Manual and background

Regarding:	Accounts for municipalities for the sectors “agriculture”, “forestry and other land use”, “waste and wastewater management”, “industrial processes and product use”. Year: 2018
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Nomenclature list

C	General: Carbon, element
C	In CRF/IPCC context: Confidential, confidential data.
CH4	Methane, greenhouse gas with GWP (Global warming potential): 25
CO2	Carbon dioxide, greenhouse gas with GWP (Global warming potential): 1
CO2-e	See: CO2-equiv.
CO2-eq	Equivalent greenhouse gas emissions, considering the individual gases GWP.
CRF	Common Reporting Format, IPCC's format for reporting NIR
DST	Denmark's Statistics
GWP	Global Warming Potential, unit for a greenhouse gas's relative greenhouse effect (CO2 = 1.0)
ha	Hectare (100 x 100 m)
IE	Included Elsewhere, used in CRF when emission is accounted for under other activity in the accounts (to avoid double accounting)
IPCC	International Panel for Climate Change, UN Climate Panel
N	Nitrogen (Nitrogen), element
N2O	Laughing gas, greenhouse gas with GWP: 298
NA	Not Applicable, is used in the CRF when activities do indeed occur, but do not have to be accounted for according to the IPCC's guidelines.
NE	Not Estimated, is used in CRF when emissions have not been estimated/calculated, typically, due to a lack of background data.
NIR	National Inventory Report, Climate accounting (national), is reported to the IPCC (As a starting point, the Danish NIR for the financial year in question is meant)
NO	Not Occurring (activity/process), is used in the CRF when a given activity/process from the standard list (IPCC) does not occur within the nation in question.
NR	Not Reported is used in the CRF when emissions from a given activity are not

	reported in the relevant NIR.
t	tons/tonsC

1 Introduction

The purpose of this climate report is to provide a status report of the total emissions of the greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which are associated with agriculture, forestry and land use. The accounts include natural carbon stock or emissions from land use as well as an estimate of harvested wood products that are in use within the municipal boundary.

The emissions from the energy and transport sectors, as well as waste and wastewater management, industrial processes and industrial product use are not calculated in this account[1].

The purpose of this account is to give the municipalities an overview of the greenhouse gas load that is associated with a number of different activities within the municipal boundary. The accounts can be used as a strategic tool to set municipal climate targets, as a planning and prioritization tool to reduce emissions from the most climate-damaging activities first, and as a tool to monitor the effect of reduction measures. The accounts are a tool for assessing the municipal contribution to achieving the EU's climate goals and the Danish government's climate goals.

The climate account can also be used as a basis for reporting greenhouse gas emissions and carbon stocks in the Baseline Emissions Inventory (BEI), which is used by the Covenant of Mayors[2] network, and in the Global Protocol for Community-scale Greenhouse Gas Emission Inventories (GPC), the CIRIS format, which used by the network C40 [3].

1.1 Methodological basis of the accounts

The accounts are structured in accordance with the guidelines adopted by the UN climate panel [4] for the calculation of greenhouse gases and with the guidelines used nationally in connection with the annual Danish reporting of the national climate accounts to the UN climate panel [5].
The UN climate panel and the national climate accounts divide the emissions into emission sectors for 1) stationary energy, 2) transport and 3) agriculture, forestry and other land use 4) waste and wastewater, - and 5) industrial processes and industrial product use. Within each of these emission sectors, a number of different activities lead to the emission or storage of greenhouse gases. With a few exceptions, the municipal climate accounts contain the same types of activities as the UN's climate accounts and the national climate accounts. If extra activities are included or selected activities are excluded, it is due to the wishes of the users. It is stated in the relevant section of this memo if extra activities are included, or selected activities are excluded.

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[1] If the municipality has had accounts prepared for these sectors by PlanEnergi, the results from these accounts can be used to create graphs of the total emission.
[2] The BEI can be accessed via https://www.eumayors.eu/IMG/pdf/seap_guidelines_en-2.pdf
[3] The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) can be accessed via https://www.c40knowledgehub.org/s/article/The-Global-Protocol-for-Community-Scale-Greenhouse-Gas-Emission-Inventories-GPC?language=en_US
For now, BASIC/ BASIC+ format is used, which does not include products that are imported with consumption within the municipal boundary. The CIRIS reporting sheet is available at https://resourcecen-tre.c40.org/resources/reporting-ghg-emissions-inventories
[4] The UN Climate Panel's guidelines can be accessed via https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
[5] The National Center for Environment and Energy (DCE) is responsible for the national reporting. The national report can be accessed via https://unfccc.int/documents/273129

For each type of activity, the UN has adopted methods for calculating emission and storage factors. The municipal accounts use these methods. In several cases, the so-called implicit emission factors from the national climate accounts' CRF tables are used. A CRF table is a table drawn up in the common reporting format (Common Reporting Format) adopted by the UN. An implicit emission factor is an aggregated factor which is calculated based on the methods and formulas adopted by the UN on the basis of national data inputs.

The UN's international climate agency IPCC opens up the possibility for UN member states to use methods and formulas of varying degrees of detail in relation to calculating the emissions associated with different types of activities. Which methods can and should be used depends on which data are available nationally. The level of detail Tier 1 describes an international standard factor, Tier 2 describes a national standard factor and Tier 3 describes modelled or measured emission and storage factors. One formula line can contain factors at different levels of detail.

The municipal climate account follows the national account with regard to the level of detail of emission factors. In certain cases, however, it is not possible to disaggregate data at a municipal level due to the quality of Danish data. Here, the municipal accounting uses distribution keys based on e.g. population or settlement area. It is clear from the documentation for each activity type which level of detail is used.

2 Structure and principle of municipal climate accounting

The climate accounting is compiled in one Excel spreadsheet. The sheet shows a tab with key figures and graphs for the energy sector and one for the biobased sectors, waste and industrial products, as well as tabs with accounts for the selected emission sectors, including energy, agriculture, forestry and other land use, waste and wastewater, as well as industrial processes and industrial product use. [6] In the overall excel sheet, there is also integrated information from accounts for CO2 emissions from the energy and transport sectors, if the municipality has had such a report prepared. [7]

Three accounting tabs comprises the emission sector for "Agriculture, forestry and other land use" - one for animal husbandry, one for plant production and one for land use and changes in land use, including the use of harvested wood products. One account is connected with each of the emission sectors "Waste and wastewater" and "Industrial processes and industrial product use".

[6] Three accounting tabs are connected to the sector "Agriculture, forestry and other land use".

[7] Calculations of emissions from the energy and transport sectors are documented in a separate background note

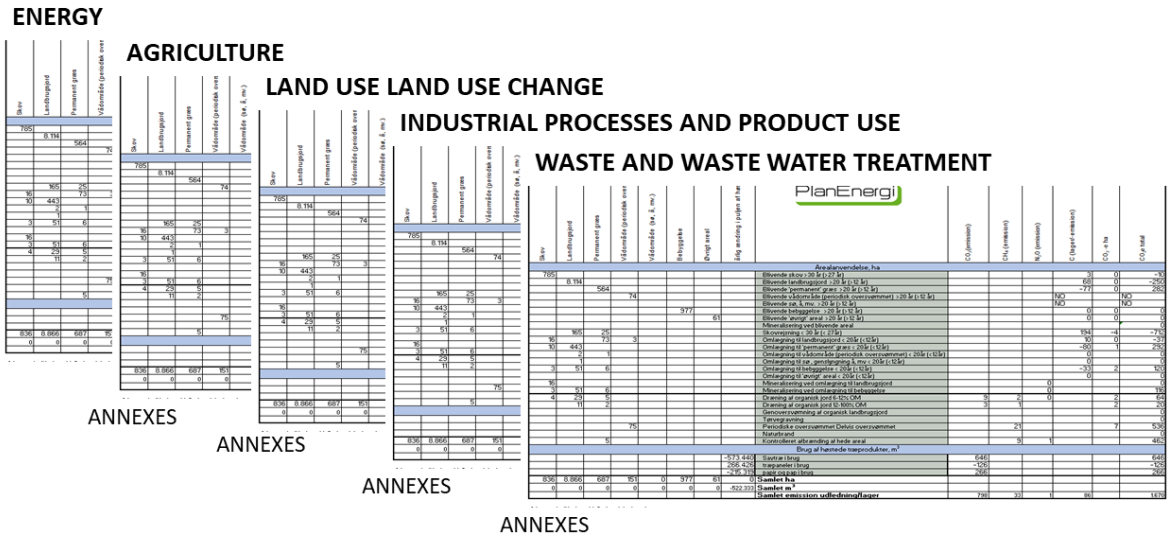
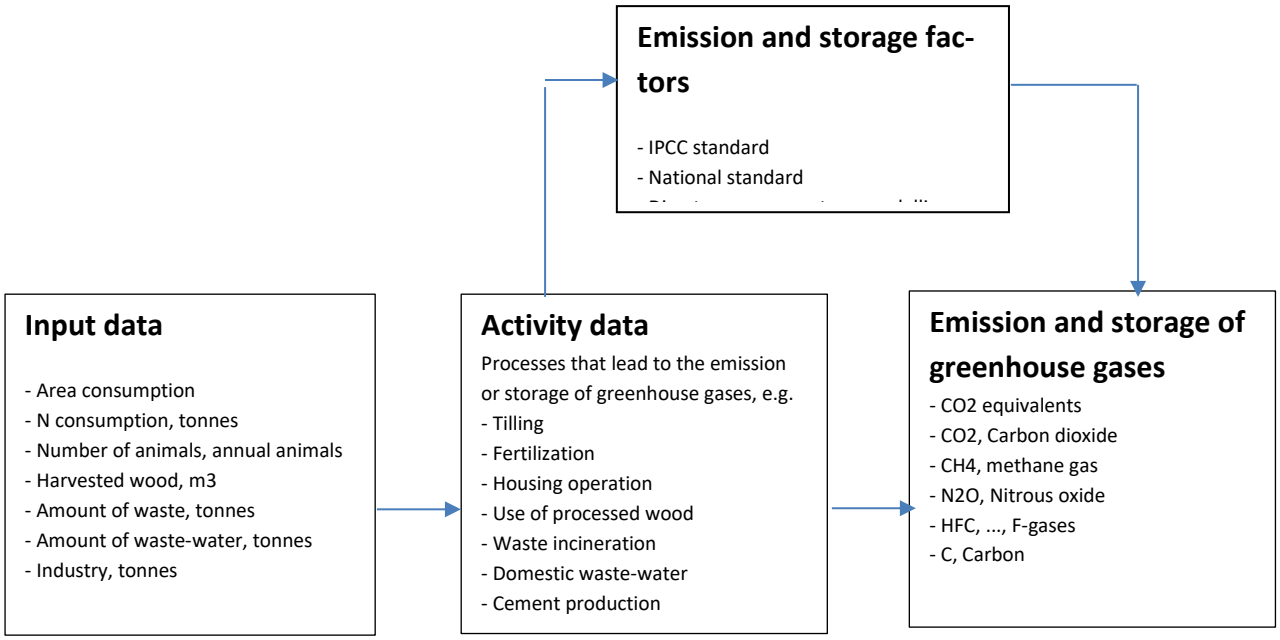


***Figure 1**. Overall structure of the accounts*

A number of annexes are similarly connected to each of the emission sectors, and show the calculation of individual activities. Each annex has its own tab. The annexes are numbered consecutively. It is indicated in each annex and in this documentation note which RF table in the national climate accounts an annex refers to. [8]

2.1 Principle of accounting structure

The principle of the accounts linked to each of the three emission sectors is shown in Figure 2.2. The figure is read like each tab with accounts from left to right:



[8] *The CRF tables can be downloaded from https://unfccc.int/ghg-inventories-annex-i-parties/2020*

Figure 2. *Principle of accounting structure*

Municipal input data obtained from national registers and area databases are entered on the left side of the accounts. In individual cases, data is entered from national or international statistics and tables, which are distributed via a distribution key at municipal level. It is clear from the annexes and from the documentation for each individual annex which registers, databases, statistics and tables have been used.

The grey box in the middle of the accounts shows that each unit is involved in an activity or process that leads to the emission or storage of greenhouse gases. In "agriculture, forestry and other land use" an activity finds place e.g. when an animal digests the feed, when an agricultural area is fertilized, when a forest is planted or an area is converted from agricultural use into a wetland.

Any activity is associated with the release or storage of greenhouse gases. On the right-hand side of the accounts, the type and quantity of greenhouse gas that a given activity gives rise to is shown, and the emission or storage of greenhouse gases is converted into CO2 equivalents. For land use, the carbon stored in the biomass, or the soil is indicated. The carbon stock is also converted into CO_2 equivalents.

The calculation of greenhouse gas production takes place in the annexes. Each column in an annex shows the individual factor of emission included in the overall calculation for each type of activity. For each factor, the source reference is also given in the annex below tables. It is also indicated which Tier level, i.e. the degree of detail with which the factor values are calculated. Under the source reference, the year of publication of the report from which the data is taken is given. The principle is illustrated in Figure 3.

