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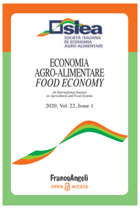

Insights in overcoming the non-adoption of voluntary agricultural GHG mitigation measures in Ireland

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Abstract

Agricultural Greenhouse Gas (GHG) emissions in Ireland are projected to increase up to 21 Mt CO_2eq by 2030 mainly driven by increased dairy cow numbers and increased nitrogen fertiliser use. In response to the growing public awareness of the GHG emissions' environmental impact, the Irish government published the Climate Action Plan in 2019, which identifies the agricultural sector's leading role in reducing GHG emission and increasing carbon removals to achieve the national GHG emission targets by 2030. Marginal Abatement Cost Curves (MACCs) on Irish GHG emissions have projected the total technically feasible mitigation potential for the Irish agriculture, forestry and land use (AFOLU) sector to be sufficient enough to achieve the set targets by 2030. Although these mitigation measures are available and when implemented, would mostly lead to a win-win situation, the voluntary adaptation rate by farmers is low. This study addresses the most significant determinants of voluntary adoption of mitigation measures by systematically examining existing literature on how and to what extent non-price determinants affect the voluntary adoption rate of technically feasible mitigation measures in the Irish AFOLU sector. The main identified non-price determining factors were the degree of farmers'

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awareness regarding man-made GHG emissions, receiving agri-environmental advice, implementation costs, profitability and size of farms, land quality and the type of farm enterprise. Integrating the gained results in the former MACC analysis enabled us to adopt the implementation rates of the cost-efficient AFOLU mitigation measures accordingly. The non-price determinants impact the voluntary uptake rate of AFOLU mitigation measures to the extent that the adjusted total Irish AFOLU abatement potential is 47% lower than technically feasible. Considering that 51.6% of the total estimated AFOLU abatement potential in 2030 is offset through Irish forestry, which at current afforestation rate will turn into a net carbon source by 2035, a significant gap occurs to any potential Irish and EU GHG reduction targets. To substantially help bring the nexus between agricultural development and GHG emission targets in Ireland closer together, policy measures, that differentiate between the different type of AFOLU mitigation measures, need to be implemented to enhance the uptake rate of cost-beneficial and cost-effective measures. This would have the potential to reduce the level of agricultural GHG emissions by 2030 in a way that it would converge towards possible EU and Irish GHG emission reduction targets.

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 (DAFM, 2018; DAFM, 2010). The agri-food sector 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). This growth is projected to continue, mainly due to a projected increase of ruminant livestock numbers (dominated by an increase in dairy cattle in response to the abolition of the EU milk quota system) (CSO, 2020; Duffy *et al.*, 2019).

At the same time, greenhouse gas (GHG) emission reduction targets have been set for Ireland's Emission Trading Scheme (ETS)[1] sector and also for the non-ETS[2] sector, which includes agriculture (accounting for 52% of non-

1. The EU Emissions Trading Scheme (EU ETS) launched in 2005 and covers more than 11,000 heavy energy consuming installations in power generation and manufacturing including food processing and manufacturing (EPA, 2019).

2. The non-ETS sector consists of those sectors not included in the EU ETS including agriculture, transportation, households and waste (EPA, 2019).

ETS emissions). The non-ETS sector reduction target for Ireland is amongst the highest in the EU Member States (Reduction of 20% in 2020 and 30% in 2030 relative to 2005 levels) (EPA, 2019). The recently published Climate Action Plan has outlined specified actions for all sectors to reach the set targets. The agriculture sector's leading role becomes thereby apparent in reducing GHG emissions and increasing carbon removals up to –15% by 2030 relative to 2030 emission projections (DCCAE, 2019).

A range of technically feasible mitigation actions for the Irish agriculture, forestry and land-use (AFOLU) sector up to 2030 and their GHG abatement potential have been identified through Marginal Abatement Cost Curves (MACCs) on GHG emissions (DCCAE, 2019; Lanigan and Donnellan, 2018; Schulte *et al.*, 2012). Although these mitigation measures are available and when implemented would mostly lead to a win-win situation, the voluntary adaptation rate through farmers occurs to be low, considering that agricultural GHG emissions have continued to increase since 2011 (Duffy *et al.*, 2019; DCCAE, 2019)[3].

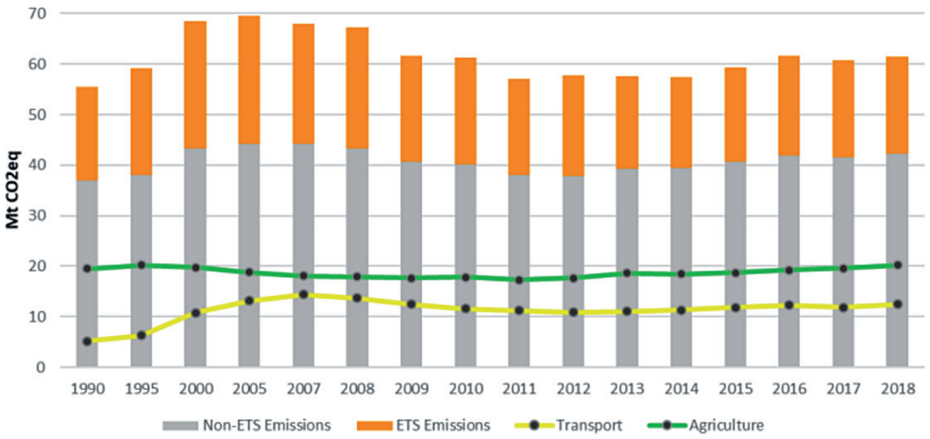
Existing Irish studies on the real term realisation of mitigation measures such as Tzemi & Breen (2018, 2019), Buckley *et al.* (2015) and Ryan & O'Donoghue (2016), identify determining factors that influence the level of adoption of mitigation tools such as degree of awareness on man-made emissions, farms' profitability, and farm type. The aim of the present study is to investigate how the most determining characteristics of Irish farmers and farms to not adopt agricultural GHG mitigation measures voluntarily, impacts the estimated Irish AFOLU abatement potential of technically feasible mitigation measures by applying a meta-analysis on the existing literature. Integrating the real term realisation studies of technically feasible mitigation measures into the Irish MACC analysis, enables to show the possible impact range that the determining factors have on the Irish AFOLU abatement potential. Determining the reasons and the degree of impact on the adoption of GHG mitigation measures enables the discussion of recommendations to overcome the non-adoption of voluntary agricultural GHG mitigation measures that can be derived for Ireland. Policy measures that address the increase of the up-take rate of specific AFOLU mitigation measures can be identified.

