ENERGY CONSUMPTION AND EMISSIONS FROM NON-ROAD MACHINERY IN DENMARK

Time series from 1980-2040

Scientific Report from DCE – Danish Centre for Environment and Energy No. 578 2023

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Morten Winther

Aarhus University, Department of Environmental Science

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Data sheet

Series title and no.: Scientific Report from DCE – Danish Centre for Environment and Energy No. 578

Category: Scientific advisory report

Title: Energy consumption and emissions from non-road machinery in Denmark
Subtitle: Time series from 1980-2040

Author: Morten Winther
Institution: Department of Environmental Science

Publisher: Aarhus University, DCE – Danish Centre for Environment and Energy ©
URL: http://dce.au.dk/en

Year of publication: December 2023
Editing completed: November 2023

Referee: Ole-Kenneth Nielsen, Department of Environmental Science
Quality assurance, DCE: Hanne Bach, DCE – Danish Centre for Environment and Energy
Linguistic QA: Ann-Katrine Christoffersen, Department of Environmental Science

Financial support: No external financial support

Please cite as: Winther, M. 2023: Energy consumption and emissions from non-road machinery in Denmark. Time series from 1980-2040. Aarhus University, DCE – Danish Centre for Environment and Energy, 132 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 578

Abstract: This report documents the Danish emission inventories and forecasts for non-road machinery used in the agriculture, forestry, building and construction, industry, commercial and institutional and residential sectors calculated with the DEMOS-NRMM model. Stock and activity data are shown for the period 1980-2040, and energy consumption and emission results are presented for the following emission components NO_x (nitrogen oxides), PM (particulate matter), CO (carbon monoxide), VOC (volatile organic compounds), NMVOC (non-methane volatile organic compounds), CH_4 (methane), CO_2 (carbon dioxide), SO_2 (sulphur dioxide), N_2O (nitrous oxide), and BC (black carbon). The total emissions of NO_x, PM, CO and VOC have decreased by 64 %, 85 %, 36 % and 69 %, respectively, from 1980 to 2021, whereas the total CO_2 emissions have increased by 20 % in the same period. From 2021 to 2040 the total of NO_x, PM, CO, VOC and CO_2 emissions are expected to decrease by 51 %, 71 %, 8 %, 36 % and 3 %, respectively. The total emissions of CH_4, NMVOC, BC and SO_2 have decreased by 70 %, 68 %, 84 % and 99.7 %, respectively, from 1980 to 2021, whereas the total N_2O emissions have increased by 53 % in the same period. From 2021 to 2040 the total emissions of CH_4, NMVOC, N_2O, BC and SO_2 are expected to decrease by 30 %, 37 %, 1 %, 77 % and 1 %, respectively.

Keywords: Non-road machinery, agriculture, forestry, building and construction, industry, commercial and institutional, residential, SO_2, NO_X, VOC, NMVOC, CH_4, CO, CO_2, N_2O, PM, greenhouse gases, acidifying components.

Layout: Ann-Katrine Holme Christoffersen
Front page photo: COLOURBOX61193665

ISBN: 978-87-7156-822-6
ISSN (electronic): 2244-9981

Number of pages: 132

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Summary

Introduction

This report documents the Danish emission inventories and projections for non-road mobile machinery (NRMM) used in the agriculture, forestry, building and construction, industry, commercial and institutional and residential sectors.

Stock and activity data, inventories and projections are shown for the period 1980-2040, and energy consumption and emission results are presented for the following emission components NO_x (nitrogen oxides), PM (particulate matter), CO (carbon monoxide), VOC (volatile organic compounds), NMVOC (non-methane volatile organic compounds), CH_4 (methane), CO_2 (carbon dioxide), SO_2 (sulphur dioxide), N_2O (nitrous oxide), and BC (black carbon).

The Danish emission inventories and projections for non-road mobile machinery (NRMM) are calculated with the DEMOS (Danish Emission model system for Mobile Sources) model[1], developed at the Department of Environmental Science (ENVS)/Danish Centre for Environment and Energy (DCE) at Aarhus University.

In the DEMOS sub-model for non-road (DEMOS-NRMM), time series of stock and activity data are modelled each year, and output emission results are calculated that automatically feeds into the total Danish atmospheric emission inventories annually prepared by ENVS/DCE at Aarhus University.

The Danish greenhouse gas emissions are reported to the EU and the UNFCCC (United Nations Framework Convention on Climate Change), and air pollutant emissions are reported to the UNECE LRTAP (United Nations Economic Commission for Europe Long-Range Transboundary Air Pollution) Convention. In addition, each year national emission projections of greenhouse gases are prepared for the Danish Climate Status and Outlook published by the Danish Energy Agency, and bi-annually projections of air pollutant emissions are prepared for the EU and the UNECE.

Input stock and operational data

In order to model the stock and activities for non-road machinery, new sales data and total stock numbers and annual operating hours are collected on an annual basis from many different data sources, e.g. national statistics, branch organisations, research institutes, large machinery importers and key experts.

The stock and activity data are collected on a machine type and engine type level. Additional information on machinery average age, maximum lifetime, engine size and engine load factors are gathered to allocate the machinery

[1] The DEMOS model consists of separate database models for each mode of transport (road, rail, air, navigation), and for the non-road mobile machinery (NRMM) used in the agriculture, forestry, building and construction, industry, commercial and institutional, and residential sectors.

stock into the relevant fuel type, engine power class and emission stage used in the model.

Input fuel consumption and emission factors

For non-road diesel engines, the fuel consumption and emission factors are grouped into the following emission stages: < 1981, 1981–1990, 1991–Stage I, Stage I, II, IIIA, IIIB, IV and V. The emission factors for each of these emission stages are divided into engine power classes that correspond with the engine size classifications in the EU emission directives for diesel fuelled NRMM.

Fuel consumption and emission factors for non-road gasoline engines are divided into 2-stroke and 4-stroke engine types, for both hand-held (SH) and non-hand-held (SN) equipment. For each engine and equipment type, the factors are grouped into the following emission stages: < 1981, 1981–1990, 1991–Stage I, Stage I, Stage II and Stage V. The factors are further grouped into the engine size classes (ccm – cubic centimeters) that correspond with the engine size classifications in the EU emission directives for gasoline fuelled NRMM.

For diesel and gasoline non-road engines, the core data source for the fuel consumption and emission factors in DEMOS-NRMM is Institut für Energie- und Umweltforschung - IFEU (2004, 2009) and this includes emission factors for engine deterioration, transient engine loads and gasoline evaporation. In model updates made over the years, the DEMOS-NRMM emission factor base has expanded to include new emission stages and machinery types not initially covered and has included supplementary emission information from additional sources (e.g. EMEP/EEA (2023), ICCT (2016)) when necessary.

The emission factors for LPG engines (forklifts) at different technology levels are taken from Notter and Schmied (2015). For ATV's the emission factors are based on emission data for conventional technology motorcycles in the Danish emission inventories for road transport (Winther, 2022a).

Calculation method

The fuel consumption and emissions are calculated for each machinery type, year and emission stage in DEMOS-NRMM as the product of the number of machines, engine size (kW), engine load factor (%), annual operating hours and fuel consumption or emission factor (g/kWh). The calculations also take into account the emission effects of engine aging (deterioration effects due to engine wear) and transient engine operation.

Stock and operating hours in 2021

Table S.1 shows the stock numbers, total operating hours, and specific operating hours for non-road machinery in 2021 per non-road sector, fuel type and engine type.