PlanEnergi **Annex K1: Methane from rumen gas**

Til index

Data from register
Transferred to accounting

Animal type	Annual or produced livestock [no.]	Conversion between produced and annual livestock	Annual livestock converted	Gross energy consumption per day [MJ]	CH_4 conversion rate	Energy content [MJ/kg CH_4]	CH_4 emission [kg/animal/year]	Emissions [ton CH_4]
Dairy cows (avg.)	103.345	1	103.345	415,47	0,06	55,7	163,50	16.897,11
Slagtekalve 0-6 mdr.	4.873	IE	4.873	66,39	0,03	55,7	6,56	31,97
Slagtekalve 6 mdr.	7.628	IE	7.628	104,18	0,03	55,7	12,17	92,83
Breeding bulls	132	1	132	159,17	0,03	55,7	31,32	4,13
Småkalve	4.636	0,5	2.318	50,85	0,065	55,7	21,68	50,26
Poultry	6.554	IE	IE	IE	IE	55,7	0,000	0,19
Total	263.014							18.942,62

Source:	*Registerdata*	*NIR Tier II Annex 3D-11 NIR, 2022 (2020)*	*NIR Tier II 2020 (2018) Tabel 5.7 og 5.8 og CRF Tabel 3.As1 2020 (2018)*	*IPCC (2006) page 10.31*	*Calculated or from DANISH EMISSION INVENTORIES FOR AGRICULTURE Inventories 1985 – 2018. Scientific Report from DCE – Danish Centre for Environment and Energy, No. 443, 2021.*

Figure 3. *Example of annex single factors, source reference and level of detail*

Columns marked in green in the annexes show that the data is input data and obtained from a register, a statistic or the equivalent. Columns marked in yellow show the results of the calculation, which are transferred to the relevant sector accounts.

The accounts have been prepared so that there is full transparency in the calculated figures. In the annexes, the user can place himself in a given cell and read in the formula line how the value has been arrived at and thus how the mathematical formula, which appears from the UN guidelines and the national climate accounts, has been translated into Excel. In the accounts themselves, a similar transparency to the annexes is given with formulas referring to the correct cell in any given annex.

Yet another layer of information is the bases-data behind the annexes which has been extracted from national databases on a municipal level. This data which is country-specific is shown in separate tabs. As it is country specific, it is given in Danish language. For any other country data would also be extracted from a local source and in local language, as would the stated sources.

And finally, the CRF tables and IPCC annexes have been incorporated into the excel sheet as separate tabs. The use of specific factors from these tables have been organized in an easy-to-overview single tab "NIR factors". For similar ease of use the tab "Index" gives the user of the accounts some shortcuts for navigating the accounts.

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2.2 Overview of input data and calculated values in the emissions account, by account

For the accounts for the 3 emission sectors 1) Agriculture, forestry and other land use, 2) Waste and wastewater as well as 3) Industrial processes and industrial product use, there is an overview given below of which values stem from which annexes - and which data has been calculated with formulas. The table below shows the relationship between (sub)accounts and attachment numbers. The individual partial accounts appear as tabs in the overall climate account for the relevant geographical unit (municipality/region).

Annex	Annex designation
Account for Agriculture – Livestock	
1	Annex 1: Methane from the digestion of livestock (CRF table 3.A)
2	Annex 2: Methane from barn systems (CRF table 3B(a))
2a	Annex 2a: Reduction of emissions from biogas treatment
3	Annex 3: Nitrous oxide from stable system (CRF table 3.B(b))
Account for Agriculture – Plant production	
4	Annex 4: Nitrous oxide from cultivating the soil (CRF table 3D)
5	Annex 5: CO_2 emission from carbon-containing fertilizers (CRF table 3G-I)
5a	Annex 5a: Carbon storage from catch crops in agricultural land
Accounting: Agriculture – Partial accounting: Land use	
6	Annex 6: Carbon storage in forests (CRF table 4A)
7	Annex 7: Carbon stocks in agricultural land, permanent grass, wetlands and settlement area (CRF table 4B-E)
8	Annex 8: Emission from drained and re-flooded area (CRF table 4II)

9	Annex 9: Direct emission of N2O as a result of mineralization and build-up or loss of organic material (CRF table 4 IV)
10	Annex 10: Emissions from burning biomass (CRF table 4V)
11	Annex 11: Carbon storage/emission from the use of wood products CRF table 4G)
Accounting: Waste and waste water	
12	Annex 12: Disposal, biological treatment and incineration of waste. (CRF table 5.A, 5.B and 5.C).
13	Annex 13: Waste water (CRF table 5.D)
14	Annex 14: Accidental fires (CRF table 5.E)
Accounting: Industrial processes	
15	Annex 15: Emissions from different types of industrial processes and industrial product use (CRF table 2(I)A-H and table 2(II))

Table 1. *Overview of codes in the summary sheets for accounting and which annexes the codes refer to*

In the excel sheet, only the relevant tabs are shown, while tabs with data and factors are hidden but can be found by right-clicking on a tab and indicating in the pop-up box which data sheets should be displayed.

2.3 Greenhouse gases, carbon and nitrogen in the climate accounts

A greenhouse gas is a type of air that captures the earth's heat radiation and sends it back to the earth, resulting in global warming.

Six greenhouse gases are included in the climate accounting. Each of the six gases has a different potential to retain heat in the Earth's atmosphere over a period of over 100 years.

The greenhouse potential (also called Global Warming Potential (GWP)) for carbon dioxide is set per definition to 1. The greenhouse potential for the other greenhouse gases is converted to CO_2 equivalents (CO_2-equivalent). CO_2-equivalent is a measure of how much the other greenhouse gases contribute to global warming compared to the greenhouse gas carbon dioxide.

The UN's climate panel has determined conversion factors for each of the greenhouse gases that are calculated in the climate accounts, here are both factors from IPCC's fourth and fifth main report (AR4 and AR5). Which report factors are to be used in the overall accounts can be selected in the Excel sheet.

Below are shown conversion factors for CO_2, CH_4 and N_2O for respectively AR4 and AR5. The F-gases are a collective term for a large number of different gases with very different greenhouse potential. [9,10]

[9] The F gases are found in many combinations (several types of HFC gases, several types of PFC gases, as well as SF6 and NF3). In the municipal accounts, there is no calculation for each of these gases, but an overall calculation based on total data in the national accounts.

[10] The greenhouse potential for the gases has previously been adjusted by the UN climate panel as new knowledge has become available. The greenhouse potential can also be adjusted in the future.

Greenhouse gas	Greenhouse potential: Conversion factor to CO_2-equivalent.	
	AR4	AR5
Carbon dioxide (CO_2)	1	1
Methane (CH_4)	25	28
Nitrous oxide (N_2O)	298	265

Table 2. *Conversion factors for greenhouse gases to CO_2 equivalents*.

In the account either AR4 or AR5 can be selected in the tab "Graphs-climate + GWP og NIR" as basis for all sector accounts.

In addition to the above factors for conversion of greenhouse gases to CO_2 eq., based on IPCC main reports, there are the following conversions from elements to CO_2 eq., based on molecular weights.

Greenhouse gas	Greenhouse potential: Conversion factor to CO_2-equivalent.
Carbon (CO_2-C) to CO_2 [11]	3,67 (44/12)
Nitrogen N_2ON– N_2O [12]	1,57 (44/28)

Table 2. *Conversion factors for elements to CO_2 equivalents.*

3 Changes in methods over years

The municipal climate accounts are adjusted in line with the national climate accounts. This means that methods and calculation factors can change from one year to another.

The municipal climate account follows the guidelines that are used nationally in connection with the annual Danish reporting of the national climate account to the UN climate panel. Between every financial year, the national climate accounting adjusts in methods and in calculation factors, as a result of new research-based knowledge[11]. PlanEnergi can also change methods or factors if there is an opportunity for more exact factors at the municipal level compared to the national level.

In addition to methodological changes, there may also be national updates for a number of years of input data – for example, updates from Statistics Denmark on sales of carbon-containing fertilizers or of roofing felt several years back. This data is also being adjusted on an annual basis.

[11] The national climate account is also evaluated by an audit group from the UN's climate panel every year, which continuously gives rise to adjustments in the national climate account.

For the sake of comparability between years, a backward adjustment must be made in the municipal climate accounts. PlanEnergi carries out the update in connection with a municipality/region choosing to update their climate accounts with a new financial year[12]. The excel sheet is prepared to include several years for presentation of a time-line. Or with two (or more) identical years for use for modelling effects of changes in the inventories in future scenarios.

4 Description of accounts and annexes for agriculture

This emission sector covers agriculture, permanent grass, forest, wetlands, built-up areas and other areas. Other area is mainly rock, dunes and beach.

Agricultural processes are a major source of greenhouse gas emissions. Just like the national climate accounts, the municipal climate accounts make separate statements of livestock farming and the part of plant breeding that consists of annual crops and grass in rotation. There is one account linked to plant breeding and one to livestock farming. In addition, there are the emissions from transport in agriculture (fuel consumption in machines, process needs for heating, etc.), which are mapped in the separate energy accounts.

The carbon storage in grass outside rotation, fruit trees, berry bushes, as well as energy willow and elephant grass and intermediate/follow-on crops is calculated, just like in the national climate account, together with other land use, while all fertilizer use continues to be attributed to agriculture. Christmas trees grown on agricultural land are counted as forest in Denmark, i.e. together with other land use [13].

Municipality-specific data regarding the entire emissions sector is obtained from a number of different sources, which are described below. The most important data sources are the Central Livestock Register (CHR), the General Agricultural Register (GLR), the Fertilizer Register (GR) and five spatially varying data sets for area data.

4.1 Description of accounts and annexes for agriculture

This section describes the accounting items and the methods for calculating the emission and storage of greenhouse gases for livestock and plant production. It is divided into one main section for livestock and one for plant production. Sections are numbered with consecutive annex numbers. For each annex section, reference is made to the numbering for the same collection of accounting items in the national climate accounts' CRF tables.

[12] In addition to method changes, changes in calculation factors, sales statistics, etc. are a large number of factors naturally variable from year to year. This applies, for example, to the content of N in the animals' excretion and the year's harvest result and all input data.

[13] It is important to note that "plant breeding" and "livestock farming" must be supplemented with data from "other land use" and from the energy and transport sectors in order to assess the total emissions of the agricultural sector.

4.1.1 Organic versus conventional agriculture

At the request of the users, an assessment has been made of the possibilities for distinguishing between emissions from organic and conventional plant breeding and livestock farming. Currently, the national climate accounts do not distinguish between organic and conventional operations, but there is a research-based investigation underway in relation to which activity data and factors should be included in a distinction.

In the municipal climate accounts, the decision as to whether a farm is organic or conventional can be made based on information on plant breeding, animal husbandry and fertilizer consumption, as well as information on conventional and organic fields. However, there is a lack of data for so many factors – including e.g. organic and conventional harvest yields, the animals' feed composition, the animals' grazing days, pesticide consumption – that a distinction *cannot* currently be determined.

In addition to the greenhouse gas effect, organic and conventional agriculture should be assessed in relation to the effect on biodiversity, which is not part of the greenhouse gas inventories.

4.2 Accounting for livestock

Livestock emit methane (CH_4) from their digestion and methane and nitrous oxide (N_2O) from the manure produced in the housing system.

4.2.1 Indgangsdata

The Central Livestock Register (CHR) contains information on farms with animals and farm address. This address is paired with Fertilizer Accounts Data (GR) information on fertilizer and barn types via CVR number and address information. In addition, animal, stable type and fertilizer information is paired via the same address with the plant production of the address. A farm/a CVR number often has animals (and plant production) at different addresses, including addresses located in different municipalities.

The distribution of livestock at municipal level is therefore difficult to calculate precisely. As a starting point, the vast majority of the livestock manure produced is expected to be spread on the farm's own fields. The climate accounting therefore includes a condition that the number of animals belonging to one farm(s) (CVR number/numbers) with the same address is distributed according to the distribution of the address's plant breeding among the individual municipalities. Furthermore, it is assumed that the trade of livestock manure between farms takes place within the individual municipal boundaries and/or that the quantity carried out by a municipality corresponds to the quantity imported to the municipality. [14]

[14] This avoids problems with the many holdings/CVR which are administered from law offices etc. in the capital area. If only the administrator's address is taken into account, this will give a misleading statement, especially for municipalities in the capital area. The calculation method used means that if e.g. 20% of a farm/CVR number/address's plant breeding is located in Fredericia municipality, 20% of the animal husbandry and fertilizer consumption are also located in Fredericia municipality.

Almost all livestock, barn types and fertilizer quantities can be distributed in this way, but some farm data (approx. 1%) cannot be matched with fields and thus cannot be verified with plant breeding. For the individual animal, barn and fertilizer types, both the ascertained quantities are therefore calculated can be distributed among the municipalities and the total quantities of the individual types. A factor is calculated for each individual type, by which the calculated quantities in the individual municipalities are multiplied. After being gathered the total quantity of the individual types will then be distributed among the 98 municipalities.[15]

The amount of fertilizer delivered to biogas plants is obtained from the Danish Agency for Agriculture's supplier register for fertilizer deliveries.

