IMPROVEMENTS TO THE NATIONAL ATMOSPHERIC EMISSIONS INVENTORY FOR NRMM – AGRICULTURAL MACHINERY

Methodology Report

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1. FOREWORD

This work on Improvements to the Emission Inventory for Non-Road Mobile Machinery for the agriculture sector was conducted in 2021-22 and was first used in the National Atmospheric Emissions Inventory (NAEI) in 2023 and was subsequently published in the Informative Inventory Report (1990 to 2021), Section 3.3.7[1] and is available on the NAEI website. Since then, there have been no further developments to the agricultural machinery model, though further investigations into forestry machinery are planned for 2025 (NAEI 2023).

2. INTRODUCTION

Non-Road Mobile Machinery (NRMM) covers a very wide range of machinery, which spans from very small machinery (e.g. household generators, lawnmowers and chainsaws) to heavy machinery (e.g. excavators, cranes, large generators, off-road trucks, mining and agricultural machinery, such as tractors, combine harvester and telehandlers). Due to its diverse nature of use, it represents an uncertain and challenging emission source to characterise. Over 70 different types of NRMM were previously covered in the UK's National Atmospheric Emission Inventory (NAEI), however, the sparsity of NRMM activity data, the lack of centralised reporting to a regulatory agency, and the resource-intensive nature of capturing further information, result in the fact that the fundamental activity data used in the NAEI to estimate emission are not routinely updated. Such issues towards activity data are characteristic of the sector and common throughout many air quality inventories, as the model aligns with the 2019 EMEP/EEA Guidebook[2], used in the compilation and reporting of these inventories, and the 2023 EMEP/EEA Guidebook[3] was not available at the time of writing. It should be noted that the 2019 and 2023 Guidebooks are equivalent for the agricultural sector.

In 2019, an inventory improvement programme for Defra was initiated which focused on improving the activity data used for estimating emissions from NRMM deployed in mostly urban environments, such as construction equipment, portable generators and mobile machinery used in industry. The project was designed to improve this evidence base through a range of stakeholder engagement and wider data gathering aimed at improving the emissions inventory for these types of NRMM, in addition to providing data for use in the design and assessment of potential policy proposals towards emission reductions and potential behavioural responses. This initial study led to data for a new NRMM emissions model for these types of machinery to help Defra further understand the structure and operation of the UK NRMM fleet.

The study, completed in 2021, excluded types of machinery used in agriculture as these are used primarily outside urban environments, but still contribute to total UK emissions from the NRMM sector. Therefore, this report details a further series of stakeholder engagement and data collation as part of an additional improvement task commissioned by Defra in June 2021 primarily looking at the agricultural machinery sector. This engagement was aimed towards providing the opportunity for stakeholders to provide further feedback on the emission inventory. The focus of this engagement was a series of Non-Road Mobile Machinery (NRMM) presentations held by Ricardo and stakeholders from bodies representing NRMM sectors were invited to attend and provide feedback. This included engagement with the Off Highway Engine and Equipment Group (OHEEG) and a survey of Service Managers to provide data on agricultural machinery by the Agricultural Engineers Association (AEA).

2.1 THE PREVIOUS NRMM INVENTORY AND UNCERTAINTIES

The previous NAEI NRMM inventory model, last used in NAEI 2020, published in 2022, was based on a detailed bottom-up approach, taking into account the power of the engine, estimates of the UK population and annual hours of use of each type of machinery. The model covered 77 different types of portable or mobile equipment powered by diesel or petrol driven engines. These were grouped into four main sectors:

- Industrial off-road (includes construction and quarrying);

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[1] UK IIR 2024 Submission
[2] 1.A.4 Non road mobile machinery 2019 — European Environment Agency (europa.eu)
[3] 1.A.4 Non road mobile machinery 2023 — European Environment Agency (europa.eu)

- Domestic house & garden;
- Aircraft support machinery; and
- Agricultural machinery (includes forestry)

The model also included a simple fleet turnover calculation used to characterise the population of each machinery type by age (year of manufacture/sale) each year and hence emission standard. Emission factors were largely taken from the EMEP/EEA Emissions Inventory Guidebook which provides g/kWh factors for different legislative classes of machinery and engine and fuel types.