3. Agricultural emissions are currently not included in any trading regime and agricultural payments are not granted for the implementation of most mitigation measures.

1. Irish AFOLU Abatement potential of Greenhouse Gas Emissions

In the last two decades, the main Irish sources of GHG emissions have been the agriculture (2018: 34%), transport (2018: 20.2%) and energy sector (2018: 17%) (EPA, 2019b; Duffy *et al.*, 2019). Distinguishing between ETS and non-ETS emissions, agricultural and transport GHG emissions account for 75% of the total Irish non-ETS emissions (Figure 1). This highlights not only the Irish agriculture's sizeable contribution as the largest single contributor to the overall GHG emissions, but also the importance of agriculture in trying to limit overall GHG emissions (DCCAE, 2017; Duffy *et al.*, 2019; EPA, 2019b)[4].

Figure 1 - Trends in Irish Greenhouse Gas Emissions 1990-2018 (Mt CO_2eq)



Source: Duffy *et al.* (2019); EPA (2019b).

Methane (CH4) 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 CH4 emissions from Irish agriculture (Duffy *et al.*, 2019). Enteric fermentation accounts for 51% of total agricultural emissions (DCCAE, 2017).

The recent growth in the Irish agricultural sector has had a substantial impact on agricultural GHG emissions. Since the abolition of the EU milk quota system, the dairy cow herd has increased by 31%, accounting for

4. 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, 2019).

approximately 20% of the total cattle herd in 2017 (CSO, 2019)[5]. Hence, the initially observed decrease in agricultural GHG emissions, after the peak in 1998, has therefore been entirely negated, currently reaching the 1990 level (Figure 1). From 2011 on, the GHG emissions in the agriculture sector have witnessed a further increase of 13.4% up to 2018 (Figure 1).

GHG emissions from Irish Agriculture are projected to increase even further (up to 21 Mt CO_2eq by 2030), even when allowing for the implementation of Project Ireland 2040 measures (DCCAE, 2019). This projected increase is mainly driven by increased dairy cow numbers (+22% on current levels) and increased nitrogen fertiliser use (+21% on current levels) (Lanigan and Donnellan, 2018; EPA, 2019b). This development will present significant challenges for Ireland to meet its targets stated under the Climate Action Plan as well as its non-ETS 2020/2030 targets under the EU Effort Sharing Regulation (Regulation (EU) 2018/842) (European Council, 2018; DCCAE, 2019). Hence, managing these emissions will become a new challenge for farming (Wreford *et al.*, 2010).

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 emissions reduction targets for their non-ETS sectors up to 2030. As well as reducing the emission intensity of agricultural produce, Ireland has the flexibility to realise 4% (1.91 Mt CO_2eq yr-1) reduction of their 2030 non-ETS GHG emission targets through 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). The theoretical abatement potential occurring through technically feasible agricultural and land-use mitigation measures for Ireland has been assessed by Lanigan and Donnellan (2018) using the MACC approach.

MAC curves have been developed to provide a solid analytical foundation on the most cost-effective pathway to reduce GHG emissions in line with decarbonisation targets (DCCAE, 2019; Bockel *et al.*, 2012)[6]. They can thereby, graphically visualise the abatement potential of GHG mitigation measures

5. 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% (CSO, 2020). After removal, a shift in livestock farms occurred due to the potential for higher returns in dairy production compared with other enterprises. Mixed dairy farms specialize in becoming pure dairy farms and some larger-scale beef and cereal farms converted to dairy production, with this trend more commonplace amongst the younger generation of farmers (DCCAE, 2017; DAFM, 2018).

6. MAC curves are thereby used to demonstrate how much abatement an economy can afford and the area of focus to achieve the emission reductions (Bockel *et al.*, 2012).

and the marginal costs per abated tonne of CO_2eq associated with each of the included measures (DCCAE, 2019; Lanigan and Donnellan, 2018)[7]. The GHG MACC analysis of Irish agriculture included 14 agricultural and 5 LULUCF specific mitigation measures (Lanigan and Donnellan, 2018)[8]. The final AFOLU abatement potential incorporates all cost- efficient measures, meaning measures that reduce GHG emissions either at negative marginal costs (cost-beneficial) or at marginal costs not exceeding a carbon price of €50/tonne CO_2 (Lanigan and Donnellan, 2018). Hence, the total AFOLU abatement potential of GHGs for the Irish agriculture sector at a carbon price of €50 per tonne CO_2 by 2030, when maximum linear uptake of cost-efficient voluntary mitigation measures is assumed to have occurred, is estimated to be 6.39 Mt CO_2eq per year (Table 1).