Register-based data has been compiled by Aarhus University

4.2.2 Accounting design

The account for livestock is designed as shown below:

Annual livestock or produced livestock (in numbers)					*(ton manure)*	*(ton NH3-N)*	*Activity*	*Emissions (ton)*				
Slaughter calves +6 months	Piglets	Heifer calves	Dairy cows, yearly	Sows, yearly	Mængde til biogas	Lattergasreducerende teknologi	PlanEnergi	CO_2	CH_4 (emission)	N_2O (emission)	CO_2-e per animal	CO_2-e total
7.628	17.968	4.636	103.345	26.600			Rumen gasses		18.942,62		1,84	530.393
83	-	-	4.678	-			Stanchion-tied		175,29	7,59	1,13	6.920
4.790	178	4.636	6.193	1.067			Deep litter		1.154,41	28,93	1,24	39.990
-	-	-	-	180			Free range		0,05	0,00	0,01	1
-	26	-	-	-			Loose housing / box		1,98	0,01	0,06	57
-	-	-	-	-			Loose housing / box/ cage		95,70	0,88	0,09	2.913
2.056	17.763	-	-	25.353			Loose housing / slatted		271,57	9,59	0,09	10.144
698	-	-	92.474	-			Loose housing - cubicles		3.900,89	139,40	1,38	146.165
					407.535		Cattle slurry for biogas (reduction)		0,00			0
					336.035		Pig slurry for biogas (reduction)		0,00			0
7.628	17.968	4.636	103.345	26.600	743.570		**Total**	**0**	**24.543**	**186**		**736.583**

Figure 4. *Accounting for animal husbandry with attachment references*

On the left-hand side of the accounts, the number of annual animals or produced animals in the municipality per kind and type are given. “Annual animal” is the term for the number of animals of a given species and type that are found on the farm on average annual basis. “Produced animals” is the number actually produced. The distinction is due to some animals living 1 year or more, and others living less than a year. The number of species and types that appear in the accounting sheet is aggregated. This means that there are more species and types in the annexes than in the main accounts. The left-hand side also shows the amount of manure delivered from agriculture to a biogas plant.

The grey column of the accounts shows a greatly reduced number of housing types. The housing types are aggregated into main groups from the total number of housing types that are registered in use in Denmark. All housing types can be found in the annexes.

Aggregation of animal species, animal types and housing types in the accounting tab has been done with the purpose of creating an overview. Due to the aggregation, the user must adjust the annexes when scenarios are to be calculated.

[15] Areas for holdings where fertilizer and animal husbandry information cannot be immediately matched are roughly proportionally distributed according to the individual municipalities' plant breeding area, which is why the calculated factors mentioned are used uniformly throughout the country

4.2.3 Annex 1: Methane from livestock digestion

Emission of CH4 from livestock digestion depends on the number of animals in the municipality (annual animals), the species of the animals, their production type, their feed intake in megajoules (MJ) per day, the proportion of feed intake that is converted to methane, as well as a factor for conversion between megajoule (MJ) and methane.

Methane from the digestion of livestock is calculated based on the formula for calculation, which is stated in Denmark's National Climate Account section 5.3.2 (NIR: 2021).

Gross energy intake is calculated at Tier II level (national standard figures). The figures are taken from DCE table Annex 3D-11 and from CRF table 3A. Background data for these tables are feed material tables from SEGES. The methane conversion rate is calculated at the Tier II level for most animals. Individual animal species are based on international averages (Tier I). The figures can be found in the national climate accounts, table, 5.7 and 5.8 (NIR: 2021) and CRF Table 3.A (CRF: 2021) as well as in the UN guidelines vol. 4 table 10.31. (IPCC 2006) The factor for converting methane to megajoules (MJ) is given in the UN guidelines, vol. 4 table 10.31 (IPCC: 2006).

4.2.4 Annex 2: Methane from housing systems

Emission of methane from stable systems depends on the number of annual animals of a given species and types, the associated amount of manure emitted from the animals, and the substrate/bedding on which the animal walks. These variables give rise to a large number of different barn types in Denmark. Emissions are also dependent on the number of (feeding) days per year when the animal grazes, as well as the proportion of volatile compounds while the animal is in stables and on grass. In addition, there is a methane conversion factor and maximum methane production capacity for a given animal.
Calculation of emissions of methane from stables is based on formulas specified in Denmark's national climate accounts section 5.4.2 (NIR: 2021). The calculation is done at Tier II level. By convention in the UN, it has been decided that the amount of volatile compounds excreted from animals on grass is counted under housing types. When calculating methane emissions from stables, Because of the quality of data, Denmark uses manure quantities as a starting point rather than feed intake. The UN guidelines use feed intake for calculation.

The quantity of manure and bedding as well as dry matter percentages are calculated at Tier II level. The figures are taken from the publication Normtal (Lund: 2020). Number of days per year in stables and on grass is calculated at Tier II level. For the entire herd, the figures are obtained from AU, DCE table Annex 3D-9.

Methane conversion factor is calculated at Tier II level, except for a few animal types, where UN standard values are used. The figures are taken from AU, DCE table 3D-13 and UN guidelines, table 10.A4-9. Maximum methane production capacity is taken from Table A4-9 (IPCC 2006).

4.2.5 Annex 2(a): Reduction of emissions from biogas treatment

Methane emissions from housing systems can be reduced by biogas production. In order to calculate the reduction potential for biogas production, the total amount of manure delivered to biogas plants from a farm situated in the municipality is calculated. Data is obtained from the Danish Agency for Agriculture's Supplier Register for manure deliveries.

The method differs from the method in the national climate accounts. The national climate account retrieves data regarding manure for biogas treatment from the Danish Energy Agency's register for Biomass input for biogas production (BIB register).
The calculation is based on the report "Consequences of biogas production for greenhouse gas emissions in agriculture" (DCE: 2016). The calculation takes place at Tier II level.

4.2.6 Annex 3: Nitrous oxide from housing systems

Direct emission of nitrous oxide from housing systems depends on the number of annual animals of a given species and type, the amount of nitrogen contained in manure from the animal, as well as the way in which manure and bedding is handled in the housing system. Indirect emission of nitrous oxide occurs as a result of evaporation of ammonia and nitrogen oxides from stables and storage of manure. Calculation of the emission of nitrous oxide from stables is based on formulas specified in the UN guidelines (IPCC: 2019, p. 10.75).

The amount of manure and nitrogen content in the manure is calculated at Tier II level. The figures are taken from the publication Normtal (Lund (ed.) 2020). Background data are the farmers' fertilizer plans for fertilizing cultivated areas.

Direct emission of nitrous oxide is based on emission factors taken from UN guidelines, Tier I level. (NIR: 2021, table 5.15). Volatilization of ammonia and nitrogen oxides is based on national data. Tier II level. (NIR:2021), p. 416) . Indirect emission of nitrous oxide in the form of ammonia and nitrogen oxides is based on a UN standard emission factor, Tier I level.

4.3 Accounting for Plant Production

Direct emission of nitrous oxide from agricultural land depends on the cultivated area; the amount of nitrogen (N) allocated to the soil as fertilizer; the amount of N contained in crop residues remaining on the soil after harvest; the amount of N that breaks down from organic matter and is mineralized in the soil, as well as the amount of N emitted from cultivated, carbon-rich soil.
Indirect emission of nitrous oxide occurs when mineralized N is leached from the soil into the aquatic environment as nitrate (via precipitation) - or when nitrogen evaporates (nitrifies) as ammonia or nitrogen oxides into the air. The latter depends on the water content of the soil.

4.3.1 Input data

When extracting municipality-specific information from the GLR register, an area is placed as belonging to a municipality, if the area (in practice the centroid of the individual fields) is located within the municipality boundary. The crops that are grown on the area appear in the GLR. In the climate accounts, the crops are divided into the same classes as used in the national accounts and on basis of crop classification from the Danish Agency for Agriculture. For the individual fields, the GLR contains information on whether the form of production is conventional or organic.

With regard to the amounts of fertilizer applied, it is the holdings that submit a fertilizer account to the register that are included. This covers the vast majority of all agricultural land in Denmark.

When the information for the individual farms/CVR/CPR is collected, there are some farms with plant breeding where fertilizer consumption cannot be matched, cf. section 4.2.1 regarding livestock keeping. There are correspondingly individual farms with fertilizer consumption where plant breeding cannot be matched. This fertilizer consumption can be called the non-recorded fertilizer quantity. The unregistered amount of fertilizer amounts to a total of approx. 1.46 million Kg N, of which approx. 1.31 million Kg N is commercial fertilizer corresponding to 0.6% of the total fertilizer consumption, while agricultural area with unrecorded fertilizer amounts was approx. 100,000 ha in 2018, corresponding to 3-4% of the total agricultural area.

The determined amounts of fertilizer are distributed proportionally according to the land assets of the individual farms. This is then added up at municipal level to provisional figures at municipal level. The unregistered 1.46 million Kg N must also be distributed among the individual municipalities. As described above under the section regarding livestock, the distribution is made by multiplying the preliminary fertilizer quantities at municipal level by a calculated factor (total quantity/established quantity) for each type of fertilizer. However, they are distributed approx. 1.31 million kg N chemical fertilizer only on the conventionally cultivated areas, as chemical fertilizer on organic cultivated area is prohibited.
Finally, the quantity of chemical fertilizers has 5% added, so that the total quantities better match Statistics Denmark's figures for sales of chemical fertilizers.
Register data has been compiled by Aarhus University.

4.3.2 Accounting design

The account for plant production is designed as shown below:

(hectares											(ton N2O-N)	ton	(ton N2O-N)		Activity	Emissions (ton)				
Lucerne	Leguminous seeds to maturity	Sugar beet, fodder beet, etc. root vegetab	Cereals and pulses for ensiling (whole gr	Grass and clover field in rotation & seeds for sowing	Grass outside of rotation	Rapeseed, flax, hemp and other industria	Tree cultures	Trees for energy (included in forest definition except energy willow)	Wetlands including mini-wetlands	Fruit and berries, vegetables free range / open air	Others	Harvested straw	Total amount of N fertilizer	Total amount of carbon-containing fertiliz (ton C)	PlanEnergi	CO_2 (emission)	CH_4 (emission)	N_2O (emission)	Carbon sink (ton C)	CO_2-e total
															Plant breeding (areas)					
101	4.639	363	24.022	36.098	12.884	10.694									Crop residues			161		42.557
															Catch crops				-16.602	0
															Plant breeding (N2O-N & C)					
													133		Organic soil (humus, soil) (N)			209		55.498
												-1.570			Straw removed from field (ton)			-25		-6.540
													22		Soil, Mineralization (N)			35		9.312
													169		Fertilizer allocation, commercial fertilizer (N)			265		70.343
													288		Fertilizer allocation, organic fertilizer (N)			453		120.060
															Fertilizer allocation, animals on pasture (N)			40		10.491
											25				Evaporation (N)			63		16.625
											40				Leaching (N)			137		36.383
											87				Lime ($CaCO_3$)	20.875				20.875
														47.447	Urea (CH_4N_2O)	121				121
														165	Calcium ammonium nitrate $Ca(NO_3)_2$	250				250
														2.271	Total	**21.247**	**0**	**1.339**	**-16.602**	**375.976**

Figure 5. *Account for plant production*

On the left-hand side of the accounts, the number of hectares planted in the municipality with a given crop or crop category is recorded. It is only annual crops and grass that appear in the plant breeding account[16]

The left side of the accounts also includes data on the amount of Nitrogen (N) allocated to crops as fertilizer.

[16] Fruit trees, berry bushes, energy willow and elephant grass are also grown, as well as catch and follow crops on agricultural land. The crops are fertilized very little, and the fertilization is attributed in the national climate account to annual crops and grass. The carbon build-up that occurs in fruit trees, etc. calculated in the national climate accounts and in the municipal climate accounts under "land use"

The grey column of the accounts shows the activities that result from agricultural operations on the area emission. The activities that lead to carbon storage, e.g. the cultivation of fruit trees or the establishment of subsequent crops does not appear in the plant breeding account, but in the account for land use.[17]

The accounting tab for plant breeding can be used for scenario creation by changing the numbers on the left side of the sheet. Note that an increased number in one cell must cause a corresponding downward adjustment in one or more other cells. In practice, changes for scenario-building should be done in the annexes or by providing a different data set as to preserve formula links.

4.3.3 Appendix 4: Nitrous oxide from cultivating the soil

Emissions of N_2O from cultivating the land occur both directly and indirectly. Direct emission occurs as a result of fertilizer allocation, it occurs from the crop residues that remain on the ground after harvest and as a result of mineralization in the soil. Indirect emission occurs as a result of evaporation and leaching.

Direct nitrous oxide emission from fertilizer allocation

The municipal climate account calculates emissions from fertilizer allocation like the national account with a UN standard factor of 1% (Tier 1 level) for how much nitrogen is converted to N2O-N. cf. (NIR 2021: table 5.27). The accounts are thus based on the premise that there is no difference between the fertilizer types such as commercial fertilizer, livestock manure and other organic fertilizer in relation to how much nitrous oxide is emitted per kg N.[18]

To convert between N2O-N and N2O, multiply by 44/28 – a factor based on molecular weights.

