DREAM

Danish Research institute for
Economic Analysis and Modelling

GREEN REFORM

Emissions in GreenREFORM

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1. Introduction

The dual purpose of the GreenREFORM model is to model the effect of economic policies on emissions and the effects of emissions regulation on the economy. To do this, GreenREFORM requires a module that forecasts emissions. This memo details how this is currently done.

The organizing principle is to calibrate emissions coefficients for each type of emissions that are sector-, fuel- and time-specific. Use these emission coefficients can then, in conjunction with other outputs of GreenREFORM, to simulate emissions.

The main data input of the economic model is a time-series of input-output tables for the Danish Economy, produced by Statistics Denmark. Statistics Denmark also construct detailed air emissions matrices that are consistent with the input-output tables. We use these as the primary source of emissions data. Where necessary, we augment this data using other sources. In particular, we use the emission inventories that the Danish Centre for Environment and Energy, DCE, submit annually to the UNFCCC (Nielsen et. al, 2020).

The air emissions matrices of Statistics Denmark contain a range of pollutants, cf. table 1.1. While this list is comprehensive, it is not exhaustive. Notably, nitrogen and phosphorous emissions to water are currently missing. The primary source of these emissions are agriculture, and we aim to include these emissions in a future version of the agricultural module of GreenREFORM (Beck, Berg, Christiansen and Jørgensen, 2020).

Table 1.1
Air emission types of Statistics Denmark

Emission type	Abbrev.	Accounting unit	GWP (CO_2e/ton)
Carbon dioxide excl. biomass	CO_2	1,000 tons	1
Carbon dioxide from biomass	CO_2	1,000 tons	1
Sulfur dioxide	SO_2	tons	0
Nitrogen oxides	NO_X	tons	0
Carbon monoxide	CO	tons	0
Ammonia	NH_3	tons	0
Nitrous oxide	N_2O	tons	298
Methane	CH_4	tons	25
Non-methane volatile organic compounds	NMVOC	tons	0
Particles < 10 μm	PM_{10}	tons	0
Particles < 2,5 μm	$PM_{2.5}$	tons	0
Sulfur hexafluoride	SF_6	tons CO2-equivalents	-
Perfluorocarbons	PFC	tons CO2-equivalents	-
Hydrofluorcarbons	HFC	tons CO2-equivalents	-

Note: *Whether biomass is included in emissions depends on the accounting scheme. GWP denotes the global warming potential in CO_2-equivalents (CO_2e). SF6, PFC and HFC are already converted to CO_2e.*
Source: *Statistics Denmark.*

For greenhouse gases (GHG, i.e. CO_2, N_2O, CH_4, SF_6, PFC and HFC), we face some additional accounting issues due to differences in the GHG accounting employed by Statistics Denmark, DCE/UNFCCC as well as the Danish Energy Agency. The main difference is that Statistics Denmark includes emissions of Danish economic activity abroad, whereas DCE/UNFCCC use a territorial demarcation. This memo lays out how we account for these differences. Table 1.2 gives an overview of our methodology.

Table 1.2
An overview of GHG data and the GreenREFORM modelling approach

	Energy related emissions	Non-energy related emissions	LULUCF emissions	Bunkering emissions	Residual emissions
Statistics Denmark data	Detailed emissions by fuel and sector	Sector totals	A total	Detailed emissions by fuel and sector	A total
DCE/UNFCCC data	Detailed emissions by CRF categories (no simple mapping to Statistics Denmark's categories)		Detailed emissions by CRF categories	Included only as memo items	-
GreenREFORM emissions modelling approach	Coefficients on energy inputs	Agriculture and waste: Specialized modules. Rest of economy: Emissions on outputs	Specialized module	Coefficients on energy inputs	Constant

Note: *CRF is the reporting format used for the UNFCCC inventories. There is no simple mapping from this format to the sector definitions used by Statistics Denmark. Bunkering emissions are emissions related to Danish economic activity that take place abroad.*
Source: Own illustration.