The population, usage and lifetime of different types of off-road machinery were based on a detailed study carried out in 2004[4] with some further updates in 2014. However, because of the sparsity of NRMM activity data, the lack of centralised reporting to a regulatory agency, and the resource-intensive nature of capturing further information through dialogue with potential stakeholders, the NAEI did not routinely update the NRMM activity data used in the compilation of the inventory each year. Rather the NAEI team at Ricardo used various proxy statistics as activity drivers for different groups of machinery types to reflect changes in machinery use each year from the 2004 base levels.

A further step in the inventory calculation involved reconciling overall bottom-up estimates of gas oil used by diesel NRMM with total gas oil consumption figures presented in the Digest of UK Energy Statistics (DUKES)[5], taking into account gas oil used for other purposes including stationary combustion, rail and marine vessel engines. This ensures an overall energy balance is maintained, a requirement in national inventory reporting, although DUKES has not thus far been able to differentiate fuel used for NRMM compared with other, stationary combustion sources. A comprehensive update and review of the current activity assumption was therefore overdue.

2.2 RECENT IMPROVEMENTS TO ACTIVITY DATA FOR NRMM

As mentioned, the previous NRMM model that underpinned the NAEI estimates was based upon activity data collated in 2004 and partially updated in 2014. Proxy data 'drivers' were used to inform the activity trends and estimate activity rates in years across the timeseries. The methodology corresponds to a Tier 3 method, in accordance with the EMEP/EEA Guidebook[1]. There existed the need, however, to update the activity data to reflect the structure of the NRMM market in recent years.

The Defra NRMM Research Project undertaken in 2019-2021: 'Research to inform policy development to address emissions from Non-Road Mobile Machinery', collated a range of new activity data from stakeholder surveys and industry data sources and then used this to estimate emissions in a modified Tier 3 emissions inventory model[2].

A model was designed in 'R', an open-source software to accommodate the new activity data and used to calculate an estimate of emissions for 2018. That project was focused on the use of machinery in urban areas where the greatest population exposure occurs, and therefore did not consider agricultural machinery. It did, however, consider a range of activity data and machinery types that could replace current estimates for the inventory sectors 1A2gvii, 'Mobile combustion in manufacturing industries and construction' and 1A3eii 'Other (airport support vehicles)'. It is also covered machinery used in the waste service industry, seaports and engines powering transport refrigeration units (TRUs) which had not previously been covered. The new model was first used to estimate emissions in NAEI 2021, published in 2023.

Further details can be found in the UK Emission Inventory for Non-Agricultural Machinery – Methodology Report (2024).

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[4] https://uk-air.defra.gov.uk/assets/documents/reports/cat15/0502141215_NRMM_report_Final_November_2004_3.pdf

[5] https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes

3. DATA FROM CESAR ON THE STRUCTURE OF THE AGRICULTURAL MACHINERY FLEET

The Construction and Agriculture Equipment Security and Registration (CESAR) scheme is supported by the Construction Equipment Association (CEA) and the Agricultural Engineers Association (AEA), along with other stakeholders including the UK Home Office. Its primary purpose is as a register to deter or recover plant theft. However, as a product of this purpose, it contains a database of plant machinery within the construction and agricultural sectors, which has a large potential towards supporting this project owing to the number of records and its estimated coverage. Such data can be used to evaluate or verify the population of different machinery types, their respective ages, and their range of standard European emission reduction stages for vehicles[6].

The CESAR dataset contained approximately 134,000 records and a CEA expert's view was that this probably represents 50% of the entire agricultural NRMM fleet in the UK. The CESAR dataset contained the following data fields: Make, Model, Asset Description (for linking to machinery type), fuel type, Gross weight (for deriving weight to power rating relationship), Date of Manufacture/Age (for linking to emission stage in combination with power rating information). The Vehicle Certification Agency's vehicle type approval number could not be supplied, only the vehicle identification number (VIN) and the engine number. We used the date of manufacture and vehicle type to inform the emissions reduction stage of the machinery. A license agreement was signed with DataTag, holders of the CESAR database, so that confidential information such as names, locations, or vehicle identification numbers would not be published as part of this study.

However, more than 70% of the records provided had missing information on the key data fields (i.e., asset description, gross weight and age) and there were also naming inconsistency issues. To address this, the CESAR dataset was gap-filled and cleaned to the extent possible within the budget and timescale available for this project, as discussed below.

