Protocol
4A: CH_4 FROM ENTERIC (RUMEN AND INTESTINAL) FERMENTATION

IPCC Category:	4A1, 4A3, 4A4, 4A6, 4A8
NFR Code:	Not applicable
NOSE Code:	Not applicable
NACE Code 2008	014

Foreword
Under the Kyoto Protocol, the Netherlands is required to set up and maintain a national system to monitor its greenhouse gas emissions. One of the elements of this system is a transparent and verifiable description of the methods and processes used in this monitoring system. These methods must meet international guideline criteria, which have been defined by the United Nations (UN) and the European Union (EU).

The Netherlands meets the aforementioned requirement, for example, by defining a series of Monitoring Protocols, which describe the methods and work processes used to determine greenhouse gas emissions and the amounts of carbon sinks available. Protocols have been written for about 40 greenhouse gas sources or sinks. This document describes the protocol for one of these sources or sinks.

The protocols have been compiled in close collaboration with experts from various sectors of society in the Netherlands, particularly experts from the Emissions Registration (ER). The ER is a collaborative group that includes institutions such as CBS, WUR, RIVM and PBL. Until 31 December 2009 this was coordinated by PBL (Planbureau for the Leefomgeving, or the Netherlands Environmental Assessment Agency), but on 1 January 2010 this coordination task was taken over by RIVM (the Netherlands institute for public health and the environment). Other institutions that have contributed to the protocols include NL Agency; Ministry of Agriculture, Nature and Food Quality; and the Ministry of VROM (Housing, Spatial Planning and the Environment).

1 Scope and significance of emission sources/activities

1.1 Scope and definition
This protocol describes the methods and work flows used to determine the emission of methane (CH_4) as a result of ruminal and intestinal fermentation for the following source categories:
4A1. cattle (ruminal and intestinal fermentation)
4A3. sheep (ruminal and intestinal fermentation)
4A4. goats (ruminal and intestinal fermentation)
4A6. horses (intestinal fermentation only)
4A8. pigs (intestinal fermentation only)

The categories 4A2. buffalo, 4A5. camels and lamas and 4A7. (mule)donkeys are reported in the CRF (common reporting format) as NO (not occurring) (Brandes *et al.*, 2006) because there is no husbandry of these categories in the Netherlands, and for that reason they are also not part of Agricultural Census. The category 4A9. poultry is reported as NE (not estimated) because there are no data on CH_4 emission as a result of intestinal fermentation in this source category. The source is very small, however, because of the anatomy of the gastrointestinal tract (relatively high passage rate of feed) and the relatively high feeding value of poultry feeds currently fed to poultry, this means that fermentation processes have a minor contribution to feed digestion. Probably for the same reason, the IPCC Guidelines also do not provide an IPCC default value and other countries also do not report emissions under this category (Brandes *et al.*, 2006).

The SBI codes for these activities are:
0141 and 0142 (breeding and husbandry of cattle)
0145 (breeding and husbandry of sheep and goats)
0143 (breeding and husbandry of horses)
0146 (breeding and husbandry of pigs)

The feeds consumed by the animal is digested in the gastrointestinal tract. This provides the energy and nutrients needed for maintenance and productive functions. Digestion takes place in the lumen of the gastrointestinal tract, which is nearly anaerobic. Part of the digestive tract accommodates a substantial microbial population, which ferments the feed or digesta. This involves the rumen and large intestine with ruminants (cattle, sheep, goats) and only the large intestine with monogastric animals (horses and pigs). In particular, with rumen fermentation a large amount of CH_4 is produced.

In addition to the microbial matter synthesised through fermentation of organic matter, volatile fatty acids and hydrogen gas are also produced as end-products. Just a small fraction of the hydrogen gas produced is utilised again (with microbial growth, with the production of propionic acid and branched chain volatile fatty acids), and the majority is released into the rumen environment. Together with carbon dioxide, which is available in excess in the rumen, the released hydrogen gas is converted into CH_4 and water by methanogens. This conversion of hydrogen into CH_4 is fairly complete, which is apparent from the fact that the partial gas pressure of hydrogen in the rumen environment is very low. A relatively small increase of the partial gas pressure would immediately have a detrimental effect on the fermentative degradation of feed in the rumen as a result of the inhibition of microbial activity. The rumen in cattle is responsible for about 90% of total CH_4 production in cattle, the remainder originating from the large intestine. Almost all CH_4 (99%) leaves the ruminant via the mouth, via respiration (via blood to the lungs) and by the frequent eructation of rumen gases and rumination of a selected part of rumen contents. Therefore, rumen fermentation processes largely determine the CH_4 emission in ruminants.