Direct nitrous oxide emission from manure from grazing animals

The emission of nitrous oxide from manure from grazing animals is calculated as in the national climate accounts. The calculation is based on an average excretion of N from an animal of a given species and type (NIR: 2021 table 5.27) and an average number of days per year that the animal is on grass (NIR Annex 3D, table 9). The calculation is made at Tier II level, with the exception of few animal types, where UN standard values are used.

Part of the amount of N allocated to the soil from grazing animals is emitted indirectly as N_2O via ammonia and NOx.

A national emission factor of 1.8% is used for how much nitrogen is converted to N_2O-N. Tier II level.

Direct nitrous oxide emission from crop residues

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[17] Det kommunale regnskab følger hermed det nationale regnskabs opbygning. En beregning af reduktionseffekten af mellem- og efterafgrøder i landbrug er mulig pba. data i det kommunale regnskab. En beregning af reduktionseffekten for andre typer afgrøder som f.eks. frugttræer eller hegn, kræver adgang til reduktionsfaktorer for de relevante afgrødekategorier.

[18] Regarding commercial fertiliser, the national climate accounts indicate different factors for different types, cf. table 5.18 (NIR: 2021). The national accounts do not calculate the amount of biogasified fertilizer that is allocated to the fields separately. As the registers contain information on biogasified fertiliser, the municipal accounts can calculate emissions provided information is provided on emission factors for the type of fertiliser.

The municipal climate account calculates emissions from crop residues as in the national climate account. The nitrous oxide emission is a function of the number of ha planted with a certain type of crop, the annual harvest result for the crop, the dry matter content of the harvested crop and dry matter residues above and below ground, the plowing rate 25 and kg N in the straw that is salvaged.

Information on the average harvest result for a given crop per ha is obtained from Denmark Statistics, the statistics bank (Statistics of Denmark: HST77). The harvest result is calculated at Tier II level.

The dry matter content in % of a given crop in is obtained from SEGES' feed material table for the current year. The dry matter content is calculated as the national average per crop per ha (Tier II level).

The dry matter residue above ground in the crop residue is calculated based on kg of dry matter per ha in the harvested crop and the slope and intercept that apply to the individual crop, as well as the plowing rate for the crop. The slope and intercept are UN standard values (IPCC: 2006, Table 11.2). Kg N per kg dry matter residue is also obtained from table 11.2. (IPCC:2006). Both values are Tier I level.

Dry matter residue below ground is a ratio that is calculated based on the biomass that is above ground. The number is a UN standard value (IPCC: 2006, table 11.2.) Kg N per kg dry matter residue is also obtained from table 11.2. (IPCC:2006). Both values are Tier I level.

The plowing rate indicates how often the field with a given crop is plowed over. The municipal climate accounting follows the standard of the national climate accounting, which is that a one-year crop is plowed once a year (1.0). Grasslands are plowed once every three years (0.33).

The quantity of salvaged straw in Denmark is calculated in hectokilo per ha (Hkg/ha). Straw salvage is calculated as a whole and not for each crop type (Statistics Bank: HST77). To calculate the N content in the straw, the municipal climate accounting uses a method provided by DCE and which is used by the Climate Council in their tool for calculating greenhouse gas emissions from agricultural enterprises (Climate Council: 2016, p. 18).

3.3.3.1 Direct nitrous oxide emission from mineralization in the soil

Nitrous oxide is emitted from cultivated mineral agricultural soil as a result of the loss of organic material in the soil. Loss of organic matter changes the C:N ratio in the soil, i.e. the ratio between carbon and nitrogen.

The national climate account calculates kg N from mineralization in the soil using C-TOOL, a dynamic modelling tool that can measure long-term changes in soil carbon content (Tier III level). The municipal climate accounting does not use C-TOOL, but a simplified version of the same method based on information in CRF table 3.D. The method is taken from the Climate Council's tool for calculating greenhouse gases on the individual farm (2016).

Information on the total amount of N from mineralization in Denmark is obtained from CRF table 3D and divided by the total number of hectares of mineral soil in Denmark to obtain a mineralization factor per hectare.

To convert between N and N2O-N, a UN standard factor of 0.01 is used (IPCC: 2006, Table 11.1)

Direct emission of nitrous oxide from organic soil

The municipal climate account calculates emissions from organic soil like the national climate account for three types of agricultural land (cf. field map from the Danish Agency for Agriculture). The three types are: 1) deep-drained agricultural land - annual crop, 2) deep-drained grass, and 3) shallow-drained grassland. The latter is defined in the national climate accounts (NIR 2021) as agricultural areas that have not been included in the EU support applications, which lies behind the source database in the calculation year, but which are still included in the agricultural area - i.e. superficially drained, nutrient-rich grass in the 2013 Wetlands supplement (IPCC 2014). These areas may have become too bad/wet to be used for production and have therefore been transferred to category (3). Some of these areas can be found in the land use data set, where they figure as "permanent wetland" or "periodic wetland" (Levin et al 2014). These areas are not included in (3). All areas are divided into slightly carbon-rich soil (6-12% OC) and very carbon-rich soil (12-100% OC). For each of the six resulting categories, a separate (estimated) emission factor is assigned (NIR 2021: p. 420). The emission factor is at Tier II level.

Indirect emission from evaporation of ammonia and nitrogen oxides

Atmospheric emission of nitrous oxide as a result of evaporation of ammonia (NH_3) and nitrogen oxide (NOx) depends on the amount of commercial fertilizer and organic fertilizer as well as manure from grazing animals that is spread on the field. In addition, part of the N evaporates from the crop residue as ammonia and nitrogen oxide.

The factors for the proportion of N that evaporates from commercial fertilizers, organic fertilizers and from crop residues is given in CRF table 3.D. The values are UN standard values at Tier I level. To convert between N and N_2O-N, a standard factor of 0.01 is used, which is taken from UN guidelines (IPCC 2006: Table 11.1)

Indirect emission from leaching

The municipal climate accounting uses the same method as the national accounting, which uses a UN standard factor at Tier I level. Here it is assumed that the same amount of N is leached from all fields. [19]

[19] The same amount of N is not leached from all fields. N leaching depends on the type of crop, on catch crops, as well as of soil types and geological conditions.

The leaching depends on the total amount of fertilizer spread on agricultural land, which the municipal climate accounting takes from the fertilizer register.

Proportion of N that leaches out is given in CRF table 3D

To convert between N and N2O-N, a UN standard factor of 0.0046 is used (IPCC 2006: table 11.1)

4.3.4 Appendix 5: CO2 emission from carbon-containing fertilizers (CRF table 3G-I)

Fertilizing soil with carbon-containing fertilizer products results in a small release of CO2. Carbonaceous fertilizer products are lime, urea and calcium ammonium nitrate.[20]

In Denmark, liming is mainly done with limestone (CaCO3). 0.0002% of liming is done with dolomite lime, which is why all liming in Denmark is considered limestone. Liming depends on the soil and how much lime the plant species removes from the soil. The municipal accounting, however, distributes liming equally on all ha of agricultural land in Denmark and the municipality.
Information on the amount of liming with limestone is obtained from CRF table 3 G-I. Information regarding lime is originally taken from SEGES' sales statistics and as far as fertilizers in private gardens are concerned the amount based on expert judgment. Information on quantities of urea and calcium ammonium nitrate is originally based on expert assessment from the Danish Agency for Agriculture. Here data is taken from CRF table 3G-I. Data is at Tier II level.
The municipal climate accounts use the same emission factors to calculate emissions of carbon dioxide as a result of fertilization with calcareous products, which appears in CRF table 3G-I. The calculation is made at Tier I level, where the UN's standard values are used.

4.3.5 Appendix 5: CO2 storage from catch crops

The national climate account and the UN's guidelines do not include the CO_2 storage resulting from the cultivation of subsequent and intermediate crops under the category of plant breeding. Instead, the storage effect is included under the land use category. Cf. CRF Table 4B. The same applies to the carbon stock from areas planted with fruit trees and shrubs, fences, energy willow and elephant grass.

On the basis of the published data, it is not possible to distinguish a storage from subsequent and intermediate crops, from the other storage effects. Based on the wishes of the users of the accounts, a separate appendix is included, where the storage effect from catch crops is calculated. However, the storage effect is not included in the accounting for plant production, as it will be included in the accounting for land use - although here without the possibility to separate out the factor from other carbon storage factors on agricultural land.

For the calculation, the municipal climate account uses the same method as the Climate Council's tool for calculating greenhouse gas emissions from agricultural enterprises (Climate Council: 2016. p. 22).

[20] The nitrous oxide emission from commercial fertilizer types that also contain nitrogen is included in the emission for commercial fertilizer.

In the Climate Council's tool, the increased carbon sequestration is the same regardless of soil type. The carbon sequestration is 0.733 tonnes of CO_2-equivalent. per ha.

Burning of crops on agricultural land

Burning of crop residues on agricultural land is prohibited in Denmark, except in connection with seed grass production and if there are wet or rotted straw bales left in the field.

The national emission from burning in connection with seed grass production is vanishingly small, with a total national emission of CH_4 of 141 tonnes and of N_2O of 4 tonnes. For the same reason, the burning of seed grass is not calculated in the municipal climate account. [21]

The national climate account estimates that 0.1% of the total straw production is burned in the field. The emissions from burning straw bales are not calculated in the national climate accounts and therefore not in the municipal climate accounts either.

4.4 Accounting for land use and changes in land use as well as use of harvested wood

This section describes the accounting items and the method basis for calculating land use and land use changes as well as emission and storage of greenhouse gases within the emission sector "Land use and changes in land use".

Land use is divided into 6 main categories, namely forest (including Christmas trees grown on agricultural land), permanent grass, agricultural land, wetlands (both permanent and periodic wetlands), settlement area and other land divided into the three soil types: mineral, carbon-rich and very carbon-rich soil. Other area is e.g. cliff and beach.

Emissions and coastal emissions from permanent land use and conversion of land use are calculated, as well as the effect of drainage or reflooding of forest, permanent grass, agricultural land and wetlands.

In accordance with guidelines in the UN's climate accounting, the carbon stock or emission associated with the consumption of harvested wood products is also estimated.

4.4.1 Input data

Land use information is based on five spatially varying datasets:

[21] It is possible to distribute the national emission equally over the total number of ha in Denmark. It is possible to calculate the total number of ha of seed grass in Denmark and a municipality via GLR. Currently, seed grass is merged with other plant breeding categories, and division is not considered worth the effort.

1) Land use - a nationally covering grid in 25×25 m resolution for the years 1990, 2020, 2005-2020 where each cell has a value that codes for a land use (Levin et al 2014) of forest, permanent grass and agricultural land. [22]

2) Carbon - a national covering grid in 30.4×30.4 m resolution where each cell describes a continuous carbon percentage in the soil (Adhikari et al., 2013),

3) Reflooding - here a grid in 25×25 m resolution is calculated based on the land use (1). A cell is flooded again if, from 2005 to 2017, it has changed from either forest, agriculture or permanent grass to a wetland (AU).

4) Peat digging - a digitized polygon data set describing area with peat digging generated based on aerial/sattelite images.

5) Drainage - a grid covering the agricultural area in 2018 in 30.4×30.4 m resolution, where each cell describes whether an area is drained or not (Møller et al., 2018).

These five geographical data are all in relatively high resolution, and it is therefore possible to scale down NIR's national land use calculations to a municipal scale. However, it should be noted that for drains, there is only geographical information in Denmark on the agricultural area and parts of the permanent grass, which was formerly agricultural area. These data cannot therefore be used for the municipal calculations for drained forest. The geographical area is therefore used for the agricultural area drainage map (Møller et al., 2018), and to estimate drained areas for forest, the estimated percentages of the national climate accounts are used (NIR 2021: section 6.9.2). An amalgamation of the five geographical layers in ArcGIS + the national percentage of drained forest makes it possible area calculations within each municipality.[23]

For the calculation of land changes and permanent land use, only data 1 and 2 (data on land use and carbon percentage in the soil) are combined, as is also the case in the calculations of the national climate accounts. Area changes are based on changes from 1990 to 2020 for forest and 2005 to 2020 for all other land uses. Input data on area changes for the municipal climate accounts are area change matrices, prepared in ArcGIS, which describe the size of area changes and remaining areas (table 5). All this information is geographically conditioned.

Below is an illustration of the area change matrix used.

[22] According to the UN guidelines, in the event that an area can fall within more than one category, priority must be given in the following order: 1) settlement area 2) agricultural land 3) forest 4) permanent grass 5) wetland 6) other.

[23] Note that the result will depend on how this data is interpreted and compiled (e.g., depending on whether average carbon content or the distribution of different classes of carbon content within the geographical areas indicated units).

