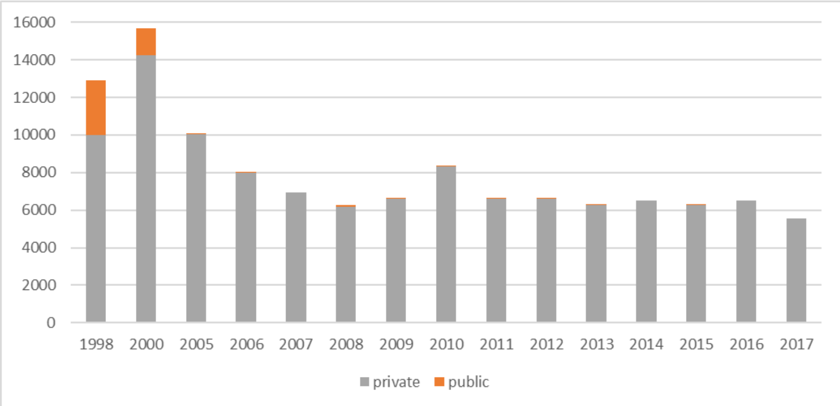
With the new EU Effort Sharing Regulation (Regulation (EU) 2018/842) in place, greater flexibilities have been provided for Member States such as Ireland that have been targeted with a high reduction rate for non-ETS sectors up to 2030. Ireland has the flexibility of achieving 4% (1.91 Mt CO_2eq yr-1) of their 2030 non-ETS GHG emission targets though the use of EU ETS allowances and 5.6% (2.68 Mt CO_2eq yr-1) through offsetting emissions by sequestering CO_2 potential through LULUCF activities during the time period 2021-2030 (European Council, 2018, Lanigan and Donnellan, 2018).

Ireland has 6.9 M ha of total land area, of which 4.5 M ha are used for agricultural purposes, with grassland being the dominant land use. Overall, 81% of the agricultural land area is in pasture, hay and grass silage (3.6 M ha) and a further 11% (0.5 M ha) is classified as rough grazing (DAFM, 2018, CSO, 2018). Unlike many other EU Member States, at only 8% (0.36 M ha) the agricultural area devoted to crops, fruit & horticulture production in Ireland is relatively small (Eurostat, 2018, DAFM, 2018, CSO, 2018). Ireland's total area of forestry covers 769,395 ha (end of 2017), or close to 11% of the total land area, which is well below the EU-28 average of 38% (Duffy et al., 2019, Eurostat, 2018). Commercial forestry in Ireland accounted for 1.4% of the total Irish GDP in 2016 (IFFPA, 2018).

Over half (50.8%) of forests are in public ownership and 378,663 ha (49.2%) are in private ownership. Since 1990, 72% of the newly afforested area was planted by the private sector, with public afforestation in decline over the same period and close to zero since 2005 (IFFPA, 2018, Figure 2). Of the private land, 82% was afforested by farmers with an average forest area of 6 ha (DAFM, 2018c). This change from public to private afforestation was largely a result of the introduction of a range of farm afforestation schemes that offered planting grants and annual forestry premia to cover up front costs and offset the lost income from agricultural livestock production. Hence, the share of private forests in the national forest estate has increased by over 6% since 2006 (DAFM, 2018c). Since 1990, over 288,321 ha have been afforested as a result of state supports (Duffy et al., 2019).

Afforestation occurs to 67% on marginal agricultural land.[7] Of this, 56% is marginal grassland (Farrelly and Gallagher, 2015). As a result, forestry and agriculture are intimately intertwined, aiming at the most efficient use of natural resources (DCCAE, 2017, Schulte and Lanigan, 2011).

Figure 2 Public vs private afforestation in Ireland by area planted in hectares (1998-2017)



Source: DAFM (2018c), IFFPA (2018).

Under the current Forestry Programme and endorsed by the Food Wise 2025 strategy paper, Ireland has a target to expand forest cover to 18% of the land area by 2050 (approximately 1.25 M ha) in order to maintain a sustainable processing sector (DAFM, 2018b, DAFM, 2015). To achieve this target, an annual afforestation target of 16,000 ha per year would be required (Farrelly and Gallagher, 2015). Whether a planting rate of 16,000 ha per year is possible is very uncertain, particularly given the recent decline in afforestation from 15,696 ha per year in 2000 to just over 5,500 ha per year in 2017 (Figure 2).

To encourage Irish farmers to plant forestry, an afforestation scheme was launched in 1989. Currently, the scheme covers all planting and establishment costs and pays an annual premium for the duration of 15 years to offset the loss of income from the time of planting until the first revenues from timber harvesting (Teagasc, 2018b). In 2007, farm afforestation was made even more financially attractive given that farmers who planted continued to receive agricultural direct payments on the afforested land (Duesberg et al., 2014, Breen et al., 2010). Now, forestry returns exceed those from beef and sheep farming and therefore afforestation should take place to a greater extent if all farmers were acting as profit maximisers (Ryan and O'Donoghue, 2016, Breen et al., 2010). Despite continuous improvements in funding, planting rates have remained below the national target (Figure 2).