Three elements are required to determine the emission stage for any specific record: the machinery type, the power rating, and the date of manufacture. Select records within the dataset already have a date of manufacture and a machinery class (the 'AssetDesc'), however the power rating needs to be directly derived from other variables. To complete the maximum number of records, each element was prioritised for gap-filling:

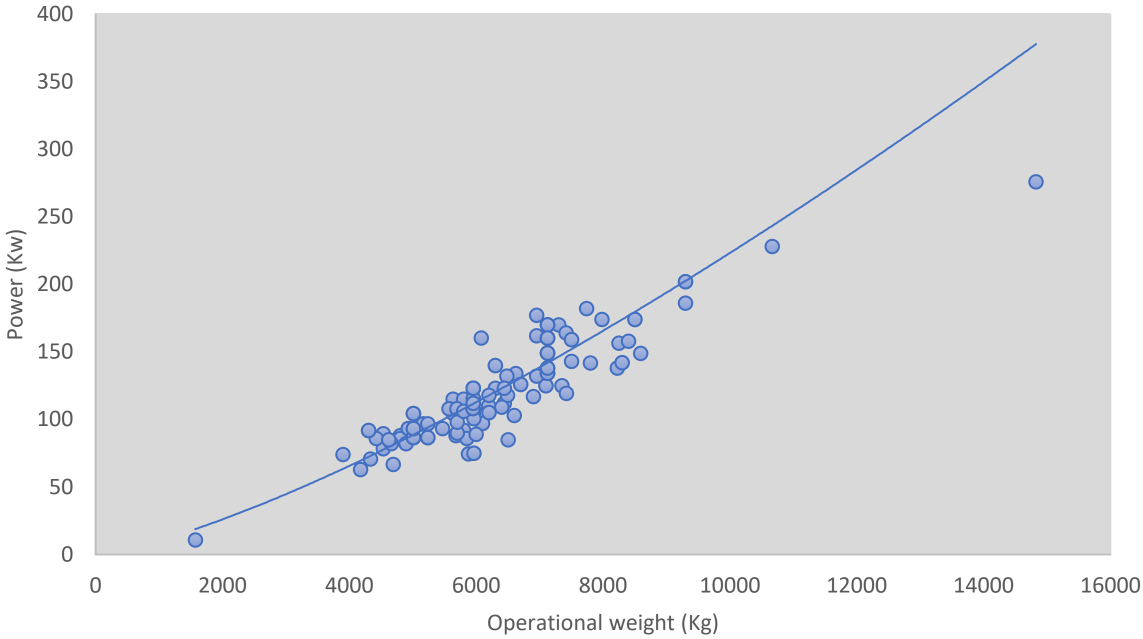
- **Machinery type description** – The raw CESAR dataset provides a characterisation of machinery type for approximately 130,000 records through the 'AssetDesc' field. The asset description field provides an initial characterisation of the type of machinery within the dataset, but owing to the free-text entry within the dataset, a number of overlapping or inconsistent classes of machinery. From our discussion with stakeholders, it was noted in the initial stages of the project that machinery types or distinctions between types can be ambiguous, with different terminologies used across different market sectors. The project team worked with stakeholders to define an agricultural machinery type list, which was subsequently mapped to the 'AssetDesc' field. This mapping corrected some duplications within the 'AssetDesc', refining the field to be consistent with other datasets and compatible with the emission model's design. Still, many of the asset descriptions had names which could not be easily and automatically mapped to machinery types used in the model. To further include and fill these entries, the 130 most populous make and model combinations were extracted and manually mapped to machinery types used in the model via an online search. Following this, around 75% of all records had a machinery type assigned. The remaining 25% were not assigned a machinery type as there were diminishing returns in spending time populating those less populous cases.

- **Power** – Power rating was taken directly from CESAR, or derived from the same sample of 130 make and models, taken from the exercise described above. Whilst determining the machinery type for these records, the weights and power ratings from the specification logs were also recorded. Plotting the weight and power (see Figure 1) revealed a relationship with a correlation coefficient of 0.78. However, this is consistent in providing a conservative estimate. Applying this relationship to the 'gross_weight'

[6] https://dieselnet.com/standards/eu/nonroad.php

field enabled an estimation of power across the dataset where the weight was available, but the power rating for some machinery was not able to be estimated if the gross weight field was empty.

