Ministry for Primary Industries
Manatū Ahu Matua

MPI Policy and Trade
Agricultural Inventory Advisory Panel Meeting
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Direct N_2O emission factors for livestock excreta ($EF_{3,PRP}$) based on hill slope

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Main Purpose: ☑ Decide ☑ Discuss ☐ Note

Purpose of this paper

1. This paper seeks recommendations from the Agricultural Inventory Advisory Panel to:

   - modify the emission factors for direct nitrous oxide (N_2O) emissions from animal excreta $EF_{3,PRP}$[1] based on stock type and hill slope
   - use the Nutrient Transfer Model outlined by Saggar et al (2015) to allocate total dung and urine between low, medium, and steep slopes for non-dairy cattle, sheep and deer

2. Attached to this paper are the reports:

   a. van der Weerden, T., Noble, A., Giltrap, D., Luo, J., Saggar, S. 2018. (unpublished) *Meta-analysis of nitrous oxide emission factors for excreta deposited from livestock on hill country*

   b. Review of *Meta-analysis of nitrous oxide emission factors for excreta deposited from livestock on hill country* by Professor Russ Tillman

   c. The inventory change approval form completed by Professor Russ Tillman

   d. Saggar, S., Giltrap, D.L., Davison, R., Gibson, R., DeKlein, C., Rollo, M., Ettema, P., Rys, G. 2015. *Estimating direct N_2O emissions from sheep, beef, and deer grazed pastures in New Zealand hill country: accounting for the effect of land slope on the N_2O emission factors from urine and dung*. Agriculture Ecosystems & Environment 205, 70–78.

[1] $EF_{3,PRP}$ will be referred to as EF_3 for the rest of this document

Background – hill country N_2O emissions and past panel discussions

3. The addition of nitrogen from livestock excreta results in N_2O emissions from both direct and indirect (volatilisation, leaching and run-off) pathways. The majority (84%) of these emissions are from direct rather than indirect pathways.

4. In 2016, direct N_2O emissions from livestock urine and dung were estimated to be 5,503 kilotonnes of carbon-dioxide equivalent (CO_2-e), or 14% of agricultural greenhouse gas (GHG) emissions. Emissions from this source have increased by 7.2% since 1990.

5. New Zealand uses country-specific emission factors to estimate direct emissions from livestock excreta (EF_3) of 0.25% for dung and 1% for urine. These values are applied irrespective of livestock type, land use or slope.

6. Past studies have shown that EF_3 values for animal urine and deposited on medium and steeper slopes are smaller than those on flatter slopes. It has been noted that the current EF_3 values may be overestimating emissions as a result.

7. In the 2014 and 2015 Agriculture Inventory Advisory Panel meetings it was proposed that the EF_3 be disaggregated by livestock type and hill slope, using the most recent data available at the time. However, in both years the panel recommended that the proposed changes not be applied. The Panel concluded that while the methodology detailed in the proposal was acceptable, the results of more trials would need to be included to generate robust emission factor figures that could be included in the inventory.

8. Since 2015, more field studies (including Luo et al. 2016[2], 2018[3]) investigating the effect of hill slope on EF_3 have been completed. The EF_3 values proposed at the 2015 Panel meeting were based on the results of 72 samples taken on hill country. For comparison, the new EF_3 values proposed in the Meta-Analysis report were based on the results of 690 replicate-level experiments.

Revised meta-analysis and calculation of emission factors

9. The attached Meta-Analysis calculated the new emission factors which are being proposed for the inventory. The Meta-analysis followed the approach used by Kelliher et al (2014)[4], but used an expanded dataset which included the results of the recent field studies.

10. The results of 1096 replicate-level experiments were included in the meta-analysis. Of these, 690 had been undertaken in areas classed as hill country. The field

[2] Luo, J., Hoogendoorn, C., van der Weerden, T., Saggar, S., de Klein, C., Giltrap, D. 2016. Nitrous oxide emission factors for animal deposited on hill country steep slopes – Final Report. MPI Agreement number 16799. Pp. 47.