Table S.1 Stock numbers, total operating hours, and specific operating hours for non-road machinery in 2021 per non-road sector, fuel type and engine type.

	Total	Diesel	Gasoline 2-stroke	Gasoline 4-stroke	Gasoline Total	LPG	El
	Stock numbers						
Agricultural machinery	96,618	78,532	-	18,036	18,036	-	50
Forestry machinery	2,754	854	1,800	-	1,800	-	100
Building and construction machinery	110,474	59,263	5,414	45,430	50,844	-	367
Industrial machinery	20,293	10,788	-	-	-	1,723	7,781
Commercial and institutional machinery	164,412	14,837	37,802	20,171	57,972	1,126	90,476
Residential machinery	2,290,198	-	254,249	448,382	702,631	-	1,587,567
Grand total	2,684,750	164,274	299,265	532,019	831,284	2,849	1,653,404
	Operating hours (million hours)						
Agricultural machinery	19.08	15.90	-	3.13	3.13	-	0.04
Forestry machinery	2.06	0.59	1.44	-	1.44	-	0.03
Building and construction machinery	36.19	27.69	0.43	7.89	8.32	-	0.18
Industrial machinery	12.73	6.97	-	-	-	1.53	4.23
Commercial and institutional machinery	32.36	6.62	3.61	5.89	9.50	0.98	15.25
Residential machinery	125.75	-	4.72	6.90	11.62	-	114.13
Grand total	228.17	57.78	10.20	23.82	34.02	2.51	133.86
	Specific operating hours (hours per machine)						
Agricultural machinery	197	202	-	174	174	-	800
Forestry machinery	747	693	800	-	800	-	250
Building and construction machinery	328	467	80	174	164	-	482
Industrial machinery	627	646	-	-	-	890	544
Commercial and institutional machinery	197	447	96	292	164	868	169
Residential machinery	55	-	19	15	17	-	72

The largest number of diesel machines are used in agriculture, followed by building and construction, commercial and institutional and industry. However, the total number of operating hours is lower for agricultural machinery than for building and construction machinery, because the weighted number of specific operating hours for agricultural machinery is low compared to the other sectors.

LPG fuelled forklifts are used in the commercial and institutional, and industrial sectors.

By far the largest stock of gasoline machines is in the residential sector. However, due to rather low specific operating hours, the total number of operating hours for private gasoline machines is only slightly higher than for gasoline machines in commercial and institutional and building and construction.

Also for electric machines the largest stock is by far in residential. The total number of operating hours are predominantly performed by robotic lawn mowers. Therefore, the average specific number of operating hours will be somewhat higher for residential than if the stock consisted only of manually operated machines. This goes as well in commercial and institutional, where robotic lawn mowers also play a major role in terms of total operating hours.

For other types of electric equipment, forklifts used in building and construction, commercial and institutional and industry are the most common type.

However, track type excavators and wheel loaders (< 5,1 tonnes) have begun to enter the stock of building and construction machinery from 2021.

In 2021, the total stock of diesel engines is widely distributed over the different engine power classes and emission levels in 2021 (Figure S.1). For diesel machinery as a whole, the shares of total operating hours (Figure S.2) are higher than stock shares of machinery (Figure S.2) for increasingly newer emission standards and increasingly larger engine power classes.

For gasoline machinery in total, 4-stroke engines are the most common engine type, and apart from agricultural ATV's, for which the emission factors are based on emission data for conventional technology motorcycles, only Stage II and Stage V engines are present in the stock in 2021 (Figure S.1). Also in the case of gasoline machinery, the shares of total operating hours (Figure S.2) are higher than stock shares of machinery (Figure S.1) for increasingly newer emission standards.

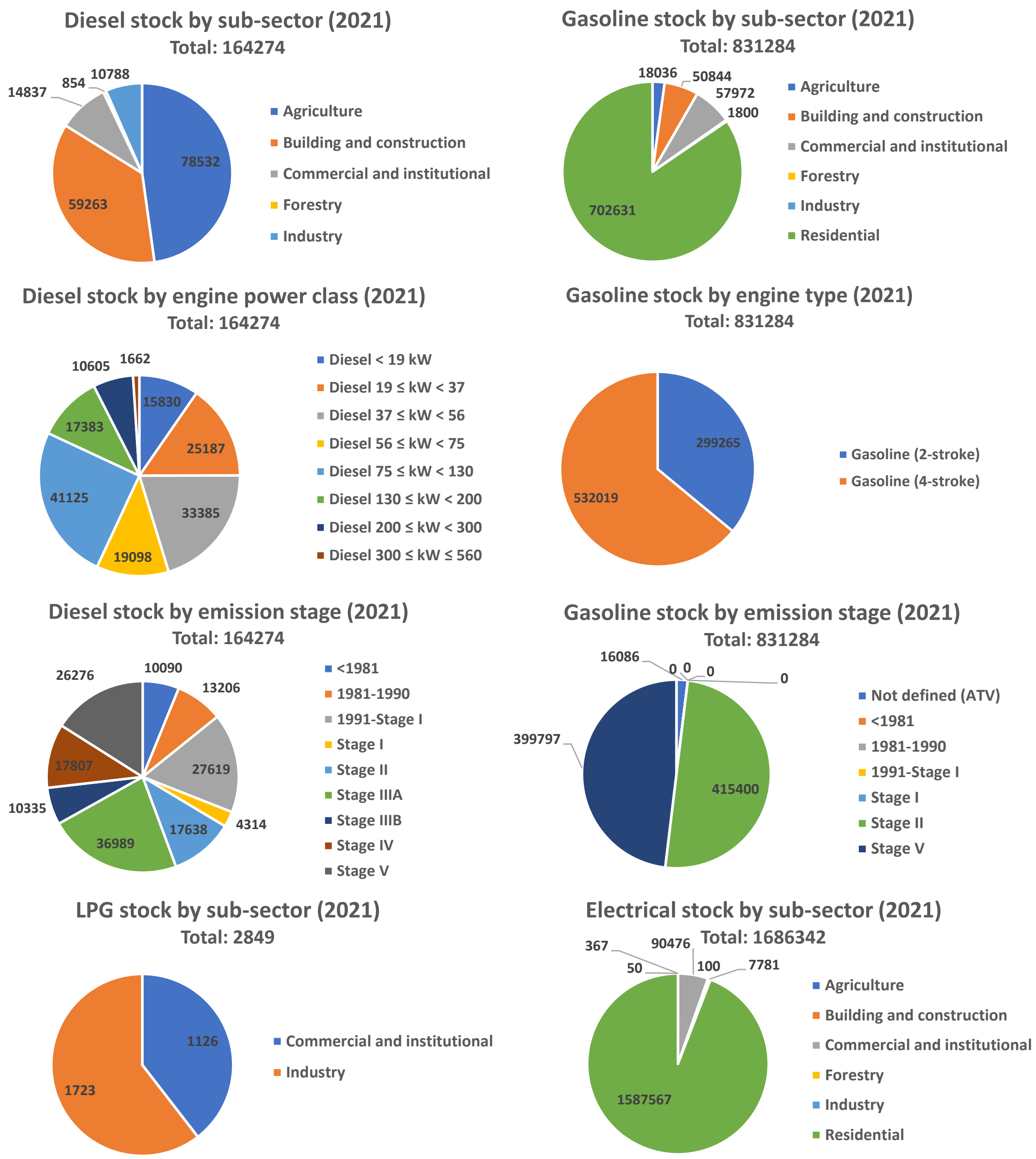


Figure S.1 Total stock by fuel type, sub-sector, rated engine power class and emission stage for non-road machinery in 2021.