The amount of CH_4 produced depends on the amount of feed consumed by the animals and the characteristics and composition of this feed (Veen, 2000; Smink *et al.*, 2003; Tamminga *et al*., 2007). The amount of feed strongly determines the amount of organic matter fermented, and with this, the amount of hydrogen gas converted into CH_4. The feed characteristics (degradability, rate of degradation, outflow to the intestine) determine which fraction of individual feed components becomes fermented in the rumen and which fraction escapes rumen fermentation and flows out to the small intestine (Dijkstra *et al.*, 1992). The chemical composition of the fermented fractions of feed determine which amount and type of volatile fatty acids and which amount of hydrogen gas is produced (Bannink *et al.*, 2006; Kebreab *et al*., 2009), and thereby determines the amount of hydrogen gas converted into CH_4 (Mills *et al.*, 2001; Ellis *et al.*, 2008; Bannink *et al*., 2010).

The amount and type of ingested feed therefore determines the so-called methane emission factor (EF) for CH_4 (i.e. the amount of CH_4 in kg CH_4/year that is produced in an animal) as well as for the so-called methane conversion factor (MCF, i.e. the fraction of gross energy in ingested feed that is converted into CH_4 energy).

1.2 Significance and influences

1.2.1 Contribution to total national emissions

The CH_4 emission by farm animals is reported under sector 4A Ruminal and intestinal fermentation. Ruminal and intestinal fermentation contributes around 3% to the total greenhouse gas emissions in the Netherlands (Van der Maas *et al*., 2009). The main part of this emission originates from cattle.

1.2.2 Developments that infuence emissions

The CH_4 emission as a result of ruminal and intestinal fermentation declined from 1990 to 2007. This decline is mainly the result of a reduction of the number of livestock (Van der Maas *et al.*, 2009). The reduction in the numbers of dairy cattle in the period 1990 to 2007 by 25% is the result of the application of a fixed milk quota in European agricultural policy, in combination with an increase in milk yield per cow. Milk production per cow increased between 1990 and 2007 by 30%. The husbandry of sheep has become less attractive, from an economical point of view, because of a reduction in the ewe premium, and the number of sheep declined in this period by 20%. The reduction in the number of pigs by 16% was due to Dutch manure policy.

The emission of CH_4 by goats and horses increased during this period. This increase is proportional to the increase of the number of goats and horses, but remains small in size compared to the amount of CH_4 emitted by cattle (Van der Maas *et al.*, 2009).

The increased milk yield per cow is realised by an increased feed intake per cow and therefore an increase of CH_4 emitted per cow, be it to a much smaller extent than the increase in milk yield. In combination with the reduction in the numbers of Dutch dairy cattle, this resulted in a 16% decrease in total CH_4 emission as a result of ruminal and intestinal fermentation between 1990 and 2007 (Van der Maas *et al.*, 2009). This reduction is not only an outcome of the changed milk yield per dairy cow, but is also due the changed composition of the diet that took place during this period. The average share of grass silage and maize silage in the diet of dairy cows increased, whereas the share of grass herbage, standard concentrates and protein-rich concentrates decreased (CBS, 2009). Also the chemical composition of the diet changed with a decrease of crude protein content and an increase in the starch and fibre content (Bannink, 2010; based on CBS, 2009).

2 Method, emission factors and activity data

2.1 Calculation method

The emission of CH_4 as a result of ruminal and intestinal fermentation in cattle is calculated by multiplying the number of animals per animal category by a country-specific emission factor for that animal category. With respect to the remaining animal categories, default values are used on which there has been international agreement. The total emission of CH_4 of all animals is calculated by summing the emission per animal category.

$$CH_4 \text{ emission} = \sum EF_i \ * [\text{ number of animals per animal category (i) }]$$

CH_4 emission : emission of CH_4 for all defined animal categories (i) in kg CH_4/year,
EF_i : emission factor for defined animal categories (i) in kg H_4/year/animal.

