Department for Environment, Food and Rural Affairs

Paper 3: Analysis

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Contents

Summary and key messages

1. Our analysis has identified a maximum technical potential for English agriculture to save **7.1 $MtCO_2e$** in nitrous oxide and methane emissions based on our current understanding of technology and the structure of the sector using the most recent set of data (2010). This estimate makes no consideration of the costs of implementation and assumes there is 0% adoption of these practices in English agriculture.

2. Of course, many farmers in England have already adopted many of the technologies and practices considered in this analysis. So when taking into account adoption rates, we estimate that advice schemes such as Catchment Sensitive Farming, incentive payments available through Environmental Stewardship schemes and Nitrate Vulnerable Zone rules have been important external drivers to deliver GHG emission reductions of between **1.4 – 1.7 $MtCO_2e$**. Reductions which are not currently accounted for in the agriculture GHG inventory.

3. With these savings 'banked', subtracting them from the maximum technical potential leaves the potential to save between 5.4 – 5.7 $MtCO_2e$. Not all of this potential however is cost effective and it is important to consider the financial implications of implementing these practices. Considering the costs of implementation, between **3.1 – 3.3 $MtCO_2e$** of GHG emission reductions could be achieved through the wider adoption of mitigation methods which **improve efficiency and save farmers money**. These mitigation methods relate to improvements in nutrient management, use of plants with improved nitrogen use efficiency, improved livestock breeding and the deployment of Anaerobic Digestion to manage poultry manure.

4. Our analysis has shown existing policies are geared towards encouraging farmers to adopt resource efficient practices. The Greenhouse Gas Action Plan is also aligned to the mitigation methods highlighted in this analysis. It is therefore well placed to work alongside the current policy landscape, to accelerate progress to a wider proportion of farmers in England.

5. Our analysis indicates the adoption of mitigation methods, focused on improving nutrient management are likely to provide multiple positive benefits for reducing wider environmental pollutants, particularly ammonia emissions to air and nitrate losses to water. Positive outcomes are also likely for phosphorous with more limited benefits for biodiversity, sediment, pesticides and energy use.

6. We recognise the multi-pollutant analysis considered here does not assess the wider environmental impacts of cost saving mitigation methods focused on livestock efficiency improvement. Research to assess the wider environmental impacts[1] of these mitigation methods is due to be completed soon and will provide an important body of evidence to inform the consideration of implementing these and other mitigation methods in the context of our wider environmental and land management objectives.

7. Looking to the future, current forecasts to 2020 indicate GHG emissions from agriculture are likely to fall by **8%** as a result of structural change in the sector. This means existing practice coupled with structural change is likely to be sufficient to reach the industry's 3 $MtCO_2e$ ambition in absolute terms. However, increases in agricultural output away from this baseline will need further emissions savings through the wider adoption of mitigation methods and therefore the industry need to be proactive in boosting the efficiency of production.

8. We are continually seeking to improve the evidence base particularly with regard to expanding the coverage of the FARMSCOPER modelling framework, the main tool used in this analysis. We recognise that the current framework, although very wide, is not fully comprehensive. We are therefore working with experts to define the best way of developing our modelling framework to include additional mitigation methods relating to soil carbon storage, livestock feed and livestock productivity improvements.

[1] Defra research project AC0226 – Wider environmental impacts of the Greenhouse Gas Action Plan

Introduction

9. This paper provides an overview of the Mapping Farm Practices to Policies and Incentives project, a workstream of the 2012 review. The project was set up in response to the Committee on Climate Change (CCC) 3rd Annual Progress Report to Parliament, which noted the relevance of the broader policy framework and recommended that the 2012 review should 'map incentives under current policies to abatement measures[2]'. This approach was echoed in discussions with stakeholders in the early stages of the review process.

10. The aim of the Mapping Farm Practices to Policies and Incentives is to:

    - 'develop a better understanding of the policy framework, the extent to which it is delivering GHG reductions currently and can be expected to deliver in the future'.

11. The project was split into two phases. The first phase sought to identify the policies and incentives most directly related to agricultural production and working in collaboration with experts from the Environment Agency, Natural England and external stakeholders, to develop qualitative links between seven policies and over 100 farm practices. The high level map developed as a result of the early work of this project is presented in Paper 1: Background of this report.

12. The second phase of the Mapping Farm Practices to Policies and Incentives project derived estimates of GHG reduction potential from these 100 farm practices and linked these results to the seven policies identified in the initial phase of the project.

Background and development of the evidence base

13. In 2008[3], the Scottish Agricultural College (SAC) produced Marginal Abatement Cost Curves (MACC) of GHG mitigation methods for UK agriculture. Focusing on the practical things that farmers can do, it evaluated the scope to reduce methane (CH_4) and nitrous oxide (N_2O) emissions within existing farming systems. This work was updated in 2010 providing revised estimates of reduction potential. These 2010 estimates have been used in the following analysis.

[2] Meeting Carbon Budgets,: 3rd Progress Report to Parliament: Committee on Climate Change: Executive Summary

[3] UK Marginal Abatement Cost (MAC) Curves for the Agriculture and Land Use, Land Use Change and Forestry Sectors out to 2022' with Qualitative analysis of options to 2050

14. The results of the SAC MACC work were peer reviewed by ADAS and AEA in 2009. As a result of this work it was agreed that English agriculture could feasibly deliver 3 $MtCO_2e$ of GHG emission reductions by 2022[4]. This potential was highlighted in the previous Government's Low Carbon Transition Plan[5], and measured against a 2007 baseline, adopted by industry in the GHGAP. The current Government has taken the view that, until better evidence is available, a 3 $MtCO_2e$ reduction by the third carbon budget should continue to be used as an indicative ambition.

15. In 2010, ADAS completed the Defra commissioned research project 'cost-curves for mitigation of multiple water pollutants, ammonia and GHG emissions on farms'. The project developed the Farm Scale Optimisation of Pollutant Emission Reduction (FARMSCOPER) decision support tool to evaluate the impact of specific mitigation methods on a wide range of environmental pollutants. The project also produced a 'User Guide[6]' published alongside the decision support tool, providing detailed qualitative descriptions of the methods considered in the analysis. The modelling framework developed is able to evaluate:

- estimates of diffuse pollutant losses at the farm scale;
- estimates of the cost effectiveness of one or more mitigation methods; and
- a methodology to identify optimal sets of mitigation methods

16. The level of specificity, coverage and multiple outputs provides a robust framework for analysis which goes over and above the work previously completed by SAC. The majority of our analysis considered in this paper therefore uses the FARMSCOPER model. However, at present the list of methods contained within this model is not comprehensive. For example, FARMSCOPER does not include mitigation methods related to livestock fertility, improved productivity and anaerobic digestion (AD). These methods were included within the original SAC work and are therefore assessed alongside our wider analysis using the FARMSCOPER tool.

17. Looking to the future, it would be helpful for the FARMSCOPER decision support tool to be updated to reflect changes in the adoption of mitigation methods, changes in prices as well as expanding its coverage of possible mitigation

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[4] Using cost estimates from 2006

[5] http://www.decc.gov.uk/publications/basket.aspx?FilePath=White+Papers%2FUK+Low+Carbon+Transition+Plan+WP09%2F1_20090724153238_e_%40%40_lowcarbontransitionplan.pdf&filetype=4

[6] Defra research project WQ0106

methods. In addition to those practices considered above, we are working to develop the evidence on additional practices which could reduce emissions related to biosecurity improvement, soil carbon storage and wider consideration of livestock feeding practices. Annex A provides a detailed mapping of the correspondence between the original SAC MACC and the associated mitigation methods contained within FARMSCOPER.

FARMSCOPER Upscaling Tool

18. The 'FARMSCOPER Upscaling Tool' has been transparently developed by Defra analysts to take the farm-level results of FARMSCOPER and elevate these estimates to the national (England) level. The tool uses the latest Agricultural Census data[7] to derive the crop areas used and number of animals located on 12 representative farm types. This is complemented with the NVZ status, soil type and rainfall of these 12 farm types (derived using GIS mapping methods). Default fertiliser application rates provided by ADAS are used to estimate the overall quantity of organic and inorganic nitrogen applied to land. These application rates are based on the idealised level of nitrogen application rates to specific crops types. Annex B lists the input conditions built across these farm types, which are then scaled up to deliver national, quantified estimates of the environmental impact, cost and uptake of the farm practices contained in FARMSCOPER.

19. Using the FARMSCOPER Upscaling Tool, our analysis estimates that emissions of nitrous oxide and methane from English agriculture in 2010 were **30.47 $MtCO_2e$.** This is around 5% of the official inventory estimate of **28.91 $MtCO_2e$** and is well within the uncertainty bands[8] of the current GHG Inventory Model.

20. Although the level of agreement between the two models is relatively close, a 5% variance in modelling results still equates to 1.5 $MtCO_2e$ per annum. An adjustment factor of 95% could be used to calibrate the results of this analysis to that of the official GHG inventory model. However the results presented in this paper have not been adjusted and are therefore modelled on an agricultural sector emitting 30.47 $MtCO_2e$ per annum.

[7] http://www.defra.gov.uk/statistics/foodfarm/landuselivestock/junesurvey/junesurveyresults/

[8] 95% confidence intervals (Source: National Inventory Report 2010)

- N_2O (soils): **+249%, -93%**;
- N_2O & CH_4 (manure management): **+/-25%**;
- CH_4 (enteric fermentation): **+/-16%**

Upscaling results – Maximum Technical Potential assuming no prior implementation of mitigation methods

21. This section considers the GHG reduction potential of the mitigation methods identified within the FARMSCOPER Upscaling tool and the SAC MAC Curve. The results are for England only and are considered on a method by method basis. The results do not take into account the potential for overlaps between two non-mutually exclusive mitigation methods – for example covering of slurry stores and the installation of an anaerobic digestion plant. The results also take no consideration of current implementation of any of the mitigation methods considered in the analysis. These figures should therefore be viewed as top end estimates. The results of this analysis have been disaggregated by cost, type of mitigation method and farm type.

22. Our analysis has identified a maximum technical potential for English agriculture to save **7.1 $MtCO_2e$** in nitrous oxide and methane emissions based on our current understanding of technology available and the structure of the sector using the most recent set of data (2010). This estimate makes no consideration of the costs of implementation and assumes there is 0% adoption of these practices in English agriculture today.