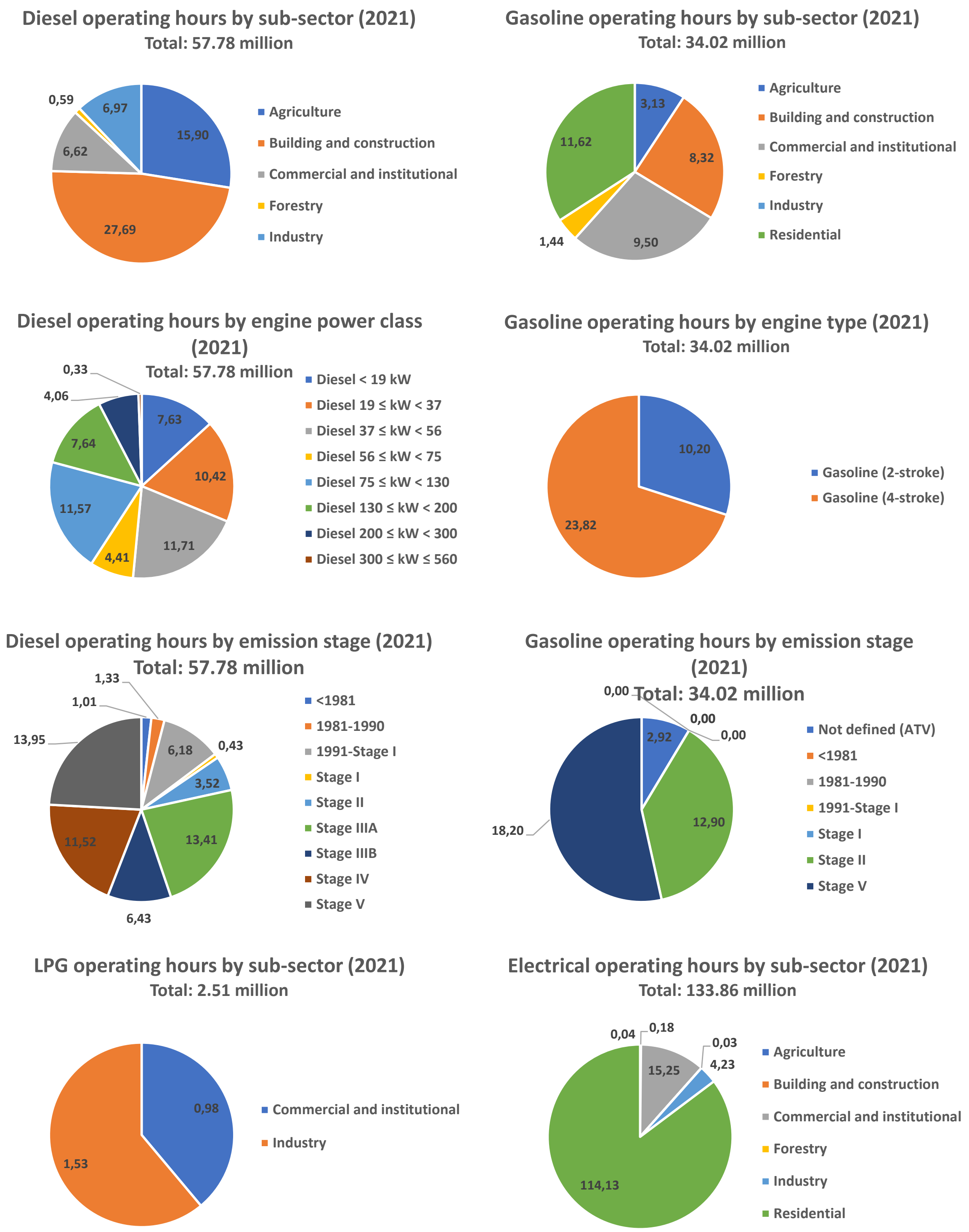


Figure S.2 Total operating hours by fuel type, sub-sector, rated engine power class and emission stage for non-road machinery in 2021.

Stock and operating hours from 1980-2040

The development of the total stock and operating hours by fuel type, sub-sector, rated engine power class and emission stage for non-road machinery from 1980-2040 are shown in Figure S.3 and Figure S.4, respectively.

The development of the total stock of diesel machinery is particularly affected by agriculture, where the number of tractors has decreased significantly in the years up to 2021. The decline in the stock will level off towards 2040, not least because the future stock of tractors is expected to be constant.

There has been a large growth in the stock of residential gasoline machines until 2010, after which the total stock of gasoline machinery decreases due to an increased switch to electricity for some of the machine types.

The number of electric machines in residential has increased a lot in the historical period up to 2021, and this stock increase is expected to continue until 2025. The number of electric forklifts used in the commercial and institutional and industrial sectors is expected to increase in the future due to the green transition in machine sales, where sales of diesel and LPG fuelled forklifts is expected to switch completely to electric towards 2030. In addition, it is clear from the Figures S.3 and S.4 how new emission standards for diesel and gasoline are gradually being implemented in the stock and will become more and more dominant towards 2040.