Year 2020 / Year 2005	Area 1	Area 2	Area 3	Area 4	Area I 2005
Area 1	Unchanged	Area change from area 1 to area 2 from 2005 to 2020	Area change from area 1 to area 3 from 2005 to 2020	Area change from area 1 to area 4 from 2005 to 2020	Total area 1
Area 2	Area change from area 2 to area 1 from 2005 to 2020	Unchanged	Area change from area 2 to area 3 from 2005 to 2020	Area change from area 2 to area 4 from 2005 to 2020	Total area 2
Area 3	Area change from area 3 to area 1 from 2005 to 2020	Area change from area 3 to area 2 from 2005 to 2020	Unchanged	Area change from area 3 to area 4 from 2005 to 2020	Total area 3
Area 4	Area change from area 4 to area 1 from 2005 to 2020	Area change from area 4 to area 2 from 2005 to 2020	Area change from area 4 to area 3 from 2005 to 2020	Unchanged	Total area 4
Area I 2020	Sum areal 1	Sum areal 2	Sum areal 3	Sum areal 4	Totalt areal

Table 5. *Theoretical area change matrix*

Estimated land use and land changes have been prepared by Aarhus University.

Information regarding the consumption of wood comes from FAO's statistics, "Forestry Production and Trade", http://www.fao.org/faostat/en/#data/FO. The municipal accounts use figures for the total Danish consumption of wood, i.e. including wood products that are imported to Denmark and excluding wood that is exported. The national Danish climate account, on the other hand, uses figures for the total Danish production of harvested wood.

Both methods are permitted according to UN guidelines. The fact that the municipal climate accounts use consumption statistics is because it is not possible to obtain data at municipal level regarding both production and consumption of harvested wood (personal communication, KU IGN). It is therefore necessary to estimate municipal use of wood based on the number of inhabitants when it comes to paper and based on the number of m2 of building area when it comes to sawn timber and wood panels.

Areas remaining in current use and changes in area use

According to international and national guidelines, a "permanent land use" is an area which has been planted with forest for over 30 years (in Denmark) or which has been permanent grass, agricultural land, wetland, settlement area or other for over 20 years. A "change in land use" characterizes an area which has been established with forest within the last 30 years or which has been established with permanent grass, cultivated agricultural land, wetland settlement area or other within the last 20 years.

Denmark has area measurements for 1990, 2005, 2011 and onwards. This means that for the entry year 2018 we know whether an area has been planted with forest 30 years ago, but not whether the area has been forested for all 30 years or longer. Similarly, we know that an area has been continuous grass, crops, wetlands or settlement area for 15 years, but not whether the area has been the same for 20 years or longer.

Denmark's national climate accounts compensate for the missing information by percentage distributions. Eg. that 85% of the forest that stood in 1990 is over 30 years old and 15% was created within 30 years. At municipal level, these percentage distributions are not appropriate, because the reference to the area-based data is thus lost. In Denmark, the areas are not geographically randomly distributed - i.e. that in some municipalities more than 85% of the forest may be over 30 years old, while in other municipalities there may be a significantly smaller proportion of the forest which is over 30 years old. Therefore, a municipality would e.g. get an area with forest which does not refer to a real area in the municipality, which is inappropriate in planning. The municipal climate account therefore approximates 30-year-old forest to be more than 30-year-old forest and 15-year-old areas with agriculture, permanent grass, wetlands or buildings to be more than 20-year-old areas.[24]

4.4.2 Accounting design

There is an account linked to "Land use and changes in land use", as shown below

[ha]							[m³]	Activity	Emissions [ton]					
Forest	Farmland	Permanent grass	Wetland (periodically flooded)	Wetland (lake, stream, etc.)	Settlement	Other area	Annual change in the pool of harvested wood products nationally	PlanEnergi	CO_2 (emission)	CH_4 (emission)	N_2O (emission)	C (sink/-emission)	ton CO_2-e/ha	CO_2-e total
								Land use						
43.879								Permanent Forest Land > 30 yrs (> 28 yrs)				-9.711	1	35.608
	252.687							Permanent Crop Land > 20 yrs (> 13 yrs)				-153.339	2	562.243
		13.055						Permanent Grassland remaining Permanent Grassland > 20 yrs (> 13 yrs)				-11.833	3	43.387
			6.999					Permanent Wetland (peat extraction) > 20 yrs (> 13 yrs)				0		0
				6.629				Permanent lake, river, etc. > 20 yrs (> 13 yrs)				IE		IE
					32.383			Permanent settlement > 20 yrs (> 13 yrs)				0		NO
						2.217		Permanent Other Land > 20 yrs (> 13 yrs)				0		NO
								Mineralization (permanent landuses)						0
	10.357	666	139	0	0	7		Conversion to Afforestation < 30 år (< 28 yrs)				6.879	-2	-25.224
307		1.388	39	0	0	18		Conversion to Crop Land < 20yrs (<13yrs)				0	0	0
257	6.354		2	0	0	6		Conversion ot Permanent Grassland < 20yrs (<13yrs)				0	0	0
26	412	177						Conversion to Wetland (periodically flooded) < 20yrs (<13yrs)				0		0
11	195	5						Conversion to lake, re-slinging of river, etc. < 20yrs (<13yrs)				0		0
89	1.916	79	6	0		36		Conversion to Settlemnet < 20yrs (<13yrs)				-2.819	5	10.337
								Conversion to Other Land < 20yrs (<13yrs)						0
307		1.388						Mineralization when converting to Crop Land			0,36			95
257	6.354							Mineralization when converting to Permanent Grassland			0,19			52
89	1.916	79						Mineralization when converting to Settlement			91,77			24.320
1.231	4.140	355						Drainage of Organic Soil 6-12% OC	980	277	3		2	9.659
	3.146	309						Drainage of Organic Soil 12-100% OC	754	153			1	5.039
	126	41						Rewetting of soil 6 - 12% OC		3				91
	64	51						Rewetting of soil 6 - 100% OC		4				125
						0		Peat excavation		0	0			0
			7.614					Organic wetlands partly water covered (periodically wet)		2.183			8	61.302
		NR						Wildfires		NR	NR			NR
		NR						Controlled burning (only Permanent Grasslands)		NR	NR			NR
								Use of harvested wood products						
							-319.095	Sawn wood (in use)	14.729					14.729
							211.587	Wood Panels (in use)	-11.473					-11.473
							-152.254	Paper and Paperboard (in use)	7.583					7.583
46.452	287.666	17.593	14.799	6.629	32.383	2.283		**Total emissions/sinks**	**12.574**	**2.627**	**96**	**-170.823**		**737.873**

Figure 6. *Accounting for land use and change in land use with attachment references.*

The left side of the accounts shows the number of ha in the municipality that are used for a given purpose or the number of m3 of semi-processed wood products estimated to be in use in the municipality. Note that the same area, e.g. can be permanent agricultural land and

[24] In the assessment year 2021, permanent forest will be able to be assessed as over 30 years old and in the assessment year 2026 all other areas will be able to be assessed as over 20 years old.

drained organic soil. The sum of the areas on the left-hand side of the account is thus greater than the municipality's total area.

The middle gray column shows the type of activity taking place on the area or the type of ongoing consumption of wood. The right side of the accounts shows the emission and storage of greenhouse gases.

Negative CO_2 equivalents indicate displacement of greenhouse gas and positive CO_2 equivalents indicate emission of greenhouse gas.

By changing the number of ha on the left side of the account, the effect of e.g. increased afforestation on former (future) agricultural land or conversion of organic agricultural land to wetlands is calculated.[25]

Each subsection of this chapter refers to an appendix. Annexes are numbered with the following annex numbers 6-11. In addition, for each subsection, reference is made to the number of the CRF table (Common Reporting format) in the national climate accounts, which shows the corresponding calculation for Denmark.

4.4.3 Annex 6: Carbon storage in forests

Forest is defined as an area with trees that is larger than 0.5 ha and at least 20 meters wide. On site, the trees must be able to reach a height of at least 5 meters with a crown cover of at least 10%.

It should be noted that agricultural areas planted with Christmas trees are also categorized as forest when they otherwise meet the above definition. This is in accordance with the national Danish accounts for greenhouse gases.

Emission factors

The municipal climate accounting uses the emission factors that are stated in Denmark's national climate accounting CRF table 4A. The emission factors are calculated at Tier II level based on the stock change method, where the difference in measured carbon content on sampled areas for $Time_1$ and $Time_2$ is converted into an annual build-up or an annual loss by dividing by 30 (year).

Stocks and emissions of greenhouse gases depend on:

- The amount of living biomass above and below ground
- The amount of dead biomass
- The thickness of the forest floor

[25] However, it should be noted that the municipal climate accounts use the same factors as the national accounts. Power calculations made according to this method will therefore e.g. show results for an average Danish forest. Forest types vary greatly locally. It may therefore be advantageous to use a table of carbon sequestration for the type of forest that is dominant in the municipality (e.g. Kvist Johansen et al, 2019).

• The carbon content of the soil

Storage and emissions depend on whether the forest is production forest or natural forest. So far, all forest in Denmark is calculated as production forest.

In addition, storage and emission depend on which tree species the forest is characterized by (e.g. coniferous forest, deciduous forest and mixed forest), on the increase including as a result of climatic conditions (e.g. temperature, rainfall), cultivation conditions (e.g. harvest, plowing depth), the input of organic material to the soil, and disturbances in the form of disease attacks or fire, etc. All these conditions are taken into account in the national calculation of emission factors and the emission factors will therefore vary from year to year år. [26] Johannsen, V.K. et al., (2019).

4.4.4 Annex 7: Carbon stocks in agricultural land, permanent grass, wetlands and settlement area

Agricultural land is areas planted with annual agricultural crops and perennial wood crops, such as berry bushes, fruit trees, willow and elephant grass. Agricultural land also contains fences and small biotopes that fall outside the definition of forest, as well as ditches and roads that fall outside the definition of settlement area.

Permanent grass is defined as moorland and bush-covered areas as well as marginal land in agriculture.

Wetlands are defined as naturally occurring lakes and streams (full water cover), fens and bogs, drained peat digging soil, as well as re-established wetlands/re-flooded areas and newly established lakes.

Settlement area is area with buildings, infrastructure, roads, as well as cemeteries and sports facilities.

Storage and emission are not counted for so-called "Other area" in Denmark. Other area is e.g. stone and rocky ground, as well as sand and dunes.

Emission factors

The municipal climate accounting uses the emission factors that are specified in Denmark's national climate accounting CRF table 4B-E.

Stocks and emissions of greenhouse gases generally depend on:

[26] In 2019, the Department of Geosciences and Natural Resources at the University of Copenhagen published the reports "Carbon effects of afforestation" and "Climate effects of untouched forest and other biodiversity forest". These reports show tables with different carbon storage for different tree species and production types. Unfortunately, it is not possible to include this knowledge in the municipal climate account's calculation of carbon stocks, as existing area databases cannot distinguish between types of forest and tree species at a sufficiently accurate level. If it becomes possible to obtain accurate area data in the future, the emission factors must be recalculated for the respective forest types and tree species.

• The amount of living biomass above and below ground

• The amount of dead biomass

• The carbon content of the soil

Farmland

For agricultural land, which remains agricultural land, there is no change in the living biomass on areas with annual crops. The carbon content of the biomass is given a standard value corresponding to the carbon content of spring barley. When converting a permanent agricultural area with annual crops to another land use, there is a corresponding loss in carbon content in living biomass. For perennial woody crops, an average value is calculated for the type of crop cf. the national accounts (NIR 2021) table 6.15 page 483. The total agricultural area with woody crops in Denmark constitutes in 2019 0.07% of the total area in Denmark. Due to the small total area with wood crops in Denmark, the municipal area with the various types of wood crops is not calculated separately in the municipal climate accounts. Calculation of carbon content in fences awaits the development of a new national fence model. Overall, the calculation takes place at a Tier II level.

There is no calculation of dead biomass for the above biomass types on agricultural land.

Carbon changes in mineral soil are calculated with the modelling tool C-TOOL, which was prepared by Aarhus University. Measurement takes place at Tier III level. Carbon change in organic soil 6-100% OM (organic material) is calculated based on Danish research results. Carbon change in organic soil 6-12% is set as 50% of carbon change of soil with 12-100% OM. The calculation is done at Tier II level.

Permanent grass

For permanent grass which remains permanent grass, no change in the carbon content of living biomass is calculated. There is no dead biomass on areas with permanent grass and therefore no carbon sequestration in dead biomass. When converting a permanent grassland, a change in living biomass is calculated with national emission factors at Tier II level. Build-up of carbon in mineral soil for permanent grass owned by agriculture is calculated under agricultural area and is indicated as not estimated (IE) under the area with permanent grass. For grassland that is not owned by agriculture, carbon build-up in mineral soil is not calculated. A national organic soil emission factor has been set for permanent grassland. The inventory is at Tier II level.

Wetland area

There is no change in the carbon stock of living and dead biomass for wetlands that remain wetlands. Only for peat excavation soil is a change in the soil's carbon content calculated based on the amount of peat that is removed from the soil. CH_4 and N_2O emissions from peat digging soil are calculated.

The change in carbon stock of living biomass is calculated for wetlands that have been established since 2012 and until 2017 (National Board of Agriculture 2019). Here, a carbon build-up of 4000 kg of dry matter per ha of living biomass above ground and 1200 kg of dry matter per ha of living biomass below ground is calculated. When a forest is converted to a wetland, an immediate loss of dead biomass of 100% is calculated. This is converted by calculating 0.5 kg C per kg dry matter. No carbon change in the soil is calculated when converting to a wetland.

