Scotland's Rural College

Estimated arable emissions and their mitigation in the Smart Inventory

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First published: 20/12/2022

Citation for pulished version (APA):
Thomson, SG., & Moxey, A. P. (2022). *Estimated arable emissions and their mitigation in the Smart Inventory*. The Scottish Government. Advance online publication. https://www.gov.scot/publications/estimated-arable-emissions-mitigation-smart-inventory/

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December 2021

Scottish Government
Riaghaltas na h-Alba
gov.scot

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Andrew Moxey & Steven Thomson, March 2021

This paper was prepared in parallel to those of the Farmer Led Groups. Hence neither it nor they cross-reference each other and there some differences in the fine detail of reported figures. However, the overall messages are consistent across the different papers.

Key points

- GHG emissions from arable production in Scotland are reported in the agricultural Smart Inventory as c.1.5 Mt CO_{2e} in 2018, essentially the same as in 1990.
- This is because reductions in emissions associated with fuel usage (which nonetheless remains the biggest agricultural component at c.36%) and nitrogen applications (c.16%) have been offset by increases in other emission categories, particularly mineralisation (c.13%).
- GHG emissions from arable production are also reported in the LULUCF Inventory, reflecting disturbance of soil carbon from tillage operations.
- The 2018 figure for cropland-remaining-cropland was c.2.3Mt CO_{2e}, with a further c.2.4Mt CO_{2e} reported for grassland-converted-to-cropland but a saving of c.-1.0Mt CO_{2e} for cropland-converted-to-grassland, all of which could be considered jointly with agricultural emissions (consistent with the whole farm approach suggested in the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019).
- Mitigation options include reduced fuel use through more efficient machinery utilised more carefully as well as shifting to alternative fuels and/or electrical power. Such changes potentially offer between 10% and (theoretically) 100% of fuel combustion emission savings.
- Collectively, the use of precision agriculture and other appropriate tillage practices, nitrite inhibitors, slow-release forms of nitrogen, cover and/or under-sown crops may offer nitrous oxide emission savings of 5% - 45%.
- Emissions from mineralisation, crop residues and soil disturbance arising from land use change may similarly be mitigated through changes in management systems, including different tillage practices and adjustments to rotational practices.
- However, realisation of potential emission reductions is constrained by practical and economic barriers to uptake. For example, electrically-powered tractors are not yet widely available, new technologies require capital investment, and farmers may lack awareness of and/or confidence in new management practices.
- Consequently, projections of actual realisable mitigation in Scottish arable production are less than implied by the example upper-bound figures implied above. For example, assumed uptake rates of 5% to 33% for different mitigation options suggest an estimated mitigation of c.0.2Mt, less than half of the overall

required reduction. This suggests that adoption rates will need to be higher and/or additional mitigation actions will be required.

- Moreover, although both the agricultural Smart Inventory and LULUCF Inventory are intended to account for changes in land cover and management practices, it is unclear to what extent the types of mitigation action considered here across diverse cropping and horticultural contexts would actually be reflected in reported emissions without further refinements.
- For example, the estimation of combustion emissions possibly needs more up-to-date and Scottish-specific information regarding the profile and usage of machinery, the representation of different tillage practices and their prevalence could be improved upon, and land use change could be derived from IACS data (actual rotations) rather than the Countryside Survey.
- The need for better data extends to policy implementation requirements since monitoring regulatory compliance and/or performance against reward criteria will in most cases require evidence of management actions. Care and imagination will be needed to minimise the administrative burden of this for farmers and administrators alike.

Introduction

1. Neither the methodology nor the underlying data used in the Smart Inventory of agricultural greenhouse gas emissions are fully in the public domain. However, additional information and guidance provided by those responsible for compiling the Inventory have been used together with published Inventory figures and insights from relevant literature to compile the following summary of estimated emissions and mitigation potentials related to arable (including horticultural) production in Scotland.

Inventory approach

2. Drawing on various strands of research, the arable component of the agricultural Smart Inventory is structured to account for variation in soil type and climate conditions, plus some aspects of management. In total, 48 different combinations of crops and sowing dates are represented, and applications of fertiliser are differentiated by type and dosage.

3. Data on cropping areas are drawn from the June Agricultural Census but are used at a 10x10km grid resolution rather than that of irregularly shaped/sized fields, farms or parishes. Soils types are based on soil texture and depth to rock (as per the standard RB209 typology used for fertiliser recommendations), and are also represented on a digital map with the 10x10km resolution. Climatic data at the same resolution are derived from the Met Office UKCP09 baseline and include daily rainfall probabilities to estimate the likelihood of precipitation following fertiliser applications.

4. Information on yields and management are derived from various surveys, most notably the British Survey of Fertiliser Practice. However, the use of more Scottish-specific data would improve accuracy, particularly with respect to the prevalence of specific tillage practices (but would require new data capture).