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2. Emissions in GreenREFORM

The emissions module consists of the following two general steps:

- **Calibrate emissions coefficients.** Emission coefficients are tied to model variables that resemble the source of emissions as closely as possible. In practice, most emissions are tied to either an input in production or consumption, e.g. fuels used for energy or the animal stock in agriculture. Where this is not possible, we model emissions as proportional to sector outputs.
- **Simulate emissions** by multiplying simulated input- and output quantities. with the emissions coefficients.

In practice, the approach taken varies slightly depending on the nature of emissions. We make a general distinction between energy-related emissions, non-energy-related emissions, emissions related to land use, land use change and forestry (LULUCF).

LULUCF emissions are only relevant for GHG emissions. We do not discuss our modeling of LULUCF emissions here. A special module of GreenREFORM handles these, aa more sophisticated approach is necessary to handle particularly the dynamics of forests (memo is forthcoming).

Currently, emission coefficients in future years are assumed constant and equal to the calibrated coefficients in the final data year of the model. Constant coefficients may be a reasonable assumption for some types of emissions such as CO_2 emissions from combustion, cf. figure 2.1 for an example. For other pollutants, emissions depend on the processes and technologies involved, cf. figure 2.2 for an example. Time trends in coefficients, where present, are typically towards lower emissions over time. Our model does not currently capture such trends.

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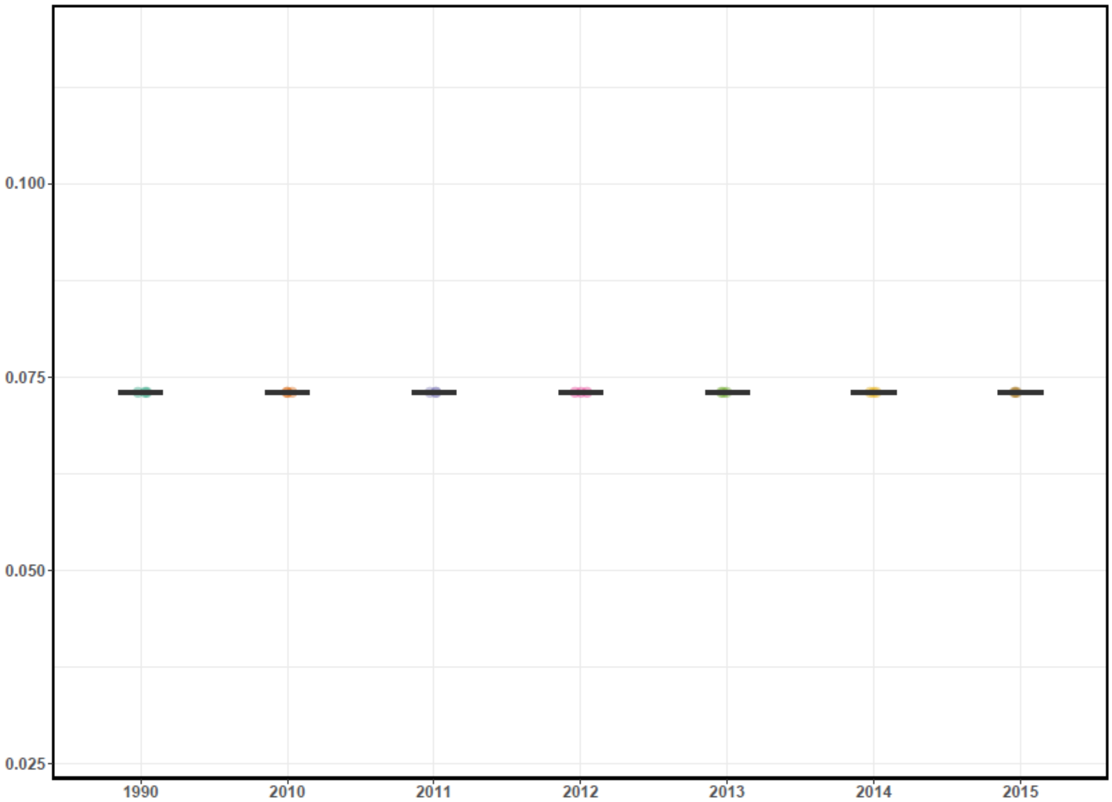
Figure 2.1
CO_2-cofficients for aviation fuel, boxplot for National Accounts sectors 1990 and 2010-2017.