Figure 1 CESAR database agricultural vehicle weight to power relationship.



4. STAKEHOLDER CONSULTATION

4.1 OFF HIGHWAY ENGINE AND EQUIPMENT GROUP (OHEEG)

The Off Highway Engine and Equipment Group (OHEEG) monitors and influences UK, European and International off-highway engine and equipment related legislation and standards and represent the viewpoints of working group members at the respective national and international legislation and standards forums. OHEEG reflects the needs of the different categories of equipment and devices, whether Original Equipment or after market, and support working group members in all technical areas concerned with manufacturing environment. OHEEG also provides advice and recommendations to the Society of Motor Manufacturers and Traders (SMMT) technical boards and Environmental Policy Committee, ensuring co-ordination with the UK government departments on off-highway engine and equipment matters.

A meeting was held with the OHEEG working group on 8th September 2021, with representatives from several major NRMM manufacturers. A presentation was made on the aims of the NRMM improvement item, and this resulted in useful comments and follow-ups, especially with the Agricultural Engineers Association (see Section 4.2).

4.2 AGRICULTURAL ENGINEERS ASSOCIATION

4.2.1 AEA Data

The Agricultural Engineers Association (AEA) was established in 1875 to promote the technical, trade and commercial interests of British manufacturers and suppliers of agricultural machinery. Since then, they have championed the cause of manufacturers of agricultural machinery and more recently outdoor power equipment. AEA were engaged to provide data on agricultural machinery to complement the data from the CESAR database.

A presentation on the project was made to AEA on 27th Sep 2021, and the association was able to provide the following information;

- Number of agricultural machines licensed for road use by year of first registration in the UK (2000-2020 and Pre-2000)
- First registrations of agricultural tractors by year, compared with the number of licensed machines at end of 2020 & 2019 (2000-2020)
- First registrations of agricultural tractors by power band and average power of registrations (2000-2020)
- First registrations of agricultural combine harvesters by year, compared with the number of licensed machines at end of 2020 & 2019 (2010-2020)
- Estimated market size for other agricultural vehicles 2011-2020 (agricultural telehandlers, forage harvesters, sprayers)

4.2.2 AEA Service Managers Group Data Collection

A second presentation was made to AEA's Service Managers Group on 5th Oct 2021 and subsequently, a data collection form was distributed amongst AEA's members to gather information for each of the machinery types on;

- Idling times
- Load factors
- Fuel consumption
- Machinery hours

Tractors were sub-divided by power range in horsepower, and this was converted to power in kW for the purposes of the project. A sample of the results from the data collection is summarised in Table 1. For a portion of the hours in use, the machinery are assumed to be idling and associated with very low load factors. AEA provided estimates of the percentage time in idle. The load factors estimated by AEA in Table 1 refer to the hours when the machinery is not idling, i.e. is doing some work under load. AEA commented that customers of agricultural machinery often buy machines that are larger and higher power, because features which customers value are only available on the larger machines. This is reflected in the relatively low load factors which are recorded.

Table 1 Sample of results from AEA's Service Managers Group (values in orange are estimated).

Machine type	Average hours worked per year					Estimated power rating (kW)	Typical load factor (%)	Time in idle (%)
	New	Year 5	Year 10	Year 15	Year 20			
Tractor 38 - 75 kW	450	450	300	150	75	70	30%	25%
Tractor 75 - 89 kW	650	600	500	250	125	82	30%	25%
Tractor 90 - 104 kW	650	600	500	250	125	97	30%	25%
Tractor 105 - 119 kW	750	750	650	325	162.5	112	35%	25%
Tractor 120 - 149 kW	800	800	700	350	175	135	40%	25%
Tractor over 149 kW	850	800	750	375	187.5	176	40%	25%
Combine harvester	350	350	250	200	150	181	65%	25%
Telehandler (agricultural)	1000	1000	800	400	200	117	30%	25%
Forager	450	450	400	300	200	472	75%	40%
Sprayer	600	600	500	250	125	165	55%	40%

This data is summarised in more detail in Appendix 1.

4.2.3 AEA Follow-up

The data provided by the AEA Service Managers Group was incomplete over a 20-year period and was mainly aimed towards newer machines less than 10 years old. Comparison with the CESAR database and calculation of fuel consumption suggested that our initial assumptions about lifetime, fuel consumption and hours of use may have been too high, especially for tractors which represented the majority of agricultural machinery.