The dominant carbon sinks in Ireland are forests (11% of total land area), grassland (58.5%) and wetlands (16.4%) (Duffy et al., 2019). Hence, they play an important role in mitigating climate change, by sequestering and storing CO_2.[8] Forestry has thereby the potential to be the largest sequester of carbon, if it is managed and cultivated correctly (DAFM, 2018). Ireland's forests have removed an average of 3.8 Mt CO_2eq per year from the atmosphere over the period 2007 to 2017. This is equivalent to almost 6% of the total Irish GHG emissions (DAFM, 2018b). Due to drainage of organic soils, Grasslands and Wetlands are, on the other hand, major sources of emissions with 6.8 Mt CO_2eq and 3.5 Mt CO_2eq in 2017 (Annex 2).

While total forest area increased by nearly 290,000 ha between 1990 and 2017, wetlands (especially peat) are declined by nearly 132,000 ha (-9.7%) and grassland area declined by 178,000 ha (-4.1%)

[7] Marginal agricultural land is defined as land moderately suitable for permanent pasture and not suitable to tillage. It is characterised through poor to moderate fertility, well to poorly drained, it can contain steep slopes, drumlin areas and peat soils (Farrelly and Gallagher, 2015, Duffy et al., 2019).

[8] Sequestering is the net removal of CO_2 from the atmosphere and storage in biomass (DAFM, 2018).

(Duffy et al., 2019, DAFM, 2018b). Considering wetlands and grassland are along with forestry the major carbon sinks, no new carbon sinks were created since 1990.

4 Technically feasible mitigation potential for the Irish AFOLU sector

Latest Environmental Protection Agency (EPA) GHG emissions projections indicate an overall increase in GHG emissions from most sectors. In 2020 the sectors with the largest contribution of emissions are likely to be the Agriculture, Transport and Energy Industries. The projected growth in emissions is largely underpinned by projected strong economic growth and relatively low fuel prices leading to increasing energy demand over the period (EPA, 2018).

In the absence of any mitigation, agricultural GHG emissions are projected to increase by 8% by 2020 and 9% by 2030 relative to the 2005 baseline up to 20.28 Mt CO_2eq and 20.45 Mt CO_2eq respectively. This projected increase is mainly driven by increased dairy cow numbers and increased fertiliser use (Lanigan and Donnellan, 2018).

The dairy cow herd is projected to increase by 10% and 22% on current levels out to 2020 and 2030 respectively. Furthermore, the remainder of the cattle population (which includes the offspring of the dairy cow herd, as well as suckler cows and their offspring) is projected to increase by 1% out to 2020 and decrease by 2% out to 2030. Nitrogen fertiliser use is projected to increase accordingly by 14% and 21% by 2020 and 2030 respectively (EPA, 2018).[9]

Studies undertaken by Teagasc have identified mitigation pathways through which Irish agriculture can contribute to mitigating Ireland's GHG emissions.

1) Reductions in the emission intensity of agricultural produce
    a. by increasing efficiencies and productivity
    b. decouple nitrous oxide emissions from production via nitrogen use efficiency
2) Offsetting emissions associated with agricultural production through carbon sequestration
    a. absorb CO_2 via carbon sequestration in forests, grassland and wetland

The theoretical mitigation potential occurring through technically feasible agricultural and land-use mitigation measures for Ireland has been assessed by Lanigan and Donnellan (2018) by using the MACC approach. A MACC thereby visualises graphically the abatement potential of GHG mitigation measures and the relative costs associated with each of these measures. It ranks the mitigation measures from cost-beneficial measures (measures that not only reduce GHG emissions, but also save money in the long-term) to cost-prohibitive measures (measures that reduce GHG emissions but are expensive in the long-term). The final abatement potential incorporates all cost-efficient measures, meaning measures that reduce GHG emissions either at no extra costs (cost-beneficial) or at costs up to a carbon price of €50/tonne (Lanigan and Donnellan, 2018).

The total agricultural mitigation potential by 2030, when maximum linear uptake of cost-efficient mitigation measures is assumed to have occurred, is estimated to be 2.89 Mt CO_2eq per year (Table 1). The identified feasible agricultural mitigation measures can be divided into two groups – production efficiency measures (964.8 kt CO_2eq per year mean mitigation potential between 2021-2030) and nitrogen and methane reducing emission measures (988.9 kt CO_2eq per year mean mitigation potential between 2021-2030) (Lanigan and Donnellan, 2018).[10,11] An increase in production efficiency is a win-

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[9] Over the last decade fertiliser use has been subject to considerable fluctuation due to both changes in fertiliser prices and variability in agronomic conditions, making the projection of future levels of fertiliser use quite challenging (EPA, 2018).

[10] Production efficiency measures identified in Lanigan and Donnellan (2018) are improved liveweight gain, beef genomics, dairy EBI (economic breeding index), extended grazing, Nitrogen-use efficiency (NUE), animal health, sexed semen, inclusion of Clover in pasture swards.

[11] Nitrogen and methane reducing emission measures identified in Lanigan and Donnellan (2018) are fertiliser type – reducing N emissions, crude protein in pigs, draining wet mineral soils, slurry amendments, adding lipids, low emission slurry spreading.

win situation that leads to lower emissions per unit product and lowers costs to the producer. However, the supply response of farmers (i.e. increasing total animal numbers) due to the increased profitability may lead to increased overall production, partly or fully negating some of the improvement in emissions intensity. As a result, this could lead to an increase in national GHGs, although the increase will be limited through efficiency measures. Contrary to efficiency measures, technical measures mainly impact on emission factors of a production system rather than the produced unit. Hence, technical measures result in a non-negatable emission reduction, even though most of them incur a cost of implementation (Lanigan and Donnellan, 2018, IPCC, 2014).