Note: This figure shows yearly emission coefficients (kt CO_2/GJ aviation fuel) for different sectors of the Danish National Accounts. There is no between-sector variation in emission coefficients within a single year, nor between years.
Source: Own calculations on data supplied by Statistics Denmark.

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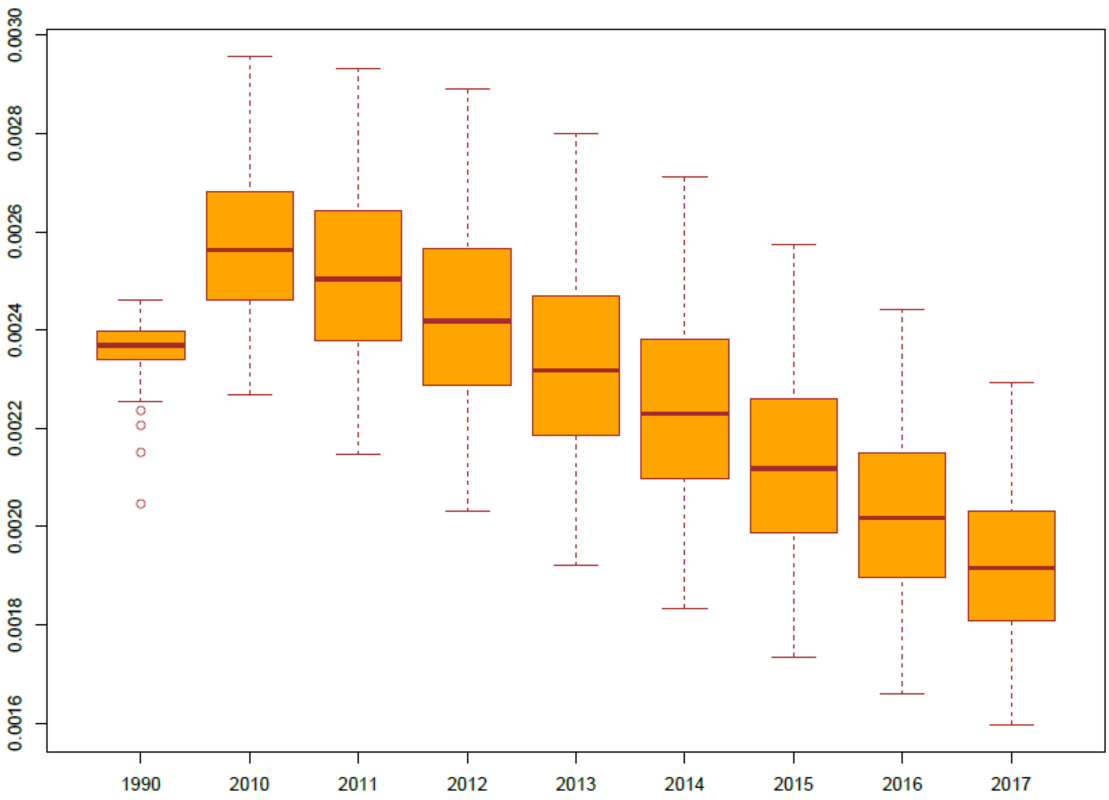
Figure 2.2
N_2O-cofficients for motor gasoline, boxplot for National Accounts sectors 1990 and 2010-2017.