A follow-up meeting with AEA was arranged on 23rd February 2022. The AEA representative highlighted that data was mainly available for newer machinery, where telemetry data were available for individual machines showing hours of use data for machinery of different ages. These data were analysed by AEA and led to the hours of use data for machinery up to 10 years old in Table 1. Initially the hours of use data were linearly extrapolated to 20 years, but there was a general view from AEA that hours of use are much lower for very old machinery compared with new machinery. It should be noted that estimation of emissions and fuel consumption from tractors in particular is very sensitive to assumptions made about usage of old machinery because there are so many old tractors that remain registered in the fleet. Records show that tractors as old as 60 years remain registered, but the view of industry experts is that many of these are seldom used and some may just be used as heritage machinery used only at agricultural shows. In the absence of firm evidence, an assumption was made that usage rates halved every additional 5 years in age from levels provided for machines 10 years old (e.g. that a 15 year old tractor does half the hours of a 10 year old tractor). This leads to the figures highlighted in orange in Table 1. In the case of combine harvesters, usage rates were provided for machines over a 20 year period and these were used without further change.

Another area that required further consideration was fuel consumption rates for different machinery and how these have changed over time, as new machines have generally become more fuel efficient than older machines as a result of improved engine technologies and machine design. AEA were able to provide fuel consumption rates for different machinery types (all with diesel engines running on gas oil) in litre per hour based on telemetry data. With the exception of combine harvesters, this was limited to new machinery as shown in Table 2. The data from AEA in litre per hour were found to be consistent with the fuel consumption factors provided for machinery in the EMEP/Emissions Inventory Guidebook in g/kWh units when used in conjunction with the engine power ratings and load factors assigned to each type. This provides some confidence in the engine ratings and load factors in Table 2 required for the emission calculations. The exception was for telehandlers where the litre per hour rates were approximately 30% lower than implied by the factors in the Guidebook. To compensate for this, the product of engine power x load factor was reduced by 30% to align the fuel consumption rate implied by the Guidebook factors with the AEA litre per hour consumption rate for telehandlers.

However, the Guidebook assumes no change in fuel consumption factors for machinery of different year of registrations or emission legislative class, implying no change in fuel efficiencies as technologies have improved. This conflicted with the views of AEA and demonstrated in the case of combine harvesters in Table 2, where there is evidence from telematics that efficiencies have improved with each generation of machines, although the view of AEA was that it is unlikely that fuel consumption rates for agricultural tractors had changed to the extent shown for combine harvesters. On this basis, an assumption was made for tractors that fuel consumption rates were as defined by the g/kWh factors in the Guidebook for machinery first registered in 2020 (consistent with the AEA litre/hour factors), but the consumption rates were 10% higher for new machines in every 5 year interval back to 2005, remaining constant going back further in registration year. In other words, a machine entering service in 2015 had 10% higher fuel consumption rate than a machine entering service in 2020, while a 2010 machine would have a further 10% higher consumption rate than a 2015 machine. The rates for foragers were assumed to follow the same trend as combine harvesters and the rates for telehandlers increased with the same trend as combine harvesters up to 10 years, but then the rate of increase in fuel consumption remained constant.

Table 2 summarises the fuel consumption rates for machines of different first registration years with the figures highlighted in orange derived from the above assumptions.

Table 2 Fuel Consumption rates in litre/hour for machinery by year of registration. Figures in in orange reflect assumed rates of increase for older machines relative to 2020 models.

Machine type	Fuel consumption rates in litre/hour			
	2020 registration	2015 registration	2010 registration	2005 registration
Tractor 38 - 75 kW	6	6.6	7.3	7.9
Tractor 75 - 89 kW	7	7.7	8.5	9.2
Tractor 90 - 104 kW	8	8.8	9.7	10.6
Tractor 105 - 119 kW	12	13.2	14.5	15.8
Tractor 120 - 149 kW	13	14.3	15.7	17.2
Tractor over 149 kW	20	22.0	24.2	26.4
Combine harvester	45	55	100	100.0
Telehandler (agricultural)	7	8.6	10.1	11.7
Forager	50	61.1	111.1	111.1
Sprayer	20	20	20.0	20.0