Table 1: MTP estimate of GHG reduction potential in England, 2010

Model	**GHG emission reduction potential ($MtCO_2e$)**
FARMSCOPER Upscaling Tool	5.0
SAC MACC	2.1
Total	**7.1**

23. It is a principal of Government policy that action to reduce GHG emissions should focus on those reductions which are most cost-effective across the whole economy so as to minimise the burden of climate change action on society. In applying this principle, Defra’s approach has been to encourage the uptake of practical mitigation methods that will deliver GHG savings along with production efficiencies which are likely to save the industry money, increase its competitiveness and guard against the risk of carbon leakage as well as the ‘export’ of wider environmental issues.

24. The analysis estimates a MTP of **3.9 $MtCO_2e$** of GHG emission savings based on mitigation methods which save farmers money. The potential to make further savings rises to **5.2 $MtCO_2e$** when we consider placing a cost on carbon emissions at an effective non-traded carbon price of £56/tCO_2e[9]. This rises further still to **6.2 $MtCO_2e$** at a cost effective price of £200/tCO_2e (the predicted non-traded carbon price for 2050). More detailed information on MTP based on our current understanding of technology and farming practice, by mitigation method and farm type are provided in annexes C and D.

Table 2: MTP estimates of GHG reduction potential in England by £/tCO_2e, 2010

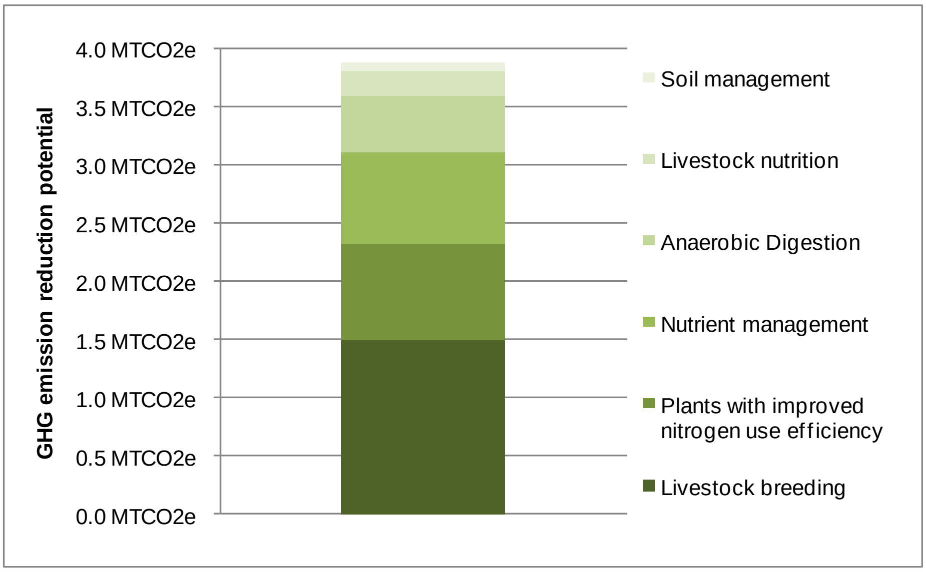
	Cost negative / cost neutral	**Cost effective @ £56 per tonne / CO_2e**	**Cost effective @ £200 per tonne / CO_2e**
FARMSCOPER Upscaling Tool	2.0	3.1	4.1
SAC MACC	1.9	2.1	2.1
Total	**3.9**	**5.2**	**6.2**

25. The chart sets out the MTP of mitigation methods which can save farmers money, broken down into categories of mitigation methods. It shows improvements in livestock breeding have the potential to save **1.5 $MtCO_2e$,** improvements in nutrient management and using plants with improved nitrogen use efficiency have an additional potential of **1.6 $MtCO_2e$**[10] and the implementation of anaerobic digestion to manage poultry manure is also highlighted as a technology with significant potential.

[9] Non-traded central carbon price in 2012

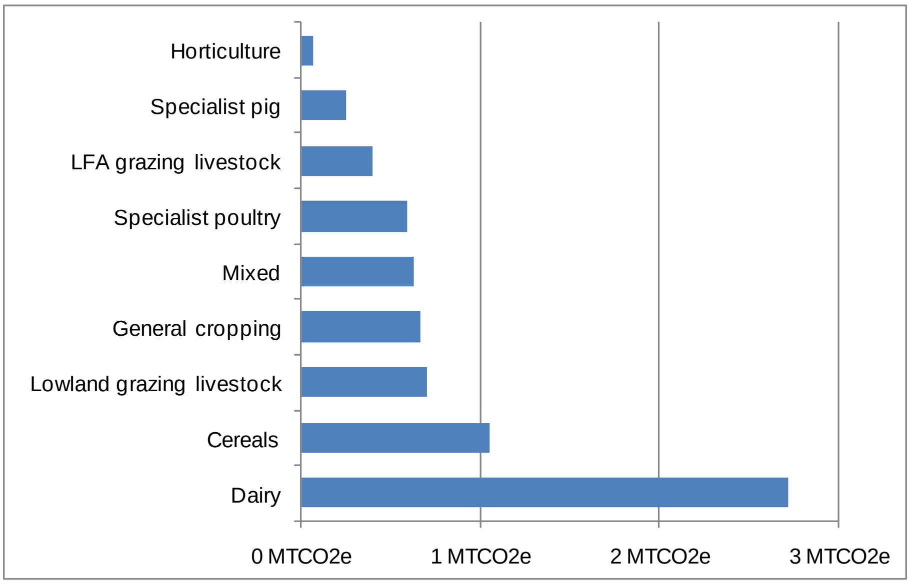
[10] These estimates do not consider the potential from propionate precursors which were included in the SAC MACC estimates. This is due to doubts over their effectiveness at low enough doses which would be financially viable on-farm.

Figure 1: MTP estimates of cost saving and cost neutral GHG reduction potential by mitigation method category, 2010



26. On a farm type basis, the second chart again shows the maximum technical potential for mitigation methods which can save farmers money. This analysis indicates the dairy sector has the largest MTP for GHG emission reduction, with improvements to breeding providing significant potential.

Figure 2: MTP estimates of cost saving and cost neutral GHG reduction potential by sector, 2010



Upscaling Results – Estimated achieved GHG emission reductions and additional GHG emission reduction potential

27. Of course, many farmers have already adopted some of the practices considered in the previous section (which assumed 0% uptake of any of the mitigation methods considered). To build our understanding of progress already made, this section considers the adoption rates of mitigation methods in English agriculture today. The results provide estimates of savings already achieved and the implied potential to achieve additional GHG emission reductions.

28. Two rates of implementation are used in this analysis:

- ADAS default implementation rate
- Survey adjusted implementation rate[11]

29. The 'ADAS default implementation rate' is a pre-determined level of adoption of mitigation methods for agriculture both inside and outside of NVZs. This is based on expert opinion which took into account information such as survey data and experience of farming practice on the ground. The 'Survey adjusted implementation rate' uses Defra surveys such as the Farm Practice Survey and the British Survey of Fertiliser Practice to identify differences between default ADAS values and the results of more recent questionnaire based surveys. Using this approach, 12 mitigation methods have been adjusted to provide an increased estimate of uptake when compared to ADAS default values. Implementation rates for both models are provided in Annex E.

30. It is not possible to apply implementation rates to the mitigation methods as outlined by the SAC MACC due to the lack of specificity in practice descriptions. For example, we are unable to identify suitable statistics to indicate the adoption of mitigation methods such as 'improve livestock productivity' and 'improve livestock fertility' because the methods are not well enough defined. In the following examples, where GHG reduction estimates identified by the SAC MACC have been included, they refer only to the overall reduction potential.

31. Using the 'ADAS default implementation rates' and 'Survey adjusted implementation rates', our analysis indicates English agriculture had already achieved between **1.4 – 1.7 $MtCO_2e$** of GHG emission reductions in 2010. These savings are provided by farmers undertaking mitigation methods such as using

[11] The analysis currently uses a single implementation rate, which is universally applied across all robust farm type.

fertiliser recommendation systems to match fertiliser inputs to crop needs, allowing slurry stores to develop natural crusts, improvements in the breeding of livestock and the use of clover to fix nitrogen from the air resulting in lower fertiliser nitrogen use.

32. The FARMSCOPER Upscaling Tool estimates a further 3.3 – 3.7 $MtCO_2e$ of additional GHG emission reduction potential, however to achieve this would require all farmers to adopt all GHG mitigation methods in full, regardless of cost. Adding in additional GHG reduction potential as identified by the SAC MACC through mitigation methods including improvements to livestock fertility and productivity as well as the adoption of Anaerobic Digestion to manage pig and particularly poultry slurry and manures, our analysis suggests a total additional reduction potential of **5.4 – 5.7 $MtCO_2e$**.

Table 3: Estimates of GHG reduction already achieved by English agriculture and MTP estimates of additional potential, 2010

	Achieved reductions ($MtCO_2e$)	**Additional reduction potential ($MtCO_2e$)**
ADAS default implementation rates	1.4	5.7
Survey adjusted implementation rates	1.7	5.4

33. Considering the costs of implementation and taking account of reductions already achieved, the analysis estimates **3.1 – 3.3 $MtCO_2e$** of savings could be achieved using mitigation methods which save farmers money. Where a carbon price of £56/tCO_2e is implemented, the potential to make cost effective GHG reductions rises to between **3.9 – 4.2 $MtCO_2e$**. At a carbon price of £200/tCO_2e per tonne, the potential rises to between **4.7 – 5.0 $MtCO_2e$**.

Table 4: Cost saving mitigation methods taking into account existing implementation rates

Mitigation method	**Additional reduction potential ($MtCO_2e$)**	**Cost implication**
Of which: FARMSCOPER mitigation methods		
Use plants with improved nitrogen use efficiency	0.53 – 0.54	Cost saving
Use a fertiliser recommendation system	0.21	Cost saving
Make use of improved genetic resources in livestock	0.16 – 0.27	Cost saving
Use clover in place of fertiliser nitrogen	0.13 – 0.21	Cost saving
Integrate fertiliser and manure nutrient supply	0.07	Cost saving
Adopt reduced cultivation systems	0.05	Cost saving
Of which: SAC MACC mitigation methods		
Improved fertility (Dairy)	0.77	Cost saving
Anaerobic Digestion (5MW Poultry Centralised AD Plant)	0.49	Cost neutral
Improved productivity	0.46	Cost saving
Maize silage (Diary)	0.21	Cost saving

Table 5: MTP estimates of additional GHG reduction potential by £/tCO_2e, 2010

	Cost negative / cost neutral	**Cost effective @ £56 per tonne / CO_2e**	**Cost effective @ £200 per tonne / CO_2e**
ADAS default implementation rates	3.3	4.2	5.0
Survey adjusted implementation rates	3.1	3.9	4.7

Mapping of farm practices to policies and incentives

34. It is difficult to pinpoint the reason(s) why some farmers adopt mitigation methods and others do not. The choices made by farmers are influenced by a wide variety of internal and external factors of which the wider policy landscape is but one part. Determining the causality between external drivers, such as policy, to the practices used by farmers is challenging and therefore any analysis of this kind needs to be approached cautiously.