Note: This figure shows calculated yearly emission coefficients (t N_2O/GJ motor gasoline) for sectors of the Danish National Accounts. Emission coefficients vary between sectors within years, and there is a trend towards lower emission coefficients over time.

Source: Own calculations on data supplied by Statistics Denmark.

2.1 Energy-related emissions

We calculate an emission coefficient for every greenhouse gas, sector, fuel and year in GreenREFORM. These are calculated on the basis of the emission accounts and the energy accounts from Statistics Denmark. The categorization of fuels and sectors in Statistics Denmark's accounts is more detailed than in GreenREFORM. For this reason, energy use and emissions are first aggregated to the set of fuels in GreenREFORM (See Kirk and Andresen, 2020, for details on the aggregation).

We note that while there is a single coefficient for each fuel used in each sector, energy usage is split into five different purposes that are covered by different types of regulation. These are emissions covered by the European Trading Scheme (ETS), transport, heating, and two types of process emissions (Kirk, 2020). It can be of interest to be able to split emissions into those covered by the European Trading System for emissions (ETS) and those that are not. This is easily accomplished, since ETS emissions are accounted for as a separate purpose. Coefficients are not calculated individually for different purposes (ordinary processes, heating, etc.), since the emission accounts are not categorized according to purposes.

Emission coefficients are calculated as:

$$coefficient_{i,t,j,k} = \frac{\sum_{j' \in j, k' \in k} emission_{i,t,j',k'}}{\sum_{j' \in j, k' \in k} energy\ use_{t,j',k'}}$$

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- i is emission gas
- t is year
- j is GreenReform sector, j' is National Accounts sector
- k is GreenReform fuel, k' is National Accounts fuel

In GreenREFORM, all energy consumption below 100 GJ is removed to avoid close to zero values:

$$\widehat{energy}\,use_{t,j',k'} = \begin{cases} 0 & for\ energy\ use_{t,j',k'} < 100GJ \\ energy\ use_{t,j',k'} & for\ energy\ use_{t,j',k'} \geq 100GJ \end{cases}$$

In addition to this, all consumption is adjusted such that total consumption of each fuel equals the total input. Finally, emissions can be calculated as the coefficients times the (model) energy use:

$$emission_{i,t,j,k} = coefficient_{i,t,j,k} \cdot \widehat{energy}\,use_{t,j,k}$$

Because of the energy use adjustments, our calculation does not exactly reproduce actual historic emissions. The actual emissions in 2015 are therefore 0.001% lower than our modelled emissions, corresponding to a difference of approx. 1000 tons of CO2e in terms of Statistics Denmark's emission accounts.

2.2 Non-energy related emissions

We also account for emissions not related to energy use. The largest sources of non-energy emissions arise during industrial processes, waste processing and management, as well as in agricultural production. For waste and agriculture, we construct specialized modules that handle emissions (For agriculture, see Beck et al. (2020); a memo on the waste sector is forthcoming).

For everything else, we assume that these emissions are proportional to the total production of the sector, or total consumption in the case of households. This implies that we calibrate a set of output- and consumption related emissions coefficients. We therefore calculate emissions coefficients based on the quantity of production and quantity of consumption, respectively.

$$coefficient_{i,t,j} = \begin{cases} \dfrac{\sum_{j' \in j} non\ energy\ emission_{i,t,j'}}{total\ consumption_{j,t}} & for\ j = Household\ sector \\ \dfrac{\sum_{j' \in j} non\ energy\ emission_{i,t,j'}}{\sum_{j' \in j} total\ production_{t,j'}} & for\ j \neq Household\ sector \end{cases}$$

- i is emission gas
- j^{GR} is GreenReform sector
- j^{DST} is National Accounts sector
- t is year

Non-energy related emissions are calculated using our model values, $total\ \widehat{consumption}_{j,t}$ and $total\ \widehat{production}_{j,t}$:

$$non\ energy\ \widehat{emission}_{i,t,j} = \begin{cases} coefficient_{i,t,j} \cdot total\ \widehat{consumption}_{j,t} & for\ j = Household\ sector \\ coefficient_{i,t,j} \cdot total\ \widehat{production}_{j,t} & for\ j \neq Household\ sector \end{cases}$$

This calculation exactly reproduces actual historic non energy-related emissions.