[3] Luo, J., Saggar, S., van der Weerden, T., de Klein, C., Lindsay, S., Rutherford, A., Carlson, B., Wise, B., Berben, P. 2018. Nitrous oxide emissions from beef and dairy cattle excreta applied to pastoral lands - Final report. MPI Agreement number 405054. Pp. 38.

[4] Kelliher, F.M., Cox, N., Van Der Weerden, T.J., De Klein, C.A.M., Luo, J., Cameron, K.C., Di, H.J., Giltrap, D., Rys, G. 2014. Statistical analysis of nitrous oxide emission factors from pastoral agriculture field trials conducted in New Zealand. Environmental Pollution 186, 63-66.

studies making up the meta-analysis were conducted across a range of different slopes, seasons, and regions within NZ.

11. The meta-analysis grouped experiments based on the slope of land they had been on:

- Flatland – land not on hill country
- Low slope – hill country land with slopes less than 12°
- Medium slope – hill country land with slopes between 12° and 24°
- Steep slope – hill country land with slopes greater than 24°

Table 1: Number of replicate-level EF_3 values for each N source and topography.

N source	flatland	H/C - low slope (0 - 12°)	H/C-medium slope (12 - 24°)	H/C - steep slope (> 24°)	Total
Dairy cattle urine	244	108	20		372
Dairy cattle dung	64	46	20		130
Non-dairy cattle urine	8	40	60	20	128
Non-dairy cattle dung		76	60	20	156
Sheep urine	36	64	60	20	180
Sheep dung	54	36	20	20	130
Total Urine	288	212	140	40	680
Total Dung	118	158	100	40	416
Total Excreta	406	370	240	80	1096

12. Using the data from these replicates, four methods were proposed for calculating appropriate emission factor values for the different livestock, excreta types and hill slopes:

- arithmetic means of available data for each of the combinations,
- geometric means of available data for each of the combinations,
- arithmetic means pooled where values were not significantly different,
- geometric means pooled where values were not significantly different.

The 406 flatland studies were excluded in the calculation of emission factors for sheep, non-dairy cattle and deer because:

- most of the flatland studies were from dairy cattle.
- very few studies were undertaken for beef cattle on flatland, and more would be needed to have confidence in a set of EF_3 values for beef on flatland.
- the average EF_3 values from the sheep studies on flatland were similar to those for the hill country low slope studies. Had they been included in the analysis, the resulting emission factors would change very little (and it would not be a significant change to the values already recommended)

Because of the lack of measurements from deer, the average of sheep and beef emission factor values were used to calculate deer EF_3 values.

13. Following an analysis of these different methods, van der Weerden et al (2018) recommended that the first method (arithmetic means of available data for each of the different combinations of slope, livestock type and excreta type) for calculating the new EF_3 values, as:

- the arithmetic mean provides the most representative ‘average’ response based on a sample population
- having separate emission factors for each combination allows single emission factor values to be updated more easily in the future

The new emission factors calculated using this method (which are also being recommended for the Inventory) are displayed in table 2.

Table 2: Recommended new EF_3 values for livestock by excreta type and slope.

Topography/ slope	Livestock class	$EF_{3PRP\text{-}dung}$	$EF_{3PRP\text{-}urine}$
flatland	all dairy cattle	0.250%	1.000%
low slope	non-dairy cattle	0.154%	0.939%
	sheep	0.056%	0.346%
	deer	0.105%	0.643%
medium slope	non-dairy cattle	0.092%	0.338%
	sheep	0.032%	0.104%
	deer	0.062%	0.221%
steep slope	non-dairy cattle	0.043%	0.007%
	sheep	0.070%	0.004%
	deer	0.057%	0.006%

14. The dairy cattle EF values for dung (0.025%) and urine (1%) are unchanged from the current values in the inventory, as it is assumed that all dairy cattle graze on lowland. Additionally, data from studies in the meta-analysis showed that slope had no effect on EF_3 for dairy.

15. Because of the lack of N_2O emissions measurements for deer, the emission factors for this livestock category were calculated by taking a weighted average (based on live weights) of the non-dairy cattle and sheep emission factors.