35. Our analysis looks to focus on the part of our wider policy landscape which directly influences the choices made by farmers when producing agricultural products, which have most direct relevance to its potential impact on GHG emissions. Using this approach, seven policies were identified as being of specific relevance to the governance of agricultural production.

- Nitrate Vulnerable Zones (NVZs)
- Soil Protection Review (SPR)
- Cross Compliance (excluding NVZs and SPR)
- Silage, Slurry and Agricultural Fuel Oil (SSAFO) Regulations
- Environmental Stewardship (ES)
- Catchment Sensitive Farming (CSF)
- Soils for Profit (S4P)

36. To develop a link between these seven policies and farm practices which can reduce GHG emissions, a peer review consisting of internal and external stakeholders tested whether these policies are linked to the mitigation methods considered in this analysis. Having established a link between a policy and a farm practice, the peer review went further and attempted to describe the scale of influence or impact these policies have at affecting the choices made by farmers. The scale used to describe these relationships are provided below:

- Very strong driver (+++)
- Strong driver (++)
- Driver (+)

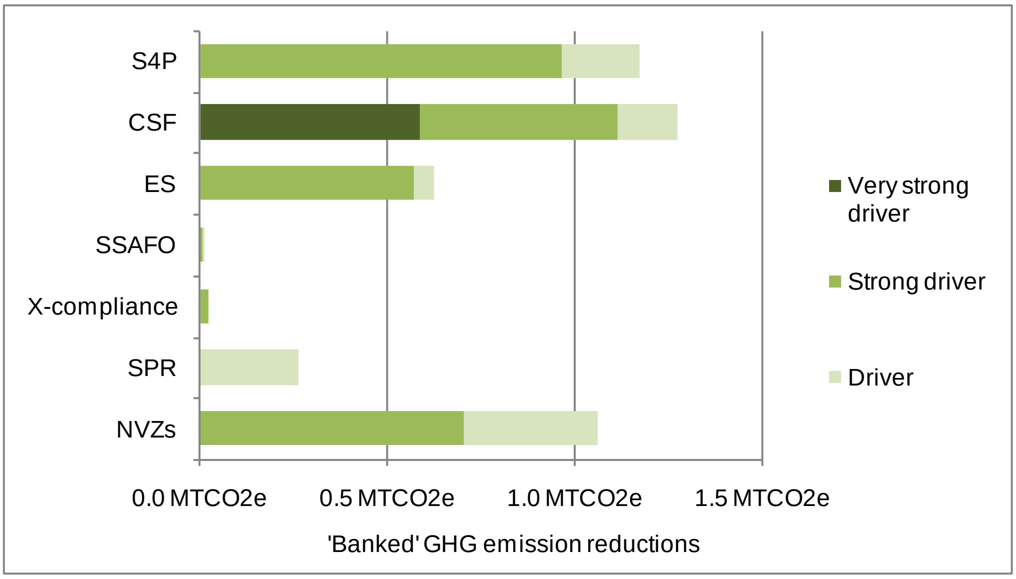
37. The definition of this scale was based on a subjective assessment of the impact of an external factor against each mitigation method in turn. Each driver is assessed against the population it is targeted towards. For example, the assessment of NVZs only considers the 60% of the country it is applied to. The subjective assessment also considered overall uptake rates within the population of interest, the retention of mitigation methods over the medium term and also the perceived ‘additionality’ of each external driver, i.e. would farmers continue to adopt these mitigation methods if the external factor were not in place. The full results of this mapping are provided alongside MTP information for each farm practice in turn in annex C.

38. The chart shows the level of correspondence between these external drivers and the mitigation methods considered in the analysis for ‘banked’ GHG emission reductions[12]. This provides an estimate of what level of overall achieved savings, is supported by each policy in turn[13].

[12] ‘Banked’ GHG emission reductions are based on the ‘survey adjusted implementation rate’

[13] The chart does not show the results of seven separate impact assessments which attribute GHG emission savings to policy interventions. Rather this chart shows the relative importance of the policy landscape in underpinning estimated achieved savings for English agriculture in 2010. Given current data limitations the chart does not distinguish the spatial or population coverage of policies.

Figure 4: Policy coverage of 'survey adjusted implementation rate' estimate of achieved GHG reductions, 2010



39. The results indicate advice schemes, such as Catchment Sensitive Farming and Soils for Profit, alongside environment stewardship incentives (all part of the Common Agricultural Policy) are important drivers to encourage and secure change. In particular, our peer review highlighted the role of Catchment Sensitive Farming as a scheme which was particularly effective at securing lasting change in the practices employed by farmers.

40. Nitrate Vulnerable Zones, are also highlighted as an important driver which can place a fixed cap on the quantity of organic nitrogen and variable cap on inorganic nitrogen applied to the land, and encourage farmers to consider ways of optimising both the timing and application rate of nutrients to crop requirements. The analysis indicates the Soil Protection Review, Cross Compliance (not including the SPR and NVZs) and SSAFO regulations play a more limited role in encouraging the adoption of the farm practices which can provide GHG emission reductions.

41. Looking towards the future and the mitigation methods which can provide additional GHG emission reductions, it is possible to use the same approach to highlight the policy coverage of the same seven external factors. In addition, we are also able to consider the scope of the industry's GHGAP to work alongside the overall policy landscape and accelerate the adoption of cost saving mitigation methods. The scale of driver between a policy and mitigation method is defined using the scale below:

- Very strong driver (+++),Very strong negative driver (- - -)

- Strong driver (++), Strong negative driver (- -)
- Driver (+), Negative driver (-)

Table 6: Policy coverage of selected cost saving FARMSCOPER farm practices

Mitigation method	**GHGAP**	**NVZs**	**SPR**	**X-Comp**	**SSAFO**	**ES**	**CSF**	**S4P**
Use plants with improved nitrogen use efficiency (528 – 537 $KtCO_2e$)	✓	+						
Use clover in place of fertiliser nitrogen (133 – 210 $KtCO_2e$)	✓					++	++	++
Use a fertiliser recommendation system (208 – 210 $KtCO_2e$)	✓	++					+++	++
Integrate fertiliser and manure nutrient supply (73 – 75 $KtCO_2e$)	✓	++					+++	++
Make use of improved genetic resources in livestock (161 – 266 $KtCO_2e$)	✓	+						
Adopt reduced cultivation systems (50 – 53 $KtCO_2e$)	✓					+	++	++

42. The table sets out the level of correspondence between cost saving mitigation methods identified by the FARMSCOPER Upscaling Tool, the industry's GHGAP and the policies considered in this analysis[14]. It indicates the GHGAP is aligned to the practices considered here, particularly for improvements to plant and livestock genetics.

43. For mitigation methods more focused on boosting the efficiency of today's nutrient management systems, the GHGAP is supported to a greater degree with advice schemes such as Catchment Sensitive Farming and NVZ rules, providing a solid framework upon which the industry can build upon.

44. It is clear the current policy landscape is geared towards encouraging farmers to adopt resource efficient practices. The GHGAP is ideally placed to work alongside this existing policy framework and accelerate progress already made to a wider population of farmers in England. Further analysis of the structure and progress achieved by the industry with its GHGAP is provided in Paper 4: Industry Action of this Report.

Multi-pollutant analysis of cost negative and cost neutral mitigation methods

45. The FARMSCOPER Upscaling tool is able to consider the impacts of mitigation methods across a range of environmental pollutants. These wider impacts include ammonia emissions to air and nitrate, phosphorus, sediment and pesticide losses to water. Additional 'indicator' metrics are also provided for biodiversity, water and energy use.

46. The table[15] provides an assessment of the wider environmental impact of the six cost saving mitigation methods highlighted by this analysis as practices which can reduce GHG emissions and save farmers money. These mitigation methods are solely defined by the FARMSCOPER Upscaling Tool and focus mainly on improvements to nutrient management practices. Additional methods highlighted by the SAC MACC, practices which can improve livestock productivity for example have not been considered.

[14] A full list of all farm practices is provided in annex C

[15] Multi-pollutant analysis can be applied across the FARMSCOPER Upscaling modelling framework to consider the impact of over 100 different farm practices. The results of the analysis are not presented in this paper, but are available on request

Table 7: Wider environmental impacts of cost saving FARMSCOPER farm practices

Mitigation method	**GHG**	**Ammonia**	**Nitrate**	**Phosphorous**	**Sediment**	**Pesticides**	**Biodiversity**	**Water Use**	**Energy Use**
Use plants with improved nitrogen use efficiency (528 – 537 $KtCO_2e$)	Positive	Positive	Positive						
Use clover in place of fertiliser nitrogen (133 – 210 $KtCO_2e$)	Positive	Positive	Positive				Positive		Positive
Use a fertiliser recommendation system (208 – 210 $KtCO_2e$)	Positive	Positive	Positive	Positive					Positive
Integrate fertiliser and manure nutrient supply (73 – 75 $KtCO_2e$)	Positive	Positive	Positive	Positive					
Make use of improved genetic resources in livestock (161 – 266 $KtCO_2e$)	Positive	Positive	Positive	Positive					Positive
Adopt reduced cultivation systems (50 – 53 $KtCO_2e$)	Positive		Positive	Positive	Positive	Positive	Positive		Positive

Positive impact	
Negative impact	

47. The results indicate the wider adoption of mitigation methods focused on improving the nutrient management system of a farm is likely to provide multiple positive benefits for reducing wider environmental pollutants, particularly ammonia emissions to air and nitrates losses to water. Positive outcomes are also likely for phosphorous with more limited benefits for biodiversity, sediment, pesticides and energy use.