It is predicted that over the period 2021 to 2030, afforestation since 1990 (i.e. all new forests planted since 1990 and up to 2020) will remove an estimated 4.5 Mt CO_2eq per year from the atmosphere (DCCAE, 2017). For the LULUCF sector associated with the agricultural sector, a MACC was generated that encompasses those measures that enhance carbon sinks or reduce carbon loss from agricultural soils in Ireland.[12] In total, a cost-effective carbon sequestration of 3.50 Mt CO_2eq per year is predicted when full uptake is achieved. The bulk of sequestration is thereby due to forestry (2.10 Mt CO2eq per year) (Lanigan and Donnellan, 2018).

Following the EU Effort Sharing Regulation (Regulation (EU) 2018/842), the cost-effective abatement potential at a carbon price of €50 per tonne for total agricultural GHG emissions projected to 2030 would be 6.39 Mt CO_2eq annually (Table 1).

Table 1: Agricultural GHG emissions projected to 2030 and the cost-effective abatement potential at a carbon price of €50/tonne

	Projected emissions or abatement (Mt CO_2eq yr-1)	
	Mean over 2021-2030 period	Abatement in 2030
Total Agriculture emissions (ex. Fuel)	20.28	20.45
Cost effective Agriculture mitigation	1.76	2.89
Cost effective LULUCF offsets[13]	2.80	3.50
Total	4.56	6.39

Source: Lanigan and Donnellan (2018).

Considering all technically feasible cost-effective mitigation measures, it appears that theoretically an abatement of agricultural GHG emissions in the region of the non-ETS emission reduction targets of 20% by 2020 and 30% by 2030 is almost achievable.

5 Best practice adoption – Determining Factors

Major underlying assumptions, when assessing the Irish abatement potential of the agricultural and LULUCF sector through the MACC approach by Lanigan and Donnellan (2018), are that the uptake rate of the identified mitigation measures is linear over the investigated time and that the mitigation measures are adopted by all farmers possible with the best available technology (Lanigan and Donnellan, 2018, DCCAE, 2017). These assumptions can be brought down to one factor – the individual farmer.

The farmer's individual behaviour considerably influences the outcome according to the Behavioural Economics approach which incorporates the Theory of Panned Behaviour (TPB) (Azjen and Madden, 1986) and the Theory of Adoption and Diffusion of New Technologies (Rogers, 1962).[14] The decision-making process with regards to land-use change according to the Giddens' theory of structuration

[12] LULUCF mitigation measures identified in Lanigan and Donnellan (2018) are grassland management, water table management of organic soils, forestry, cover crops, straw incorporation.

[13] According to the EU Effort Sharing Regulation (EU 2018/842) the offset of GHG emissions through LULUCF will be capped at 2.68 Mt CO_2eq per year (European Council, 2018).

[14] The TBP can be used to predict behaviour and explore the underlying motivations for adopting a particular behaviour. It consists of behavioural intentions, attitudes, subjective norms and perceived behavioural control (OECD, 2012).

(Giddens, 1984) is influenced by structural, socio-demographic and individual farmer factors (Duesberg et al., 2014). Numerous case studies (Buckley et al, 2015, Tzemi and Breen, 2018, Hamilton-Webb et al., 2017, Duesberg et al., 2014) identified several major determining factors that influence the behaviour of individual farmers (OECD, 2012).[15] These case studies mainly use multi/binomial logit or probit models and descriptive statistics on representative farm surveys.[16] The identified non-price determining factors for Ireland can be divided into two groups – the farmer's individual attitudes and the farm structure and its business profile (Buckley et al., 2015, OECD, 2012, Duesberg et al., 2014).

5.1 Determining farmer's attitudes for agricultural mitigation measures

From studies undertaken for different countries, it appears that there is no single formula determining the most important factors in the farmer's decision-making process. Furthermore, an understanding of the local conditions is key to understanding this decision-making process (OECD, 2012). Recent representative studies on Irish farmers by Tzemi and Breen (2018), as well as Tzemi and Breen (forthcoming) and Buckley et al. (2015) have found the uptake of mitigation measures in Ireland is significantly impacted by the following individual farmers' attitudes. The main attitudes identified are in relation to:

1) The degree of awareness that man-made GHG emissions contribute to global climate change, increases the willingness to adopt mitigation measures
2) Receiving or seeking agri-environmental advice increases the willingness to adopt mitigation measures
3) Cost occurring through the uptake of mitigation measures decrease the willingness to adopt mitigation measures

The awareness of the contribution of man-made GHG emissions to global climate change of Irish farmers at 53% is slightly lower than the awareness of the Irish general public at 68%. Among Irish farmers, sheep farmers are the least aware of the link, with 50% being uncertain (Tzemi and Breen, 2018). However, Irish farmers awareness of the link between the contribution of man-made GHG emission to global climate change appears to be much higher than compared with farmers from other developed countries. In general, it is observed that people tend to underestimate the cumulative effects of singular behaviour (OECD, 2012). In a survey of tillage farmers in 11 US States, 68% of the farmers believed that climate change is occurring but only 10% were aware that it is man-made (Arbuckle et al., 2013). A survey with Australian agricultural advisors came up with similar results (Fleming and Vanclay, 2010).