Comparison to IPCC GPG methodology
For all animal categories, excluding cattle, default IPCC emission factors are applied in agreement with IPCC methodology, as described in the GPG (IPCC, 2001, p 4.23). For cattle, excluding mature dairy cattle, the Tier 2 approach is applied, with intake of gross energy being calculated according to a country-specific method. In this method the EF is calculated using the MCF and the gross energy intake from feed (GE). Default IPCC values in agreement with GPG (IPCC, 2001) are used for MCF.

For mature dairy cattle, a country-specific Tier 3 approach is applied by using a dynamic simulation model which describes the mechanisms of the fermentation processes in the gastrointestinal tract. The model predicts the consequences of nutrition on microbial fermentation and the accompanying production of CH_4 in the rumen and the large intestine. The simulation model predicts GE and the production of CH_4 in the rumen and large intestine from feed intake and dietary characteristics (dry matter intake, chemical composition, rumen degradation characteristics). Subsequently, the model calculates MCF from predicted CH_4 emission and GE. The model therefore makes no use of a (constant) MCF value as an assumption or a model input, as is the case with the Tier 2 approach.

Section 2.3 of this protocol further explains the activity data required. The method of calculating emission factors is explained further in Section 2.2.

2.2 Emission factors

All animal categories, except cattle
For all animal categories (excluding cattle) a Tier 1 approach is applied with default values for all emission factors as described in the GPG (IPCC, 2001) and the IPPC Guidelines (1997 p.4.10).

Table Emission factors

Animal category	**Emission factor in kg CH_4/animal/year**
Sheep	8.00
Goats	5.00
Horses	18.00
Pigs	1.50

Source: IPCC, 1997

Cattle excluding mature dairy cattle
Cattle are considered a key source (Van der Maas *et al.*, 2009) and because of this, for all cattle categories excluding mature dairy cattle, a Tier 2 approach is followed to calculate the country-specific emission factor. The emission factor is expressed by the following equation :

$$EF_i = (MCF_i \times GE_i \times 365) / 55{,}65$$

EF_i : Emission factor (kg CH_4/animal /year) for animal category i,
GE_i : Gross energy intake (MJ/animal/day) for animal category i,
MCF_i : Methane conversion factor for animal category i (fraction of gross energy intake (GE) that is converted into CH_4).
It is assumed that 1 kg CH_4 has a standard energy content of 55.65 MJ (IPCC, 2001), and the factor 365 is used to calculate EF on a yearly basis.

Default values are used for MCF as described in the GPG (IPCC, 2001). The MCF for veal calves is 0.04 and the MCF for the other cattle categories (apart from mature dairy cattle) is 0.06. The GE is calculated according to the following equation:

$$GE_i = DM_i \times 18{,}45$$

DM_i : Dry matter intake (kg dry matter/animal/day) for animal category i,
GE_i : Gross energy intake (MJ/animal/day) for animal category i.
It is assumed that 1 kg dietary dry matter has a gross energy content of 18.45 MJ/kg dry matter (IPCC, 2001).

Mature dairy cattle
For mature dairy cattle a Tier 3 approach is applied to calculate the country-specific emission factor. A simulation model is used which describes CH_4 production as a result of microbial fermentation processes in the gastrointestinal tract of mature dairy cattle. The simulation model has been developed by Dijkstra *et al.* (1992), Mills *et al*. (2001), and Bannink *et al*. (2005, 2008, 2010) and is described in scientific (peer-reviewed) journals. Mills *et al*. (2001) added a representation of CH_4 production to the model of rumen fermentation processes developed by Dijkstra *et al*. (1992), including a representation of the fermentation processes in the large intestine. This model extension allowed calculations to be made of the production of volatile fatty acids and hydrogen according to Bannink *et al.* (2006). More recently, Bannink *et a*l. (2008, 2010) developed an improved representation of production of volatile fatty acids and hydrogen by making it, amongst others, dependant on the acidity of rumen contents. This version of the simulation model was developed for cattle, and is currently applied as a Tier 3 approach to calculate CH_4 emissions in mature dairy cattle. The model may in principal also be used with other cattle categories but is not applied for this purpose.