48. We recognise the multi-pollutant analysis considered here does not assess the wider environmental impacts of cost saving mitigation methods highlighted by the SAC MACC, which are mostly focused on livestock efficiency improvement. Research to assess the wider environmental impacts of these mitigation methods is due to be completed soon and will provide an important body of evidence to inform the consideration of implementing these and other mitigation methods in the context of wider environmental and land management objectives.

Estimating feasible uptake of farm practices and mitigation options

49. The analysis so far has considered the extent to which mitigation methods are already in use by farmers and the additional potential for savings if farmers were to implement these practices in full on all farms. We understand however that some farmers' local circumstances could make it challenging to implement some mitigation methods in every case and that the incentives and drivers to increase resource efficiency are unlikely to be felt uniformly across all farms. This section considers what is the most likely level of uptake, taking into account the variability of farm circumstances i.e. the realistic or **'feasible potential'.**

50. For illustrative purposes we set the feasible potential (FP) of each cost saving farm practice to at least 50% uptake, consistent with the approach used within the original SAC MACC work. For those farm practices which already have greater than 50% uptake, we use that higher rate of uptake.

51. As with previous sections of this paper, this analysis uses 2010 Agriculture Census data to estimate the potential savings associated with an increase in uptake of cost-saving farm practices to at least 50%. This suggests that in addition to the **1.4 – 1.7 $MtCO_2e$** already delivered by the sector, English agriculture could deliver a further 0.6 – 1.0 $MtCO_2e$ by increasing uptake of cost saving farm practices to at least 50%. This would represent a total emissions saving of 2.4 $MtCO_2e$ in 2010. Including the additional cost-saving SAC MACC measures not covered by FARMSCOPER, and applying the same uptake assumption of 50%, increases this estimate by a further **1.0 $MtCO_2e$** to **3.4 $MtCO_2e$**.

Table 8: Central feasible potential estimates of GHG reductions, 2010

	Abatement potential ($MtCO_2e$)	**Cumulative abatement potential ($MtCO_2e$)**
Achieved abatement in 2010	1.4 – 1.7	1.4 – 1.7
CFP of additional FARMSCOPER cost-saving practices	0.6 – 1.0	2.4
CFP of additional cost-saving SAC MACC measures	1.0	3.4

52. This is a simple yet limited approach for estimating a feasible level of abatement potential. We would recommend that further analysis, ideally led by industry, consider a more thorough analysis exploring the practicality of each farm practice in order to determine a credible yet ambitious level of implementation across different agricultural sectors which take into account the barriers and incentives in place. This work would ideally be tailored across relevant farm types, sizes and local conditions (including soil type and average rainfall).

Looking forward: abatement potential in 2020

53. The structure of the agricultural sector is relatively flexible and changes in response to a variety of external and internal factors. So far, all analysis has been based on 2010 activity data, which is the latest year for robust statistical information. However, we are also interested in looking ahead to understand the impact of structural change on absolute emissions from agriculture as well as the associated impact for generating greater efficiency within agricultural sub-sectors.

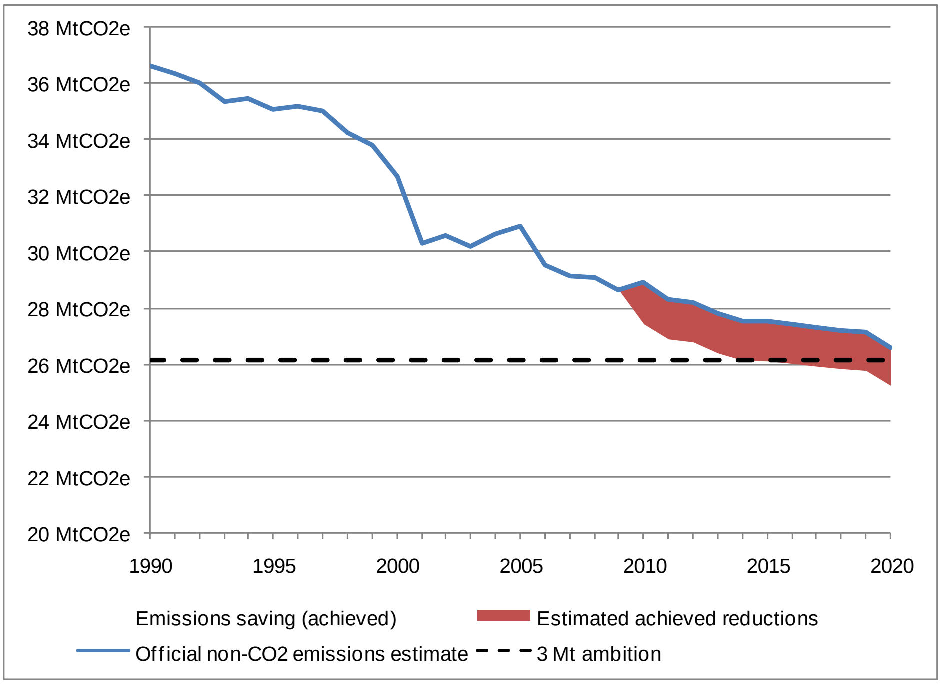
54. We have used the latest FAPRI-UK[16] model of agricultural activity to begin to assess the GHG emission reduction potential from England in 2020. This is the same model used to project national non CO_2 emissions from the agricultural sector, providing consistency across GHG policy analysis. As a result of the

[16] The FAPRI-UK modelling system was created, and is maintained, by the Agri-Food Biosciences Institute (AFBI) and the Queen's University Belfast. The FAPRI-UK model covers the areas governed by the Devolved Administrations (DAs), while endogenously modelling key variables for the following commodities: Dairy, Beef, Sheep, Pigs, Poultry, Wheat, Barley, Oats, Rapeseed and Liquid Biofuels. The 2011 FAPRI-UK model projects agricultural activity data out to 2020.

changes estimated by the FAPRI-UK model, non CO_2 emissions from English agriculture are projected to decline by **8%** between 2010 and 2020[17], primarily due to reductions in livestock numbers and fertiliser application rates.

55. This structural change to the industry will likely reduce the absolute savings potential from current practice. However, given the limitations of our current analytical tools these potential changes are not fully reflected here. Instead we assume current practice is maintained and is able to deliver the same proportion (**5.1%**) of emissions savings between 2010 and 2020.

Figure 5: GHG emissions estimates for English agriculture 1990 – 2020 with estimated achieved GHG reductions



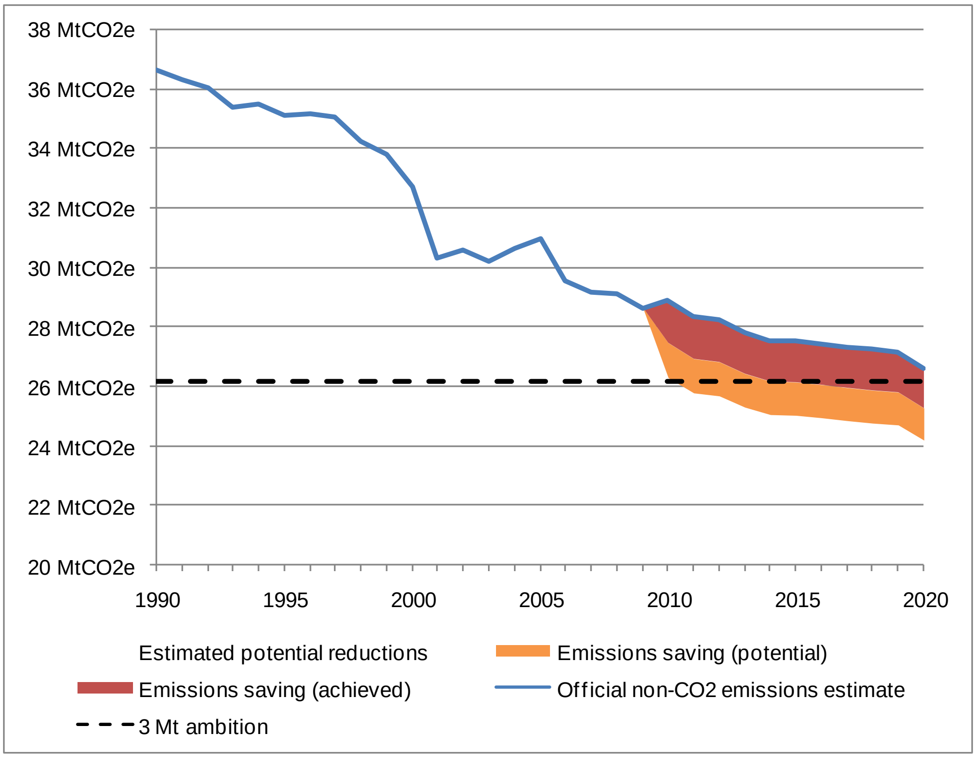
56. The chart demonstrates that given the economic outlook for the sector as well as current uptake of emissions reducing farm practices, English agriculture is well placed to achieve the ambition of a 3 $MtCO_2e$ reduction in non-CO_2 emissions measured against a 2007 baseline.

57. The same methodology is used to consider how a feasible uptake of farm practices and mitigation options may influence overall emissions out to 2020. The feasible potential is defined as set out earlier in the paper, with uptake of cost-saving practices set to at least 50%. In 2020 this was estimated to deliver a

[17] Detailed figures are available on: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=15542

reduction of **8%** in total GHG emissions which is applied across the time series. The second chart illustrates this result.

Figure 6: Non-CO_2 GHG emissions estimates for English agriculture 1990 – 2020 with estimates of achieved and additional cost-saving GHG reductions



The effect of changes in production on total emissions

58. This analysis has considered what level of emissions will be associated with a given level of output. That is, the emissions intensity of agricultural production in England. The farm practices in this analysis will lower this emissions intensity by altering the way inputs are managed to achieve the same outcomes. Given their potential to deliver financial savings to farmers they may also reduce the costs of production.

59. In a competitive market, a reduction in the costs of production for a firm can lead to an increase in output and market share given a constant price level. At the aggregate, national level output may be increased through increased exports or import substitution. This has the potential to increase overall emissions as output increases. The net impact on overall emissions is uncertain and will depend on whether changes in the intensity of emissions or changes in overall output dominate.

60. The following are illustrative examples of how changes in output away from the FAPRI-UK baseline out to 2020 could affect overall emissions and what this could mean for uptake of practices to reduce them.