16. Table 2 shows that EF_3 values are generally lower for steeper slopes. This finding is consistent with research from the United Kingdom, and may be a result of lower soil fertility and soil microbial activity. The lower emission factors for urine on steep land could also be due to the effect of slope spreading urine over a larger area (leading to lower inputs of N per unit of area).

17. The urine EF_3 for sheep and non-dairy cattle on steep slopes are close to zero, with the uncertainty ranges including negative values. This implies that emissions from urine patches on steep slopes are not much higher than background emissions (i.e. emissions from soil not due to urine or dung) on these slopes.

How the proposed emission factors will be implemented in the inventory

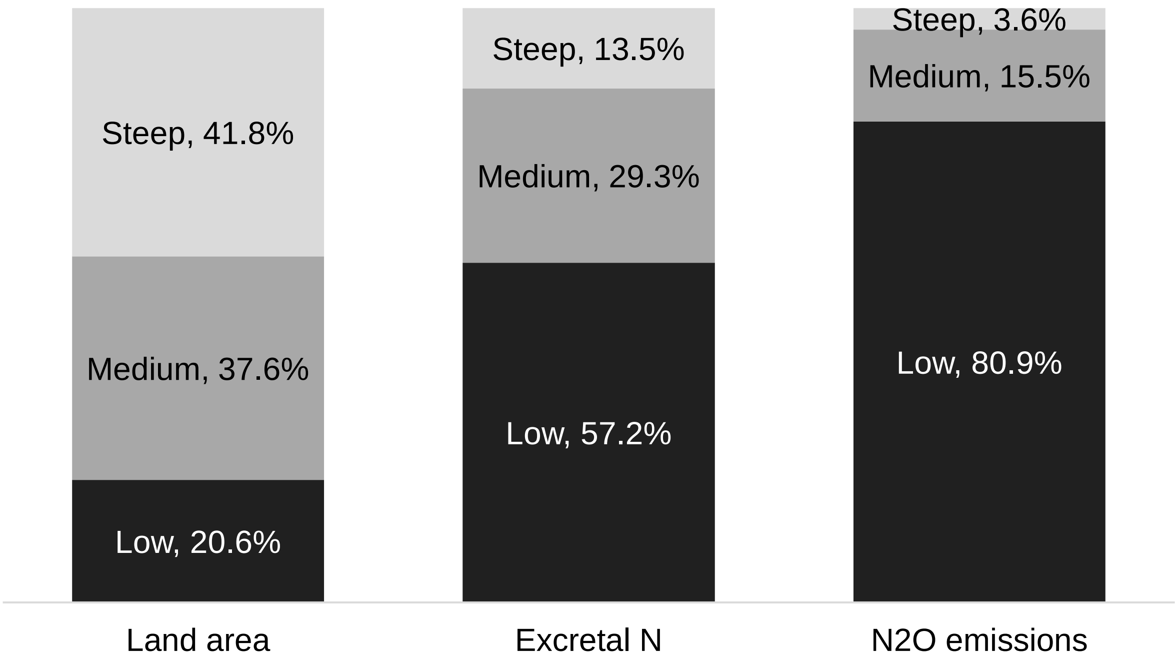
18. The diagrams in the appendix summarise how the proposed improvement would be implemented into the Inventory Model calculations (figure 5, appendix), compared with the current inventory methodology (figure 4, appendix).

19. In order to implement the new methodology, the Nutrient Transfer Model outlined by Saggar et al (2015) is used to allocate total dung and urine (calculated elsewhere in the inventory model) between low, medium, and steep slopes. The Nutrient Transfer Model was discussed by the Agriculture Inventory Panel in 2015, who agreed that the methodology used in the Nutrient Transfer Model was appropriate. Updated data from Beef+Lamb NZ (on the topography and number of animals on different farm types) is also required to implement the new methodology.

20. Figures 2 and 3 in the appendix shows how the Nutrient Transfer Model dung and urine is allocated between low, medium, and steep slopes based on the proportion of land in different slope types. Animals spend more time on flatter land, so the proportion of dung and urine deposited on low slopes is greater than the proportion of low slope land area.