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

	Projected emissions or abatement (Mt CO2eq yr-1)	
	Mean over 2021-2030 period	**Abatement in 2030**
Total Agriculture emissions (ex. Fuel)	20.82	21.04
Cost effective Agriculture mitigation	1.76	2.89
Cost effective LULUCF offsets[9]	2.80	3.50
Total AFOLU	4.56	6.39

Source: EPA (2019b); Lanigan and Donnellan (2018).

The identified feasible agricultural mitigation measures can be divided into two groups – production efficiency measures and technical efficiency measures (Lanigan & Donnellan, 2018). An increase in production efficiency is a win-win situation that leads to lower emissions and lower costs per unit

7. The costs include the costs of the initial investment, the costs of operation for the full lifetime as well as net lifetime cost savings of the technology (DCCAE, 2019). 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) (Lanigan and Donnellan, 2018).

8. For more detail on the Irish MACC analysis please see Lanigan and Donnellan (2018).

9. According to the EU Effort Sharing Regulation (EU 2018/842) the offset of GHG emissions through LULUCF will be capped at 2.68 Mt CO2eq per year (European Council, 2018).

product. All production efficiency measures included in the Irish agricultural MACC analysis are cost-beneficial. Contrary to production efficiency measures, technical efficiency measures mainly impact on emission factors of a production system rather than the produced unit. Even though most of them incur a cost of implementation, technical measures result in a non-negatable emission reduction (Lanigan & Donnellan, 2018; IPCC, 2014). Most of those mitigation measures, except adding lipids and low emission slurry spreading, have been identified as cost-efficient in the MACC analysis.

Box 1 - Irish Forestry Sector

The dominant carbon sinks in Ireland are forests (11% of total land area), grassland (58.5%) and wetlands (16.4%) (Duffy *et al.*, 2019). While total forest area increased by nearly 290,000 ha between 1990 and 2017, wetlands (especially peat) have declined by nearly 132,000 ha (–9.7%) and grassland area declined by 178,000 ha (–4.1%) (Duffy *et al.*, 2019; DAFM, 2018b).

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). Nearly half (49.2%) of forests are in private ownership. Since 1990, 72% of the newly afforested area was planted by the private sector of which 82% was afforested by farmers (DAFM, 2018b). 67% of afforestation occurs on marginal agricultural land. Of this, 56% is marginal grassland (Farrelly & Gallagher, 2015). Over the same period public afforestation declined to close to zero since 2005 (IFFPA, 2018). As a result, forestry and agriculture are intimately intertwined, aiming at the most efficient use of natural resources (DCCAE, 2017; Schulte & Lanigan, 2011).

This change from public to private afforestation was largely a result of the introduction of a range of farm afforestation schemes in 1989 that offered planting grants and annual forestry premia to cover forest establishment costs and offset the lost income from agricultural livestock production (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 (Ryan & O'Donoghue, 2016; Breen *et al.*, 2010).

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 & Gallagher, 2015). Whether a planting rate of 16,000 ha per year is achievable is 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 2018 (DAFM, 2018c; IFFPA, 2018).

For the LULUCF sector associated with the agricultural sector, a GHG MACC was generated that encompasses those measures that enhance carbon sinks or reduce carbon loss from agricultural soils in Ireland. Of the five measures, only grassland management was cost-beneficial with an abatement potential of 0.26 Mt CO_2eq per year. The usage of cover crops and straw incorporation were not incorporated in the analysis as they were identified as cost-prohibitive measures. The bulk of carbon sequestration is thereby due to forestry (2.10 Mt CO_2eq per year) (Lanigan & Donnellan, 2018; see Box 1).

Considering all technically feasible cost-effective mitigation measures, theoretically, an abatement of agricultural GHG emissions in the region of the stated EU targets for non-ETS emission reduction by 2020/2030 as well as the agriculture sector target by 2030 stated in the Irish Climate Action Plan (DCCAE, 2019) is mostly achievable.

2. Methodology

Major underlying assumptions, when assessing the Irish abatement potential of the AFOLU 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 & Donnellan; 2018, DCCAE, 2017)[10]. The main factor underlying these assumptions is thereby the individual farmer.

The farmer's individual behaviour influences the outcome considerably according to the Behavioural Economics approach which incorporates the Theory of Planned Behaviour (TPB) (Azjen & Madden, 1986) and the Theory of Adoption and Diffusion of New Technologies (Rogers, 1962)[11]. The decision-making process with regards to land-use change according to the Giddens' theory of structuration (Giddens, 1984) is influenced by structural, socio-demographic and individual farmer factors (Duesberg *et al*., 2014). Numerous studies (Buckley *et al*., 2015; Tzemi & Breen, 2018; Hamilton-Webb *et al*., 2017; Duesberg *et al*., 2014) identified several major determining factors that influence the behaviour of individual farmers (OECD,

10. The maximum uptake rate reflects thereby the full biophysical potential occurring by 2030 (Lanigan & Donnellan, 2018).

11. The TPB 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).

2012)[12]. These studies mainly use multi/binomial logit or probit models and descriptive statistics on representative farm surveys.

To systematically examine existing literature following Minviel and Latruffe (2017) on how non-price determinants affect the voluntary adoption rate of technically feasible mitigation measures in the Irish AFOLU sector, eligibility criteria for selecting cited studies have been set. Studies have been included that have undertaken an analysis of the decision-making process in the (Irish) AFOLU sector influencing the uptake of GHG mitigation measures. These criteria have led to the inclusion of fourteen studies in our analysis which were carried out during the period 2005-2017. The strength of systematically examining existing literature lies in its ability to combine the results from various studies (Russo, 2007).