61. Our estimates of **1.4 – 1.7 $MtCO_2e$** achieved reductions in 2010 is based on the understanding that changes in the production level are already captured by the inventory. This means that achieved reductions are driven by reduced emission intensity. The achieved reductions equate to a **4.6% – 5.6%** improvement in GHG emission intensity across the whole sector. For individual sectors this rate will vary, but statistical information on uptake of practices by farm type is not currently available to inform this. At the aggregate level and given current practice, this suggests that for emissions to stay at the reported 2010 level, the sector could grow by up to **5.6%**.

62. If aggregate production levels and practices were to remain constant between now and 2020, achieving the industry's 3 $MtCO_2e$ ambition requires non-CO_2 emissions to be no greater than 26.15 $MtCO_2e$. This represents a reduction of **9%** compared to the reported level of 2010 emissions, close to double what has been estimated for progress so far.

63. A growing English agriculture sector would need to deliver even greater progress in GHG emission intensity to achieve the 3 $MtCO_2e$ ambition. For example, a sector growing 5% between 2010 and 2020 would, all else being equal, be responsible for emitting around 30.4 $MtCO_2e$, requiring a **14%** improvement in intensity to achieve the ambition. A sector growing by 10% would need to deliver an **18%** improvement in GHG emission intensity[18].

64. The feasible potential analysis suggested that 0.6 – 1.0 $MtCO_2e$ of additional GHG reduction potential could be delivered by increasing uptake of cost-saving farm practices to at least 50%. Realising 50% of the additional SAC MACC mitigation methods increases this figure by a further 1.0 $MtCO_2e$ to between 1.6 – 2.6 $MtCO_2e$ overall. Taken together with 'banked' emissions, this analysis indicates it is feasible to deliver an **11%** improvement in GHG emission intensity.

65. This highlights the risks to delivering the ambition from increases in agricultural output given our current understanding of mitigation methods.

[18] These illustrative figures do not take account of potential yield gains. The impact of increased yields on emissions is uncertain and will depend on how any yield increases are achieved. Analysing this is beyond the capability of our existing tools.

Table 9: Emissions intensity reductions associated with central feasible potential estimates of GHG reductions

	Absolute emissions savings potential, 2010	**Implied GHG intensity change**
Achieved abatement	1.4 – 1.7	4.6 – 5.6%
Additional CFP achievement of FARMSCOPER practices	2.4	8%
Additional CFP achievement of FARMSCOPER practices and SAC MACC measures	3.4	11%

Conclusions

66. This analysis has explored the potential to reduce GHG emissions from English agriculture through a range of mitigation methods using the FARMSCOPER Upscaling Tool developed by Defra analysts, along with additional mitigation methods taken from the SAC MACC.

67. The analysis has identified a maximum technical potential for English agriculture to save **7.1 $MtCO_2e$** in nitrous oxide and methane emissions through the adoption of mitigation methods.

68. Taking expert judgement and survey data into account, we estimate that in 2010 the sector had already achieved between **1.4 – 1.7 $MtCO_2e$** of savings supported by a range of policies including Nitrate Vulnerable Zones, Catchment Sensitive Farming and Environmental Stewardship.

69. Of the remaining 5.4 – 5.7 $MtCO_2e$ of savings available, between **3.1 – 3.3 $MtCO_2e$** of savings could be achieved using mitigation methods which save farmers money.

70. Our analysis demonstrates the industry's ambition to reduce English agricultural production emissions by 3 $MtCO_2e$, by the third carbon budget period compared to a 2007 emission level, is a credible level of ambition.

71. The industry led GHGAP is well aligned to the mitigation methods which can save farmers money and it clearly has a role to play in broadening uptake of mitigation methods – continuing to build on the impact of the overall policy landscape. Further, mitigation methods related to improvements in nutrient management are likely to provide multiple wins for other environmental pollutants (such as ammonia and nitrates) and work in support of our wider efforts on biodiversity.

72. Although the FARMSCOPER Upscaling tool alongside the SAC MACC considered over 100 farm practices, this analysis has not considered all mitigation methods available to farmers. It is our intention to build on the analysis completed here to include additional options relating to livestock feeding, biosecurity and farm practices targeted at improving livestock productivity. We are also working with experts to explore the possibility of including soil carbon storage within the modelling framework to go alongside the environmental stewardship options already included within the analysis.

Annex A: Comparison of SAC MACC abatement options and FARMSCOPER farm practices

GHG Action Plan priority area	**Category**	**SAC MAC Curve Mitigation Methods**	**FARMSCOPER mitigation methods**	**Comments**
Crop nutrient management	Plants with improved nitrogen use efficiency	• Crops-Soils-BiolFix • Crops-Soils-SpeciesIntro • Crops-Soils-ImprovedN-UsePlants (Cost effective, 0.7 – 1.4MT CO2e)	• Use clover in place of fertiliser nitrogen • Use plants with improved nitrogen use efficiency (Cost effective, 0.8MT CO2e)	Good correspondence between mitigation methods presented in the SAC MACC and FARMSCOPER Both models produce similar results based on comparable analysis
	Nutrient management	• Crops-Soils-AvoidNExcess • Crops-Soils-FullManure • Crops-Soils-MineralNTiming • Crops-Soils-OrganicNTiming • Crops-Soils-ControlledRelFert • Crops-Soils-SlurryMineralNDelayed • BeefManure-CoveringLagoons • BeefManure-CoveringSlurryTanks • DairyManure-CoveringLagoons • DairyManure-CoveringSlurryTanks (Cost effective, 0.7 – 3.1MT CO2e)	• Fertiliser spreader calibration • Use a fertiliser recommendation system • Integrate fertiliser and manure nutrient supply • Do not apply manufactured fertiliser to high-risk areas • Avoid spreading manufactured fertiliser to fields at high-risk times • Use manufactured fertiliser placement technology • Increase the capacity of farm slurry stores to improve timing of slurry applications • Manure Spreader Calibration	FARMSCOPER provides a wider coverage of nutrient management practices compared to SAC MACC mitigation methods. Both models produce similar results based on comparable analysis

			• Do not apply manure to high-risk areas • Do not spread slurry or poultry manure at high-risk times • Use slurry band spreading application techniques • Use slurry injection application techniques • Do not spread FYM to fields at high-risk times • Incorporate manure into the soil • Incorporate a urease inhibitor into urea fertilisers • Use liquid/solid manure separation techniques • Install covers to slurry stores (Cost effective, 1.7MT CO_2e)	
Soil and land management	Soil management	• Crops-Soils-Drainage • Crops-Soils-ReducedTill	• Allow field drainage systems to deteriorate • Adopt reduced cultivation systems	Good correspondence between the mitigation methods contained in the SAC MACC and FARMSCOPER However the ‘business case’ for improving or deteriorating land drainage is unclear and highly dependent on local circumstances. Similarly it is unclear whether reduced tillage farming systems provide long term abatement

	Land management	• Forestry-Afforestation		FARMSCOPER does not include mitigation methods specifically related to afforestation FARMSCOPER does however include a wider range of land management practice targeted at reducing pollution to water courses. It also includes a number of ELS options Carbon storage is not included in FARMSCOPER A recommendation for future work is to investigate this aspect of farming practice in more detail.
Livestock nutrition	Livestock nutrition	• BeefAn-Concentrates • DairyAn-MaizeSilage (Costs vary between effective and positive, 0.1 – 0.2MT CO2e) Banned measures (not included in estimates above) • BeefAn-Ionophores • DairyAn-Ionophores • DairyAn-bST	• Adopt phase feeding of livestock • Reduce dietary N and P intakes (Cost positive, 0.1MT CO2e)	Coverage of diet manipulation across both the SAC MACC and FARMSCOPER is not as comprehensive as it could be. A recommendation for future work is to investigate this aspect of farming practice in more detail.
Livestock health	Breeding	• BeefAn-ImprovedGenetics • DairyAn-ImprovedFertility • DairyAn-ImprovedProductivity	• Make use of improved genetic resources in livestock (Cost effective, 0.3MT CO2e)	The SAC MACC and FARMSCOPER provide good coverage of using improved genetic resources in breeding

		(Cost effective, 0.6 – 1.5MT CO2e) Banned measures (not included in estimates above) • DairyAn-Transgenics		regimes with modelling results broadly similar FARMSCOPER does not provide associated practices relating to fertility and productivity improvements – one or both may be linked to biosecurity practices for example. A recommendation for future work is to investigate this in more detail
Energy efficiency and renewable generation	Anaerobic Digestion	• CAD-Poultry-5MW • OFAD-BeefLarge • OFAD-BeefMedium • OFAD-DairyLarge • OFAD-DairyMedium • OFAD-PigsLarge • OFAD-PigsMedium		FARMSCOPER does not include the use of AD within the model and given its construction – it would be difficult for it to be included. The use of AD as a mitigation method would therefore need to be considered separately

Annex B: FARMSCOPER Upscaling Tool input assumptions

- Farm types, average annual rainfall within and not in a NVZ

Robust farm type	FARMSCOPER model farms	Average annual rainfall - NVZ	Average annual rainfall – non NVZ
Cereals	Mixed combinable	601 to 700 mm	701 to 900 mm
	Mixed combinable with pig manure	601 to 700 mm	701 to 900 mm
General cropping	Roots & combinable	601 to 700 mm	701 to 900 mm
	Roots & combinable with poultry litter	601 to 700 mm	701 to 900 mm
Horticulture	Horticulture	601 to 700 mm	701 to 900 mm
Specialist pigs	Indoor pig	601 to 700 mm	701 to 900 mm
	Outdoor pig	601 to 700 mm	701 to 900 mm
Dairy	Dairy	701 to 900 mm	901 to 1200 mm
LFA Grazing Livestock	LFA	901 to 1200 mm	1201 to 1500 mm
Lowland Grazing livestock	Lowland grazing	701 to 900 mm	901 to 1200 mm

Mixed	Mixed	601 to 700 mm	701 to 900 mm

- Soil type within and not in a NVZ

NVZ status	**Soil type**
NVZ	Free draining
Not in a NVZ	Other

- Fertiliser application rates

Cropping	**Fertiliser application rates**	
	N (kg/ha)	**P_2O_5 (kg/ha)**
Permanent pasture	120	8
Rotational grassland	184	15
Winter Wheat (Feed)	154	19
Winter Wheat (Milling)	154	19
Winter Barley (Malting)	141	18
Winter Barley (Feed)	141	18
Spring Barley	70	12
Winter OSR	199	16.6
Maize	64	25
Potatoes	157	52.8
Sugar Beet	95	16.6

Peas	0	9.2
Beans	0	9.2
Fodder Crops	70	12
Other Crops	55	9
Vegetables (Brassica)	193	26
Vegetables (Other)	91	28
Orchards	49	5
Soft Fruit	68	28

Annex C: Maximum technical potential of farm practices and the alignment of these farm practices to the GHGAP and Defra policies

- The maximum technical potential of the farm practices considered in this analysis are calculated using models and data sets which incorporate varying uncertainty factors which have not been fully considered in this analysis. The cost information used in this analysis is also sensitive to changes in market prices and care therefore, should be taken in its use.