Settlement area

There are no changes to the carbon stock in living biomass, dead biomass or the soil in settlement area which remains settlement area. When converting to settlement area, there is a build-up in the carbon pool of living biomass above ground of 2200 kg dry matter per ha and in live biomass below ground of 2200 kg dry matter per ha. The soil's carbon content is 96.7 tonnes of C per ha, which builds up over 100 years.

4.4.5 Annex 8: Emission from drained and rewetted area

Emissions are calculated from drainage of forest, agricultural land, permanent grass, as well as from the wetland categories peat digging soil and partially water-covered wetland.

The municipal climate account uses the same emission factors as are indicated in Denmark's national climate account CRF table 4II.

Forest

A UN standard value is used to calculate N2O emission from drained organic forest soil and N2O emission from re-flooded forest area is set to 0. The calculation is done at Tier I level.

The CH4 emission factors for drained organic forest soil are IPCC standard values at Tier I level. (Cf. table 6.12 in the national climate accounts (NIR 2021). Emissions from reflooded organic forest soil have not been estimated. There is no CH4 emission from reflooded mineral forest soil.

Agricultural land and permanent grass

N2O emissions from agricultural land and permanent grass are calculated under the accounts for plant breeding. One UN standard value is used to calculate CH4 emission from re-flooded organic agricultural land with an organic content of 12-100% OM and another UN standard value for emission from re-flooded organic permanent grassland. For soil with an organic content of 6-12%, the emission factors are halved.

Wetland area

The factors for calculating N2O and CH4 emissions from peat digging soil are UN standard values at Tier I level. They appear in table 6.12 in the national climate accounts (NIR 2021).

4.4.6 Annex 9: Direct emission of N_2O as a result of mineralization and storage or loss of organic material

The nitrogen content (N) in the soil can be calculated from the carbon content (C) via a C:N ratio.

A UN standard value of 1% of the soil's nitrogen content is emitted as N_2O in connection with conversion from one area to another. Tier I level. However, nitrous oxide is only emitted when an area with a lower carbon content than the previous area is added.

The municipal climate account uses the same emission factors for calculating the emission of nitrous oxide as a result of mineralization in the soil, which appears in CRF table 4III. The calculation is therefore done at Tier II level, where national values are used for the carbon content in the soil in the various land types. The national calculation is based on equation no. 11.8 in IPCC 2019 (2006) vol. 4. ch. 11 page 11.20.

Regarding direct nitrous oxide emissions, it should be noted that all fertilization of agricultural land, including fertilization of Christmas trees, is calculated in the accounts for agriculture and not in the accounts for land use and changed land use. This corresponds to the method in the national climate accounts.

4.4.7 Annex 10: Emissions from burning biomass

Wildfires rarely occur in Denmark due to the humid climate. Normally between 0 and 10 ha per year burns.

Information on controlled burning of moorland is obtained annually from the Norwegian Nature Agency, which calculates moorland burning within state forest districts. There may be other heath areas that are burned within the municipal boundary than those owned by the state. A municipality must approve all heath burning within the municipal boundary. If a municipality therefore has better information about areas where heath burning is carried out, the municipality can enter these figures for the relevant year.

A UN standard factors at Tier 1 level is used to calculate emissions from controlled burning

4.4.8 Appendix 11 Carbon storage/emission from the use of wood products

The UN's climate accounting allows different methods to calculate carbon stocks or emissions from the pool of harvested wood products that are in use in a single year. In accordance with UN guidelines, a country or a municipality chooses whether the stock should be calculated based on the quantity of semi-finished wood products produced within the country/municipality border or the quantity consumed within the country/municipality border.

The national Danish climate account estimates the carbon stock in or the emission from harvested wood products based on Danish production of the semi-finished wood products, sawn timber, wood panels and paper products and cardboard. This method cannot be used at municipal level. This is due to a lack of data for production at municipal level, as well as the fact

that production is very different from forest to forest. The number of hectares of forest within the municipal boundary cannot be used as a key for the distribution of the national production of harvested wood products.

Therefore, the municipal climate account uses the UN's method to estimate carbon stocks based on the national consumption of sawn timber, wooden panels and paper products and cardboard.

The consumption of sawn timber and wooden panels is distributed according to the total number of square meters in the municipality's building stock in relation to the total number of square meters in the national building stock. This is based on the assumption that the consumption is fairly evenly distributed per m^2 building area[27].

The consumption of stationery and cardboard is distributed according to the number of inhabitants in the municipality in relation to the total number of inhabitants in Denmark. This is based on the premise that consumption is distributed fairly evenly per inhabitant in Denmark.

The municipal estimate for carbon stocks or emissions from harvested wood products is thus calculated at Tier 1 level. Due to the calculation method, a municipality cannot measure an increased carbon build-up when using wood in the municipal building stock. Only a general national effort will be measurable at municipal level.

Calculation of the pool of harvested wood products

According to UN guidelines, harvested wood products are divided into 3 semi-finished product categories, namely sawn timber, wooden panels and paper and cardboard. The figure below shows how these product categories are part of the value chain for wood products.

Figure 12.3 **Examples of different processing stages of wood products along the process and value chain**

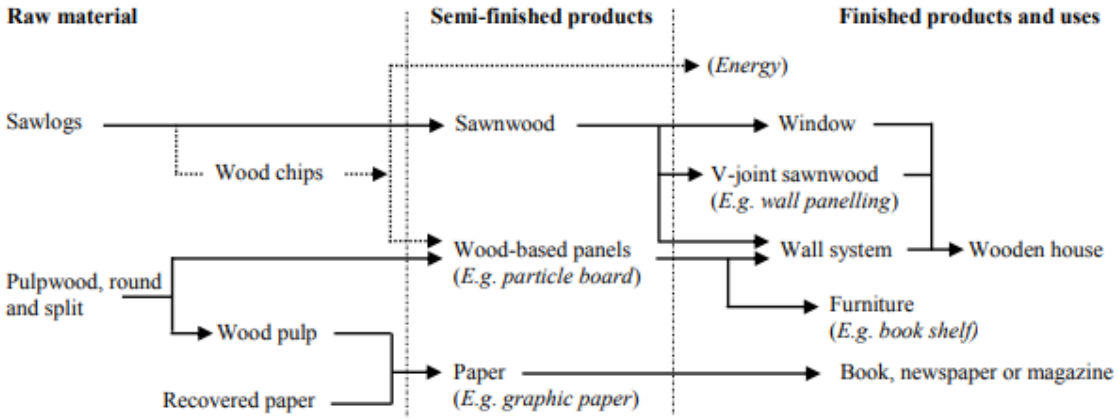

Figure 7. *The value chain for wood products. Source: Figure 12.13 in IPCC 2006, Volume 4*

[27] The area of the building stock is so far estimated to be the best available distribution key, but this may be an area for further development of the municipal climate accounting. Information on the area of the building stock is obtained from https://www.statistikbanken.dk/BYGB34

The size of the annual carbon content and annual net change in the pool of harvested wood products that are in use is estimated from the annual inflow of wood products into the pool and the annual outflow.

An inflow is calculated as the sum of Danish production and imports minus exports of Danish produced wood (cf. formula 12.6 IPCC 2019 ch. 4).

An outflow is calculated based on the UN's standard half-life for the 3 product categories sawn timber, wooden panels and cardboard and paper. The standard half-life is an estimate of the number of years it takes for half of a wood product of a certain type to be taken out of the pool – i.e. cease to be in use. (Cf. formula 12.2. in IPCC 2019 chapter 4.) The half-life for sawn timber is given by the IPCC as 35 years, for wood panels it is 25 years and for paper and cardboard the half-life is 2 years including recycling.

In order to estimate the carbon pool in wood products in a given year and changes between years, it is necessary to know the historical use of wood products. This means that the historical inflow and outflow from the pool must be included in the calculation. Here, the municipal accounting (just like the national Danish climate accounting) uses the assumption that the carbon pool was at a stable stage in 1990. This stable stage is calculated based on UN guidelines (Cf. formula 12.4. In IPCC 2019 ch. 4).

Calculation of carbon stock and CO_2-equivalent. in the pool of harvested wood products

The carbon content in harvested wood products is calculated based on the dry matter content per m^3 and the carbon content in each of the three product categories sawn timber, wood panels and paper and cardboard. The carbon conversion factor is given in table 12.1 (IPCC 2019 ch. 4).

The municipal climate account uses the UN's standard values to calculate the carbon content in the carbon pool (The national Danish climate account uses national values, but for wood produced in Denmark).

The total CO_2 storage in harvested wood products is calculated as the sum of carbon content in the 3 product categories.

5 Accounting for waste and wastewater

This chapter describes the methods and accounting entries for calculating greenhouse gas emissions for the waste and wastewater sector.

The sector is divided into the following emission categories: Disposal of solid waste, biological treatment of solid waste, incineration and open burning of waste, wastewater treatment and discharge, and accidental fires.

In Denmark, waste and wastewater production is a limited source of greenhouse gas emissions. As a whole, the sector contributes approximately 2.8% of the total national emissions of greenhouse gases. The sector's total emission of greenhouse gas has fallen by almost 35% in the period 1990 to 2018, primarily as a result of a 65% reduction in emissions from landfills. As a result of a previously adopted ban, emissions from landfill will continue to fall going forward.

To calculate emissions from the waste and wastewater sector, the municipal climate account uses data from the national climate account (NIR) and distributes the total national emission relatively per inhabitant of the municipality.

A account tab for "waste, wastewater and accidental fires" is provided with a design as shown in the figure below.

(no.)	*(ton)*				*Activity*	*(ton)*			
Accidental fires	Waste water	Incineration of waste	Biological treatment of solid waste	Disposal of solid waste	PlanEnergi	CO2	CH4	N2O	CO2-e total
					Waste:				
				24.646	Managed disposal sites		789		22.085
				NO	Unmanaged disposal sites		NO		
				NO	Uncategorized disposal sites				0
			NO[1)]		Composting		150	10	6.822
			NO[1)]		Anaerobic turnover in biogas plants		355		9.935
		41			Waste incineration	NO	0	0	10
		NO			Open waste incineration	NO	NO	NO	
					Waste water:				
	NO[1)]				Domestic waste water		71	7	3.830
	NO[1)]				Industrial wastewater			1	216
	NO[1)]				Other				0
					Accidental fires:				
269					Accidental building fires	3.573	4	0	3.672
89					Accidental vehicle fires	223	0		236
357	0	41	0	24.646	**Total**	**3.796**	**1.369**	**18**	**46.804**

Figure 8. *Accounting for waste and wastewater*

The left side of the account shows the main categories in which the waste and wastewater sector is reported. T he middle gray column shows the activity which within a main category causes greenhouse gas emission. The right side of the accounts shows the emission of various greenhouse gases in ton.

The main category, 'solid waste disposal' includes CH_4 emissions from solid waste deposited in landfills and is one of the primary sources of the waste sector's total emission of CO_2 equivalents.

The main category, 'Biological treatment of solid waste', consists of the activity 'composting' and the activity 'anaerobic turnover in biogas plant'. Composting includes CH_4 and N_2O emissions from composting garden and park waste, organic waste from households, sludge and home composting of garden and vegetable food waste. Anaerobic turnover at biogas plants relates to the accidental methane release and flaring from biogas plants.

The main category, 'Incineration and open burning of waste', deals with emissions that are primarily included in the energy sector, as all incineration of municipal, industrial, medical and hazardous waste etc. in Denmark takes place with energy utilization. Emissions from the combustion of waste at incineration plants are reported in the energy sector. Incineration of waste also includes CH_4 and N_2O emissions from human and animal cremation.

The main category 'Wastewater treatment and discharge' deals with emissions from the treatment and discharge of wastewater. Several larger treatment plants are energy-producing and the emissions from these are included in the energy sector. Emissions from burning dried sludge are also included in the energy sector, while emissions from spreading sludge on fields are included in the agricultural sector during plant breeding.

The main category, 'other', includes CO_2, CH_4 and N_2O emissions from accidental building fires and accidental vehicle burning.

5.1 Waste

The municipal climate account for waste is based on the national account for emission of greenhouse gases, which is based on national databases administered by the Danish Environmental Protection Agency under the Ministry of the Environment and Food.

In 2010, the Danish Environmental Protection Agency implemented a new waste data system (ADS) to collect data and compile waste statistics. This waste reporting system contains statistics on waste quantities according to the waste producer and the amount of waste by type of treatment, e.g. deposit. The statistics refer to the recipient, i.e. recipients of produced waste (waste collection companies and recipients of waste for treatment).

In the national accounts, there is still uncertainty regarding the reported data. The uncertainty regarding waste data in ADS becomes even greater when these are considered for the individual municipalities.

In the municipal climate accounts, it has therefore been chosen to use the available national data, which is distributed proportionally at the municipal level in relation to the number of inhabitants. Thus, no account is taken of the origin of the waste and nor of the characteristics of waste treatment, the composition of the waste, facility-specific conditions, etc., in the areas where the individual municipality may be different from the country as a whole. Data is at Tier I level.

5.1.1 Annex 12: Disposal, biological treatment and incineration of waste

The emissions relating to waste that is used for energy purposes are included in the energy account for the municipality where the waste processing and utilization of the energy takes place.