In the next step, we adopt the implementation rate of the cost-efficient AFOLU mitigation measures according to the non-price determining factors. This enables us to derive an adjusted possible AFOLU abatement potential for each mitigation measure. Furthermore, this analysis reveals the predominantly impacted mitigation measures and the extent to which they are impacted by non-price determinants.

3. Best practice adoption – Determining Factors

The identified non-price determining factors for Ireland can be divided into three groups – the farmer's individual attitudes, the farm structure and its business profile and LULUCF related factors (Buckley *et al.*, 2015; OECD, 2012; Duesberg *et al.*, 2014). From the studies undertaken for different countries, it appears that there is no single formula for 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).

Determining farmer's attitudes to AFOLU mitigation measures

Recent representative studies on Irish farmers have found the following individual farmers' attitudes significantly impact the uptake of mitigation measures in Ireland. The principal attitudes identified concern:

1. The degree of awareness that man-made GHG emissions contribute to global climate change increases the willingness to adopt mitigation measures.

12. 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 & Breen, 2019; Tzemi & Breen, 2018; Howley *et al.*, 2012).

2. Receiving or seeking agri-environmental advice increases the willingness to adopt AFOLU mitigation measures.
3. Cost occurring through the uptake of mitigation measures decrease the willingness to adopt mitigation measures

In general, it is observed that people tend to underestimate the cumulative effects of singular behaviour (OECD, 2012). 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% (Tzemi & Breen, 2018). However, Irish farmers' degree of awareness appears to be much higher compared to farmers from other developed countries. In a survey of tillage farmers in 11 U.S. 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 & Vanclay, 2010).

It is of interest to note that 58.1% of Irish farmers do not consider GHG emissions from agriculture, more specifically ruminants and land tilling (Lynch *et al.*, 2016), to be significant sources of GHG emissions (Tzemi & Breen, 2018). Farmers have been found to view other sectors such as the automotive, aviation and manufacturing industries as pollutants (Bruce, 2013). As a result, they fail to recognise agricultural practices like the use of artificial fertilisers, as an important source of GHG emissions (Tzemi & Breen, 2018)[13]. Receiving agri-environmental advice, as well as advice on afforestation schemes and adopting advisory systems plays, therefore, a significant role in increasing the awareness of the impact of agriculture on the environment and its contribution to global climate change[14]. This also significantly increases the willingness of farmers to adopt AFOLU mitigation measures such as adjusted growing practices, nutrient management practices and afforestation (OECD, 2012; Tzemi & Breen, 2018; Hamilton-Webb *et al.*, 2017; Buckley *et al.*, 2015; Ryan & O'Donoghue, 2016b; Duesberg *et al.*, 2014)[15].

Receiving environmental subsidies, on the other hand, increases awareness but not necessarily the willingness to adopt mitigation measures (Tzemi & Breen, 2018; Howley *et al.*, 2012; Hamilton-Webb *et al.*, 2017)[16]. The rate of

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

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

15. Of Irish farmers questioned, 87% were aware of the availability of the afforestation scheme of which only 10% were interested in afforesting. Respondents with no intention of planting were provided with detailed information of the scheme. This increased the total numbers of farmers considering afforestation from 10% to 26% (Duesberg *et al.*, 2014).

16. 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

farmers adopting mitigation measures, even in the absence of subsidies, is similar to the rate of adoption among those receiving subsidies (OECD, 2012).

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 fertiliser usage (OECD, 2012)[17]. Of Irish farmers, 77.6% stated that they would be unwilling to take up any measures that would incur any increase in their production costs (Tzemi & Breen, 2018). The higher the additional costs of new technology, the less likely farmers are to adopt this new measure such as slurry amendments or addition of lipids (Howley *et al.*, 2012). Farmers undertake actions that are seen as part of standard practices 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 & Donnellan, 2018; Ghadim *et al.*, 2005). Although aware of climate change, it has been observed that farmers feel they had more critical immediate concerns to worry about other than climate change (Hamilton-Webb *et al.*, 2017; OECD, 2012), 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 & Breen, 2018).

Determining economic farm structure for AFOLU 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 & Breen, 2018; Howley *et al.*, 2012):

1. Profitability and size of farms increases the willingness to adopt AFOLU mitigation measures.
2. Dairy farmers are more willing to adopt agricultural mitigation measures than farmers in other sectors.

Profitability has a significantly positive effect on the uptake of mitigation measures such as nutrient management practices, spring slurry spreading and water table management (Tzemi & Breen, 2019; Buckley *et al.*, 2015). Irish farmers with higher family farm income, indicating a higher production efficiency, have a greater willingness to adopt AFOLU mitigation measures

environmental consciousness (Tzemi and Breen, 2018). In a study of English farmers, even when funded, only 24% of the farmers stated that they would install mitigation activities that lead to additional costs (Hamilton-Webb *et al.*, 2017).

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

(Tzemi & 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, these Irish farmers appear to be more open to changing farm management practices to increase profitability further (Tzemi & Breen, 2019).

The size of a farm also determines the likelihood to uptake AFOLU mitigation measures such as improvement of genomics, sexed semen, or afforestation. Therefore, based on literature, these technologies are most likely to be adopted on larger farms of 56 ha or more (Duesberg *et al*., 2014; Howley *et al*., 2012b; Hamilton-Webb *et al*., 2017; Ryan & O'Donoghue, 2016, 2016b).