Although aware of climate change, 76.3% of the Irish farmers either felt climate change is only a long-term problem, no problem or are unsure as to whether it is a problem (Tzemi and Breen, 2018). This appears to be a major issue as farmers do not see climate change as a critical immediate problem (OECD, 2012, Hamilton-Webb et al., 2017). If the farmers are aware of the impact of agriculture on the environment, it significantly increases their willingness to adopt mitigation measures (Tzemi and Breen, 2018, Hamilton-Webb et al., 2017, Buckley et al., 2015). It further appears that experiencing climate change (through flood, drought and other natural hazards) is a major factor increasing farmers' awareness and, related to this, their willingness to adopt mitigation measures (Hamilton-Webb et al., 2017). The highest rate of willingness to adopt mitigation measures is hence seen among Irish farmers who manage grassland on lesser quality soils, where droughts are less easily compensated (Tzemi and Breen, 2018).

[15] Contrary to the Behavioural Economics approach, determining factors not found significant for Irish farmers to implement agricultural mitigation measures are own equipment, age, stocking rate of livestock, land-owned and farm size (Tzemi and Breen, forthcoming, Tzemi and Breen, 2018, Howley et al., 2012).

[16] Under a logit/probit model the probability of a binary outcome is identified (Duesberg et al., 2014).

It is of interest to note, that 58.1% of the Irish farmers do not consider GHG emissions from agriculture, more specifically ruminants and land tilling (Lynch et al., 2016), to be important sources of GHG emissions (Tzemi and Breen, 2018). Farmers have been found to view other sectors such as the automotive, aviation and manufacturing industry as pollutants (Bruce, 2013) and as a result, they fail to recognise agricultural practices such as the use of artificial fertilizers, as an important source of GHG emissions (Tzemi and Breen, 2018).[17]

Hence, receiving advice and adopting advisory systems has a crucial role in the willingness of farmers to adopt mitigation measures (OCED, 2012). In the study by Tzemi and Breen (2018), 32% of Irish farmers had received agri-environmental advice. This thereby had a significant positive effect on the willingness of farmers to adopt mitigation measures.[18] A total of 67.8% of Irish farmers indicated that they had not received any agri-environmental advice at the time of the study.[19] Furthermore, 28.5% would like to receive advice in the future and 39.3% would not want to receive advice at any point in time. Of this group 51% were cattle rearing farmers (Tzemi and Breen, 2018).

Of all the Irish farmers questioned, only 35.2% are willing to adopt an advisory tool that would quantify the potential reduction in GHG emissions. With 58.8%, dairy farmers are the group that have shown the greatest willingness to adopt such an advisory tool. These results correspond with the finding that receiving agri-environmental advice significantly increases the willingness of Irish farmers to adopt a tool that would quantify potential reductions in GHG emissions (Tzemi and Breen, forthcoming, Tzemi and Breen, 2018, Buckley et al., 2015, Howley et al., 2012). Furthermore, cattle rearing farmers, had the highest proportion of farmers state that they were not willing to use an advisory tool to quantify their farms GHG emissions (Tzemi and Breen, 2018).

In general, the win-win outcome of a mitigation measure must be greater and more direct than the possible medium-term trade-offs of the adopted measure, such as a decrease in yield or an increase in pesticide or fertilizer usage (OECD, 2012).[20] Of Irish farmers, 77.6% are unwilling to take up any measures that would incur any increase in their production costs (Tzemi and Breen, 2018). Farmers undertake actions that are seen as a part of normal practice leading to a win- win situation as these actions increase productivity, reduce energy, reduce inorganic fertiliser usage, improve field drainage. Currently, these actions are primarily undertaken for their risk reduction and not for climate change effects (Hamilton-Webb et al., 2017, Lanigan and Donnellan, 2018, Ghadim et al., 2005). It has been observed that farmers feel they had more pressing concerns to worry about other than climate change (Hamilton-Webb et al., 2015). Of the questioned farmers, 18% would be willing to have up to 5% additional costs through mitigation measures (Tzemi and Breen, 2018). The higher the additional costs of new technology, the less likely farmers are to adopt this new measure (Howley et al., 2012).

5.2 Determining economic farm structure for agricultural mitigation measures

The main determining factors significantly impacting the uptake of mitigation measures in Ireland derived from the economic structural profile of a farm are: (Buckley et al, 2015, Tzemi and Breen, 2018, Howley et al., 2012)

1) Profitability of farms increases the willingness to adopt mitigation measures
2) Receiving environmental subsidies increases awareness but not necessarily the willingness to adopt mitigation measures

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[17] The same can also be seen for farmers in other countries such as UK (Bruce, 2013).

[18] The causality between the farmers' awareness of potential GHG emission sources and receiving agri-environmental advice is thereby not clear (Tzemi and Breen, 2018).

[19] The high number of farmers indicating that they had not received any agri-environmental advice is surprising given the high uptake of agri-environmental schemes such as REPS in the past (Tzemi and Breen, 2018).

[20] The win-win situation of mitigation measures occurs if the implemented mitigation measure leads to lower emission per unit product and lower costs to the producer (Lanigan and Donnellan, 2018).

3) Dairy farmers are more willing to adopt mitigation measures than farmers in other sectors

Profitability has a significant positive effect on the uptake of mitigation measures (Tzemi and Breen, forthcoming, Buckley et al., 2015). Irish farmers with higher family farm income, indicating a higher production efficiency, have a greater willingness to adopt mitigation measures (Tzemi and Breen, 2018, Buckley et al., 2015). It appears that profitable farmers recognise the potential to increase their profitability even further by adopting these win-win measures (Howley et al., 2012, Hamilton-Webb et al., 2017). Furthermore, it appears that these Irish farmers are more open to changing farm management practices in order to increase profitability further (Tzemi and Breen, forthcoming).