2.3 Residuals

The emissions accounts of Statistics Denmark includes three types of residuals, namely so-called biomass, road and energy residuals. These are relatively small; in 2015, the sum of absolute GHG residual values make up 1.09% of total GHG emissions, whereas the net sum of

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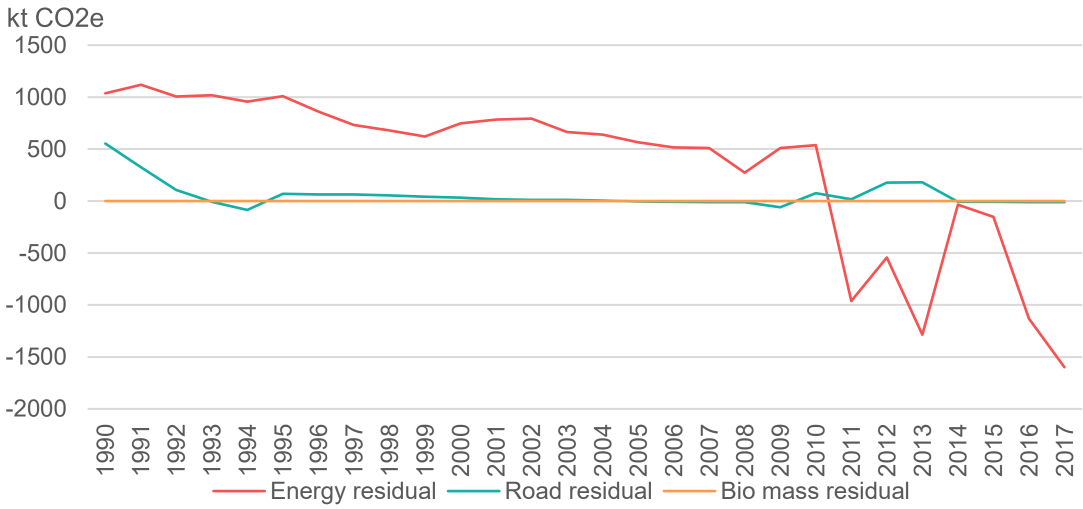
residuals make up 0.16% of total GHG emissions. For future periods these are naively forecasted as being constant at the latest observed level. We make this modelling choice as there does not appear to be any consistent trend in historic residual emissions levels, cf. figure 2.3.

Figure 2.3
Emissions accounts residuals



Source: Statistics Denmark

3. Greenhouse gas accounting rules and historic levels

This section describes some additional accounting issues that are particularly relevant for GHG emissions. These are 1) differences in GHG accounting demarcations between Statistics Denmark and DCE/UNFCCC and 2) differences in historic emissions levels between Statistics Denmark and DCE/UNFCCC on one hand and the Danish Energy Agency on the other hand. We address these two issues in turn below.

We first note that total greenhouse gas emissions are made up of the sum of emissions of CO_2, CH_4, N_2O as well as SF_6, PFC and HFC. We use standard emission factors of 25 and 298 to convert CH_4 and N_2O to CO_2-equivalents, as shown in table 1.1.