21. Figure 1 compares sheep, beef and deer farms by land area and the amount of excretal N by hill slope in 2015, which is calculated using the Nutrient Transfer Model. The calculated proportion of direct N_2O emissions by hill slope is also shown. The proportions below will vary slightly in different years depending on the number of animals on different land classes.

Figure 1: Proportion of land area, excretal N and N_2O emissions by hill slope category for sheep, beef cattle and deer farms in 2015



Proposed improvement to inventory

22. It is proposed that the emissions factors for direct nitrous oxide (N2O) emissions from animal excreta ($EF_{3,PRP}$) be modified to the values recommended by van der Weerden et al (2018) in table 2.

23. This change is recommended because it is more consistent with research conducted in New Zealand. The change will also improve the accuracy of New Zealand's emissions estimates.

Estimated impact on inventory

24. Table 3 shows how the new emission factors, if implemented in the inventory, would affect estimated agricultural emissions in 1990, 2005 and 2016. A more detailed assessment is provided in the appendix (table 4).

25. Compared to the status quo, estimated agricultural emissions would be 2.6 Mt CO_2-e (7.4%) lower in 1990 and 1.7 Mt CO_2-e (4.4%) lower in 2016. The large fall in sheep population in this time period helps explain the difference between the 1990 change and the 2016 change. Another reason for the difference between the 1990 and 2016 change is due to the decreased proportion of sheep on lower sloped land. In 1990 just under half (49%) of sheep were on farms classed as 'high country' or 'hill country'. By 2015 however 61% of sheep were on farms classed as 'high country' or 'hill country'.

Table 3: Effect of proposed inventory change on emissions estimates in 1990, 2005 and 2016.

	1990	2005	2016
Absolute effect of change (kt CO_2-e)	-2,552	-2,354	-1,702
Percentage effect of change on direct N2O emissions from nitrogen excreta for sheep, beef and deer	-67.6%	-64.9%	-63.8%
Percentage effect of change on agricultural soils emissions	-38.1%	-27.3%	-19.8%
Percentage effect of change on total agriculture sector emissions	-7.4%	-5.9%	-4.4%

Reviewer comments

26. The Meta-Analysis (and its associated recommendations) was reviewed by Russ Tillman, who concluded that there was enough evidence to justify changing the emission factors, and that the proposed changes were scientifically defensible.

Uncertainty

27. While the accuracy of emissions estimates should improve with the introduction of these new emission factors and methodology, the overall uncertainty of the emissions figures is likely to increase. The effect of the new emission factors and methodology on uncertainty were not assessed in the meta-analysis. Uncertainty in

the agricultural soils section of the inventory is currently calculated using the method developed by Kelliher, Henderson and Cox (2016)[5].

Risks

28. Changes to country-specific methodologies and/or emission factors are heavily scrutinised by an expert review team under the United Nations Framework Convention on Climate Change (UNFCCC), and there is a small risk that this team will recommend that this team revert back to using the current emission factors. However, this risk is mitigated by the intention to apply the new emission factors consistently across the time series, and the fact that there is peer-reviewed research associated with the new emission factors and methodology.

Opportunities

29. Under the UNFCCC, countries should consider ways to improve their inventory. By continuing to develop new methodologies that best suits its circumstances, New Zealand is showing that it is meeting its UNFCCC obligations.

[5] Kelliher, F., Henderson, H., & Cox, N. (2016). The uncertainty of nitrous oxide emissions from grazed grasslands: A New Zealand case study. Manuscript submitted to journal for publication.

Recommendations

It is recommended that the Agricultural Inventory Advisory Panel:

30. ***Recommend*** that Beef + Lamb NZ data and the Nutrient Transfer Model outlined by Saggar et al (2015) be used to allocate total dung and urine between low, medium, and steep slopes for non-dairy cattle, sheep and deer.

Agree / not agreed

31. ***Recommend*** that the emissions factors for direct nitrous oxide (N2O) emissions from animal excreta ($EF_{3,PRP}$) be disaggregated based on stock type and hill slope, using the following values recommended by van der Weerden et al (2018).