5. Emissions from on-site usage of fossil fuels (but not electricity) relating to stationary (e.g., heaters) and mobile (e.g., tractors) agricultural equipment are also reported within the Smart Inventory. Different types of equipment with different emission factors are catered for, with installed equipment and fuel usage derived from survey data. However, arable is not reported separately from grassland, and indeed the headline figures also include forestry and fishing.

6. Separately, arable emissions arising from soil disturbance following land use change are also reported elsewhere under the LULUCF Inventory. Information on land use change is estimated from the Countryside Survey[1].

Estimated emissions

7. The published Smart Inventory figures include arable emissions arising by a variety of routes as nitrous oxide (N_2O). Although the published headline figures for these categories include both arable and grassland, unpublished disaggregated figures are available and are summarised below. For example, the direct emissions from fertiliser applications are included, as are indirect losses through leaching and run-off plus emissions from soil mineralisation and from the cultivation of organic soils.

8. In addition, arable contributes to aggregate published figures for emissions arising from on-farm combustion usage of fossil fuels. A sectoral split of the published agricultural total for this is not available, but arable's share has been inferred for inclusion here by reference to other information.[2] This figure should, however, be viewed only as indicative.

9. Table 1 shows that estimated total arable emissions reported in the agricultural Smart Inventory were similar for 1990 and 2018. However, arable's share of the overall agricultural total has increased slightly (reflecting declines in other sectors) whilst the composition of emissions has altered slightly.

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[1] https://countrysidesurvey.org.uk/content/land-cover-map

[2] e.g., Warwick HRI (2007), Whitaker et al. (2010), Morrison et al., (2012); as cited by Moxey & Thomson (2021) Disaggregating headline Smart Inventory figures. Report to SG-RESAS.

Table 1: estimated arable emissions (kt CO2e), composition, change and share (%) in 1990 & 2018

Sources	1990		2018		Change
	Kt CO2e	%	Kt CO2e	%	
Fertiliser/Urea/Sewage sludge	308	20.5%	236	15.8%	-23.4%
Leaching, run-off	143	9.5%	159	10.7%	+11.2%
Liming	165	11.0%	157	10.5%	-4.8%
Mineralisation	63	4.2%	195	13.1%	+209.5%
Cultivation of organic soils	45	3.0%	36	2.4%	-20.0%
Crop residues	151	10.1%	161	10.8%	+6.6%
Field burning	16	1.1%	0	0.0%	-100.0%
Fuel usage (inferred)	611	40.7%	545	36.6%	-10.8%
Arable total	**1,502**	**100%**	**1,489**	**100%**	**-0.9%**
Agricultural total	**8,891**		**7,474**		**-15.9%**
Arable share of total	**16.9%**		**19.9%**		**+3.00 % points**

10. In particular, emissions from fertiliser and fuel usage have declined (consistent with a smaller cultivated area, but also perhaps due to improved fertiliser management and more efficient machinery usage) but mineralisation has increased (possibly consistent with localised shifts between livestock and arable on particular soil types, even as overall arable land use has declined). Field burning was a minor source of emissions in 1990, but is now banned.

11. Separately, emissions associated with arable farming are also reported under the LULUCF Inventory. These relate to emissions from disturbed soil following a land use change, with effects lasting for 20 years. The 2018 emissions for cropland-remaining-cropland were c.2.3Mt CO_{2e}, with a further c.2.4Mt CO_{2e} reported for grassland-converted-to-cropland. There was, however, a saving of c.-1.0Mt CO_{2e} for cropland-converted-to-grassland. All of these could justifiably be considered jointly with agricultural emissions (consistent with the whole farm approach suggested in the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019).[3]

Mitigation potential

12. Inferred fuel usage emissions are the largest component of total arable emissions within the Smart Inventory, accounting for c.36% in 2018. Whilst some of this is attributable to static machinery, most is attributable to mobile machinery used for field operations and on-farm transport. As such, mitigation can chiefly be attempted

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[3] It should be noted that the forthcoming 2019 figures for both the agricultural Smart Inventory and the LULUCF Inventory will be based on a revised methodology introduced to account better for (amongst other things) peatlands and peaty soils. This is anticipated to increase estimated emissions in a number of categories, including ‘cultivation of organic soils’ and ‘grasslands-converted-to-cropland’. Scottish figures are due to be released in June 2021.

through reducing the volume and/or nature of field operations (which may also affect emissions in other categories), and/or by improving the fuel efficiency of machinery.