Disposal of solid waste

The most important activity in the sector is the disposal of solid waste on land with CH_4 emissions, contributing just over 50% of the sector's total greenhouse gas emissions. CH_4 emissions from solid waste disposal have decreased by 65% since 1990 as a result of bans on landfilling organic waste and an overall decrease in landfilling due to waste being increasingly recycled or incinerated for power and heat production.

CH4 emission from landfilling of waste results from anaerobic decomposition of carbon in the deposited material, which occurs over time. In the calculation of the annual emission, both previous years' deposited waste and the same year's deposited waste are included. Gradual degassing from landfills will continue in the years to come and approach 0 in the year 2050.

Emissions from Danish solid waste landfills are calculated according to equations 7.2.1, 7.2.2, 7.2.3, 7.2.4, 7.2.5, 7.2.6, 7.2.7, 7.2.8 and 7.2.9 in Denmark's national climate accounting, Chapter 7.2 (NIR 2021).

Reference can also be made to Annex 3F Waste (DCE 2021):

• Table 3F-1.1 Emissions from the waste sector, CO_2 equivalents.

• Table 3F-2.1 All nationally produced waste categorized by management method collected for the ISAG database 1994-2009 and the new waste reporting system for 2010-2016

• Table 3F-2.2 Annual quantities of landfilled waste, gross methane emission, recovered methane for biogas production, oxidized methane in the upper layer and resulting net discharge for Danish waste depots.

• Table 3F-2.3 Annual quantities of landfilled inert[28] and degradable waste allocated according to 18 identified waste types characterized according to their DOCi[29] and degradation rate quantified by their half-life, t½.

Biological treatment of solid waste

Biological treatment of solid waste is the second largest contributor to the waste sector's total greenhouse gas emissions in 2018.

The biological treatment of solid waste contributed nationally to the total waste sector's emission of CO_2 equivalents by 39% in 2018.

In the period 1990 to 2018, the emissions from biological treatment of solid waste have increased by 1161% for CH_4 and 234% for N_2O, as a result of an increase in the number of biogas

[28] Waste that does not undergo significant physical, chemical or biological transformations

[29] Content of decomposable organic carbon.

plants and the amount of biowaste that is composted in Denmark. The reason why emissions from composting and biogas production have increased since 1990 is thus an increase in the amount of waste that is composted and converted anaerobically and leakage of greenhouse gasses from these activities. Emissions are expected to continue to rise due to increased production of biogas. However, the biogas industry has set a target of a methane leakage of a maximum of 1% of the total biogas production from a biogas plant. Currently, there is variation in the methane leakage from Danish plants.

Calculation of emissions from biological treatment of solid waste appears in Denmark's National Inventory Report 2021, Chapter 7.3, including calculation of emissions from composting, Chapter 7.3.1 and emission from biogas plants, Chapter 7.3.2.

Reference can also be made to Annex 3F Waste DCE 2021):

• Table 3F-3.1 National emissions from composting - 1990 to 2018.

• Table 3F-3.2 Activity data for composting waste.

• Table 3F-3.3 Activity data and methane emissions from anaerobic turnover at manure-based biogas plants.

Incineration and open burning of waste

Since the majority of the waste, including municipal, industrial and hazardous waste, which is included in 'Incineration and open combustion of waste' is used in power and heat production, emissions from this are included in the energy sector.

In addition to emissions from municipal, industrial and hazardous waste, emissions from incineration and open burning of waste also consist of emissions from cremation of people and animals. Calculation of emissions from the category incineration and open burning of waste can be found in Denmark's National Inventory Report 2021, Chapter 7.4.

Reference can also be made to Annex 3F Waste (DCE 2021):

• Table 3F-4.1 Total emission of greenhouse gases from cremation of people and animals.

• Table 3F-4.2 Activity data for human cremation.

• Table 3F-4.3 Activity data for cremation of pets, (direct contact with all Danish crematoria for pets).

5.2 Wastewater

The municipal climate account for wastewater is based on the national greenhouse gas account, which is based on national databases administered by the Norwegian Nature Agency under the Ministry of the Environment and Food.

From 2007, the municipalities took over the role of authority for municipal treatment plants and thus the data responsibility for a number of wastewater data, stipulated in the data responsibility agreement between KL, the regions and the Ministry of the Environment. Data is reported by the municipalities themselves (www.miljøportalen.dk).

The national account of greenhouse gases from the treatment and discharge of wastewater, which appears in the national climate account (NIR 2020), chapter 7.5, deals with CH_4 and N_2O from wastewater treatment processes and from outlet wastewater. CH_4 emission from wastewater treatment comes from anaerobic treatment processes at the municipal treatment plants, while N_2O comes from anaerobic as well as aerobic treatment processes, which is why contribution from the outlet wastewater is included in the accounts.

In 2018, wastewater treatment contributed 15.8% of the total waste sector's emission of CO_2 equivalents. In the period from 1990 to 201_9, CH_4 emissions from wastewater management have increased by 27.3%, while N_2O emissions have decreased by 40%.

In the municipal climate accounts, Tier 1 level is used in connection with the calculation of emissions for wastewater, where the national emission data for wastewater is distributed at municipal level in relation to the number of inhabitants in the municipality in question.

The background for this is that, firstly, in several cases the treatment and discharge of wastewater does not follow the municipal boundaries and, secondly, that the discharge of CO_2 equivalents from wastewater treatment only accounts for around 16% of the waste sector's total discharge of CO_2 equivalents, which as previously mentioned for 2018 is only 2.8% of the national greenhouse gas account.

The Tier 1 method does not take into account the wastewater's origin, characteristics, plant-specific treatment processes and unequal distribution in the type of industries as well as contributions to the municipal treatment plants. The national emissions include contributions from freshwater and saltwater pond farming, scattered settlements, rainwater-related discharges and separate industry. At Tier 1 level, the geographically uneven distribution of sources is not taken into account in the calculation of CH_4 and N_2O emissions at municipal level, as the national emission is exclusively distributed according to the number of inhabitants in the municipality.

The emissions relating to wastewater, which is used for energy purposes, are included in the energy account for the municipality where the wastewater treatment and utilization of the energy takes place.

5.2.1 Annex 13: Treatment and discharge of wastewater

Data regarding wastewater treatment, including e.g. data for NP, biological oxygen demand (BOD) and chemical oxygen demand (COD) are collected by the Danish Environmental Protection Agency for all point sources in connection with the National Monitoring Program for Water Environment and Nature (NOVANA).

The part of the population that is not connected to the municipal sewage system typically has septic tanks, many of which are emptied once a year. The sludge collected from here is taken to the municipal sewage treatment plant and is included in the accounting for this.

Any contributions to CH4 emissions from anaerobic pre-treatment of industrial wastewater, prior to discharge to the municipal sewer system, are not included in the national inventory.

Data on energy production from wastewater treatment plants with anaerobic sludge treatment are reported in the energy statistics. Data for this is received from the Danish Energy Agency and appears in the table 7.5.1 and Appendix 3F, Table 3F-5.1 (NIR 2021). This data does not include venting or flaring information, which is included in the reported gross production data

Calculation of CH4 emissions from treatment plants is calculated according to equations 7.5.1, 7.5.2, 7.5.3 and 7.5.4, while N2O emissions are calculated according to equations 7.5.6, 7.5.7 and 7.5.8 in Denmark's National Inventory Report 2021, Chapter 7.5.

Reference can also be made to Annex 3F Waste (DCE 2021):

• Table 3F-5.1 Produced, recovered and discharged CH4 from wastewater treatment, 1990-2019.

• Table 3F-5.2 N2O emissions from wastewater, 1990-2019.

• Table 3F-5.3 Time series for contribution from industrial wastewater to the inflowing TOW at Danish wastewater treatment plants, population, measured BOD and COD data and resulting COD/BOD ratio, 1990-2019.

• Table 3F-5.4 Nitrogen content in the inflowing wastewater.

5.3 Accidental fires

Accidental fires, which are a subcategory of CRF category 5.E Other, include accidental fires in buildings and vehicles.

5.3.1 Annex 14: Accidental fires

The national accounting for greenhouse gases from accidental fires appears in NIR 2021, chapter 7.6.

The emissions in the form of CH_4, N_2O and CO_2 are found in table 7.6.1. In addition, reference can be made to Annex 3F Waste DCE 2021) table 3F-6.1-3F-6.8.

6 Industrial processes and industrial product use

This chapter describes the methods and accounting items for calculating emissions of greenhouse gases for the emissions sector "Industrial processes and industrial product use".

The sector is divided into the following emission categories: mineral industry, chemical industry, metal industry, non-energy-related use of fuel and solvents, electronics industry, product uses as substitutes for ozone-depleting substances, as well as other product manufacture and use.

Industrial processes make up to 4.2% of the total greenhouse gas emissions for Denmark in 2018. The majority (68%) of the emissions in the sector come from the mineral industry. Within the mineral industry, cement production is by far the largest source of emissions with over 80% in all years from 1990-2018. 18% of the sector's total emissions in 2018 come from product uses as substitutes for substances that deplete the ozone layer. 9% of the sector's emissions come from non-energy-related use of fuel and solvents. 5% comes from other product use and manufacturing. Chemical industry and electronics industry together make up less than 0.1% of the total emission.

6.1 Accounting for Industrial processes and product use

There is an account linked to "Industrial processes and industrial product use", as shown in the figure below.

Industrial production (ton)							*Activity*	*Emissions (ton)*				
Mineral industry	Chemical industry	Metal industry	Use of fuel and solvent (not energy related)	Electronics industry	Ozone-replacing products	Other product manufacture and use	PlanEnergi	CO_2	CH_4	N_2O	F-gasses (HFC, PFC) - CO_2-e	CO_2-e total
							Cement and brick production	0				0
							Lime production					0
			1.806				Lubricant consumption	1.114				1.114
			708				Consumption of paraffin wax	2.066	0	0		2.073
			25.659				Consumption of solvents	2.136				2.136
			143.885				Asphalting of roads	49	1			67
			2.069				Production of roofing felt	1				1
			1.319				Urea used in catalysts	315				315
							Optical fibers					0
							Cooling at extremely low temperature					0
					IE		Cooling and air-conditioning				16.671	16.671
					IE		Foam blowing agents				28	28
					IE		Aerosols				449	449
						0	Medical consumption			6		1.652
						0	Propellant for pressure and aerosol products			0		78
						6	Fireworks	0	0	0		4
						6	Tobacco		0	0		1
						8	Charcoal (grilling charcoal)		0	0		1
						NO	Use of electronic equipment				0	0
						NO	Other use of products (e.g. running shoes, double-glazed windows, laboratory)				41	41
1.580	2.087	21	175.445	0	0	21	**Total**	**6.392**	**1**	**7**	**17.189**	**25.341**

Figure 9. *Accounting for Industrial processes and industrial product use*

The left side of the account shows the quantity in tonnes of a given raw material or product that is used within an industrial category. The middle gray column shows the type of industrial production or activity that causes emissions. The right side of the accounts shows the emission of various greenhouse gases in tonnes and the greenhouse gases converted to ton CO_2 equivalents.

A changed quantity on the left side of the account causes changes on the right side of the account. In this way, municipalities can calculate the effect of changed or discontinued production.

Municipality-specific data on the left side of the accounts

Information regarding the quantities of mineral raw materials, chemical substances, metallurgical raw materials, etc. used is obtained in the national climate accounts from Denmark's statistics and the companies' reports to the EU's emissions trading system (EU ETS).

Part of the consumption during industrial processes and product use can be calculated on the basis of point sources. When a consumption can be calculated based on point sources, the municipal climate accounting obtains emission data from the companies' reporting to the EU-ETS. Concretely, the municipal climate accounts receive data from the Danish Energy Agency, which registers reports and forwards these to the EU-ETS.

Data, for the part of industrial production and consumption that cannot be calculated from point sources, the municipal accounting takes directly from the national climate accounting's CRF tables 2(I) and 2(II). Data is typically at Tier II level.

Emissions from point sources are attributed to the municipality where the company's CVR. no. or P- number belongs. Companies have P-numbers for each physical location that is used for activities that concern the company – and which in this case involve the emission of greenhouse gases.[30]

If a given activity is calculated based on point sources - and there are no point sources for emissions from a given activity in a municipality, the relevant cell on the left side of the account is empty. Data for point sources is at the Tier III level, as it is based on company-specific information.

Calculation of emissions in the right-hand side of the accounts

The municipal accounts include calculations for the emission of CO_2, CH_4, N_2O as well as for different types of hydrofluorocarbons (HFC), different types of perfluorocarbons (PFC) and sulphur hexafluoride SF6. The last three gases are collectively referred to as F gases.[31]

The national climate account collects information on the consumption of F-gases from importers, agencies, wholesalers and supply companies, recycling companies and Denmark's statistics. The municipal climate account takes the information directly from the national climate account's CRF tables, where the F-gases are calculated exclusively as CO2 equivalents.

[30] In cases where the company's emissions of greenhouse gases cannot be attributed to one physical location in one municipality, but only to the company's CVR number, the greenhouse gas emissions are distributed among the municipalities where the company has a number.