Topography/ slope	Livestock class	$EF_{3PRP\text{-}dung}$	$EF_{3PRP\text{-}urine}$
flatland	all dairy cattle	0.250%	1.000%
low slope	non-dairy cattle	0.154%	0.939%
	sheep	0.056%	0.346%
	deer	0.105%	0.643%
medium slope	non-dairy cattle	0.092%	0.338%
	sheep	0.032%	0.104%
	deer	0.062%	0.221%
steep slope	non-dairy cattle	0.043%	0.007%
	sheep	0.070%	0.004%
	deer	0.057%	0.006%

Agree / not agreed

Approved/ Not Approved/ Approved as Amended

Gerald Rys
Principal Science Advisor, Science and Skills Policy
Chair Agricultural Inventory Panel

Date

Appendix

Table 4: Effect of inventory change on emissions estimates.

		Direct N2O emissions from nitrogen excreta for sheep, beef and deer	Total agricultural soils emissions	Total agriculture sector emissions	NZ total emissions (gross)
Estimated **1990** emissions (kt CO_2-e)	*without* hill slope emission factors (i.e. current methodology)	3,777	6,697	34,582	65,815
	with hill slope emission factors (i.e. proposed methodology)	1,225	4,145	32,030	63,263
	Difference in estimates compared to current inventory	-2,552	-2,552	-2,552	-2,552
	Percentage difference in estimates	-67.6%	-38.1%	-7.4%	-3.9%
Estimated **2005** emissions (kt CO_2-e)	*without* hill slope emission factors (i.e. current methodology)	3,625	8,619	40,161	83,278
	with hill slope emission factors (i.e. proposed methodology)	1,271	6,265	37,807	80,924
	Difference in estimates compared to current inventory	-2,354	-2,354	-2,354	-2,354
	Percentage difference in estimates	-64.9%	-27.3%	-5.9%	-2.8%
Estimated **2016** emissions (kt CO_2-e)	*without* hill slope emission factors (i.e. current methodology)	2,666	8,593	38,727	78,727
	with hill slope emission factors (i.e. proposed methodology)	964	6,891	37,025	77,025
	Difference in estimates compared to current inventory	-1,702	-1,702	-1,702	-1,702
	Percentage difference in estimates	-63.8%	-19.8%	-4.4%	-2.2%
Change in emissions estimates between **1990 and 2016**	*without* hill slope emission factors (i.e. current methodology) (absolute)	-1,111	1,896	4,145	12,912
	without hill slope emission factors (i.e. current methodology) (percentage)	-29.4%	28.3%	12.0%	19.6%
	with hill slope emission factors (i.e. proposed methodology) (absolute)	-260	2,746	4,996	13,762
	with hill slope emission factors (i.e. proposed methodology) (percentage)	-21.3%	66.2%	15.6%	21.8%
Change in emissions estimates between **2005 and 2016**	*without* hill slope emission factors (i.e. current methodology) (absolute)	-958	-25	-1,434	-4,551
	without hill slope emission factors (i.e. current methodology) (percentage)	-26.4%	-0.3%	-3.6%	-5.5%
	with hill slope emission factors (i.e. proposed methodology) (absolute)	-307	626	-782	-3,900
	with hill slope emission factors (i.e. proposed methodology) (percentage)	-24.1%	10.0%	-2.1%	-4.8%

Figure 2: Proportion of excretal N applied to low (0-12º) slopes using Nutrient Transfer Model, split by urine and dung