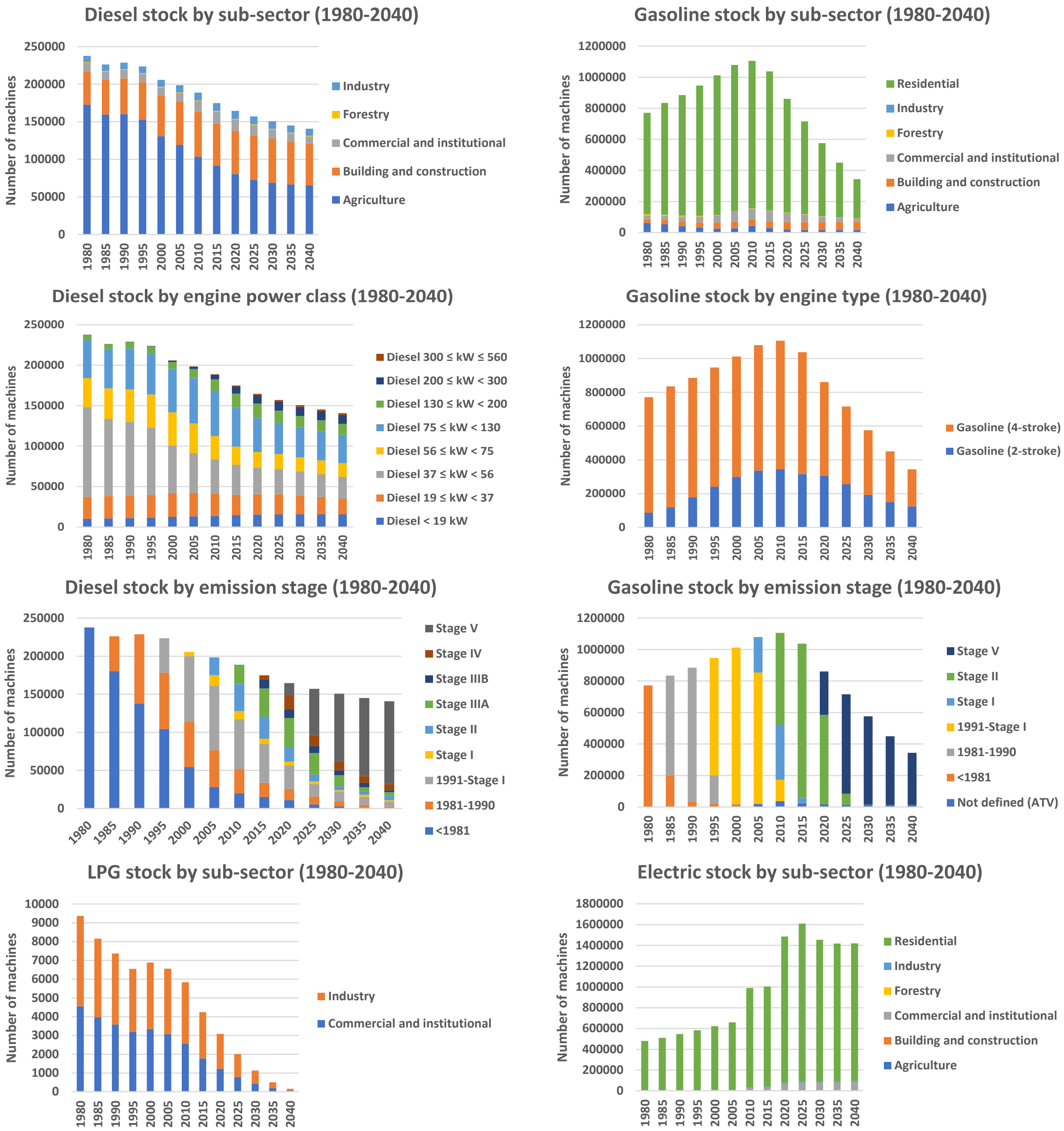


Figure S.3 Total stock by fuel type, sub-sector, rated engine power class and emission stage for non-road machinery (1980-2040).

In most cases, the development in the total operating hours follows the same pattern as the stock development in the period 1980-2040. However, it is worth noting the following. A major reason why the total number of operating hours for diesel increases slightly towards 2010, in contrast to the development in the total stock, is due to the development within the size category 37-56 kW, where especially many older agricultural tractors with low specific operating hours exited the stock.

For gasoline machines, the total number of operating hours decreases less than the total stock numbers from 2010 onwards, because the specific operating hours for the machine types not being replaced by electric machines, are generally higher than the average specific operating hours for the total stock. This is particularly true for residential non-road machinery.

From 2015 onwards for electrical machinery robotic lawn mowers has a very high share of the total number of operating hours in the commercial and institutional and residential sectors. The number of robotic lawn mowers has grown substantially in the later years, and for robotic lawn mowers, the machine specific operating hours are very high.

For all years throughout the 1980-2040 period for diesel and gasoline machinery, the shares of total operating hours (Figure S.4) are higher than stock shares of machinery (Figure S.3) for increasingly newer emission standards and increasingly larger engine power classes.

Figure S.4 Total operating hours by fuel type, sub-sector, rated engine power class and emission stage for non-road machinery 1980-2040.

Energy consumption and emissions in 2021

The energy consumption results for non-road machinery in 2021 per non-road sector, fuel type and engine type are shown in Table S.2.

Table S.2 Energy consumption results for non-road machinery in 2021 per non-road sector, fuel type and engine type.

	Total	Diesel	Gasoline 2-stroke	Gasoline 4-stroke	Gasoline Total	LPG	El
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
Agricultural machinery	8.64	8.50	-	0.15	0.15	-	0.00
Forestry machinery	0.59	0.54	0.05	-	0.05	-	0.00
Building and construction machinery	7.66	7.33	0.02	0.31	0.32	-	0.01
Industrial machinery	1.10	0.66	-	-	0.00	0.27	0.17
Commercial and institutional machinery	2.56	1.49	0.08	0.71	0.79	0.15	0.14
Residential machinery	0.41	-	0.08	0.31	0.39	-	0.01
Grand total	20.97	18.51	0.23	1.47	1.71	0.42	0.33
				% of total			
Agricultural machinery	41	46	0	10	9	0	0
Forestry machinery	3	3	23	0	3	0	0
Building and construction machinery	37	40	7	21	19	0	2
Industrial machinery	5	4	0	0	0	65	50
Commercial and institutional machinery	12	8	34	48	46	35	41
Residential machinery	2	0	36	21	23	0	7
Grand total	100	100	100	100	100	100	100

For non-road machinery in total in 2021 the energy consumption shares for diesel, gasoline 2-stroke, gasoline 4-stroke, LPG (forklifts) and electrical engines were 88 %, 1 %, 7 %, 2 % and 2 %, respectively (derived from Table S.2).

In total for 2021, most of the fuel is used by the machines in agriculture (41 %) and building and construction (37 %), whereas smaller fuel consumption shares are calculated for the machines in commercial and institutional (12 %), industrial (5 %), forestry (3 %) and residential (2 %).

The most prominent sectors of diesel consumption are agriculture (46 %), building and construction (40 %) and commercial and institutional (12 %) in 2021. In the case of gasoline, most of the fuel is used in the non-road sectors commercial and institutional (46 %), residential (23 %) and building and construction (19 %). The LPG is used in the industrial (65 %) and commercial and institutional (35 %) sectors, whereas most of the electricity is used in the industrial (50 %) and commercial and institutional (41 %) sectors and by residential machinery (7 %).