The relationship between financial compensation (subsidies) and the adoption of measures or participation in a programme cannot be expressed by a simple formula. Although it is seen that it increases the awareness of climate change, it does not necessarily increase the willingness of farmers to adopt mitigation measures (OECD, 2012). The rate of farmers adopting mitigation measures, even in the absence of subsidies, is similar to the rate of adoption among those receiving subsidies (OECD, 2012).

In the different Irish studies, it was found that a positive impact of environmental subsidies can be found, although it is marginal (Tzemi and Breen, 2018, Howley et al., 2012). The direction of causality is thereby not clear – either Irish farmers are more environmentally conscious and therefore they receive subsidies, or the subsidy raised their environmental consciousness (Tzemi and Breen, 2018). In a study on English farmers, even when funded, only 24% of the farmers stated that they would install mitigation activities that lead to additional costs. Funding is thereby not a significant motivator (Hamilton-Webb et al., 2017).

The willingness to adopt mitigation measures differs between different farm enterprises. Generally, in Ireland, livestock production and the livestock production intensity increase the adaptation rate (Buckley et al., 2015). Among livestock farms, those Irish farmers with the highest gross margins per livestock unit were found more likely to use new technology (Howley et al., 2012). As dairy farms in Ireland throughout the years have had the highest average family farm income, dairy enterprises show the greatest willingness to adopt mitigation measures (Tzemi and Breen, 2018, Teagasc, 2018). At the same time, dairy farms have the highest investment rate of all farm types. Significantly, sectors that are willing to adopt mitigation measures are also those sectors that invest the most in Ireland (Tzemi and Breen, forthcoming). The dairy and beef sectors have been the sectors that have substantially increased their investment over the last decade (Dillion et al., 2018).[21]

5.3 Determining LULUCF factors

Specific determining factors occur which influence the probability of farmers to take financial risks and consider afforestation under the current Irish support scheme (Duesberg et al., 2014, Ryan and O'Donoghue, 2016). Taking into account that land use change from agriculture to forestry in Ireland is a permanent decision due to the 1946 Forestry Act (Breen et al., 2010), the determining factors appear to be slightly different than the ones for agricultural mitigation measures.

The land-use and land-use change decisions towards afforestation of Irish farmers are influenced by the structure and individual agents' actions which go beyond simply maximising economic returns: (Ryan and O'Donoghue, 2016, Duesberg et al., 2014)

1) Larger farm size increases the likeliness to afforest
2) Receiving advise on afforestation scheme increases the probability to afforest
3) Dairy farmers are less likely to afforest than other farmers

[21] From 2016 to 2017 the on-farm investments in Ireland went up by 16%. Thereby 49% of the farm investment was on dairy farms (Teagasc, 2018).

4) Farmers are more likely to afforest land that is less suitable for agriculture

Contrary to the factors found to influence the uptake of agricultural mitigation measures significantly, the only variable that consistently emerged as influencing land use change in Ireland is farm size. Farmers with a larger than average farm (>56 ha) are more likely to afforest (Duesberg et al., 2014, Howley et al., 2012b). Subsequent studies, by Ryan and O'Donoghue (2016 & 2016b) and Howley et al. (2015), found that the average farm size with an increased likelihood to afforest had grown to 62 ha.

Receiving advice on the existing Irish afforestation scheme has a significantly positive impact on the farmer's probability to afforest (Ryan and O'Donoghue, 2016b). Of the Irish farmers questioned, 87% are aware of the availability of the afforestation scheme of which only 10% are interested in afforesting. Respondents with no intention of planting were provided, in a second round, with detailed information of the scheme. This increased the total numbers of farmers considering afforestation from 10% to 26% (Duesberg et al., 2014). Still, 84% of farmers do not intend to afforest their land for any level of forest subsidy. Even if made aware that they would achieve a higher income through afforestation than through agriculture (even when taking agricultural subsidies into account), only 6% of farmers would consider planting (Ryan and O'Donoghue, 2016).

Dairy farmers in Ireland have been found to be less likely to afforest, even when they have been in receipt of advice on the benefits of the afforestation scheme (Ryan and O'Donoghue, 2016b, Duesberg et al., 2014, Howley et al., 2012b). These farms are specialised and highly profitable (having the highest family farm income on average) and higher returns per hectare than the other main farming enterprises on average. The agricultural opportunity costs to afforest are higher than the resulting benefits through afforestation (Ryan and Donoghue, 2016, Duesberg et al., 2014). Generally, higher family farm income negatively impacts on the probability to afforest (Ryan and O'Donoghue, 2016b). Additionally, dairy farms do not generate any financial benefits through afforestation, no matter what type of soil their farm consists of (Ryan and O'Donoghue, 2016).

Cattle and sheep farms which account for 76% of all Irish farms have been found to be more likely to afforest (Howley et al., 2015). With an average family fam income that does not cover all production costs through market returns and a farm system that is less intensive, they try to increase their family farm income by diversification through afforestation, as they benefit financially no matter on what type of soil they farm (Ryan and O'Donoghue, 2016 & 2016b, Duesberg et al., 2014, Howley et al., 2012).