The willingness to adopt agricultural mitigation measures which increase the production efficiency or reduce nitrogen and methane emissions differs between different farm enterprises. Generally, in Ireland, livestock production and the livestock production intensity increase the adoption 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 significantly show the highest willingness to adopt mitigation measures (Tzemi & Breen, 2018; Teagasc, 2018). At the same time, dairy farms have the highest investment rate of all farm types and have increased their investment substantially over the last decade (Dillion *et al*., 2018)[18]. Significantly, sectors that are willing to adopt mitigation measures are also those sectors that invest the most in Ireland (Tzemi & Breen, 2019). As dairy farmers are also the biggest group to receive agri-environmental advice, this result corresponds 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 & Breen, 2019; Tzemi & Breen, 2018; Buckley *et al*., 2015; Howley *et al*., 2012).

Determining factors for LULUCF mitigation measures

Specific determining factors occur which influence the probability of farmers to take financial risks and consider changes in land-use, mainly afforestation under the current Irish support scheme (Duesberg *et al*., 2014; Ryan & O'Donoghue, 2016). Taking into account that land-use change from agriculture to forestry in Ireland is a permanent decision due to the

18. 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).

1946 Forestry Act (Breen *et al*., 2010), the determining factors appear to be slightly different to the ones for agricultural mitigation measures.

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

1. Farmers are more likely to afforest land that is less suitable for agriculture.
2. Dairy farmers are less likely to afforest than other farmers.

The highest rate of willingness to adopt land-use mitigation measures such as grassland management or afforestation is seen among Irish farmers who manage grassland on lesser quality soils, where the compensation for extreme weather effects (like floods, droughts and other natural hazards) are more complicated (Tzemi & Breen, 2018; Hamilton-Webb *et al*., 2017). Farming on marginal agricultural land significantly increases the probability of Irish farmers changing land use, e.g. afforesting (Howley *et al*., 2015; Duesberg *et al*., 2014). Afforestation stands in conflicting land-use with food production, and hence productive agricultural land has a significantly negative impact on the probability to afforest (Ryan & O'Donoghue, 2016; Duesberg *et al*., 2014). Of the Irish farmers, 40% regard forestry as a land use only for 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 by many farmers.

In deciding to afforest or change land-use of some of the farmers' agricultural land, it is assumed that farmers are unlikely to change land-use on land which gives a higher return in another farm enterprise (such as dairy) (Ryan & O'Donoghue, 2016). Hence, especially dairy farmers in Ireland are less likely to afforest, even when they have been in receipt of advice on the benefits of the afforestation scheme (Ryan & 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. Generally, higher family farm income negatively impacts on the probability to afforest, and dairy farms do not generate any financial benefits through afforestation, no matter what type of soil their farm consists of (Ryan & O'Donoghue, 2016, 2016b; Duesberg *et al*., 2014).

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 farm income that does not cover all production costs through market returns and a less intensive farm system, they may try to increase their family farm income by diversification through afforestation, as they will typically benefit financially from afforestation irrespective of the type of soil they farm (Ryan & O'Donoghue, 2016, 2016b; Duesberg *et al*., 2014; Howley *et al*., 2012).

Still, 74% 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 & O'Donoghue, 2016).

Impact of behavioural barriers on the Irish AFOLU Abatement potential

As agricultural emissions are largely regulated on a voluntary basis and not included in any trading regime, taking the determining characteristics of individual farmers into account when projecting the abatement potential in the Irish agriculture sector is a key factor to be considered. The systematic examination of existing literature on how non-price determinants affect the theoretically possible adoption rate of technically feasible mitigation measures in the Irish AFOLU sector has indicated to what degree these characteristics affect the theoretically feasible adoption rate of the different AFOLU mitigation measures.

Currently, as pointed out in our literature analysis, production efficient and cost-beneficial agricultural mitigation measures included in the MACC analysis (Lanigan & Donnellan, 2018) such as improved liveweight gain, nitrogen-use efficiency, economic breeding index (EBI), extended grazing, animal health, sexed semen and the inclusion of clover in pasture swards are undertaken by farmers as they are embedded in good agricultural practices and achieve positive profitability and production potential at farm level (Buckley *et al.*, 2015). However, most of the farmers do not consider (76.3% of the Irish farmers) the importance of agriculture's contribution to GHG emissions even though 32% of the Irish farmers receive agri-environmental advice (Tzemi & Breen, 2018). It should therefore be assumed that currently, less than 32% of the Irish farmers implement mitigation measures to reduce GHG emissions.

Technically it would be feasible to adopt most of the cost-beneficial mitigation measures in 2030 by nearly 100% of all relevant farmers. Bearing in mind that 39.3% of the Irish farmers have stated that they do not want to receive advise (Tzemi & Breen, 2018), and receiving agri-environmental advice is a significant factor for the willingness to adopt mitigation measures, the possible uptake rate of cost-beneficial mitigation measures applied in the MACC analysis in 2030 should not exceed 60.7% assuming a linear up-take rate from 2021 on. This would assume that all farmers who receive agri-environmental advice consequently implement relevant mitigation measures.

Although the identified cost and technical efficient agricultural mitigation measures in the MACC analysis such as replacing 50% of CAN fertiliser, reducing crude protein in pig diets, draining wet mineral soils and the amendment of slurry can be adopted at lower costs than an assumed shadow carbon price of €50/tonne (Lanigan & Donnellan, 2018), it has been shown that 77.6% 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 & 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 voluntarily take up these cost-efficient mitigation measures by 2030 assuming a linear up-take rate from 2021 on.