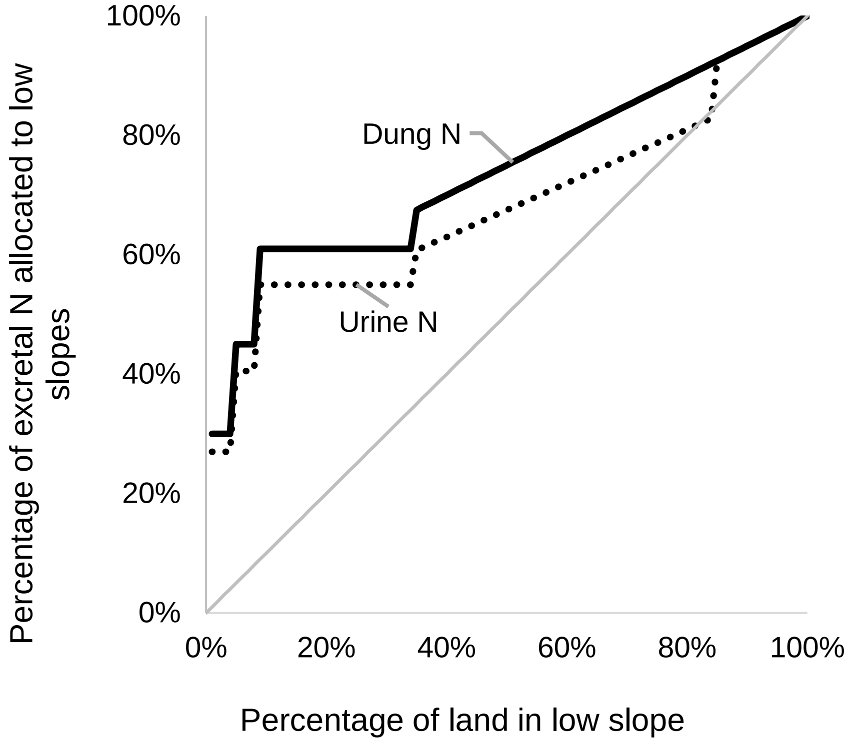


Figure 3: Proportion of excretal N applied to steep (>24º) slopes using Nutrient Transfer Model, split by urine and dung

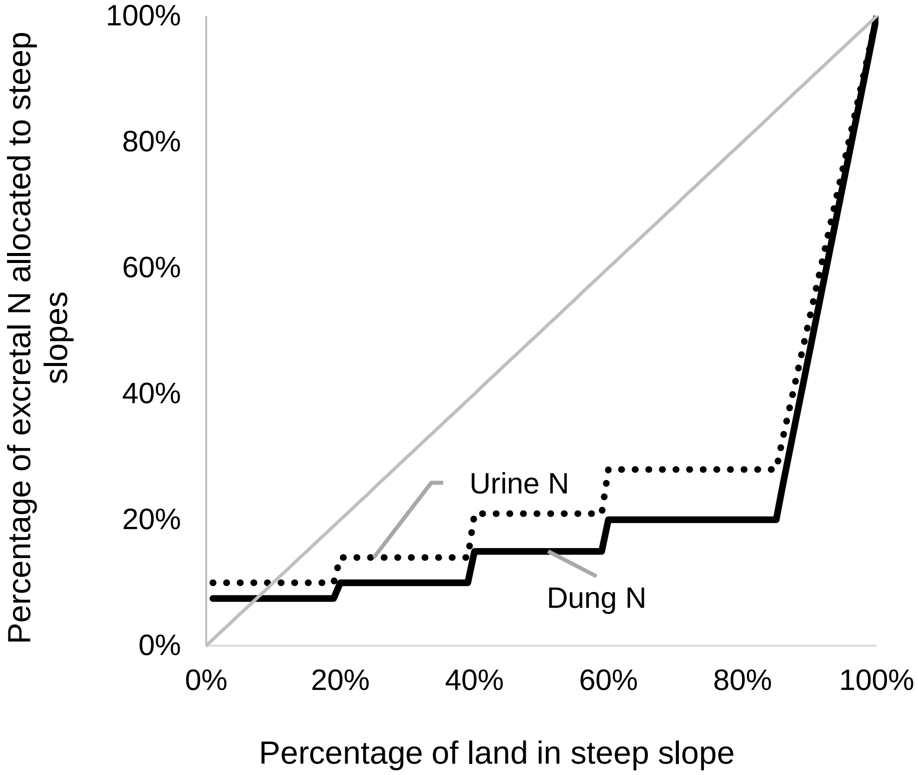


Figure 4: Simplified diagram showing how direct N_2O emissions from sheep, beef and deer are calculated using the *current* inventory methodology