In making the decision to afforest some of their agricultural land, it is assumed that farmers are unlikely to afforest land which gives a higher return in another farm enterprise (such as dairy) (Ryan and O'Donoghue, 2016). Farming on marginal agricultural land significantly increases the probability of Irish farmers to afforest (Howley et al., 2015, Duesberg et al., 2014). Of the Irish farmers, 40% regard forestry as a land use for only marginal land that is not suited to other agricultural activities (Howley et al., 2015). Productive agricultural land that generates a positive return under agricultural usage, is not considered for afforestation, as it stands in conflicting land-use with food production and hence has a significantly negative impact on the probability to afforest (Ryan and O'Donoghue, 2016, Duesberg et al., 2014).

6 Adjusted mitigation potential for the Irish AFOLU sector

As demonstrated by the literature reviewed, the characteristics of individual farmers have an important impact on the level of adoption. Taking these characteristics into account will lead to a reduction potential for total agricultural GHG emissions lower than that predicted by a pure MACC approach. Hence, in this study, the uptake rate of agricultural and LULUCF mitigation measures in the MACC approach will be adapted according to the rates found in the literature.

Based on the resulting determining factors, the agricultural mitigation potential needs to be adjusted as follows:

- ***For cost-beneficial production efficient mitigation measures an uptake of 75% is more likely***

In the study by Lanigan and Donnellan (2018), it is assumed that the general adaptation is implemented to the full potential where possible. Production efficient measures are undertaken by a high percentage of farmers, as they are embedded in good agricultural practices and achieve positive profitability and production potential at farm level. Studies of Irish farmers found the maximum possible uptake rate of 75% for specific measures. (Buckley et al., 2015)

- ***For cost-efficient measures an 18% uptake rate is more likely***

Although the identified cost-efficient measures by Lanigan and Donnellan (2018) can be adapted at lower costs than an assumed carbon price of €50/tonne, it has been shown that 77.7% of the Irish farmers are not willing to pay any additional costs to adopt mitigation measures. Among Irish farmers, 18% are willing to pay an additional 5% of their production costs to adopt mitigation measures (Tzami and Breen, 2018). The additional costs stated in the MACC approach for the cost-efficient measures lie below 5% of the average farm production costs taken from the Annual Review and Outlook by DAFM (2018). Therefore, it is assumed that 18% of the farmers will take up these cost-efficient mitigation measures. The mitigation potential for the slurry amendments is based on an 18% uptake instead of 20%, as assumed in the MACC approach by Lanigan and Donnellan (2018).

- ***For cost-prohibitive measures the uptake rate of zero is adopted***

These mitigation measures save GHG emission but exceed the set carbon price. Farmers will therefore not take up these measures. Following Lanigan and Donnellan (2018), an uptake rate of zero is applied.

The LULUCF mitigation potential associated with the agricultural sector needs adjustment, based on the derived determining factors, as follows:

- ***For cost-beneficial production efficient mitigation measures, the uptake rate remains unchanged***

As a win-win situation occurs for the farmers, determining factors are very low and adoption of more efficient grassland management can be expected for 450,000 ha, as estimated by Lanigan and Donnellan (2018).

- ***For Water Table Management of organic soils, the uptake rate of total 4,000 ha is more likely***

The rewetting rate since 2005 on all kinds of organic soils (grassland, forest and wetland) has not exceeded 800 ha per year, ranging mostly around 400 ha per year (Duffy et al., 2019). Assuming a rewetting of 40,000 ha by 2030 seems therefore out of reach. An abatement potential of 4,000 ha seems more likely in the absence of policy or regulation that enforces a higher rate and so this lower level is assumed.

- ***For Forestry the uptake rate by farmers is reduced to 6,000 ha per year***[22]

The study by Lanigan and Donnellan (2018) assumes afforestation up to 2030 at a rate of 7,000 ha per year. Since 2007, this afforestation rate has not been achieved even though subsidies have continuously improved. In 2017, the Irish afforestation rate was at its lowest level since 1998 of 5,500 ha (Duffy et al., 2019).

One main determining factor in the decision-making process by farmers to afforest is the quality of their land. Of the area identified as suitable for forestry (3.75 M ha in Ireland), 1.08 M ha is identified as marginal agricultural land, of which 61% is marginal dry grassland (COFORD, 2016).[23,24] Considering, that dairy farmers rarely take up afforestation, and that mainly farmers above a farm size of 56 ha afforest, available land for possible conversion into forest is reduced to 56,378 ha. Afforestation

[22] This would lead to a total area covered by forest in Ireland of 12% by 2030 (Own compilation).

[23] Forest productivity is measured by the yield class system. Land needs to be off yield class 14 for an afforestation grant aid (Farrelly and Gallagher, 2015).

[24] Reclaimed and wet grassland have been excluded as they may be brought back into production through drainage and reclamation works at reasonable costs depending on the market development (Farrelly and Gallagher, 2015).

undertaken to the predicted extent would lead to low land-use competition, as it is undertaken on marginal agricultural land, which according to Farrelly and Gallagher (2015) is not predicted to be brought back into production at reasonable costs. Taking these factors into account, assuming a yearly rate of 6,000 ha seems more realisable up to 2030.

- ***For cost-prohibitive measures the uptake rate of zero is adopted***

As for direct agricultural measures, these mitigation measures save GHG emissions but exceed the set carbon price. According to Lanigan and Donnellan (2018), farmers will therefore not take up these measures.

Considering all the derived adjustments, the adjusted cost-effective abatement potential at a carbon price of €50 per tonne for total agricultural GHG emissions projected to 2030 would be 4.54 Mt CO_2eq annually (Table 2).