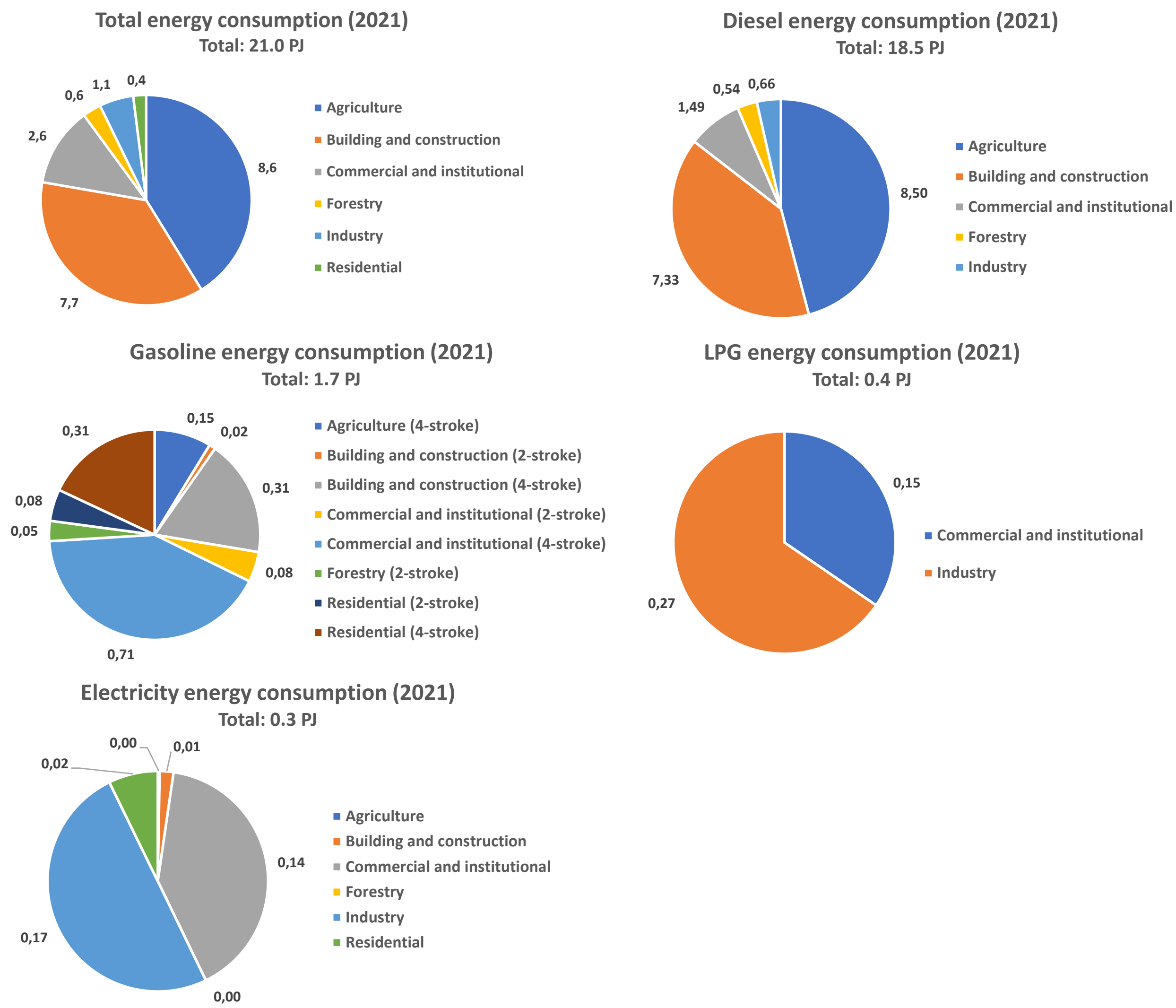


Figure S.5 Energy consumption by fuel type and sub-sector for non-road machinery in 2021.

In Table S.3 the total emissions per non-road sector and percentage shares of totals are shown for 2021.

Table S.3 Total emissions per non-road sector and percentage shares of totals for 2021

	SO_2	NO_x	PM	CO	VOC	CO_2	NMVOC	CH_4	N_2O	BC
	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes
Agricultural machinery	4.04	2294.0	196.4	4843.7	472.6	639.7	443.1	29.5	30.6	115.7
Forestry machinery	0.28	32.2	5.7	1043.4	219.8	43.6	206.9	13.0	2.0	1.2
Building and construction machinery	3.57	1645.0	102.5	10104.1	597.7	565.3	578.8	18.9	26.1	72.2
Industrial machinery	0.31	337.3	37.8	206.8	60.4	66.0	58.7	1.7	3.1	22.7
Commercial and institutional machinery	1.04	476.5	38.8	27035.8	761.5	173.8	731.6	29.9	6.7	18.8
Residential machinery	0.17	34.4	15.9	11638.1	891.4	26.7	871.0	20.4	0.5	0.8
Grand total	9.40	4819.4	397.1	54872.0	3003.5	1515.1	2890.0	113.4	69.1	231.4
	Emissions (% of total)									
Agricultural machinery	43	48	49	9	16	42	15	26	44	50
Forestry machinery	3	1	1	2	7	3	7	11	3	1
Building and construction machinery	38	34	26	18	20	37	20	17	38	31
Industrial machinery	3	7	10	0	2	4	2	1	5	10
Commercial and institutional machinery	11	10	10	49	25	11	25	26	10	8
Residential machinery	2	1	4	21	30	2	30	18	1	0
Grand total	100	100	100	100	100	100	100	100	100	100

The largest emissions of NO_x, PM, CO_2, SO_2, N_2O and BC in 2021 are calculated for agricultural non-road and building and construction.

The primary reasons for the high emission contributions in the two above mentioned non-road sectors are the large fuel consumption of primarily diesel and the high diesel related emission factors, in the case of NO_x, N_2O and BC. For PM, CO_2 and SO_2 the high emission contributions are primarily due to the high fuel consumption calculated for these sectors.

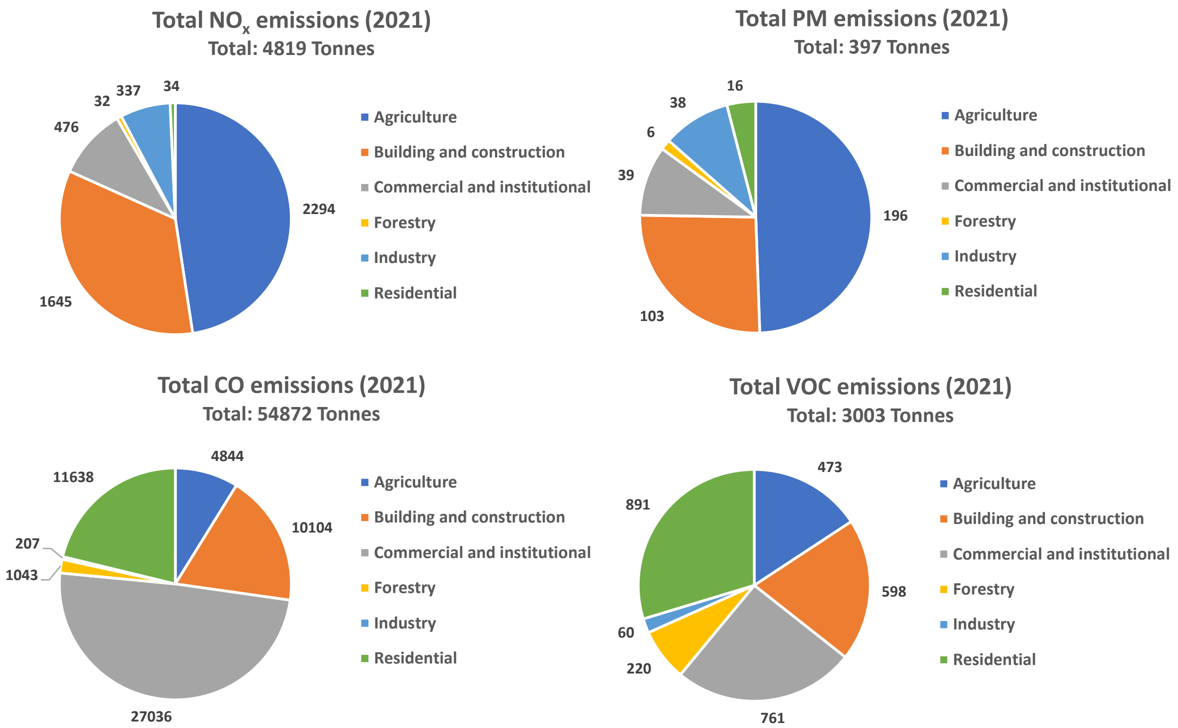


Figure S.6 Emissions of NO_x, PM, CO and VOC per sub-sector for non-road machinery in 2021.

For CO, VOC, NMVOC, CH_4 the largest emissions in 2021 are calculated for residential non-road and commercial and institutional, followed by building and construction. This is due to relatively large gasoline consumptions in these sectors, and high fuel related emission factors for gasoline.

