Extended Abstract

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Paper/Poster Title	Assessment of measures for ammonia mitigation in Irish agriculture using marginal abatement cost curve analysis.

Abstract prepared for presentation at the 98th Annual Conference of The Agricultural Economics Society will be held at The University of Edinburgh, UK, 18th - 20th March 2024.

Abstract	*200 words max*
Agriculture accounts for over 99% of ammonia emissions across the Republic of Ireland. Additionally, the country has not met emissions targets as set down under the EU National Emissions Ceilings Directive. This research explores the cost-effectiveness of a suite of ammonia mitigation measures relevant to animal based agriculture that pre-dominated across the Republic of Ireland and under three economic activity scenarios (i.e. business as usual scenario, low activity and high activity levels, and three technology adoption rates (i.e. low, moderate and high) over the 2022 to 2030 period. Findings show the significant influence of assumptions about future agricultural activity and adoption rates on emissions projections, emphasising the importance of these uncertainties when assessing the ability to achieve ammonia emission reduction targets. From the 13 mitigation measures examined for bovine, pigs, poultry farms, the potential ammonia mitigation ranged from 0.03 (Reducing Crude protein in pigs diet – medium adoption) to 13.22 (Low Emissions Slurry Spreading, Bovine -high adoption) kilotonnes over the study period. The use of protected urea, clover establishment in intensive dairy farms, and reduction of crude protein in bovine and pig diets were found to be cost-negative in all three economic activity scenarios and three technology adoption rates. On average about 75% mitigation potential is delivered by switching to trailing shoe and hose and protected urea. Finally, medium and high technology adoption rates assumed in this study will allow the Republic of Ireland to abate a sufficient quantity of ammonia to comply with the EU NEC Directive limits under the business as usual and low economic activity scenarios. However, without higher technology adoption rates meeting the EU NEC Directive ammonia target is unachievable across all economic activity scenarios.	

Keywords	Marginal abatement cost curve, activity scenarios, technology adoption rates, ammonia emission, agriculture, livestock, dairy, beef
JEL Code	Q16 see: www.aeaweb.org/jel/guide/jel.php?class=Q)

Introduction	*100 – 250 words*

The Republic of Ireland (henceforth called Ireland) and other European countries have committed to reducing emissions of ammonia (NH3) under the European Union's National Emission Ceiling (NEC) Directive (2016/2284/EU) (EC, 2016). This Directive implements the Gothenburg Protocol targets (part of the Convention on Long-Range Transboundary Air Pollution; CLRTAP) for EU Member States. In 2020, the NEC Directive established new national emission reduction commitments for each EU Member State, according to which Ireland is obliged to reduce its NH3 emissions by 1% between 2021 and 2030 and by 5% post-2030 on the 2005 emission level (EPA, 2022). Ireland has exceeded its previous EU NEC Directive limits in seven of the ten reporting years, as well as the 2021 limit. Furthermore, in January 2023, the European Commission issued an infringement notice to Ireland for not meeting the NECD requirements (EPA, 2023).

Simultaneously, EU Member States must comply with the EU Habitats Directive (92/43/EEC) to preserve biodiversity and undertake measures to maintain or restore natural habitats and wild species. Recent reporting under the EU Habitats Directive highlighted declining conditions in sensitive Irish habitats (National Parks & Wildlife Service, 2019). Moreover, a recent integrated policy analysis from de Vries et al. (2021) concluded that a reduction in N inputs of 59% may be necessary for Ireland to protect its water, air and biodiversity. Similarly, a United Nations Economic Commission for Europe (UNECE) report confirmed that a reduction of 30-50% in NH3 emissions is required in UNECE countries to avoid damage to ecosystems and health (UNECE, 2020).

Methodology	***100 – 250 words***

Ammonia emissions projections are estimated based on emission factors applied to projections of future agricultural activity data. This analysis is conducted at a national aggregate level scale over the 2022 to 2030 temporal horizon, with 2022 as the base year.

This analysis uses activity data, including animal and fertiliser use projections, sourced from the FAPRI-Ireland economic model of the Irish agricultural sector (Donnellan & Hanrahan, 2021). The FAPRI-Ireland model incorporates macroeconomic projections, including GDP growth rates, inflation, exchange rates, and population figures, from the ESRI COSMO model of the Irish macroeconomy (Bergin et al., 2016). This study employs three scenarios generated by the FAPRI-Ireland model: Business as usual (S1), Low (S2), and High (S3) activity level scenarios (Donnellan and Hanrahan, 2021). These scenarios were developed for sensitivity analysis in the context of reporting emissions under the Monitoring Mechanism Regulation and account for uncertainties in commodity markets and policies influencing future agricultural activity in Ireland through 2030.

The emissions factors applied to the activity level data (under S1 to S3) followed that of Hyde et al. (2022) in reporting Ireland's emissions to the secretariat of the UNECE convention on long-range transboundary air pollution and to the European Union under Directive (2016/2284/EU).