Table 2: Agricultural GHG emissions projected to 2030 and the adjusted cost-effective abatement potential at a carbon price of €50/tonne

	Projected emissions or real term abatement (Mt CO_2eq yr-1)		
	Mean over 2021-2030 period		Abatement in 2030
Total Agriculture emissions (ex. Fuel)	20.28		20.45
Cost effective Agriculture mitigation	1.14		1.92
Teagasc MACC estimate	1.76	(-35%)	2.89
Cost effective LULUCF offsets	2.10		2.62
Teagasc MACC estimate	2.80	(-25%)	3.50
Total	3.24		4.54
Teagasc MACC estimate	4.56	(-29%)	6.39

Source: Own compilation.

Taking Irish farmers' behaviour into account, the estimated cost-effective agricultural mitigation potential will be 1.92 Mt CO_2eq per year in 2030 (Table 2). This accounts for 9.4% of the total estimated agricultural GHG emissions, which is 35% below the MACC estimation. Measures undertaken mainly by farmers in the LULUCF sector, associated with the agriculture sector, can effectively offset agricultural GHG emissions by 2.62 Mt CO_2eq per year by 2030 (Table 2). This would offset 13% of the total estimated agricultural GHG emissions, which would be 25% less than predicted in the MACC approach.

In total, this would lead to a possible abatement potential of annual agricultural GHG emissions of 4.54 Mt CO_2eq per year by 2030 (29% less than the MACC estimation). This would reduce the agricultural GHG emission level below the reference level of 18.75 Mt CO_2eq in 2005, slowing down the increase of agricultural GHG emissions produced, but still leaves a significant gap to any potential reduction target derived from the non-ETS emission reduction targets (Annex 1).

7 Policy relevance and implications – Conclusion

The strong positive development of the Irish agriculture sector up to 2017 shows that the agricultural growth targets set in the Food Harvest 2020 and Food Wise 2025 strategy paper look likely to be achieved respectively by 2020 and 2025. However, this growth comes with a significant increase in agricultural GHG emissions (+4.4% since 2005). With voluntary adoption of abatement technologies and the determining factors of farmers to adopt mitigation measures, the analysis in the preceding chapter has shown a significant gap between achievable GHG emissions reduction and the non-ETS emission reduction targets for Ireland. This demonstrates the intertwined nature of the agriculture sector and the GHG emissions. The Irish agricultural and GHG emission targets appear to be in contradiction as they drift further apart (Annex 1).

GHG emission mitigation measures which improve the productivity and competitiveness of the agriculture sector and also reduce GHG emissions, could be linked to support payments in order to increase the uptake rate of these mitigation measures. With a transition period in which the stringency of conditions is phased-in, there is an improvement not only in the productivity, but also in the environmental performance of the agriculture sector (Gray et al., 2017). Increasing the uptake rate of cost-effective, cost beneficial mitigation measures to the technically feasible potential could increase the abatement achieved through these measurements considerably.[25] To increase the uptake rate of cost-effective mitigation instruments that incur costs, farmers would need to receive support to remove barriers that determine their behaviour (OECD, 2012).[26] Support could be in form of on-farm investments in innovations (i.e specific mitigation measures) that are targeted towards increasing climate efficiency. Specific instruments might include innovation allowances and credits. Thereby, it would be important to coordinate any new measure with existing frameworks (Gray et al., 2017).

Incorporating climate policy more directly into agricultural policy would hence open the possibility of reversing the recent trend of continuously growing agricultural GHG emissions. Just agricultural mitigation measures could then reduce the level of agricultural GHG emissions by 2030 that would diverge towards possible GHG emission reduction targets.

Due to natural restrictions of the agriculture sector (especially in the ruminant livestock sector), an increase of the abatement potential above the technically possible potential is limited. Adding the LULUCF abatement potential to the agricultural mitigation capacity has the potential to abate a significant share of agricultural GHG emissions. As the main proportion of afforestation is undertaken by farmers, future forestry expansion will thereby depend on a change in land use from agriculture to forestry (Farrelly and Gallagher, 2015).

To increase the annual farm afforestation rate, our study has pointed out that farmers need to be informed more about existing afforestation scheme benefits to incorporate afforestation as a part of a wider farm management decision. Reaching those framers through a linked agriculture and forestry advice could possibly increase the farm afforestation rate (Ryan and O'Donoghue, 2016). More knowledge transfer needs to take place which depicts afforestation and agricultural land use decisions as a way of diversifying and stabilising farmers income. Taking into account, that over 600,000 ha of dry grassland have been identified as being of limited agricultural use (COFORD, 2016), converting an additional 1,500 ha per year of marginal land into forest, to maintain the Irish forest as a net carbon sink, will change the structure of some farms but will increase land-use competition in Ireland only marginally.[27]

Although an increase in afforestation could lead to a LULUCF abatement potential above the maximum level accountable for the agricultural sector due to the cap in the EU Effort Sharing Regulation, it could increase the abatement potential considerably, contributing to Ireland's image as a green and sustainable food producer. Hence, afforestation could become a key measure in Ireland's strategy to address climate change.

Policy measures need to be implemented in order to increase the abatement potential of the AFOLU sector, to substantially help bring the nexus between agricultural development and GHG emission targets in Ireland closer together. One main factor influencing the uptake rate of mitigation measures is the farmers' understanding of the issues and measures available to tackle these. Therefore, the behavioural changes of farmers need to be understood and to reduce agricultural GHG emissions, polices are needed that remove the barriers to behavioural change.