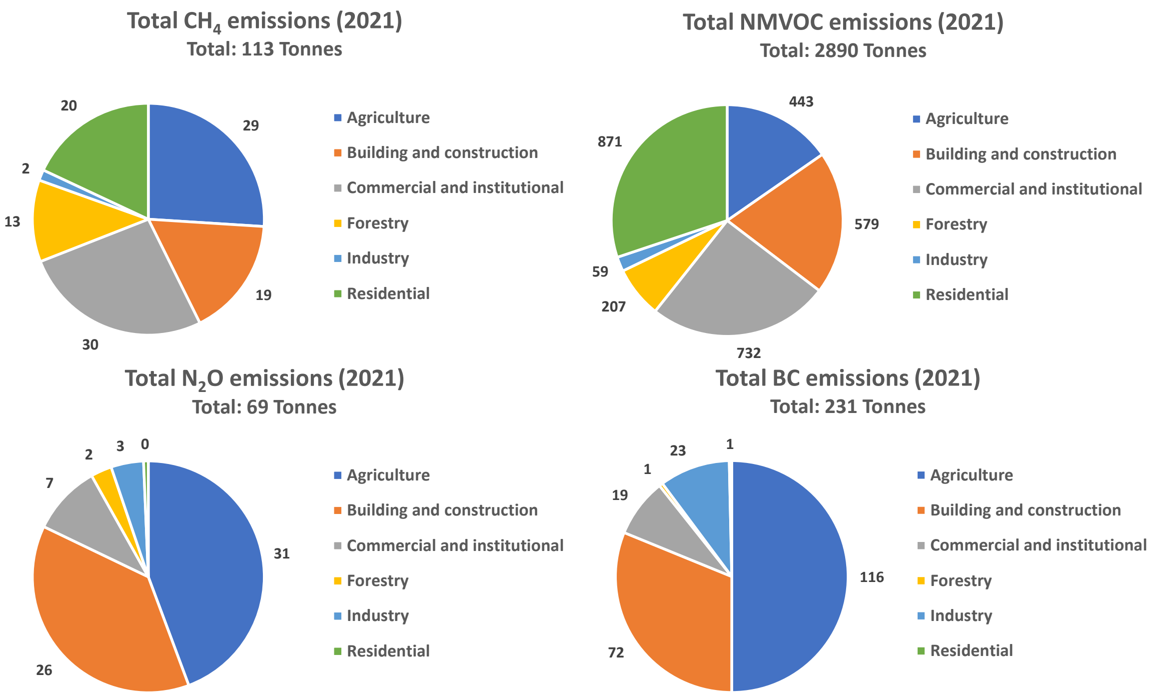


Figure S.7 Emissions of CH_4, NMVOC, N_2O and BC per sub-sector for non-road machinery in 2021.

Energy consumption and emissions from 1980-2040

Figure S.8 shows the relative energy consumption development per fuel type and as total for non-road machinery in 1980-2040.

The total non-road fuel consumption has increased by 21 % from 1980 to 2021. For diesel, gasoline, LPG and electricity the fuel consumption has changed by 35 %, -17 %, -72 % and 303 %, respectively (derived from Figure S.8).

From 2021 to 2040 a minor decrease of 2 % is calculated for the total non-road fuel consumption. For diesel, gasoline, LPG and electricity, the calculated fuel consumption has changed by -1 %, -11 %, -98 % and 50 %, respectively (Figure S.8).

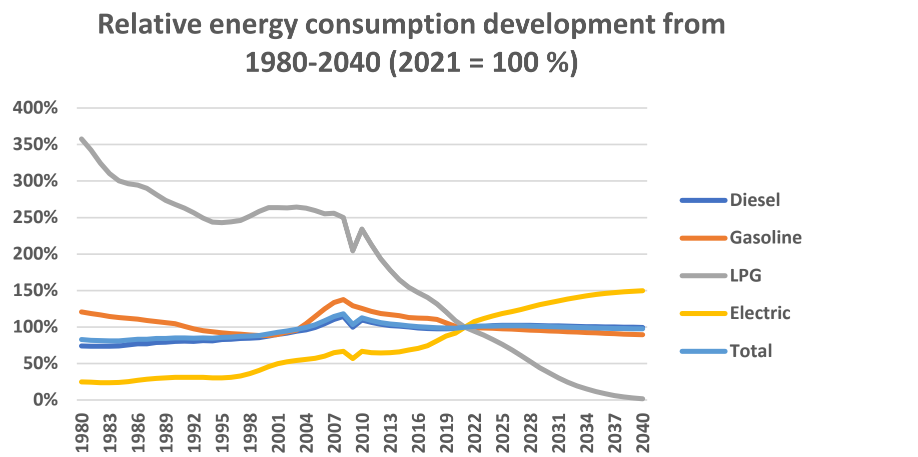


Figure S.8 Relative energy consumption development per fuel type and total for non-road machinery 1980-2040.

Figure S.9 shows the development of the energy consumption for non-road machinery as totals, per fuel type and non-road sector from 1980-2040.

The development of the energy consumption in agriculture throughout the period 1980-2040 has a major impact on the development of the total energy consumption and separately for the total diesel consumption development during the period.

For gasoline, the fuel consumption development in the historical period from 1980 to 2021 is mostly influenced by the following trends. The gasoline consumption has decreased in agriculture and forestry towards 2005 due to the phasing out of gasoline-powered tractors and less use of chainsaws, respectively. Also, the number of gasoline-powered machines in the commercial and institutional and residential sectors has increased significantly from 2000 to 2010, after which the stock of gasoline machines decreases again due to a shift in new sales towards electric machinery.

The number of gasoline-powered machines and thus gasoline consumption are expected to decrease in the future, due to a further increase towards 2040 in the new sales share and total operating hours for electric powered machines.

Because of the development of the stock and activities for electric machinery, the calculated consumption of electricity increases substantially from 1980 to 2021, and the calculated electricity consumption is expected to increase further until 2040.

From 1980 until 1995, the consumption of LPG decreased due to a decrease in the number of LPG forklifts and hence total operating hours during this period. A significant decline in the total LPG consumption is noted from 2010 onwards, and this LPG consumption decrease is expected to continue in the future towards 2040, due to the transition in forklift new sales towards purely electric machinery from 2030 onwards.