- Many of the farm practices highlighted in this table are defined in detail in the 'User Guide' (module 5, WQ0106)

FARM-SCOPER ID	Farm Practice	MTP ($KtCO_2e$)	£/tCO2e	GHGAP	NVZ	SPR	X-Comp	SSAFO	ES	CSF	S4P
43	Additional targeted bedding for straw-bedded cattle housing	0								++	
53	Adopt batch storage of slurry	0		✓				-			
34	Adopt phase feeding of livestock	11	538							+	
7	Adopt reduced cultivation systems	71	-404	✓					+	++	++
55	Allow cattle slurry stores to develop a natural crust	249	10								
16	Allow field drainage systems to deteriorate	-515	-468				- -			+	
122	Avoid irrigating at high risk times	0	40,644							++	
92	Avoid PPP application at high risk timings	0				+				++	
26	Avoid spreading manufactured fertiliser to fields at high-risk times	4	5,961	✓	++				+	++	++
107	Beetle banks	1	17,976						++	++	
90	Calibration of sprayer	0								++	

120	Capture of dirty water in a dirty water store	9	79		+			+++		++	+
59	Compost solid manure	0									
77	Construct bridges for livestock crossing rivers/streams	12	943							++	+
96	Construct bunded impermeable PPP filling/mixing/cleaning area	0								+++	
39	Construct troughs with concrete base	231	84						++	+++	+
49	Convert caged laying hen housing from deep-pit storage to belt manure removal	0									
62	Cover solid manure stores with sheeting	2	5,468	✓						++	+
9	Cultivate and drill across the slope	8	5,731	✓			+			++	++
8	Cultivate compacted tillage soils	127	127						++	+++	++
6	Cultivate land for crops in spring rather than autumn	47	2,370	✓							
25	Do not apply manufactured fertiliser to high-risk areas	591	37	✓	++				++	++	++
68	Do not apply manure to high-risk areas	5	791	✓	++				++	++	++
32	Do not apply P fertilisers to high P index soils	0		✓						+++	++
72	Do not spread FYM to fields at high-risk times	150	13	✓	++				+	++	++
69	Do not spread slurry or poultry manure at high-risk times	139	13		++				+	++	++
94	Drift reduction methods	0								++	
5	Early harvesting and establishment of crops in the autumn	25	4,516	✓	+				++	++	+
81	Establish and maintain artificial wetlands - steading runoff	3	1,262		+			+		+	
4	Establish cover crops in the autumn	236	284	✓	+		+		++	++	+
13	Establish in-field grass buffer strips	1	17,691	✓					+++	++	+
80	Establish new hedges	0	103,322	✓					++	+	

14	Establish riparian buffer strips	2	14,747	✓	++	++	+		+++	+++	++
83	Establish tree shelter belts around livestock housing	0		✓							
36	Extend the grazing season for cattle	-645	-39		+			+			
79	Farm track management	0							+	+++	+
76	Fence off rivers and streams from livestock	32	956				+		+++	+++	+
21	Fertiliser spreader calibration	14	572	✓	+					+++	++
91	Fill/Mix/Clean sprayer in field	0								++	
46	Frequent removal of slurry from beneath-slat storage in pig housing	0									
301	Incorporate a urease inhibitor into urea fertilisers for arable land	0									
300	Incorporate a urease inhibitor into urea fertilisers for grassland	0									
73	Incorporate manure into the soil	0	-103,146	✓	+++					++	+
42	Increase scraping frequency in dairy cow cubicle housing	0		✓						++	
52	Increase the capacity of farm slurry stores to improve timing of slurry applications	5	5,349		++			++		+++	++
51	In-house poultry manure drying	0									
48	Install air-scrubbers or biotrickling filters in mechanically ventilated pig housing	0		✓							
54	Install covers to slurry stores	0		✓	+			+		+++	++
23	Integrate fertiliser and manure nutrient supply	190	-1,158	✓	++					+++	++
180	Intensive ditch management on arable land	17	152			++					
181	Intensive ditch management on grassland	68	64			++					
82	Irrigate crops to achieve maximum yield	6	10,137								
121	Irrigation/water supply equipment is maintained	0					+			++	

	and leaks repaired										
10	Leave autumn seedbeds rough	3	15,481	✓			++			++	++
115	Leave over winter stubbles	47	3,081				+		++	+	+
116	Leave residual levels of non-aggressive weeds in crops	0							+		
118	Locate out-wintered stock away from watercourses	96	64				+		++	++	+
15	Loosen compacted soil layers in grassland fields	127	304	✓			+			++	++
19	Make use of improved genetic resources in livestock	273	-648	✓	+						
11	Manage over-winter tramlines	3	9,676	✓						++	+
105	Management of field corners	1	88,453							+	
103	Management of in-field ponds	1	19,794						++	+	
102	Management of woodland edges	0							+++		
67	Manure Spreader Calibration	8	1,811	✓	+					++	+
570	Minimise the volume of dirty water produced (sent to dirty water store)	0	135,665		+			++		+++	++
571	Minimise the volume of dirty water produced (sent to slurry store)	3	6,205		+			++		+++	++
50	More frequent manure removal from laying hen housing with manure belt systems	0									
38	Move feeders at regular intervals	231	168	✓			+		++	+	+
47	Part-slatted floor design for pig buildings	0									
106	Plant areas of farm with wild bird seed / nectar flower mixtures	3	57,679						++		
95	PPP substitution	0								++	
101	Protection of in-field trees	0	6,500						+++		
331	Reduce dietary N and P intakes: Dairy	112	472		+					+	
332	Reduce dietary N and P intakes: Pigs and	21	269		+					+	

	Poultry										
37	Reduce field stocking rates when soils are wet	137	292	✓					++	++	++
35	Reduce the length of the grazing day/grazing season	645	124		-			-	++	++	+
291	Replace urea fertiliser to arable land with another form	0									
290	Replace urea fertiliser to grassland with another form	0									
78	Re-site gateways away from high-risk areas	10	1,653						+	+++	+
60	Site solid manure heaps away from watercourses/field drains	2	994		+++				+	++	++
109	Skylark plots	0							++		
61	Store solid manure heaps on an impermeable base and collect effluent	10	994							++	++
114	Take field corners out of management	1	85,600						+++	++	
97	Treatment of PPP washings through disposal, activated carbon or biobeds	0								+++	
110	Uncropped cultivated areas	233	1,300						++		
108	Uncropped cultivated margins	1	71,333						++		
113	Undersown spring cereals	56	3,077						++	+	+
111	Unfertilised cereal headlands	1	72,160						++		
112	Unharvested cereal headlands	1	144,321						++		
1040	Unintensive hedge and ditch management on arable land	-17	-870						+++	+	
1041	Unintensive hedge and ditch management on grassland	-68	-363						+++	+	
22	Use a fertiliser recommendation system	598	-100	✓	++					+++	++
31	Use clover in place of fertiliser nitrogen	232	-999	✓					++	++	++
117	Use correctly-inflated low ground pressure tyres	4	10,507	✓						++	+

	on machinery										
119	Use dry-cleaning techniques to remove solid waste from yards prior to cleaning	6	105							++	
123	Use efficient irrigation techniques (boom trickle, self closing nozzles)	4	1,039							++	
63	Use liquid/solid manure separation techniques	1	17,300	✓	+			+		++	+
27	Use manufactured fertiliser placement technologies	12	675	✓	+					++	++
20	Use plants with improved nitrogen use efficiency	598	-200	✓	+						
64	Use poultry litter additives	0									
70	Use slurry band spreading application techniques	-21	-1,242							++	++
71	Use slurry injection application techniques	24	1,370							++	++
44	Washing down of dairy cow collecting yards	0			-			-			
	Improved productivity (Dairy)	456	-144	Unmapped SAC MACC measure							
	Improved fertility (Dairy)	765	-86	Unmapped SAC MACC measure							
	Maize silage – nutrition (Dairy)	213	-263	Unmapped SAC MACC measure							
	Large on-farm AD plant (Pigs)	106	36	Unmapped SAC MACC measure							
	Medium on-farm AD plant (Pigs)	36	33	Unmapped SAC MACC measure							
	5MW centralised AD plant (Poultry)	487	0	Unmapped SAC MACC measure							

Annex D: Maximum technical potential of farm practices and mitigation methods by farm type

Table D1: Dairy

Farm Practice	MTP ($KtCO_2e$)	£/tCO_2e
Adopt reduced cultivation systems	9	-320
Allow cattle slurry stores to develop a natural crust	249	10
Avoid spreading manufactured fertiliser to fields at high-risk times	1	1,271
Construct bridges for livestock crossing rivers/streams	10	676
Construct troughs with concrete base	57	61
Cultivate compacted tillage soils	8	96
Cultivate land for crops in spring rather than autumn	3	2,960
Do not apply manufactured fertiliser to high-risk areas	77	17
Do not apply manure to high-risk areas	3	674
Do not spread FYM to fields at high-risk times	19	14
Do not spread slurry or poultry manure at high-risk times	138	12
Early harvesting and establishment of crops in the autumn	6	5,504
Establish cover crops in the autumn	17	355
Fence off rivers and streams from livestock	13	526
Fertiliser spreader calibration	1	654
Increase the capacity of farm slurry stores to improve timing of slurry applications	5	4,305
Integrate fertiliser and manure nutrient supply	80	-2,209
Intensive ditch management on arable land	3	99
Intensive ditch management on grassland	25	50
Leave over winter stubbles	3	3,848
Locate out-wintered stock away from watercourses	22	64
Loosen compacted soil layers in grassland fields	8	839
Make use of improved genetic resources in livestock	119	-541
Manure Spreader Calibration	3	670
Minimise the volume of dirty water produced (sent to slurry store)	3	6,205
Move feeders at regular intervals	57	122
Plant areas of farm with wild bird seed / nectar flower mixtures	1	31,259
Reduce dietary N and P intakes: Dairy	99	469
Re-site gateways away from high-risk areas	3	711
Store solid manure heaps on an impermeable base and collect effluent	1	1,248
Uncropped cultivated areas	66	226
Undersown spring cereals	3	3,964
Use a fertiliser recommendation system	80	-68