According to our analysis, the voluntary uptake of the cost-efficient LULUCF mitigation measures associated with the agricultural sector is also impacted through farmers' behaviour. Managing grassland efficiently is identified as a cost-beneficial mitigation measure in the MACC analysis when implemented by farmers (Lanigan & Donnellan, 2018). In 2017, the improvement of grassland management was not put into practice in Ireland (DCCAE, 2019). As a win-win situation occurs for the farmers, determining factors are very low, and adoption of more efficient grassland management, embedded in good agricultural practice could lead to a possible increase in the area being managed efficiently of up to 273,000 ha by 2030. This would assume that a linear uptake rate occurs from 2021 on and that all farmers who receive agri-environmental advice in the future (up to 60.5% according to Tzemi & Breen, 2008) will adopt more efficient grassland management.

Efficient water table management as a cost-efficient mitigation measure has not exceeded 800 ha per year since 2005 on all kinds of organic soils (grassland, forest, and wetland) ranging mostly around 400 ha per year (Duffy *et al*., 2019). Assuming a voluntary rewetting of 40,000 ha by 2030 (Lanigan & Donnellan, 2018) seems, therefore, out of reach. An abatement potential of 756 ha by 2030, assuming a linear up-take rate from 2021 on, seems more likely in the absence of policy or regulation. This increase in the rewetting rate would assume that farmers who wish to receive agri-environmental advice in the future (28.5% according to Tzemi and Breen, 2018) will adopt efficient water table management.

In 2018, the rate of Irish afforestation, as a cost-efficient mitigation measure, was at its lowest level since 1998 of 4,000 ha even though subsidies have continuously improved (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). Considering, that dairy farmers rarely take up afforestation and that mainly farmers above a farm size of 56 ha afforest, without a change in farmers attitudes to afforestation the available land for possible conversion into forestry would be reduced to

56,378 ha. Afforestation 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 agricultural production at reasonable costs. Taking these behavioural factors into account, a yearly voluntary rate of 6,000 ha up to 2030 is projected, assuming a linear up-take rate from 2021 on.

Cost-prohibitive AFOLU mitigation measures, meaning that the marginal abatement costs of these measures exceed the set shadow carbon price, such as adding lipids, low emission slurry spreading, cover crops, and straw incorporation, will not be considered as our systematic examination of the existing literature has shown that they are unlikely to be adopted widely by farmers unless some form of policy incentives are introduced (Lanigan & Donnellan, 2018; Tzemi & Breen, 2018).

Considering all the derived adjustments of the single AFOLU mitigation measures, the voluntarily achievable cost-effective abatement potential at a shadow carbon price of €50 per tonne for total agricultural GHG emissions projected to 2030 could amount to 3.49 Mt CO_2eq annually (Table 2). This would result in an Irish AFOLU abatement potential 45% lower than technically feasible.

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

	Projected emissions and adjusted abatement (Mt CO_2eq yr-1)	
	Mean over 2021-2030 period	**Abatement in 2030**
Total Agriculture emissions (ex. Fuel)	20.82	21.04
Cost effective Agriculture mitigation	1.08	1.52
Technically feasible MACC estimate	1.76 (–38%)	2.89 (–47%)
Cost effective LULUCF offsets	1.74	1.97
Technically feasible MACC estimate	2.80 (–38%)	3.50 (–44%)
Total	2.82	3.49
Technically feasible MACC estimate	4.56 (–38%)	6.39 (–45%)

Source: Own compilation.

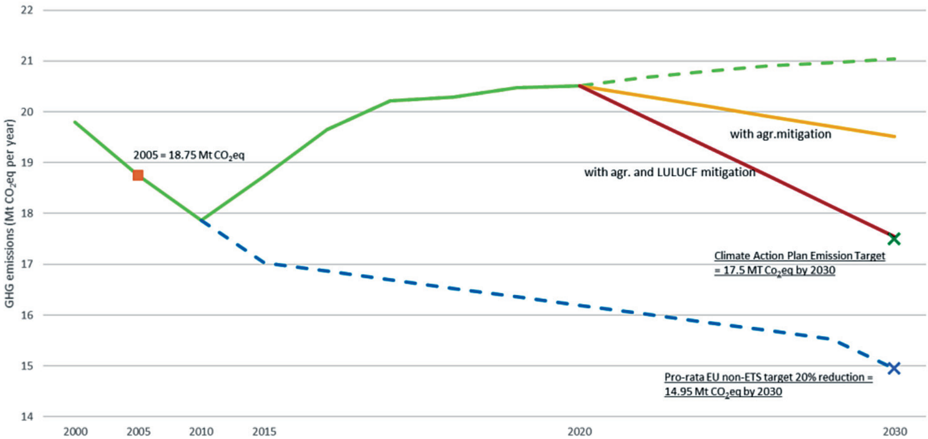
The adjusted estimated cost-effective agricultural abatement potential would amount to 1.52 Mt CO_2eq per year in 2030 (Table 2). This accounts for 7.2% of the total estimated agricultural GHG emissions in 2030, which is 47%

below the technically feasible agricultural abatement potential. The highest difference between technically feasible and newly estimated abatement potential of agricultural mitigation measures can be seen for production efficient mitigation measures. As these measures are cost-beneficial, the implementation should technically be feasible for most farmers, and therefore, the impact of the determining factors is most pronounced.

LULUCF mitigation measures undertaken by farmers, associated with the agriculture sector, can effectively offset agricultural GHG emissions by 1.97 Mt CO_2eq per year by 2030 (Table 2). This would offset 9.4% of the total estimated agricultural GHG emissions, which would be 44% less than predicted as technically feasible in the MACC approach. The reduction in abatement potential is higher than for agricultural mitigation measures due to a lower estimate of afforestation potential.