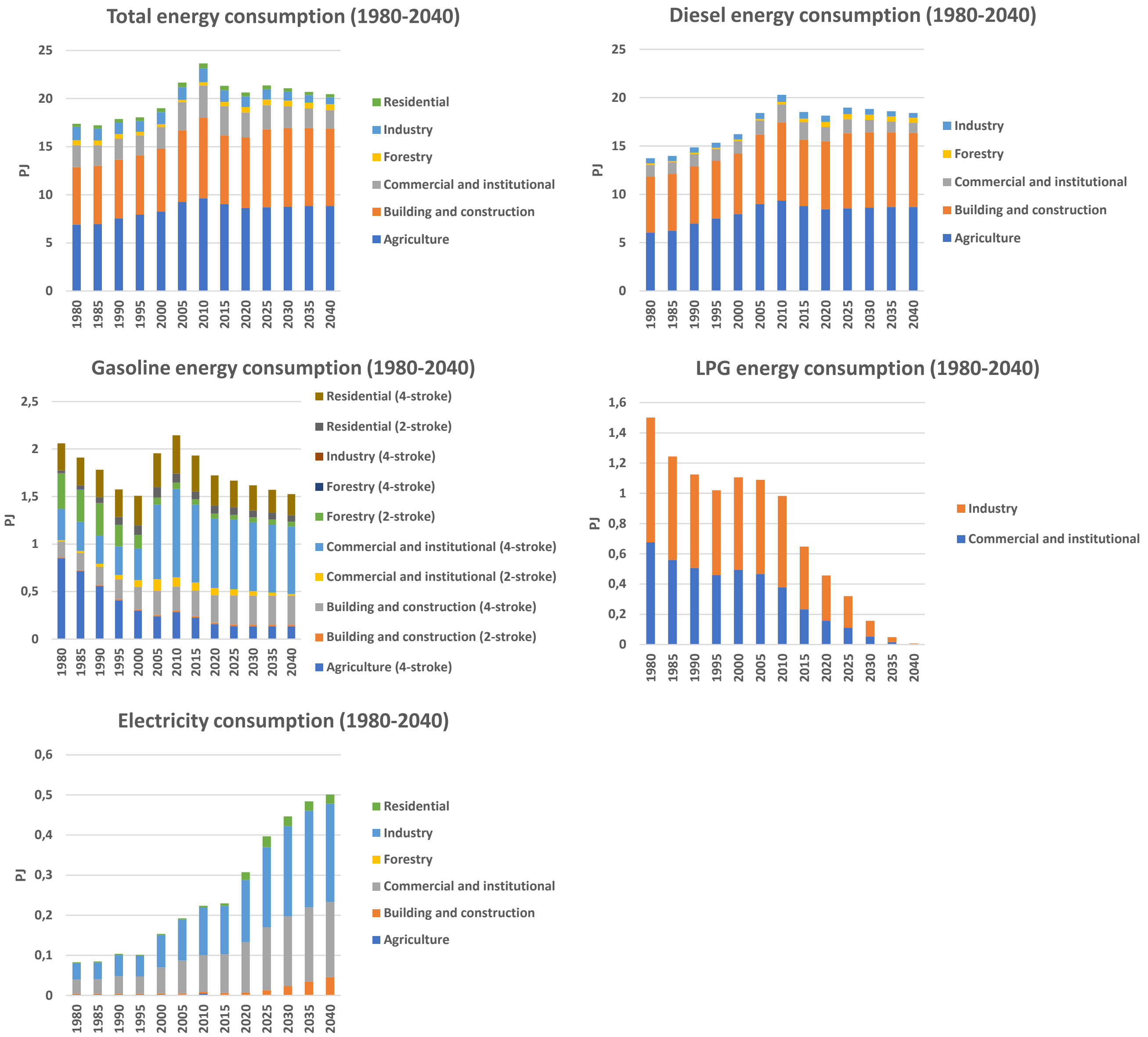


Figure S.9 Energy consumption by fuel type and sub-sector for non-road machinery 1980-2040.

Figure S.10 shows the relative development of the emissions of NO_x, PM, CO, VOC and CO_2 (left) and the emissions of CH_4, NMVOC, N_2O and BC (right) for non-road machinery in 1980-2040.

The total emissions of NO_x, PM, CO and VOC have decreased by 64 %, 85 %, 36 % and 69 %, respectively, from 1980 to 2021 (derived from Figure S.10). The total CO_2 emissions have increased by 20 % in the same period (derived from Figure S.10).

From 2021 to 2040 the total NO_x, PM, CO, VOC and CO_2 emissions are expected to decrease by 51 %, 71 %, 8 %, 36 % and 3 %, respectively (Figure S.10).

The total emissions of CH_4, NMVOC, BC and SO_2 have decreased by 70 %, 68 %, 84 % and 99.7 %, respectively, from 1980 to 2021 (derived from Figure S.10). The total N_2O emissions have increased by 53 % in the same period (derived from Figure S.10).

From 2021 to 2040 the total emissions of CH_4, NMVOC, N_2O, BC and SO_2 are expected to decrease by 30 %, 37 %, 1 %, 77 % and 1 %, respectively (Figure S.105).

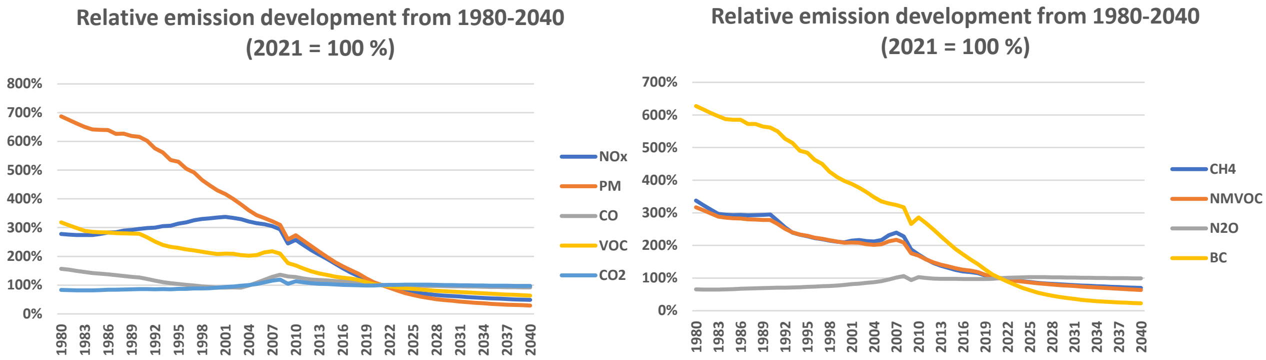


Figure S.10 Relative development of the emissions of NO_x, PM, CO, VOC and CO_2 (left) and CH_4, NMVOC, N_2O and BC (right) for non-road machinery 1980-2040.

Figure S.11 shows the development of the NO_x, PM, CO and VOC emissions per sub-sector for non-road machinery in 1980-2040.

During the period 1980-2040, most of the NO_x and PM emissions come from the diesel machinery used in agriculture and building and construction.

For NO_x, the emissions have increased from 1980 until 2000 mainly due to an increase in the emissions from agriculture. From 2000, the emissions have been reduced sharply towards 2021, due to the gradual shift towards newer emission stages in new sales for diesel machinery, which is visible in the distribution of the stock and total operating hours in all sub-sectors, and in turn reduces the NO_x emission factors. For the same reasons, the NO_x emissions are expected to decline further towards 2040.

The total PM emissions have fallen sharply from the early 1990s until 2021, and the emissions are also expected to decline further towards 2040. This emission development for PM can be explained by changes in the distribution of the stock and operating hours towards newer engine technologies for diesel engines. Predominantly due to the continuous shift of the diesel engines towards Euro V standards, the emissions of PM for agricultural machinery are expected to decline further towards 2040.