4.2.4 Current Off-Road Model

A detailed description of the current Off-Road model now used in the NAEI (including Agriculture) is available in the UK Informative Inventory Report (1990 to 2022), Section 3.3.7.[7] For agricultural off-road machinery, the trends in gas oil allocated to agriculture in DUKES[8] are used and updated every year. In some years, the NRMM model calculates the bottom-up gas oil use as being greater than that is available in DUKES. As the UK energy statistics are a top-down methodology, with a greater degree of certainty, there is required to be a fuel reconciliation such that the fuel use is distributed to sectors appropriately. This is described in Annex 4.2.1.4 of the UK Greenhouse Gas Report 1990-2022.[9] Results are presented in the IIR report and are available on the NAEI website.

5. SUMMARY AND CONCLUSIONS

New activity data on the population and usage of agricultural machinery have been collected, analysed and gap-filled to improve the emissions inventory for this sector. A significant amount of useful information was derived from the CESAR agricultural database provided by the Construction Equipment Association's (CEA) and from stakeholder consultation with the Agricultural Engineers Association (AEA), represented through the Off Highway Engine and Equipment Group (OHEEG).

Whilst some activity data came from data held by AEA from telematic systems on-board more modern machinery including hours of use, idling time and fuel consumption rates, it was generally necessary to make assumptions for these for older machinery remaining in the fleet, in particular how hours of use drops off with age of machine.

The new activity data for both agricultural machinery and all other NRMM types were combined with emission factors based on the EMEP/EEA Emissions Inventory Guidebook that underpin the current NAEI. The new model was developed in R and was used to calculate fuel consumption and pollutant emissions for each type of machinery.

[7] UK IIR 2024 Submission (energysecurity.gov.uk)
[8] Digest of UK Energy Statistics (DUKES) 2024 - GOV.UK
[9] UK NIR Submission (energysecurity.gov.uk)

The latest Off-Road model is described in the UK Informative Inventory Report (1990 to 2022). Note that emissions from tyre and brake wear are not included for NRMM in the NAEI as the EMEP Guidebook does not provide a method for this. In some years, the NRMM model calculates the bottom-up gas oil use as being greater than that is available in DUKES. As the UK energy statistics are a top-down methodology, there is required to be a fuel reconciliation such that the fuel use is distributed to sectors appropriately. This is described in Annex 4.2.1.4 of the UK Greenhouse Gas Inventory Report 1990-2022.

Our search for potential NRMM activity data across all sectors in both this and in our previous Defra research project on NRMM has been extensive, involving all key stakeholders, and it is highly unlikely further data are currently available to reduce uncertainty in emission and fuel consumption estimates, but it is acknowledged that there remains a significant reliance on assumptions, particularly on hours of use, albeit guided by expert judgement from stakeholders. This reliance may be reduced in future as more and more machinery are equipped with telematics which could provide more robust data on usage patterns of NRMM if such data can be provided readily to the NAEI.

APPENDIX 1 – RESPONSE FROM AGRICULTURAL ENGINEERS ASSOCIATION SURVEY

Responses from AEA (figures in orange cells have been extrapolated) – Note: tractor powers converted from horsepower (hp) to kilowatts (kW)

	Average hours worked per year							Under load	Under load
Machine type	New (Year 1)	Year 5	Year 10	Year 15	Year 20	Typical load factor (%)	Time in idle	transport	in field
Tractor 38 kW and under	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Tractor 38 - 75 kW	450	450	300	150	75	30%	25%	10%	65%
Tractor 75 - 89 kW	650	600	500	250	125	30%	25%	10%	65%
Tractor 90 - 104 kW	650	600	500	250	125	30%	25%	10%	65%
Tractor 105 - 119 kW	750	750	650	325	162.5	35%	25%	10%	65%
Tractor 120 - 149 kW	800	800	700	350	175	40%	25%	10%	65%
Tractor over 149 kW	850	800	750	375	187.5	40%	25%	10%	65%
Combine harvester	350	350	250	200	150	65%	25%	10%	70%
Telehandler (agricultural)	1000	1000	800	400	200	30%	25%	n/a	n/a
Forager	450	450	400	300	200	75%	40%	10%	50%
Sprayer	600	600	500	250	125	55%	40%	20%	40%

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