[25] The abatement potential of production efficiency measures can be slightly offset by a possible increase in production due to the increase in productivity (Lanigan and Donnellan, 2018).

[26] As these measures impact on the emission factors of a production system rather than the produced unit (Lanigan and Donnellan, 2018), they are of interest as their abatement potential is less likely to be offset by an increase in production.

[27] To maintain the Irish forest as a net carbon sink, 7,500 ha per year of afforestation are required (COFORD, 2016).

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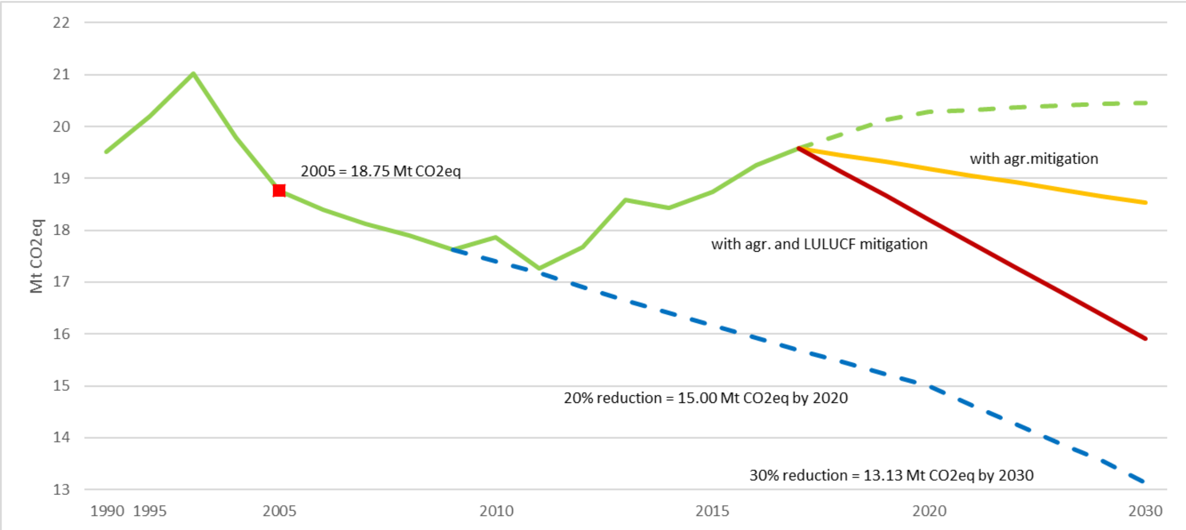
Annex

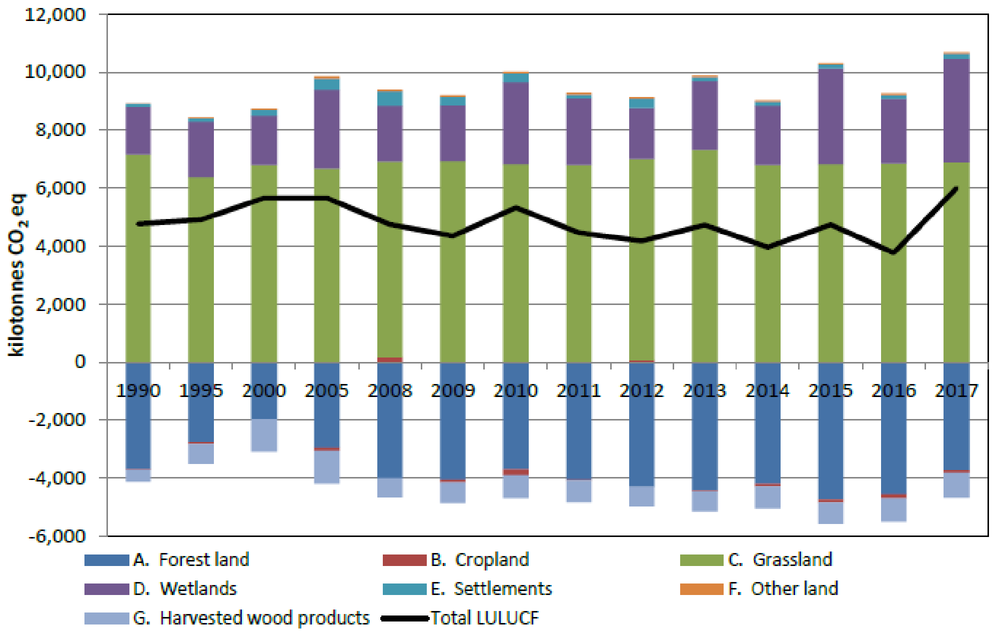
*Annex 1 Irish agricultural GHG emissions projected to 2030 without (green) and with **adjusted** mitigation (yellow and red) and the potential sectoral emissions reduction path up to 2030 (blue)*



Note: In the EU Effort Sharing Decision, the 2005 level of non-ETS GHG emission sets the reference point for future reductions of non-ETS GHG emissions. For the Agriculture sector, following the assumptions made in Lanigan and Donnellan (2018), this would result in a reduction of GHG emission from 18.7 Mt CO_2eq down to 15 Mt CO_2eq by 2020 and 13.13 Mt CO_2eq by 2030.

Source: Own compilation, Duffy et al. (2019).

Annex 2 Trend in Emissions and Carbon Sequestration potential from LULUCF 1990-2017



Source: Duffy et al. (2019).