3.1 GHG accounting

Statistics Denmark calculates emissions as part of their Green National Accounts (GNA). As with the regular National Accounts, they use an economic demarcation. This means that they include emissions from Danish economic activity taking place abroad, i.e. international bunkers. This is in contrast to the UNFCCC accounting rules, where a territorial demarcation is used. The relationship between the two accounting systems can be stated as follows:

$$GHG_{GNA} = (GHG_{UNFCCC} - GHG_{LULUCF}) + GHG_{Bunkers} + GHG_{residual}$$

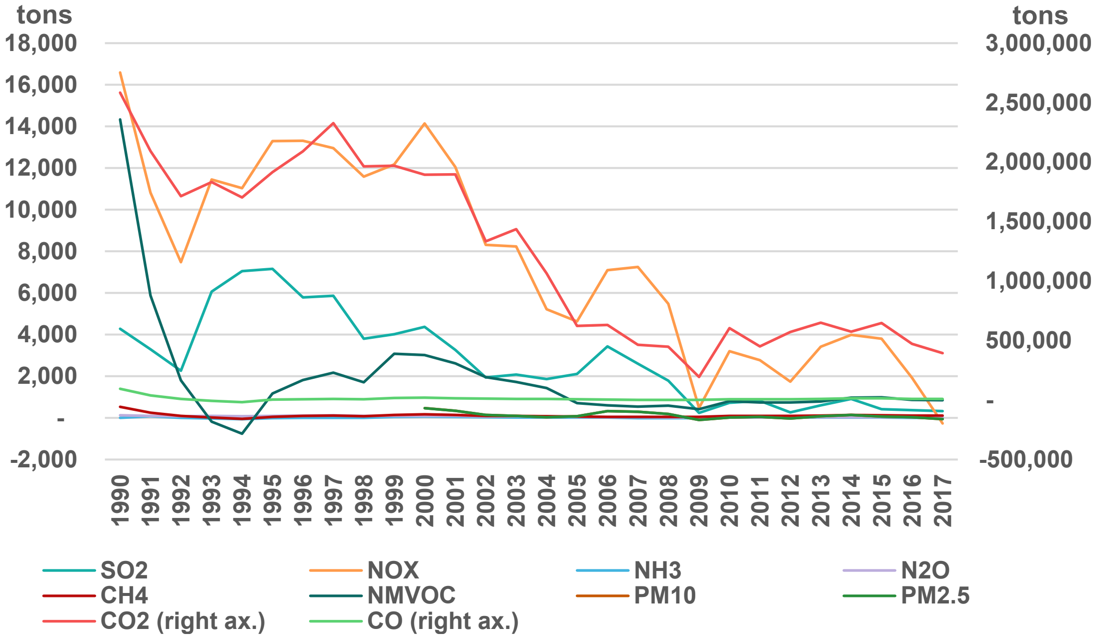
Thus, the GNA account is made up of the UNFCCC emissions total without LULUCF emissions, the international bunkers and a small residual related to other accounting differences. It is crucial that GreenREFORM can calculate the different right hand side terms individually, since national and international emissions targets tend to use the UNFCCC accounting rather than the GNA rules. Fortunately, Statistics Denmark publishes sufficiently detailed statistics to make this possible.

Three fuels of the National Accounts correspond exactly to international bunkers from aviation, navigation and road transport and together make up the $G_{Bunkers}$ term. Emissions from LULUCF are described in detail in the CRF-tables, and can be subtracted from the total.[1]

The residual is related to differences in accounting of transport and cross-border trade between the Statistics Denmark and the DCE/UNFCCC accounting scheme. It is available as a total for each type of emission, including for non-GHG emissions. The accounting residuals are relatively small, and are therefore not crucial for the results of model simulations. We assume that the accounting residuals are at a constant level in the projection years, as there is no apparent upwards trend in these over time - in fact, the residuals seem to be attenuated in later years, cf. figure 3.1. As all residuals are small in more current years, assumptions made about the residuals are not crucial for the properties of the model.

[1] Statistics Denmark also publishes a conversion table of the accounting identity in (1). This table corresponds exactly to the corresponding values in the CRF tables of DCE.

Figure 3.1
Accounting scheme residuals



Source: Statistics Denmark table MR01.