Use clover in place of fertiliser nitrogen	66	-634
Use liquid/solid manure separation techniques	1	16,166
Use manufactured fertiliser placement technologies	1	660
Use plants with improved nitrogen use efficiency	80	-136
Use slurry injection application techniques	24	1,366
Improved productivity	456	-144
Improved fertility	765	-86
Maize silage - nutrition	213	-263

Table D2: Least Favoured Area Grazing Livestock

Farm Practice	**MTP ($KtCO_2e$)**	**£/tCO_2e**
Capture of dirty water in a dirty water store	9	79
Construct troughs with concrete base	44	91
Do not apply manufactured fertiliser to high-risk areas	29	14
Do not apply manure to high-risk areas	1	390
Do not spread FYM to fields at high-risk times	27	13
Establish and maintain artificial wetlands - steading runoff	3	1,262
Fence off rivers and streams from livestock	4	1,859
Fertiliser spreader calibration	1	1,087
Integrate fertiliser and manure nutrient supply	10	-633
Locate out-wintered stock away from watercourses	25	64
Make use of improved genetic resources in livestock	40	-764
Manure Spreader Calibration	1	1,759
Move feeders at regular intervals	44	181
Plant areas of farm with wild bird seed / nectar flower mixtures	1	35,198
Reduce field stocking rates when soils are wet	42	67
Reduce the length of the grazing day/grazing season	166	34
Re-site gateways away from high-risk areas	2	715
Store solid manure heaps on an impermeable base and collect effluent	1	1,222
Uncropped cultivated areas	28	3
Use a fertiliser recommendation system	28	-144
Use clover in place of fertiliser nitrogen	28	-1,730
Use dry-cleaning techniques to remove solid waste from yards prior to cleaning	6	105
Use plants with improved nitrogen use efficiency	28	-289

Table D3: Lowland Grazing Livestock

Farm Practice	MTP ($KtCO_2e$)	£/tCO_2e
Adopt reduced cultivation systems	7	-408
Avoid spreading manufactured fertiliser to fields at high-risk times	1	2,242

Construct troughs with concrete base	65	92
Cover solid manure stores with sheeting	1	6,690
Cultivate compacted tillage soils	5	115
Cultivate land for crops in spring rather than autumn	4	2,324
Do not apply manufactured fertiliser to high-risk areas	49	28
Do not apply manure to high-risk areas	1	1,002
Do not spread FYM to fields at high-risk times	59	12
Early harvesting and establishment of crops in the autumn	3	3,892
Establish cover crops in the autumn	21	279
Fence off rivers and streams from livestock	9	1,292
Fertiliser spreader calibration	1	1,502
Integrate fertiliser and manure nutrient supply	22	-722
Intensive ditch management on arable land	2	152
Intensive ditch management on grassland	24	71
Leave over winter stubbles	4	3,021
Locate out-wintered stock away from watercourses	37	64
Loosen compacted soil layers in grassland fields	5	2,228
Make use of improved genetic resources in livestock	69	-747
Manure Spreader Calibration	1	1,840
Move feeders at regular intervals	65	184
Reduce field stocking rates when soils are wet	75	80
Reduce the length of the grazing day/grazing season	280	43
Re-site gateways away from high-risk areas	2	1,635
Site solid manure heaps away from watercourses/field drains	1	1,216
Store solid manure heaps on an impermeable base and collect effluent	3	1,216
Uncropped cultivated areas	43	270
Undersown spring cereals	4	2,975
Use a fertiliser recommendation system	51	-147
Use clover in place of fertiliser nitrogen	43	-1,670
Use plants with improved nitrogen use efficiency	51	-295

Table D4: Mixed

Farm Practice	**MTP (KtCO_2e)**	**£/tCO_2e**
Adopt reduced cultivation systems	12	-425
Construct bridges for livestock crossing rivers/streams	1	2,882
Construct troughs with concrete base	28	72
Cultivate and drill across the slope	1	5,586
Cultivate compacted tillage soils	16	123
Cultivate land for crops in spring rather than autumn	6	2,455
Do not apply manufactured fertiliser to high-risk areas	71	38
Do not spread FYM to fields at high-risk times	45	13

Do not spread slurry or poultry manure at high-risk times	1	20
Early harvesting and establishment of crops in the autumn	2	4,716
Establish cover crops in the autumn	28	295
Fence off rivers and streams from livestock	6	728
Fertiliser spreader calibration	1	607
Integrate fertiliser and manure nutrient supply	38	-416
Intensive ditch management on arable land	3	153
Intensive ditch management on grassland	9	62
Leave over winter stubbles	6	3,191
Locate out-wintered stock away from watercourses	13	65
Loosen compacted soil layers in grassland fields	16	252
Make use of improved genetic resources in livestock	44	-679
Manure Spreader Calibration	1	1,433
Move feeders at regular intervals	28	143
Reduce dietary N and P intakes: Dairy	14	489
Reduce field stocking rates when soils are wet	24	250
Reduce the length of the grazing day/grazing season	92	131
Re-site gateways away from high-risk areas	1	2,116
Store solid manure heaps on an impermeable base and collect effluent	2	1,223
Uncropped cultivated areas	29	1,312
Undersown spring cereals	9	3,141
Use a fertiliser recommendation system	72	-98
Use clover in place of fertiliser nitrogen	28	-859
Use correctly-inflated low ground pressure tyres on machinery	1	10,242
Use manufactured fertiliser placement technologies	1	717
Use plants with improved nitrogen use efficiency	72	-196

Table D5: Cereals

Farm Practice	**MTP (KtCO_2e)**	**£/tCO_2e**
Adopt reduced cultivation systems	22	-502
Avoid spreading manufactured fertiliser to fields at high-risk times	1	12,272
Beetle banks	1	20,733
Construct troughs with concrete base	15	106
Cultivate and drill across the slope	4	6,608
Cultivate compacted tillage soils	60	140
Cultivate land for crops in spring rather than autumn	11	2,709
Do not apply manufactured fertiliser to high-risk areas	229	46
Early harvesting and establishment of crops in the autumn	1	5,310
Establish cover crops in the autumn	55	325
Establish in-field grass buffer strips	1	20,403

Establish riparian buffer strips	1	16,997
Fertiliser spreader calibration	6	414
Intensive ditch management on arable land	6	172
Intensive ditch management on grassland	3	78
Leave autumn seedbeds rough	1	17,623
Leave over winter stubbles	11	3,521
Loosen compacted soil layers in grassland fields	60	53
Manage over-winter tramlines	1	11,014
Management of field corners	1	102,017
Move feeders at regular intervals	15	213
Plant areas of farm with wild bird seed / nectar flower mixtures	1	80,032
Reduce field stocking rates when soils are wet	10	0
Reduce the length of the grazing day/grazing season	49	0
Re-site gateways away from high-risk areas	1	3,383
Take field corners out of management	1	98,726
Uncropped cultivated areas	28	5,607
Uncropped cultivated margins	1	82,272
Undersown spring cereals	22	3,418
Use a fertiliser recommendation system	229	-98
Use clover in place of fertiliser nitrogen	28	-686
Use correctly-inflated low ground pressure tyres on machinery	2	12,115
Use manufactured fertiliser placement technologies	6	675
Use plants with improved nitrogen use efficiency	229	-196

Table D6: General Cropping

Farm Practice	**MTP ($KtCO_2e$)**	**£/tCO_2e**
Adopt reduced cultivation systems	14	-344
Construct troughs with concrete base	17	113
Cultivate and drill across the slope	2	6,300
Cultivate compacted tillage soils	31	115
Cultivate land for crops in spring rather than autumn	17	2,309
Do not apply manufactured fertiliser to high-risk areas	110	42
Early harvesting and establishment of crops in the autumn	11	4,455
Establish cover crops in the autumn	83	277
Fertiliser spreader calibration	3	434
Intensive ditch management on arable land	3	141
Intensive ditch management on grassland	5	92
Irrigate crops to achieve maximum yield	5	10,350
Leave over winter stubbles	17	3,001
Loosen compacted soil layers in grassland fields	31	128
Move feeders at regular intervals	17	226

Reduce field stocking rates when soils are wet	12	0
Reduce the length of the grazing day/grazing season	60	0
Re-site gateways away from high-risk areas	1	3,861
Uncropped cultivated areas	28	2,336
Undersown spring cereals	13	2,920
Use a fertiliser recommendation system	110	-98
Use clover in place of fertiliser nitrogen	28	-831
Use correctly-inflated low ground pressure tyres on machinery	1	11,549
Use efficient irrigation techniques (boom trickle, self closing nozzles)	3	1,132
Use manufactured fertiliser placement technologies	3	614
Use plants with improved nitrogen use efficiency	110	-197

Table D7: Indoor Pigs

Farm Practice	MTP ($KtCO_2e$)	£/tCO_2e
Adopt phase feeding of livestock	7	323
Adopt reduced cultivation systems	1	21
Allow field drainage systems to deteriorate	1	2,992
Cultivate compacted tillage soils	1	158
Cultivate land for crops in spring rather than autumn	3	1,571
Do not apply manufactured fertiliser to high-risk areas	2	118
Establish cover crops in the autumn	14	188
Integrate fertiliser and manure nutrient supply	26	-81
Leave over winter stubbles	3	2,042
Loosen compacted soil layers in grassland fields	1	0
Manure Spreader Calibration	1	3,433
Reduce dietary N and P intakes: Pigs and Poultry	12	326
Store solid manure heaps on an impermeable base and collect effluent	1	587
Use a fertiliser recommendation system	2	-239
Use plants with improved nitrogen use efficiency	2	-477
Large on-farm AD plant	106	36
Medium on-farm AD plant	36	33

Table D8: Outdoor Pigs

Farm Practice	MTP ($KtCO_2e$)	£/tCO_2e
Adopt phase feeding of livestock	1	466
Construct troughs with concrete base	1	107
Cultivate compacted tillage soils	2	78
Do not apply manufactured fertiliser to high-risk areas	5	40
Establish cover crops in the autumn	2	335