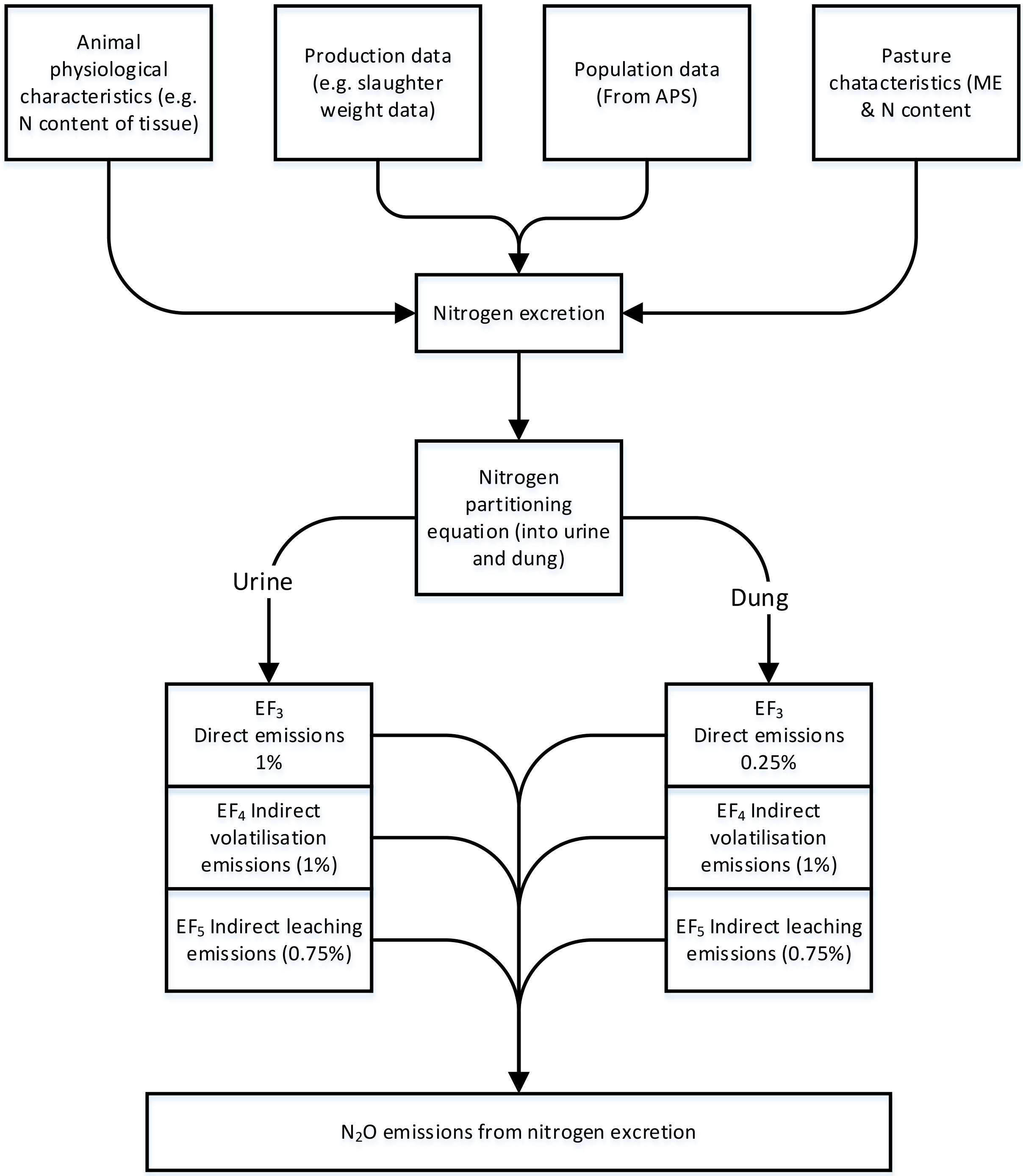


Figure 5: Simplified diagram showing how direct N_2O emissions from sheep, beef and deer are calculated using the *proposed new* inventory methodology and emissions factors