Attaining this total adjusted AFOLU abatement potential in 2030 would reduce the agricultural GHG emissions level below the 2005 EU reference level of 18.75 Mt CO_2eq reaching the emission target set under the Climate Action Plan of 17.5 Mt CO_2eq (Figure 2). This would slow down the increase in projected agricultural GHG emissions to be produced by 2030.

Figure 2 - Irish agricultural GHG emissions projected to 2030 without additional mitigation (green) and with adjusted agricultural (yellow) and AFOLU (red) GHG abatement potential



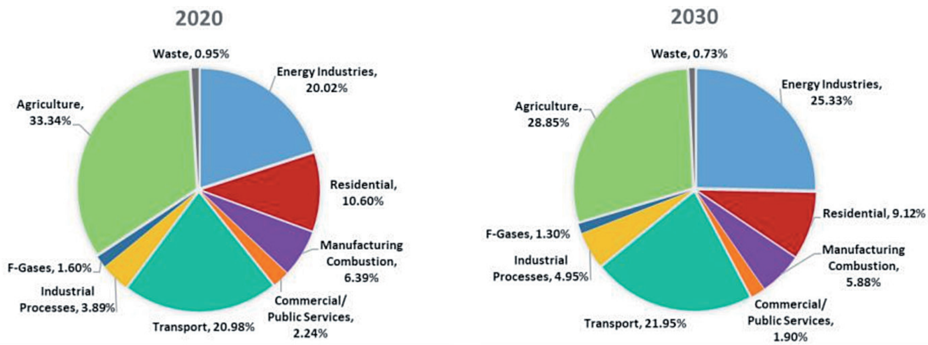
Note: In the EU Effort Sharing Decision, the 2005 level of non-ETS GHG emission sets the reference point for future reductions of non-ETS GHG emissions. For the Agriculture sector, following the assumptions made in Lanigan and Donnellan (2018), this would result in a pro-rata reduction of GHG emission down to 15 Mt CO_2eq by 2030 (blue line). In 2019, in the Climate Action Plan, a target for the AFOLU sector of 10%-15% reduction in 2030 was set, resulting to 17.5 Mt CO_2eq by 2030 (dark green).
Source: Own compilation, Duffy *et al.* (2019); DCCAE (2019); EPA (2019b).

It should be noted, that 1.8 Mt CO_2eq in 2030 (51.6% of total abatement potential) will be offset through Irish forestry. Simulations undertaken by COFORD have shown that for the national forest resource to remain as a net carbon sink beyond 2035, the annual afforestation rate needs to be above 7,500 ha per year (COFORD, 2016). Remaining at the adjusted afforestation rate of 6,000 ha per year will lead to a situation where the Irish forest area becomes a net source of GHG emissions from 2035 onwards. Hence, if the Irish afforestation rate does not increase strongly in the next ten years, the total AFOLU abatement potential is reduced to 1.69 Mt CO_2eq per year (cost-effective agriculture abatement in 2030, yellow line) leaving a significant gap to the emission target under the Climate Action Plan and any potential reduction target derived from the EU non-ETS emission reduction targets for Ireland (Figure 2). This demonstrates the intertwined nature of the AFOLU sector and GHG emissions. Currently, the Irish agricultural and GHG emission targets appear to be in contradiction as they drift further apart (Figure 2).

4. Policy implications

The Irish agriculture sector is the most significant contributor to total Irish GHG emissions (33.34% of total GHG emissions in 2020) and will likely continue to be (28.85% of total GHG emissions in 2030) if the adoption of AFOLU mitigation measures remains voluntary (Figure 3).

Figure 3 - Irish GHG emission projections by sector out to 2030 with adjusted voluntary AFOLU abatement included



Source: EPA (2019b), Own compilation.

To increase the efficiency of the actions stated under the Climate Action Plans (DCCAE, 2019) and to move into the direction of the pro-rata EU agricultural target, Irish farmers' need to be encouraged to incorporate low carbon farming into their best agricultural practice. Therefore, the farmer's decision-making process needs to be supported to remove barriers that determine their behaviour (OECD, 2012). Gray *et al.* (2017) argue that the occurring market failure between technical achievable and voluntarily undertaken abatement should be addressed through politically implemented market-based instruments. Depending on the type of AFOLU mitigation measure, different approaches to overcome the market failure need to be followed.

Due to the high reluctance towards agri-environmental advice (39.3% of Irish farmers, Tzemi and Breen, 2018), it can be derived that voluntary adoption of cost-beneficial agricultural mitigation measures encouraged through knowledge transfer will not lead to the technically feasible uptake rate necessary to meet national and EU targets. The Irish Climate Action Plan states the improvement of animal production efficiency (through EBI) and the improvement of animal health as major production efficiency measures to reduce GHG emissions (DCCAE, 2019). Linking GHG mitigation measures which improve the productivity and competitiveness of the agriculture sector and also reduce GHG emissions such as improved liveweight gain, nitrogen-use efficiency, EBI, animal health, and extended grazing, to carbon abatement support payments could increase the uptake rate of these agricultural mitigation measures. With a transition period in which the stringency of conditions is phased in, there could be an improvement not only in the productivity but also in the environmental performance of the Irish 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 considerably[19].