[31] The national climate accounts include a number of other air pollutants and heavy metals. An overview can be found in tables 0.3 and 0.4 in Hjelgaard, K.H. & Nielsen, O.-K. 2018. Danish emission inventory for industrial processes. Results of inventories up to 2016. Aarhus University, DCE – Danish Center for Environment and Energy, 192 pp. Scientific Report No. 292 http://dce2.au.dk/pub/SR292.pdf . These air pollutants are not included in the municipal climate accounts.

There is one appendix attached to the accounts for Industrial processes and industrial product use.

The appendix contains all 7 industrial categories where greenhouse gas emissions are calculated.

6.1.1 Annex 15: Emissions from different types of industrial processes and industrial product use

In the annex sections below, a very concise description of the calculation of the individual accounting items is given. Detailed methodological documentation can be found in Hjelgaard, K.H. et al., (2018) .

Mineral industry, cement production

Cement production emits CO_2 in connection with calcination. There is one point source in Denmark, namely the cement factory, Aalborg Portland.

The municipal climate account receives information on emissions from the EU-ETS system to which Aalborg Portland itself reports. The emission is calculated based on the quantity of raw materials (limestone, magnesium carbonate, sand, fly ash, etc.), process technology and produced quantities of clinker.

Emissions data are at Tier level III.

Mineral industry - lime production

Lime production emits CO_2 via the oxidation of carbonates when the limestone is heated. There are only a few point sources in Denmark.

The municipal climate accounts receive information on emissions from lime works reporting to the EU-ETS. Data quality is at Tier III level.

Mineral industry - production of glass and glass wool

Container glass, industrial art glass (Holmegaard) and glass wool are produced in Denmark. Glass production emits CO_2 in connection with heating the raw materials, which are soda ash, dolomite lime, limestone and recycled glass.

The municipal climate account collects information on CO_2 emissions from companies reporting to the EU-ETS. Data is at Tier III level.

Mineral industry - Ceramic production

Production of bricks, tiles and expanded clay products such as cat litter emits CO_2. The CO_2 emission is linked to the carbon content of the clay. The point sources are brickworks scattered in several places in the country. There are also the pier manufacturers at Fur og Mors – and a manufacturer of expanded clay products in Favrskov.

The municipal climate account collects information on CO_2 emissions from companies reporting to the EU-ETS. Data is at Tier III level.

Mineral industry - Production with other uses of soda ash

It is unknown what other industries use soda ash, apart from glass production. Emissions from other uses of soda ash are therefore based on information on the import and export of the raw material minus the consumption for glass production.

Emissions from other uses of soda ash are distributed per inhabitant in Denmark. Information on quantity and emission factors is obtained from CRF table 2(I)

Mineral industry – Wet flue gas cleaning

Wet flue gas treatment takes place at certain cogeneration plants and waste incineration plants in Denmark.

CO_2 emissions are emitted as a result of desulphurisation of the flue gas, where limestone is used.

The municipal climate accounts receive information on emissions from wet flue gas cleaning via the companies' reporting to the EU-ETS. Data quality is at Tier III level.

Mineral industry – Production of stone wool

There is one producer of stone wool in Denmark, namely Rockwool. Rockwool produces at three locations in Denmark. CO_2 is emitted as a result of the use of e.g. lime binder.

Information on quantities is reported by Rockwool to the EU-ETS. The municipal climate accounts obtain data from this report. Data is at Tier III level.

Chemical industry – Production of catalysts and fertilizers

There is one producer of catalysts and artificial fertilizers (potassium nitrate) in Denmark, namely Haldor Topsøe A/S. CO_2 is emitted from raw materials in production, which contain carbonates.

Metal industry – production of recycled lead

There is one producer in Denmark that produces recycled lead from scrap metal, namely Hals metal.

Reworking of lead also takes place at a number of craftsmen scattered throughout the country.

The national climate account estimates the amount of recycled lead and uses the UN's standard emission factor.

The municipal climate account uses information from CRF table 2(I) and distributes emissions per inhabitant of the municipality/Denmark. Data is at Tier I level.

Non-energy related use of fuel and solvents – use of lubricant

CO_2 is emitted as a result of oxidation when using lubricants.

Lubricants that are burned in machines or used lubricants that are subsequently burned as part of waste treatment are reported in the energy sector and the waste sector respectively

The national climate account obtains information on lubricant consumption from the Danish Energy Agency and uses a UN standard emission factor at Tier I level.

The municipal climate accounting uses information from CRF table 2(I) and distributes emissions per resident of the municipality/Denmark.

Non-energy related use of fuel and solvents – Use of paraffin wax

Paraffin wax is used in wax candles and CO_2, CH_4 and N_2O are emitted when candles are burned.

Paraffin wax is also used in products such as corrugated cardboard, coated paper, glue, food production, packaging etc. but emissions from burning this type of waste are not included in the national climate accounts.

The national climate account draws information on consumption from Denmark's statistics, imports and exports. An emission factor at Tier II level is used.

The municipal climate account retrieves information from CRF table 2(I) and distributes emissions per resident of the municipality/Denmark.

Non-energy related use of fuel and solvents – Solvent use

There, among other things, solvents are used in paint, as well as in connection with degreasing and dry cleaning and in chemical product manufacturing

The use of solvents causes the release of CO_2 during oxidation.

The national climate account estimates the amount of pure solvent that is consumed, and estimates associated emission factors according to UN guidelines. A more detailed description of emission factors can be found in Annex 3C-29 (DCE 2021).

The municipal climate account finds information on quantities and emissions in CRF table 2(I) and distributes emissions per resident of the municipality/Denmark.

Non-energy related use of fuel and solvents – Asphalting of roads

Asphalt contains different types and amounts of solvent. Asphalting roads causes an indirect release of CO_2 as a result of, among other things, CH_4 and CO emissions, which are calculated in the national climate accounts.

The municipal climate account finds information on quantities and emissions in CRF table 2(I) A-H and distributes emissions per resident of the municipality/Denmark.

Non-energy related use of fuel and solvents – Production of roofing felt

As part of the production of roofing felt, the asphalt is polymerized so that it becomes weatherproof.

The process causes an indirect release of CO_2 and is calculated in the national climate accounts.

The municipal climate account finds information on quantities and emissions in CRF table 2(I) A-H and distributes emissions per resident of the municipality/Denmark.

Non-energy related use of fuel and solvents – Urea used in catalysts

CO_2 is emitted from urea-based additives in catalysts for heavy vehicles in connection with the catalysts reducing particle pollution with NOx gases.

In the national accounts, the consumption of urea is estimated based on road transport and the emission calculated with a standard emission factor

The municipal climate account finds information on quantities and emissions in CRF table 2(I) A-H and distributes emissions per resident of the municipality/Denmark.

Electronics industry – optical fibres and cooling at extremely low temperatures

F-gases (HFC and PFC) are emitted as part of protection (etching) and as part of the cleaning in the production process of optical fibres. In addition, HFCs and PFCs are emitted when using refrigerant at extremely low temperatures of over minus 60 ° Celsius (e.g. in laboratories).

The national climate account obtains information on the use of F gases for optical fibres from the importers' annual sales reports. The emission factor is estimated to be 100%.

The municipal climate account finds information on quantities and emissions in CRF table 2(II) and distributes emissions per resident of the municipality/Denmark.

Products to replace ozone depleting products – Refrigeration and air conditioning

F-gases (HFC and PFC) are emitted from commercial freezers, household freezers, industrial cooling and cooling during transport, as well as from mobile and stationary air conditioning systems and from heat pumps.

The national climate account estimates the amount of HFCs and PFCs based on the amount of gas that is filled in new products, the amount that is in use and the amount that remains after use. The emission factors vary by product type.

The national climate accounts estimate the quantity of F-gases in accordance with guidelines from the UN based on the import and export of products containing HFCs and PFCs as well as based on the products' lifetimes.

The municipal climate account finds information on quantities and emissions in CRF table 2(II) and distributes emissions per resident of the municipality/Denmark.

Products to replace ozone-depleting products - Foam blowing agents

F-gases (HFC and PFC) are emitted from the production of hard foam, which is used in e.g. freezers and soft foam which is used in e.g. running shoes. At the end of their useful life, the products are incinerated without the emission of F-gases as a result.

The national climate account estimates national consumption at Tier II level and uses the UN's standard emission factors.

The municipal climate account finds information on quantities and emissions in CRF table 2(II) and distributes emissions per resident of the municipality/Denmark.

Products to replace ozone-depleting products – Aerosols

Aerosols contain F-gases which are used as propellants in spray cans and inhalers for medical use.

The national climate account collects information on quantities from producers and the medical trade statistics. The emission factors take into account the lifetime of the products and the half-life of the gases.

The municipal climate account finds information on quantities and emissions in CRF table 2(II) and distributes emissions per resident of the municipality/Denmark.

Other product manufacture and use - Nitrous oxide from medical applications

N_2O is used for medical use (anaesthesia) in hospitals, vets and dentists and to a lesser extent in laboratories.

The national climate accounting collects information on quantities from distributors and via communication with the only producer in Denmark. All N_2O for medical use is counted as emission.

The municipal climate account finds information on quantities and emissions in CRF table 2(I) and distributes emissions per resident of the municipality/Denmark.

Other product manufacture and use - Propellant for pressure and aerosol products

N_2O is used as a propellant in the food industry for canned whipped cream.

The national climate accounts estimate the quantity based on sales and the emission factor is 100%.

The municipal climate account finds information on quantities and emissions in CRF table 2(I) and distributes emissions per resident of the municipality/Denmark.

Other product manufacture and use – Fireworks, tobacco and cigarettes

CH_4, N_2O and CO_2 are emitted from fireworks, charcoal and cigarettes. However, CO_2 emissions are only included from fireworks, as charcoal and cigarettes are biogenic combustion.

Information on import, export and production is obtained from Denmark's statistics and emission factors are used at tier II level.

The municipal climate accounting finds information on quantities and emissions in CRF table 2(I) and distriutes emissions per resident of the municipality/Denmark.

7 Graphical illustrations

This climate account calculates greenhouse gas emissions from the climate sectors 1) agriculture, forestry and other land use, 2) waste and waste water and 3) industrial products and product use at municipal level. It also comprises a an energy account including stationary energi production and use and transportation.

Two tabs with graphs provides illustration of emissions from all sectors. All graphs include presentation of two years. The account was originally made to include the years 2018 and 2020, but has been altered to include only one year in two copies for use as a scenariobuilder.

In addition the graphs and summary presentations of figures includes an estimate of emissions for 1990. The emissions in 1990 for the energy and transport sector are borrowed from the full municipal Energy Accounts (1990), which was prepared on the basis of historical data obtained at municipal level. For the other sectors 1) agriculture, forestry and other land use, 2) waste and waste water, and 3) industrial products and product use, a rough estimate has been made based on the % deviation between 1990 and 2018 in Denmark as a whole. According to the national climate accounts,

- Emissions in the sectoral accounting for plant breeding reduced by 31% since 1990
- Emissions in the sector accounts for animal husbandry reduced by 2% since 1990
- Emissions in the sectoral accounts for land use increased by 2% since 1990
- emissions in the sectoral accounts for waste and waste water reduced by 35% since 1990
- emissions in the sector accounts for industrial processes and product use reduced by 9% since 1990.

8 Data quality and international perspectives

Seen in an international context, the national and municipal climate accounts are of high quality, simply because in Denmark much information is registered, systematized and made available to the public.

In an assessment of the national and municipal quality of the climate accounts, a distinction should be made between the quality of input data and the quality of emission and storage factors.

Regarding input data, it applies to most data that they are originally calculated at CVR/CPR level, per ha, or raster data with higher resolution, via the companies' own reports, etc. For these data, the quality in the municipal climate accounts is the same as in the national accounts.

However, it applies to certain input data that they are originally calculated as national sales figures or national estimates of production and consumption. This data can only be broken down at municipal level by using distribution keys based on population. Where distribution keys have been used, the quality of the municipal climate accounting is automatically downgraded in relation to the quality of the national accounts.

The quality of the emission factors in the municipal climate accounts reflects the quality of the factors in the national accounts with one significant exception, namely emissions and carbon stocks for forests. Here, the quality of the municipal climate accounting has been downgraded from high to medium. This is because the national factors are based on average Danish forest, which cannot be found at municipal level.

The accounts have originally been intended for monitoring of the local development in climate gas emissions. Their construction makes it possible though, to also use them as a planning and scenario tool with few adaptions. This is due to their property of being prepared to include more than one year.

By use of the same dataset for a given year and duplicating, triplicating or even quadrupling all accounts and annexes, one of the versions can be used as baseline and the other versions as a budget for future expected emissions. By simply changing the input data for all budget versions where relevant, the graphs and summary accounts will visualize the effects of the changes. They then will constitute a reduction path.

In an international context finding data for a given region or geographical area of a similar quality as the data for the Danish municipalities may be difficult. Even in this case, use of national data from the country specific inventory report coupled with local data for areas, populations of people and livestock, estimates on settlement areas etc. it seems plausible, that a baseline of sufficient quality can be established and used for planning and policy-building.

9 Litterature

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