3.2 Historic GHG emissions

The Danish Energy Outlook (Danish Energy Agency, 2020), published yearly, contains a time series of GHG emissions from 1990 to the latest year with data (2018 for the 2020 report) as well as a "frozen policy" projection of emissions to 2030.

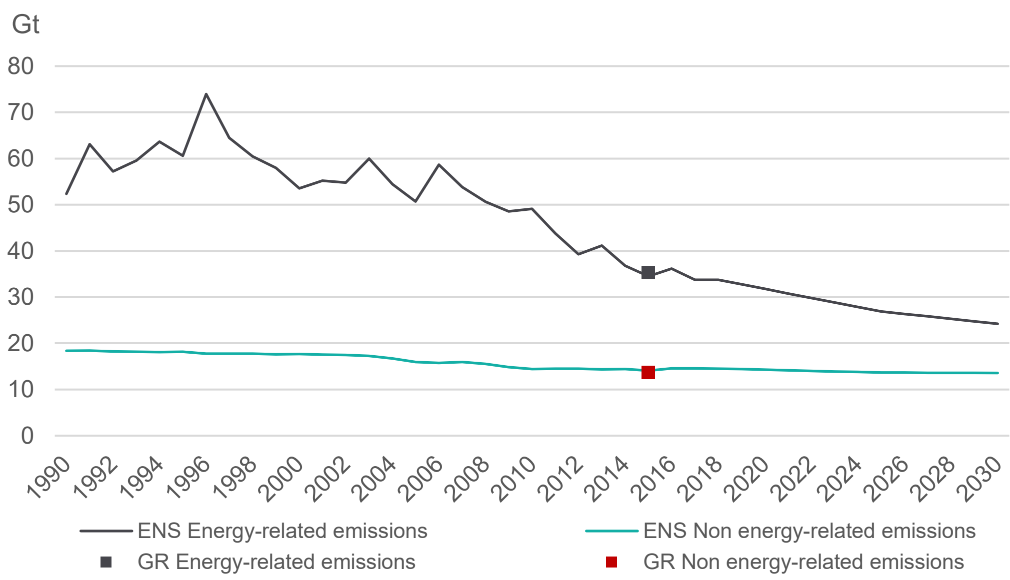
However, the historic time series deviates slightly from the one published by DCE. For 2018, the latest year for which data is published, the deviation is around 0,2 million tons. The Danish Energy Agency attributes this to statistical deviations and rounding errors. We simply note this discrepancy here, but it should be kept in mind when comparing the time series of GreenREFORM with that of the Danish Energy agency.

4. Emissions levels

In this section, we show what the emissions projections of GreenREFORM currently looks like and compare them to the projections of the Danish Energy Outlook ("basisfremskrivningen"). We show this for overall energy-related and non-energy-related emissions (figure 4.1) as well as subgroups within these categories (figure 4.2 and 4.3).

For the current levels of total non-energy and energy-related emissions, there is a high degree of agreement between the GreenREFORM account and the Danish Energy Outlook.[2] This agreement is not currently achieved on a more disaggregated level, however. For emissions related to transport, the emissions from energy used for transport in the GreenREFORM model is consistent with transport emissions from The Danish Energy Agency. However, this is not the case for emissions from public electricity and heat production as well as agriculture. This implies that the current (relatively crude) GreenREFORM categorization of these emissions is substantially different from that of The Danish Energy Agency.