13. Reductions in the volume of field operations can be achieved through using data and analytics to better target applications of chemical inputs in terms of where and when they are needed (i.e., precision agriculture) and/or through changing tillage systems (e.g., Controlled Traffic Farming, no-till systems). Fuel, and by extension emission, savings of 10% to 35% are claimed for such changes, although the effect on net emissions can be less due to increased N_2O emissions in other categories.[4]

14. Improved fuel efficiency can be sought through investment in newer equipment and/or better utilisation of equipment. The latter includes appropriate maintenance but also more purposeful planning of field operations to optimise engine workloads (which links back to data analytics). Such changes may yield savings of up to 15%.[5]

15. Newer equipment will tend to be more fuel efficient by design, including shifts towards using non-fossil-fuel energy such as biofuels, hydrogen and electricity. Although the latter is in its infancy, developments are advancing and would offer significant potential savings, theoretically up to 100%.[6]

16. Emissions arising from the application of nitrogen, both directly from applications (c.16% in 2018) and indirectly via leaching and run-off (c.11% in 2018), are the next largest components of arable emissions within the Smart Inventory. Mitigation of both can be attempted through reducing nitrogen applications and/or changing how they are implemented and/or how nutrients are utilised.

17. For example, the use of data, analytics and modern machinery (‘precision agriculture’) enables applications to be better targeted spatially and over a season to match crop requirements, thereby reducing overall usage. Emissions may also be addressed through the use of nitrite inhibitors, slow-release forms of nitrogen, cover and/or under-sown crops to reduce periods of bare soil, ploughing along contour lines, and maintenance of buffer strips. Collectively, depending on current practice and uptake, such actions may offer emission savings of 5% - 45%.[7] Similar proportionate savings may apply to applications of lime (which accounted for c.11%of arable emission in 2018).

18. Emissions from mineralisation, crop residues and soil disturbance arising from land use change may similarly be mitigated through changes in management systems, including different tillage practices and adjustments to rotational practices. However, the latter can cause difficulties with respect to, for example, build-ups of pests and weeds, and enhancing soil carbon requires sustained effort over decades.[8]

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[4] e.g., Bora et al., (2012), Balafoutis et al. (2017), Ashworth et al., (2018)

[5] e.g., Hoy et al., (2014), Janulevičius et al., (2016), Lovarelli & Bacenetti (2019)

[6] e.g., Gonzalez-de-Soto et al., (2016), Ghobadpour et al., (2019), Ahmed et al., (2020)

[7] e.g., Balafoutis et al. (2017), Snyder (2017), Pedersen et al., (2019)

[8] e.g. Lehtinen et al., (2014), Poeplau et al., (2017)

19. More problematically, realisation of potential emission reductions is constrained by practical and economic barriers to uptake. For example, electrically-powered tractors are not yet widely available, new technology requires capital investment, and farmers may lack awareness of and/or confidence in new management practices.[9]

20. Consequently, projections of actual realisable mitigation in Scottish arable production are less than implied by the example upper-bound figures implied above. For example, assumed uptake rates of 5% to 33% for different mitigation options suggest an estimated mitigation of c.0.2Mt (20%) of non-CO_{2e} emissions, less than half of the overall required reduction.[10] This suggests that adoption rates will need to be higher and/or additional mitigation actions will be required if targets are to be met.

Measuring mitigation

21. Although both the agricultural Smart Inventory and LULUCF Inventory are intended to account for changes in land cover and management practices, it is unclear to what extent the types of mitigation action considered here would actually be currently reflected in reported emissions – particularly given the diversity of individual cropping and horticultural enterprises in terms of their business and environmental context (e.g., alongside other enterprises, in different geographical locations etc.).

22. For example, the estimation of combustion emissions appears to be based on intermittent survey data that may not accurately reflect the profile and vintage of equipment in Scottish agriculture, or how it is used. New types of equipment and modes of operation would need to be explicitly included if their impacts were to register.

23. Similarly, whilst fertiliser practices may be well represented, the characterisation of different tillage practices and their prevalence could be improved upon, particularly in the LULUCF Inventory. Deriving measures of land use change directly from IACS rather than from Countryside Survey data might also help to improve estimates of change for particular soil-climate combinations,[11] and is already being investigated.

24. All of the above implies a need to gather more farm-level data to inform Inventory estimates, but the need for better data extends also to policy implementation requirements. Specifically, since emissions are not observed directly but are inferred from management actions, monitoring for regulatory compliance and/or performance against reward criteria will in most cases require evidence of such management actions.

25. This suggests a possible need for recording of, for example, input purchases (e.g., slow-release fertilisers), operational planning (e.g., work schedules), taking account of relevant data (e.g., nutrient budgets), and implementation of field operations (e.g.,

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[9] e.g., Feliciano et al., (2014), Wreford et al., (2017), Soto et al., (2019)

[10] Derived from Eory et al., (2020)

[11] e.g., Bertaglia et al., (2016)

date-stamped photos of field operations). Care and imagination will be needed to minimise the administrative burden of this for farmers and administrators alike.

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Any enquiries regarding this publication should be sent to us at

The Scottish Government
St Andrew's House
Edinburgh
EH1 3DG

ISBN: 978-1-80201-746-5 (web only)

Published by The Scottish Government, December 2021

Produced for The Scottish Government by APS Group Scotland, 21 Tennant Street, Edinburgh EH6 5NA
PPDAS901286 (12/21)