The main cost and technically efficient agricultural mitigation measures stated by the Climate Action Plan are the 50% replacement of CAN fertiliser and the implementation of slurry amendments (DCCAE, 2019). As these measures impact on the emission factors of a production system rather than the produced unit, their abatement potential is less likely to be offset by an increase in production ensuring GHG emission reduction in the long-term (Lanigan & Donnellan, 2018). To increase the uptake rate of these mitigation measures as well as crude protein in the diet of pigs, and draining wet mineral soils that all incur marginal abatement costs, farmers would

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

need to receive support in the form of on-farm investments in carbon-reducing innovations targeted towards increasing climate efficiency. Specific instruments might include innovation allowances and credits. Thereby, it would be essential to coordinate any new measure with existing frameworks (Gray *et al.*, 2017).

Due to natural restrictions of the agriculture sector (especially in the ruminant livestock sector), the prospect of an increase in the agricultural abatement potential above the technically possible potential is limited. Adding the cost-efficient LULUCF abatement potential to the agricultural abatement capacity has the potential to abate a significant share of agricultural GHG emissions. As the main potential of LULUCF abatement occurs through forestry and rewetting of organic grassland soils in Ireland also stated in the Climate Action Plan, and the main proportion of afforestation and rewetting is undertaken by farmers, future expansion will thereby depend on a change in land use from agriculture to forestry or wetlands (Farrelly & Gallagher, 2015).

To increase the annual farm afforestation rate, this study has pointed out that farmers need to be informed more about existing afforestation scheme benefits to incorporate afforestation as a part of a broader farm management decision. Reaching those farmers through a linked agriculture and forestry advice could possibly increase the farm afforestation rate (Ryan & O'Donoghue, 2016). In addition, Irish cattle farmers could be encouraged to become low carbon producers by certifying low carbon Irish beef (Lau, 2019)[20]. Carbon farming could be supported through additional carbon abatement support payments. The farm's cattle emissions could thereby be offset through paying other farmers to sequester carbon through Irish afforestation or rewetting or through sequestering carbon themselves (European Commission, 2020).

By highlighting LULUCF mitigation measures such as afforestation and agricultural land use-change decisions as a way of diversifying and stabilising farmers' income could increase the up-take rate of these measures substantially[21]. This would ensure GHG emission reduction in the Irish agriculture sector in the long-term.

20. In 2019, Australia's largest beef producer got its beef certified as carbon-neutral beef. This was mostly achieved through purchasing offsets (Lau, 2019).

21. Taking into account, that over 600,000 ha of dry grassland have been identified as being of limited agricultural use (COFORD, 2016), converting 7,500 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.

5. Conclusion

The agricultural sector has been over time the largest single contributor to Irish overall GHG emissions. Thereby, methane and nitrous oxide are the most significant agricultural GHGs emitted mainly through Irish cattle. The strong growth of the Irish agriculture sector (mainly dairy) up to 2018 has led to a substantial increase in agricultural GHG emissions (+4.4% since 2005). This growth is projected to continue, mainly due to an excepted increase in dairy cow numbers and nitrogen fertiliser use.

Under the Climate Action Plan (DCCAE, 2019) and the EU Effort Sharing Regulation (European Council, 2018) GHG reduction targets have been set that make the agriculture sector's leading role apparent in reducing GHG emissions and increasing carbon-removals. With the new EU Effort Sharing Regulation (2019), Ireland is given the flexibility to reduce their agricultural GHG emissions by offsetting them through LULUCF activities.

This study addresses some of the main potential barriers of voluntary adoption of mitigation measures by systematically examining existing literature on how non-price determinants affect the voluntary adoption rate of technically feasible mitigation measures in the Irish AFOLU sector. The main identified non-price determining factors were the degree of farmers' awareness regarding man-made GHG emissions, receiving agri-environmental advice, implementation costs, profitability and size of farms, land quality and the type of farm enterprise. Through integrating the results on the extent of adoption on the former MACC analysis it enabled the implementation rates of the cost- efficient AFOLU mitigation measures to be adapted accordingly.

These factors impact the voluntary uptake rate of AFOLU mitigation measures to the extent that the adjusted total Irish AFOLU abatement potential is 47% lower than technically feasible. This would slow down the increase of the projected agricultural GHG emissions by 2030 but still leave the Irish agriculture sector as the most significant contributor of GHG emissions in 2030. Considering that 51.6% of the total estimated AFOLU abatement potential in 2030 is offset through Irish forestry, which at current afforestation rate will turn into a net carbon source by 2035, a significant gap occurs to any potential Irish and EU GHG reduction target.

While the systematic approach on examining existing literature has allowed the results from various studies to be incorporated, basing the analysis on published studies can lead to a publication bias meaning that the impact of an identified non-price determinant may be overestimated as studies that do not report significant results are generally not published. Furthermore, for some feasible mitigation measures, studies have not been conducted regarding their potential up-take rate. Up-take rates have been generalised for the different groups of mitigation measures. Further research on the individual up-take rate of mitigation measures could improve the outcome.

Policy measures need to be implemented 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. Polices are needed that remove the barriers to farmers' behavioural change. Incorporating carbon abatement policy more directly into agricultural policy and establishing LULUCF mitigation measures as a way to diversify and stabilise Irish farmers' income could open the possibility of reversing the recent trend of continuously growing agricultural GHG emissions.

Unlike many other sectors, the agriculture sector has the ability to sequester carbon out of the atmosphere, contributing to Ireland's image as a green and sustainable food producer. Enhancing the uptake rate of cost-beneficial and cost-effective AFOLU mitigation measures to achieve the technically feasible uptake rate that has the potential to reduce the level of agricultural GHG emissions by 2030 in a way that would converge towards possible EU GHG emission reduction targets.

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