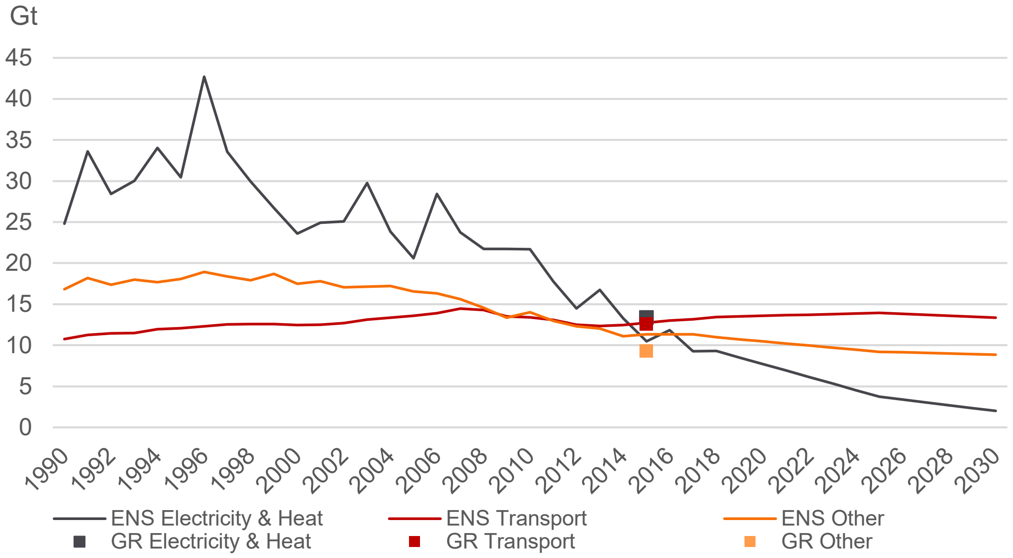
Figure 4.1
Energy- and non-energy-related emissions



Source: Own calculations based on GreenREFORM and Danish Energy Agency (2020).

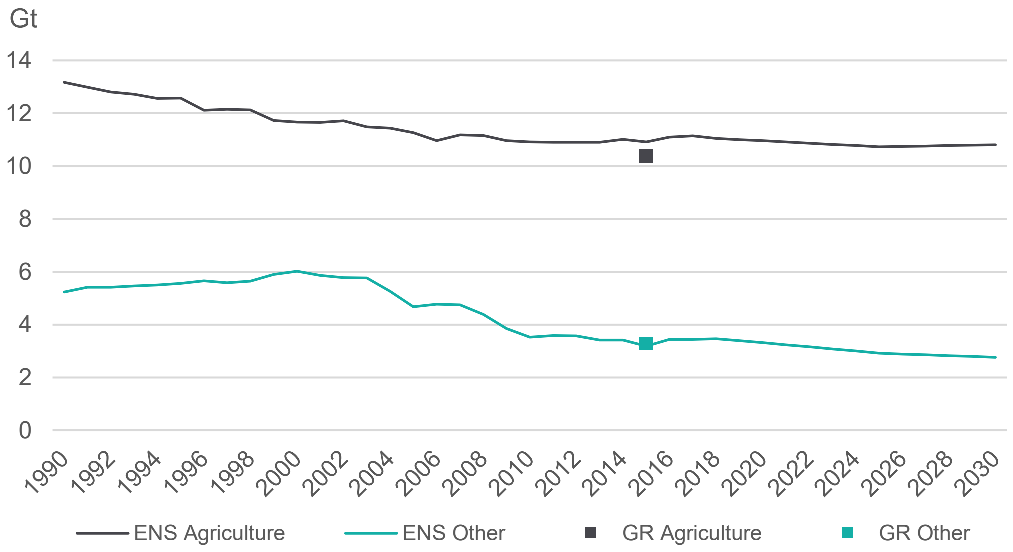
[2] Remaining small discrepancies are caused primarily by the discrepancy between the Danish Energy Outlook emissions and the official UNFCCC accounts. The censoring of small energy inputs in the GreenREFORM model system also contributes to the differences.

Figure 4.2
Energy-related emissions



Source: Own calculations based on GreenREFORM and Danish Energy Agency (2020).

Figure 4.3
Non energy-related emissions



Source: Own calculations based on GreenREFORM and Danish Energy Agency (2020).

5. References

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