NH3 abatement measures were selected based on an extensive review of international literature (Misselbrook et al., 2006; Reis et al., 2015; Bittman et al., 2014). Whenever possible, Irish-specific emission factors and cost data for these measures have been incorporated. In cases where Irish data was unavailable, the best available international data sources were used. Adoption rates for these measures were determined by considering the current adoption rate, as indicated by the Teagasc National Farm Survey data 2022, Ag Climatise (2020) policy and with considerations of economic and biophysical constraints. Ag Climatise (2020) policy has set targets for the use of low emission slurry spreading equipment, protected urea, liming and, covered slurry storage tanks. The high technology adoption rates assumed in this study for the above measures are stretch targets based on these respective policy targets.

Overall, the three adoption rates were defined by two key aspects: i) the level of adoption projected for 2030 and ii) the speed at which that level would be achieved, represented by the slope of the adoption pathway. These measures were categorised into four groups: i) fertiliser measures (protected urea, establishing clover in grass swards and liming), ii) bovine measures (low emission slurry spreading equipment, reduced crude protein in diet, covered slurry storage tanks and, slurry additives iii) pig measures (low emission slurry spreading equipment, reduced crude protein in diet, covered slurry storage tanks and, slurry additives) and iv) poultry measures (drying manure and adding manure additives). Table 1 shows the three technology adoption rates assumed under each of the activity scenarios.

Table 1 Scenarios modelled.

Activity Level	**Business as usual (S1)**			**Low activity (S2)**			**High activity levels (S3)**		
Adoption Rates	Low	Medium	High	Low	Medium	High	Low	Medium	High
Scenario name	S1L	S1M	S1H	S2L	S2M	S2H	S3L	S3M	S3H

Results	***100 – 250 words***

Results indicate that four measures are cost-negative (protected urea, inclusion of clover, lowering of crude protein content of bovine and pigs concentrate diets) across all activity scenarios and adoption rates. Implementation of these cost negative measures could provide a potential cost saving of €39.70 (S1), €39.99 (S2) and €40.00 (S3) million per annum assuming the average rate of adoption is maintained. However, a number of these savings are predicated on efficiency gains driven by best management practice adoption, with associated reductions in chemical N fertiliser application. If farmers do not adjust management practices (e.g. chemical fertiliser application rates) to reflect efficiency gains achieved through implementation of mitigation measures, then the level of ammonia abatement would be lower than anticipated in this analysis.

Figure 1 below outlines the aggregate emissions using the EPA national emission inventory model (Hyde et al., 2022) for the agricultural sector in Ireland under the S1 activity level scenario with low, medium and high adoption rates. The yellow line reflects the NH3 emission targets as set down under the EU NEC Directive 2016/2284 for each year.

Figure 1: NH_3 Emissions under Business as Usual scenario (S1)

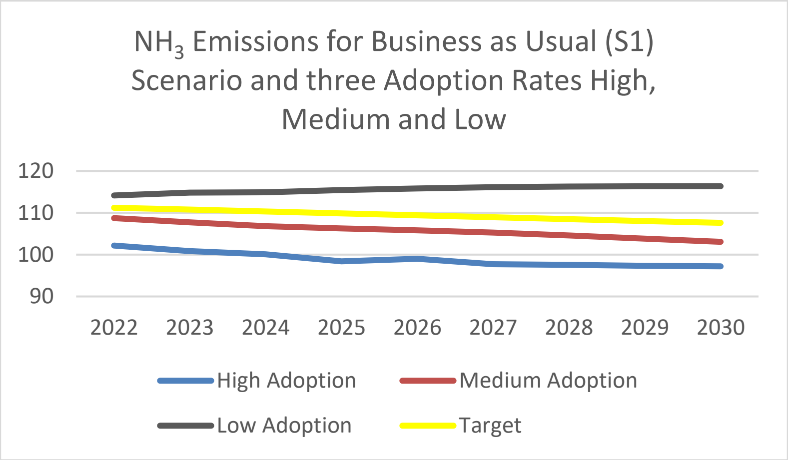
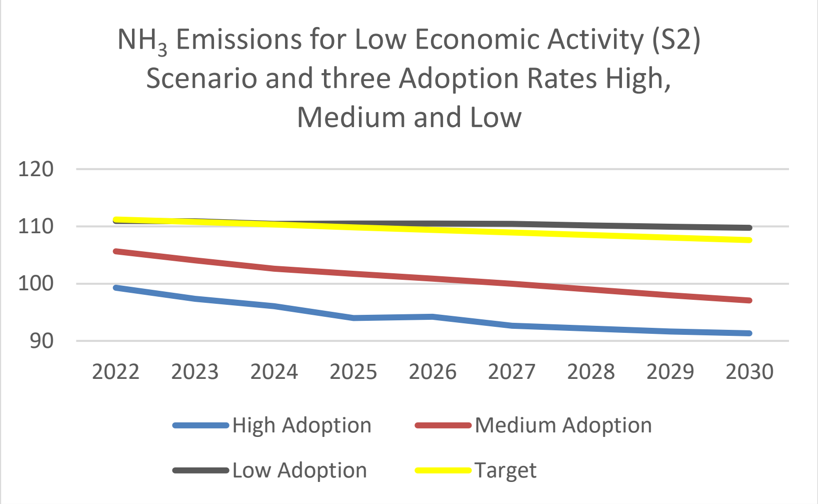


Figure 2 illustrates that, under the S1 scenario (business-as-usual) achieving emission reduction targets for Ireland is possible with high and medium levels of mitigation measure adoption rates. However, continuing with low adoption rates would result in NH3 emissions not meeting targets by 2030.