The EF, GE and MCF of mature dairy cattle are calculated yearly using the simulation model of the Tier 3 approach (Bannink, 2010). The most important difference with the Tier 2 approach according to the IPCC methodology is that the simulation model (as Tier 3) predicts EF from feed intake and dietary characteristics as model inputs, without using the values of GE or MCF. Another important difference with the Tier 2 approach is that the simulation model takes into account several dietary characteristics to predict the fermentation processes in the rumen and large intestine, instead of making use only of the net energy value for milk production and maintenance as a dietary characteristic. A final difference between the simulation model is that it calculates GE from dry matter intake and dietary composition.

Based on predicted values of EF and GE the simulation model finally calculates an MCF value. The MCF is therefore exclusively an output of the model and is not used in the model equations. From the values of the emission factor (EF) and the Gross Energy intake (GE) per year, the MCF can be calculated as follows:

$$MCF = EF \times 55.65 / (GE \times 365)$$

EF : Emission factor (kg CH_4/animal/year) calculated by the simulation model,
GE : Gross energy intake (MJ/animal/day) calculated by the simulation model.
MCF : Methane conversion factor (fraction of gross energy intake (GE) converted into CH_4).
It is assumed that 1 kg CH_4 has a standard energy content of 55.65 MJ (IPCC, 2001), and the factor 365 was used to calculate GE on a yearly basis.

Should the results from the simulation model not be available in a particular year, a secondary (simplified) approach will be used to calculate the emission factor, where the MCF and GE/DM from the three preceding years will be used (as a back-up option). The following equation can then be used to calculate the emission factor:

EF = (DM × 365 × GE / DM (gross energy content in dry matter; average of year n-1 to year n-3) × MCF (average year n-1 to year n-3)) / 55.65

DM : Dry matter intake (kg dry matter/animal/day),
EF : Emission factor (kg CH_4/animal/year),
GE : Gross energy intake (MJ/animal/day),
MCF : Methane conversion factor (fraction of gross energy intake (GE) converted into CH_4).
It is assumed that 1 kg CH_4 has a standard energy content of 55.65 MJ (IPCC, 2001), and the factor of 365 is used to calculate DM on a yearly basis.

The emission factor is calculated more accurately with the latter equation, with a decrease in variation in dietary characteristics between the three consecutive years n-3 to n-1. The MCF depends on all input data to the simulation model: 1) the level of feed intake, 2) the chemical composition of ingested feed, and 3) the degradation characteristics in the rumen. The origin of these data is described in Section 2.3.

2.3 Activity data

Information on animal numbers is needed in order to execute the calculations according to the method described in Section 2.1 of this protocol. Basal data and assumptions for the calculation of emission factors were described in Section 2.2. This section provides a more detailed description of the data required as well as the origin of these data.

Animal Numbers
The following main distinction of livestock is applied:
- Mature dairy cattle
- Mature cattle, excluding non-milking and non-calving cows
- Cattle youngstock
- Pigs
- Sheep
- Goats
- Horses

Within each main category, several subcategories are distinguished every year in the yearly Agricultural Census in the Netherlands. Under this Agricultural Census, all agricultural businesses are taken into account which have their main office in the Netherlands and which are larger than three Dutch so-called ‘large animal’ units (grootte-eenheden; nge). For population statistics the reader is referred to the Centraal Bureau voor de Statistiek, CBS (2009; www.cbs.nl) and Van der Maas *et al.* (2009).

Should there be an outbreak of an animal disease in the year covered by the Agricultural Census, and for this reason a deviating number of animals are kept throughout the year, the Working Group of Uniforming Manure and Mineral data (in Dutch ‘de Werkgroep Uniformering berekening Mest- en Mineralencijfers, WUM) modifies the number of animals. These updated numbers are used for the emission calculations. The WUM calculations are reported by the CBS (2009; www.cbs.nl).

Feed intake and ration of cattle, excluding mature dairy cattle
Dry matter intake DM (kg dry matter/animal/day) is derived from calculations by WUM. The intake of diverse components in the ration (grass silage, maize silage, standard concentrates, protein-rich concentrates and wet by-products) is calculated yearly per cattle category based on national statistics on the amounts of these products that have been traded or produced. These cover part of the total energy requirement that is calculated yearly according to a country-specific method for the various cattle categories. Subsequently, it is assumed that the remainder of the energy requirement is covered by the intake of grass herbage. From 1990 onwards, the WUM calculates the DM yearly which is also input for the method used to calculate manure production and mineral excretion by farm animals (Van Bruggen 2003 through 2008). The first release appeared in 1994 (WUM, 1994) and the most recent and revised calculation of the rations (from 1990 to 2008) appeared in 2009 (CBS, 2009). The DM of cattle, excluding mature dairy cattle, is given in the report written by Smink (2005) and in the appendices of the national emission registration of greenhouse gas emissions (NIR; Brandes *et al*., 2006; Van der Maas *et al*., 2009).