Loosen compacted soil layers in grassland fields	2	90
Move feeders at regular intervals	1	213
Reduce dietary N and P intakes: Pigs and Poultry	3	461
Reduce field stocking rates when soils are wet	1	0
Reduce the length of the grazing day/grazing season	3	0
Uncropped cultivated areas	1	1,860
Undersown spring cereals	1	3,629
Use a fertiliser recommendation system	5	-93
Use clover in place of fertiliser nitrogen	1	-693
Use plants with improved nitrogen use efficiency	5	-186

Table D9: Poultry

Farm Practice	MTP ($KtCO_2e$)	£/tCO_2e
Adopt phase feeding of livestock	3	0
Adopt reduced cultivation systems	1	-210
Construct troughs with concrete base	2	63
Cultivate compacted tillage soils	1	109
Cultivate land for crops in spring rather than autumn	2	477
Do not apply manufactured fertiliser to high-risk areas	11	19
Early harvesting and establishment of crops in the autumn	1	941
Establish cover crops in the autumn	9	57
Integrate fertiliser and manure nutrient supply	14	-157
Intensive ditch management on grassland	1	30
Leave over winter stubbles	2	620
Loosen compacted soil layers in grassland fields	1	214
Manure Spreader Calibration	1	3,441
Move feeders at regular intervals	2	125
Reduce dietary N and P intakes: Pigs and Poultry	6	49
Reduce field stocking rates when soils are wet	1	0
Reduce the length of the grazing day/grazing season	5	0
Store solid manure heaps on an impermeable base and collect effluent	1	0
Uncropped cultivated areas	8	362
Undersown spring cereals	2	994
Use a fertiliser recommendation system	11	-46
Use clover in place of fertiliser nitrogen	8	-229
Use plants with improved nitrogen use efficiency	11	-93
5MW centralised AD plant	487	0

Table D10: Horticulture

Farm Practice	MTP ($KtCO_2e$)	£/tCO_2e

Adopt reduced cultivation systems	3	-385
Construct troughs with concrete base	2	106
Cultivate compacted tillage soils	2	156
Cultivate land for crops in spring rather than autumn	2	2,770
Do not apply manufactured fertiliser to high-risk areas	10	49
Establish cover crops in the autumn	8	332
Intensive ditch management on arable land	1	167
Irrigate crops to achieve maximum yield	1	12,063
Leave over winter stubbles	2	3,601
Loosen compacted soil layers in grassland fields	2	133
Move feeders at regular intervals	2	213
Reduce field stocking rates when soils are wet	1	0
Reduce the length of the grazing day/grazing season	5	0
Uncropped cultivated areas	3	2,511
Undersown spring cereals	1	3,469
Use a fertiliser recommendation system	10	-108
Use clover in place of fertiliser nitrogen	3	-690
Use plants with improved nitrogen use efficiency	10	-216

Annex E: Uptake rates of FARMSCOPER farm practices

Farm Practice	ADAS default uptake rate (%)		Survey uptake rate (%)	
	Within NVZ	Outside NVZ	Within NVZ	Outside NVZ
Additional targeted bedding for straw-bedded cattle housing	0%	0%		
Adopt batch storage of slurry	0%	0%		
Adopt phase feeding of livestock	80%	80%		
Adopt reduced cultivation systems	25%	25%	30%	30%
Allow cattle slurry stores to develop a natural crust	80%	80%		
Avoid irrigating at high risk times	25%	25%		
Avoid PPP application at high risk timings	80%	80%		
Avoid spreading manufactured fertiliser to fields at high-risk times	10%	0%		
Beetle banks	2%	2%		
Calibration of sprayer	80%	80%		
Capture of dirty water in a dirty water store	0%	0%		
Compost solid manure	2%	2%		
Construct bridges for livestock crossing rivers/streams	2%	2%	30%	30%
Construct bunded impermeable PPP filling/mixing/cleaning area	2%	2%		
Construct troughs with concrete base	2%	2%		
Convert caged laying hen housing from deep-pit storage to belt manure removal	0%	0%		
Cover solid manure stores with sheeting	2%	0%		
Cultivate and drill across the slope	10%	10%	80%	80%
Cultivate compacted tillage soils	10%	10%		
Cultivate land for crops in spring rather than autumn	2%	2%		
Do not apply manufactured fertiliser to high-risk areas	25%	10%		
Do not apply manure to high-risk areas	50%	25%		
Do not apply P fertilisers to high P index soils	10%	10%		
Do not spread FYM to fields at high-risk times	25%	0%		
Do not spread slurry or poultry manure at high-risk times	10%	0%		
Drift reduction methods	50%	50%		
Early harvesting and establishment of crops in the autumn	0%	0%		
Establish and maintain artificial wetlands - steading runoff	0%	0%		
Establish cover crops in the autumn	2%	2%		
Establish in-field grass buffer strips	2%	2%	10%	10%
Establish new hedges	2%	2%		

Establish riparian buffer strips	10%	10%	3%	3%
Establish tree shelter belts around livestock housing	0%	0%		
Farm track management	0%	0%		
Fence off rivers and streams from livestock	25%	25%	50%	50%
Fertiliser spreader calibration	2%	2%	80%	80%
Fill/Mix/Clean sprayer in field	10%	10%		
Frequent removal of slurry from beneath-slat storage in pig housing	0%	0%		
Incorporate a urease inhibitor into urea fertilisers for arable land	0%	0%		
Incorporate a urease inhibitor into urea fertilisers for grassland	0%	0%		
Incorporate manure into the soil	25%	10%		
Increase scraping frequency in dairy cow cubicle housing	0%	0%		
Increase the capacity of farm slurry stores to improve timing of slurry applications	10%	2%		
In-house poultry manure drying	10%	10%		
Install air-scrubbers or biotrickling filters in mechanically ventilated pig housing	0%	0%		
Install covers to slurry stores	10%	2%		
Integrate fertiliser and manure nutrient supply	80%	25%		
Intensive ditch management on arable land	25%	25%		
Intensive ditch management on grassland	25%	25%		
Irrigate crops to achieve maximum yield	50%	50%		
Irrigation/water supply equipment is maintained and leaks repaired	25%	25%		
Leave autumn seedbeds rough	10%	10%		
Leave over winter stubbles	10%	10%		
Leave residual levels of non-aggressive weeds in crops	0%	0%		
Locate out-wintered stock away from watercourses	2%	2%	30%	30%
Loosen compacted soil layers in grassland fields	10%	10%		
Make use of improved genetic resources in livestock	0%	0%	40%	40%
Manage over-winter tramlines	2%	2%		
Management of field corners	10%	10%		
Management of in-field ponds	2%	2%		
Management of woodland edges	2%	2%		
Manure Spreader Calibration	2%	0%		
Minimise the volume of dirty water produced (sent to dirty water store)	10%	2%		
Minimise the volume of dirty water produced (sent to slurry store)	10%	2%		
More frequent manure removal from laying hen housing with manure belt systems	0%	0%		
Move feeders at regular intervals	10%	10%		
Part-slatted floor design for pig buildings	0%	0%		

Plant areas of farm with wild bird seed / nectar flower mixtures	10%	10%		
PPP substitution	2%	2%		
Protection of in-field trees	10%	10%		
Reduce dietary N and P intakes: Dairy	80%	80%		
Reduce dietary N and P intakes: Pigs and Poultry	80%	80%		
Reduce field stocking rates when soils are wet	10%	10%	60%	60%
Replace urea fertiliser to arable land with another form	0%	0%		
Replace urea fertiliser to grassland with another form	0%	0%		
Re-site gateways away from high-risk areas	0%	0%		
Site solid manure heaps away from watercourses/field drains	50%	25%		
Skylark plots	2%	2%		
Store solid manure heaps on an impermeable base and collect effluent	25%	10%		
Take field corners out of management	2%	2%		
Treatment of PPP washings through disposal, activated carbon or biobeds	2%	2%		
Uncropped cultivated areas	0%	0%		
Uncropped cultivated margins	2%	2%		
Undersown spring cereals	0%	0%		
Unfertilised cereal headlands	0%	0%		
Unharvested cereal headlands	0%	0%		
Unintensive hedge and ditch management on arable land	25%	25%		
Unintensive hedge and ditch management on grassland	25%	25%		
Use a fertiliser recommendation system	80%	25%		
Use clover in place of fertiliser nitrogen	0%	0%	40%	40%
Use correctly-inflated low ground pressure tyres on machinery	2%	2%	60%	60%
Use dry-cleaning techniques to remove solid waste from yards prior to cleaning	50%	50%		
Use efficient irrigation techniques (boom trickle, self closing nozzles)	10%	10%	20%	20%
Use liquid/solid manure separation techniques	2%	2%	10%	10%
Use manufactured fertiliser placement technologies	10%	10%		
Use plants with improved nitrogen use efficiency	0%	0%		
Use poultry litter additives	0%	0%		
Use slurry band spreading application techniques	2%	2%		
Use slurry injection application techniques	2%	2%	10%	10%
Washing down of dairy cow collecting yards	80%	80%		
Training in land management and the application of crop inputs	0%	0%		

Select varieties and breeds suited to local conditions and market requirements (integrated farm management)	0%	0%		
Utilise carbon storage opportunities	0%	0%		
Use high sugar grasses where appropriate	0%	0%		
Monitor and amend soil nutrient status and pH following regular sampling	0%	0%		
Use a nutrient management plan	0%	0%		
Use nitrification inhibitors	0%	0%		
Match (optimise) fertiliser application to crop needs	0%	0%		
Handle livestock and crops to minimise losses and damage during transit, storage and processing	0%	0%		
AD (5MW Poultry Centralised AD Plant)	0%	0%		
AD (Large on farm pig AD Plant)	0%	0%		
AD (Medium on farm pig AD Plant)	0%	0%		
Use a diet management plan for livestock	0%	0%		
Use a ration formulation programme or nutritional advice from an expert when planning the feeding regime of your livestock	0%	0%		
Use feed technology and additives to improve feed use efficiency	0%	0%		
Maize Silage (Dairy)	0%	0%		
Use an animal health plan	0%	0%		
Reduce incidence of disease and lameness, to improve productivity	0%	0%		
Improved productivity (Dairy)	0%	0%		
Improved fertility (Dairy)	0%	0%		

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