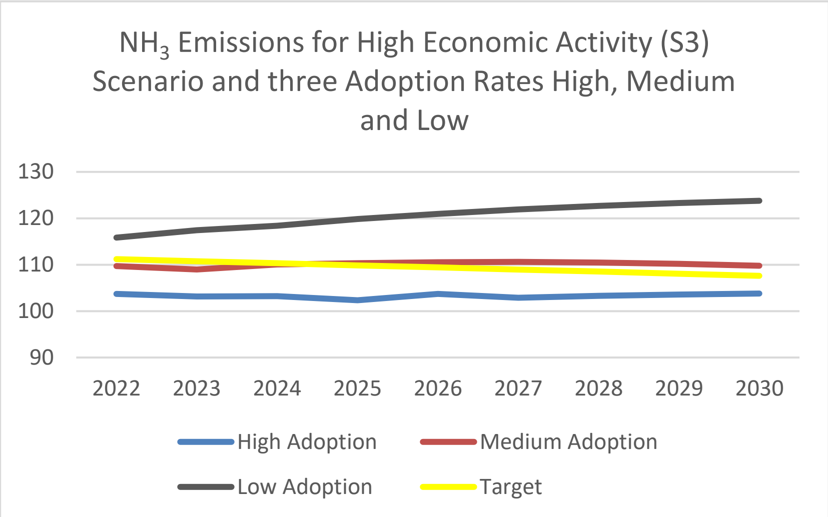
Similar to the results under S1, Figure 2 shows that under S2 emission reduction targets are met with high and medium levels of mitigation measure adoption rates. However, if the low technology adoption rate were to continue then ammonia emissions would exceed the target limits, with the difference between emissions and the target increasing year on year towards 2030.

Figure 2: Total NH3 Emissions under Low economic activity (S2) scenario and three technology adoption rates



As shown in figure 3 if higher activity levels were to prevail in Ireland from 2022 to 2030, then the reduction targets cannot be achieved under the low or medium technology adoption rates assumed in this analysis.

Figure 3: Total NH3 Emissions under High economic activity (S3) scenario and three technology adoption rates



Discussion and Conclusion	***100 – 250 words***

The estimated ammonia emissions reduction outlined in this study depends on mitigation measure adoption rates, projected agricultural activity levels and emissions factors. The results here estimate NH3 abatement potential with high adoption rates for the mitigation pathways at 23.35 (S1), 22.20 (S2) and 25.25 (S3) kilotonnes of NH3 during the study period and 17.67 (S1), 16.60 (S2) and 18.88 (S3) kilotonnes of NH3 with medium technology adoption rates. This is significantly higher than the mitigation potentials estimated in the previous ammonia abatement analyses of between 10.6 and 12.05 kilotonnes NH3 per annum (Lanigan et al., 2015) and 15.26 kt NH3 (Buckley et al., 2020). In contrast, under the low adoption rate scenarios the NH3 abatement potential was 5.30 (S1), 4.33 (S2), and 5.77 (S3) kt respectively.

These findings highlight the substantial impact of differing assumptions about future agricultural activity on the emissions projections before factoring in mitigation measures. These uncertainties are crucial when evaluating Ireland's capacity to meet ammonia emission reduction targets.

The successful realisation of ammonia (NH3) mitigation potential hinges on the actual adoption of low emission farming practices by the Irish farmers. Various barriers have been identified that affect the adoption of these measures, including cost, knowledge and awareness levels, the ability to employ certain technologies at the farm level, individual farm-specific constraints, and the availability of equipment or raw materials needed for mitigation actions (Moerkerken et. al., 2020). To achieve the full potential of NH3 mitigation, it is essential to gain a deeper understanding of these barriers hindering the uptake of mitigation measures.

Furthermore, strong linkages to extension services and providing farmers with the knowledge and guidance based on local farm conditions is required. The process of knowledge transfer and co-creation of mitigation measures has long been recognised as critical in maximising the adoption of these measures and realising the identified mitigation potentials (Rogers, 1995).

Finally, the results from this analysis indicate that the high and medium adoption rates used in this manuscript will allow Ireland to mitigate an amount of NH3 sufficient to comply with emission reduction commitments (conditional on the assumed measure uptake) under the S1 (business as usual) and S2 (lower) activity level scenarios. Under S3 (higher activity levels), compliance cannot be achieved without high adoption rates and additional measures would be required to meet obligations under this scenario

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Disclosure statement
The authors report there are no competing interests to declare.

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