Feed intake and rationing of mature dairy cattle
Important input data for the simulation model are:

1) Feed intake levels, as calculated by WUM (CBS, 2009), according to the same method as described above for cattle, excluding mature dairy cattle.

2) The chemical composition of dry matter in the various dietary components (grass herbage, grass silage, maize silage, standard concentrates, protein-rich concentrates and wet by-products). A distinction is made between soluble carbohydrates (including sugars), starch, cell walls (hemi-cellulose, cellulose, lignin), crude protein (including a distinction of the ammonia fraction), crude fat and crude ash. Data on the chemical composition are derived from national statistics as gathered and published by CBS. The data on roughages (grass

herbage, grass silage, maize silage) are derived from the laboratory BLGG at Oosterbeek, which analyses roughages, and from producers of compound feed. The data used have been previously described by Smink *et al.* (2005). With a recent revision of the WUM rations from 1990 to 2008 by CBS (CBS, 2009), new calculations have been conducted and data of chemical composition have been attached to the report written by Bannink (2010). Part of ensiled roughage is not fed to dairy cattle in the same year as the roughage analysis performed. The current protocol makes no correction for this, and it is assumed that the annual provision of data on chemical composition are representative for the diets calculated by the WUM for that particular year (CBS, 2009).

3) Rumen intrinsic degradation characteristics of starch, crude protein and fibre. The report by Bannink (2010) also gives the assumptions on these degradation characteristics (soluble fraction, fraction that is potentially degradable, undegradable fraction and the fraction rate of degradation of the fraction that is potentially degradable).

These data vary with changes in the proportion of individual dietary components (grass herbage, grass silage, maize silage, standard concentrates, protein-rich concentrates, wet by-products) and with changes in chemical composition and intrinsic degradation characteristics of these chemical fractions

The fractional passage rate of fermentable matter and acidity of contents in the rumen and the large intestine are also important model parameters that have a considerable influence on predicted CH_4 production. However, this concerns internal model parameters which do not need to be given as an input to the model. Starting point in the current protocol is that the simulation model predicts the fractional passage rate as a function of DM, and acidity as a function of predicted concentration of volatile fatty acids (Mills *et al.*, 2001).

3 Working processes

Process for assessment (t-1)
Provisional data for the year (t-1) are derived in the middle of the year (t). The process indicated below is followed for these calculations. The provisional data of the work field leader are calculated by extrapolating the data for the years preceding (t-1), [hence (t-2)] is based on the developments in the most important activity data of the year (t-1).

When calculating the CH_4 emission as a result of enteric fermentation, the results of animal numbers for the year (t-1) are multiplied by the emission factors that have been derived for the year (t-2) (see process for final determination (t-2)).

INPUT	PROCESS	OUTPUT	WHO
Provisional data work field leader (t-1)	Inclusion t-1data in emission registration database (ER-db)	ER-db with (t-1) data	Work field leader Other GHG ER working group agriculture and land use
ER-db with (t-1) data	Evaluation emission data: Comparison to previous years (trend) Possible adaptation, and documentation of the whole	ER-db (t-1) with possibly adapted data	ER working group agriculture and land use

Process for final assessment (t-2)

The final emission data for the year (t-2) (as described in this protocol) will be derived in December of the year (t-1) and published in the NIR of year (t). The calculations will take place according to the following process.

INPUT	**PROCESS STEP**	**OUTPUT**	**WHO**
Data for emission factors cattle Dry matter intake (DM) & intake of individual dietary components per cattle category (WUM/CBS) Chemical composition dietary components mature dairy cattle (Bannink, 2010), according to the report by CBS and obtained from annual statistics of BLGG and compound feed producers MCF other cattle categories. (IPCC,1997)	Calculation of CH_4 emission factors - Mature dairy cattle by a simulation model (Dijkstra *et al.*, 1992; Mills *et al.*, 2001; Bannink *et al.*, 2005, 2008 and 2010; Bannink, 2010) - Other cattle categories by DM x 18,45 x MCF / 55,65	CH_4 emission factors enteric fermentation per cattle category: Mature dairy cattle (A1) Other cattle categories (A2)	Work field leader other GHG ER working group agriculture and land use
CH_4 emission factors Mature dairy cattle (A1) Other cattle categories. (A2) Other animals (IPCC, 1997) (A3) Animal numbers per animal category (Statline CBS, or WUM if reassessment is required as a result of the outbreak of animal diseases) (B)	(A1 x B1) (A2 x B2) (A3 x B3)	CH_4 emission per animal category in Excel spreadsheet (C) = C1 + C2 + C3	Work field leader other GHG ER working group agriculture and land use
CH_4 emission (C)	First validation emission data via trend analysis and expert judgement	Validated emission data in Excel spreadsheet (=final data work field leader (t-2)) (D)	Work field leader other GHG ER working group Agriculture and land use
Final data Work field leader (t-2) (D)	Inclusion t-2 data in Emission registration database (ER-db)	ER-db with (t-2) data (E)	Work field leader other GHG ER working group agriculture and land use
ER-db with (t-2) data (E)	Evaluation and trend analysis atmospheric emissions: explanation of deviations or adaptation of results	Final determination of emission data t-2 (F)	TNO

4 Uncertainty and quality

4.1 Estimating uncertainties

A Tier-1 uncertainty analysis is implemented every year before the NIR is submitted by the ER, based on the greenhouse gas inventory and in compliance with IPCC guidelines. The assumptions used and the results thereof are described in a background report to the NIR. In addition to this, where included in the QA/QC programme for the relevant period, extra analyses are implemented regularly in specific situations, which include any updating of the Tier-2 uncertainty analyses. The Tier-2 uncertainty assessment was last updated in 2006. This assessment showed that a Tier-1 uncertainty assessment is sufficiently reliable and that Tier-2 uncertainty assessments need only be implemented at periodic intervals of around 5 years, unless a major change in an important source is sufficient to require earlier reassessment.

- Source-specific uncertainty

The uncertainty estimate $_{total}$ concerns the root of the sum of uncertainty in the data sources used (AD_{onz}) in the square and the uncertainty of the emission factor (EF_{onz}) in the square. The extent of the total uncertainty is here primarily determined by the greatest AD or EF uncertainty.

$$\text{Uncertainty estimate}_{\text{total}} = \sqrt{EF_{onz.}^{\;2} + AD_{onz.}^{\;2}}$$

The uncertainty estimates concerning the data sources (AD) and emission factors (EF) used, and the total uncertainty estimate, are listed in the following table.

IPCC	Category	Gas	AD uncertainty.	EF uncertainty	Uncertainty estimate $_{total}$
4A1	Emission with ruminal and intestinal fermentation: mature dairy cattle	CH_4	5	15	16
4A1	Emission with ruminal and intestinal fermentation: other cattle	CH_4	5	20	21
4A8	Emission with intestinal fermentation: pigs	CH_4	5	50	50
4A	Emission with intestinal fermentation: other	CH_4	5	30	30

The uncertainty of CH_4 emissions as a result of ruminal and intestinal fermentation is based on expert judgement. Uncertainty in activity data (= animal numbers) is about 5% and uncertainty in the CH_4-EF for other cattle (excluding mature dairy cattle), pigs and other animals (horses, sheep, goats) is resp. 20, 50 and 30% (Olivier *et al.*, 2009).

Uncertainty of the CH_4-EF for ruminal and intestinal fermentation in mature dairy cattle is based on an analysis of the effect of uncertainty of input data for a simulation model, used as a Tier 3 approach, on predicted EF and MCF (Bannink, 2010). Because the model is not applied with other cattle, the low estimate of uncertainty for mature dairy cattle is not applicable to this category of cattle.

4.2 Quality assurance and quality control (QA/QC)

The ER work package leaders check that:

1. the basic data are well documented and adopted (check for typing errors, use of the correct unit sizes and correct conversion);

2. the calculations have been implemented correctly;
3. assumptions are consistent, also whether specific parameters (e.g. activity data) are used consistently;
4. complete and consistent data sets have been supplied.

Any actions that result from these checks are noted on an ‘action list’. Before defining the data, supervisors check whether the relevant actions on this list, plus the QC checks, have all been completed. Defining the data is carried out by the WEM (working group on emissions monitoring), and confirmed in writing via an e-mail from the institute representatives to the ER project leader at PBL.

The work package leaders fill out a new documentation sheet when adding new data. For reasons of efficiency a minimum level has been set for obligatory documentation, i.e. 5% changes at target group level, and 0.5% at levels concerning the national total. These documentation sheets form part of the trend analysis, as well as the eventual definition of the data set.

The ER work package leaders communicate by e-mail regarding these QC checks, results and actions. They send a printed copy to the ER secretary, who keeps a logbook and compiles these e-mails into an ‘action list’. This shows explicitly that the required checks and corrections have been carried out.

4.3 Verification

In order to check the quality of the emission figures for the sources in this protocol, general QA/QC procedures have been followed that are in line with the IPCC guidelines. These are described further in the QAQC programme used by the National System, and the annual working plans published by the ER.

- Sector-specific QC

No additional specific verification procedures are implemented for the sources defined in this protocol.

4.4 Possibilities for improvement compared to the current calculation method

4.4.1 History

At the beginning of the 1990s, as predecessor of the IPCC Guidelines, country-specific emission factors were derived only once, which applied to the situation around 1990 (Van Amstel *et al.,* 1993). This work was summarised later by Spakman *et al.* (1997).

Halfway through 2004, following IPCC-GPG (IPCC, 2001), emission factors for cattle were updated for the NIR 2005, based on the IPCC Tier 2 approach (Smink *et al.*, 2004). The most pronounced change was that the yearly increase in milk yield of mature dairy cattle was taken into account, in contrast to the old emission factors that had been applied until then. Furthermore, for the entire period, from 1990 to 2003, information on animal weights and rations were taken completely from WUM information.

Furthermore, there is a consistent time series since the NIR 2005. With cattle, a distinction was made between rosé-veal calves and white-veal calves for 1990 to 1994 (just as for the following years). Also, a complete time series exists since then because horses were also added as a source.

A main objection to the IPCC's Tier 2 method for calculating CH_4 production as a result of ruminal and intestinal fermentation is that this method does not take into account the mechanism of fermentation processes that are responsible for the effect of feed intake and dietary characteristics on CH_4 production. Changes in dietary composition, that result in a reduction of CH_4 production in reality, are sometimes calculated to lead to an increase of CH_4 production via the IPCC Tier 2 approach. This is the case for example, with an increased proportion of maize silage in the diet. Also the intake of dry matter, calculated according to the IPCC method, did not correspond with the dry matter intake calculated by the WUM.

For this reason, emission factors were updated again for the NIR 2006 (Brandes *et al.*, 2006) and the choice was made to apply the Dutch method for calculating energy intake by cattle (according to methods used by WUM) as the basis for calculating CH_4 production. From this moment onwards, the CH_4 production in mature dairy cattle was calculated via the simulation model and CH_4 production in other cattle via default values for dietary energy content in combination with default MCF values from IPCC (2001). The MCF value used is the IPCC default value of 0.06 (except for an MCF of 0.04 for white-veal calves).

At the beginning of 2006, another change involved the emission factor for goats. No reference is available for the country-specific input data needed to estimate the country-specific emission factor that has been used since 1993. Because the contribution of this source is small, a Tier 2 approach is not obligatory and the approach could fall back on the IPCC default emission factor.

All emission factors for cattle were recalculated in 2009. With the previous approach the estimated dry matter intake was not corrected for feeding losses. Simultaneously, within the WUM, it became apparent that the efficiency of feed conversion into milk by mature dairy cattle was lower, and hence feed intake must have been higher to achieve the milk production that was realised. Both adaptations were introduced simultaneously and affected the calculations of CH_4 from cattle as well as N_2O from manure and agricultural soils.

4.4.2 Future
Not applicable

5 Remaining aspects

5.1 Point source criteria
Not applicable

5.2 Substance profiles
Not applicable

5.3 Regionalisation
Not applicable

5.4 Time-based variations in source strength
Not applicable

6 References and additional information

6.1 References

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6.2 Additional information

Not applicable