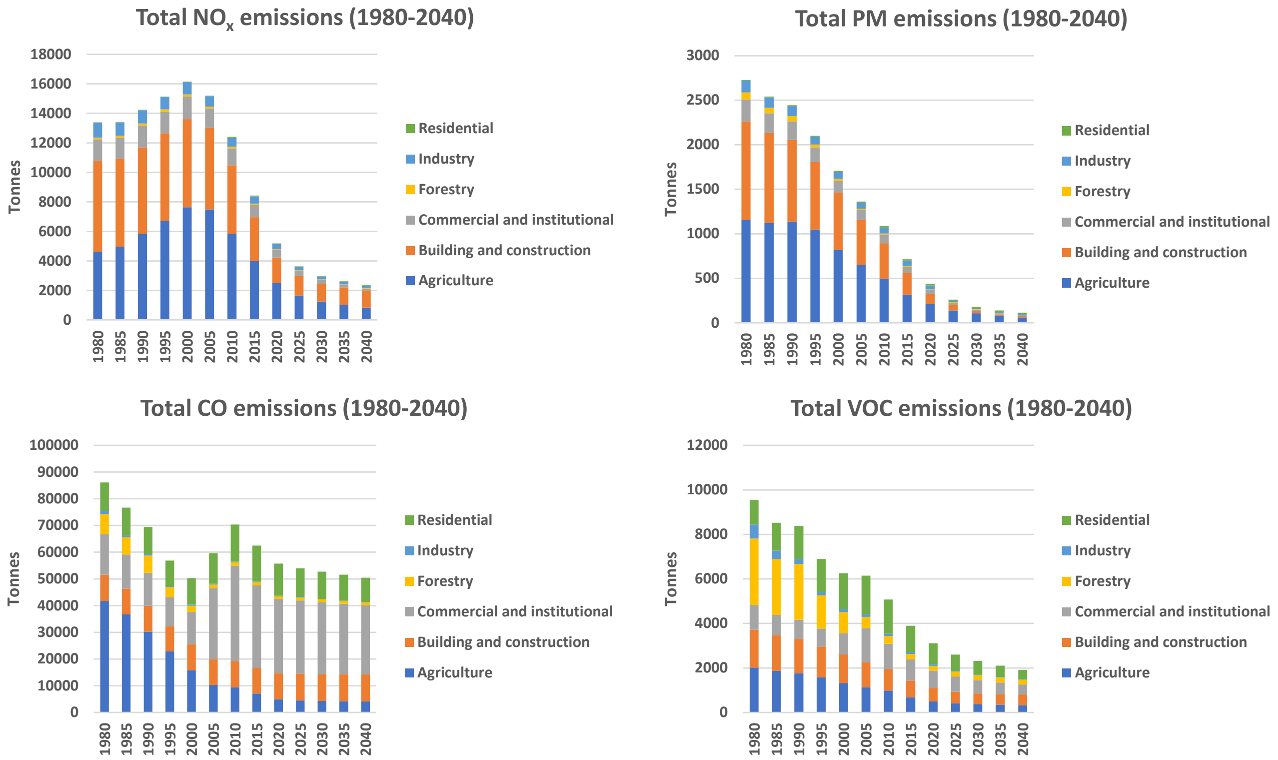


Figure S.11 Emissions of NO_x, PM, CO and VOC per sub-sector for non-road machinery 1980-2040.

The decline in the total CO emissions from 1980 to 2000 is by large caused by the phasing out of gasoline fuelled vintage tractors. From 2000 to 2010 the total CO emissions increased significantly, mainly due to a large increase in the activities made by gasoline machinery in the commercial and institutional sector, for which the emissions from 4-stroke engines play a dominant role. After that, the CO emissions gradually reduce mainly due emission factor reductions and because of the increasing shift from gasoline to electric machinery in many machinery cases. Moderate decreases in the CO emissions are expected from 2021 towards 2040.

The total emissions of VOC have decreased significantly from 1990 to 2005 mainly due to the phasing out of gasoline fuelled vintage tractors in agriculture and the large reduction of the stock and total operating hours for gasoline 2-stroke engine chain saws used in forestry. The VOC emissions reduce in all non-road sectors from 2005 onwards mainly due to emission factor reductions and the increasing shift from gasoline to electric machinery in many machinery cases.

Sammendrag

Indledning

Denne rapport dokumenterer de danske emissionsopgørelser og fremskrivninger for mobile ikke-vejgående arbejdsmaskiner, der anvendes inden for landbrug, skovbrug, bygge og anlæg, industri, handel og service samt husholdninger.

Bestands- og aktivitetsdata, emissionsopgørelser og fremskrivninger er vist for perioden 1980-2040, og resultater er vist for energiforbrug samt emissioner af NO_x (kvælstofoxider), PM (partikler), CO (kulmonoxid), VOC (flygtige organiske forbindelser), NMVOC (ikke-metan flygtige organiske forbindelser), CH_4 (metan), CO_2, (kuldioxid)), SO_2 (svovldioxid), N_2O (lattergas) og BC (black carbon).

De danske emissionsopgørelser og fremskrivninger for mobile ikke-vejgående arbejdsmaskiner (på engelsk benævnt som NRMM (non-road mobile machinery) og i det følgende benævnt som non-road maskiner) beregnes med modellen DEMOS (Danish Emission model system for Mobile Sources)[2], udviklet på Institut for Miljøvidenskab (ENVS)/Nationalt Center for Miljø og Energi (DCE) ved Aarhus Universitet.

I DEMOS-delmodellen for non-road maskiner (DEMOS-NRMM) modelleres bestands- og aktivitetsdata hvert år i tidsserier, og som output beregnes emissionsresultater, der automatisk indgår i de samlede danske opgørelser over atmosfæriske emissioner, der årligt udarbejdes af ENVS/DCE ved Aarhus Universitet.

De danske drivhusgasemissioner rapporteres til EU og UNFCCC-konventionen (United Nations Framework Convention on Climate Change), og de luftforurenende emissioner rapporteres til UNECE LRTAP-konventionen (United Nations Economic Commission for Europe Long Range Transboundary Pollution). Derudover udarbejdes der hvert år nationale emissionsfremskrivninger af drivhusgasser til Energistyrelsens Klimastatus og -fremskrivning, og hvert andet år afrapporteres fremskrivninger af luftforurenende emissioner til EU og FN/ECE.

Inputdata for bestande og aktiviteter

Til brug for modelleringen af bestande og aktivitetsdata for non-road maskiner indhentes data for nysalg, samlet bestand og årlige driftstimer fra mange forskellige datakilder, f.eks. nationale statistikker, brancheorganisationer, store importører af maskiner og forskellige brancheeksperter.

Bestands- og aktivitetsdata indsamles på et maskintype- og motortypeniveau. Yderligere oplysninger om maskinernes gennemsnitsalder, maksimale leveti-

[2] DEMOS-modellen består af separate databasemodeller for hver af transportens delsektorer (vej, bane, fly, søfart) og for de mobile ikke-vejgående arbejdsmaskiner, der anvendes inden for landbrug, skovbrug, byggeri og anlæg, industri, handel og service samt husholdninger.

der, motorstørrelser og motorbelastningsfaktorer indsamles også for at gruppere maskinbestanden i henhold til den opdeling efter brændstoftype, motoreffektklasse og emissionstrin, der anvendes i modellen.

Inputfaktorer for brændstofforbrug og emissioner

For dieseldrevne non-road maskiner, grupperes brændstofforbrug og emissionsfaktorer i de følgende emissionstrin: < 1981, 1981-1990, 1991-trin I, trin I, II, III A, IIIB, IV og V. Indenfor hvert af disse emissionstrin er emissionsfaktorerne opdelt i motoreffektklasser, der svarer til de motorstørrelsesintervaller der benyttes i EU's emissionsdirektiver indenfor non-road.

Brændstofforbrug og emissionsfaktorer for benzindrevne non-road maskiner er opdelt i 2-takts og 4-takts motortyper for både håndholdt (SH) og ikke-håndholdt (SN) udstyr. For hver motor- og udstyrstype, grupperes faktorerne i følgende emissionstrin: < 1981, 1981-1990, 1991-trin I, trin I, trin II og trin V. Faktorerne grupperes yderligere i motorstørrelsesintervaller (ccm), der svarer til motorstørrelsesintervallerne i EU's emissionsdirektiver for benzindrevne arbejdsmaskiner.

For diesel- og benzindrevne non-road maskiner, er IFEU (2004, 2009) den vigtigste datakilde til de faktorer for brændstofforbrug og emissioner der bruges i DEMOS-NRMM. I modelopdateringer, der er foretaget hen over årene, er emissionsfaktorbasen i DEMOS-NRMM blevet udvidet med nye emissionstrin og maskintyper, og i nogle tilfælde er der inddraget supplerende emissionsdata fra yderligere kilder i modellen (f.eks. EMEP/EEA (2023), ICCT (2016)).

Emissionsfaktorerne for LPG-motorer (gaffeltrucks) på forskellige teknologitrin kommer fra Notter og Schmied (2015). For ATV'er er emissionsfaktorerne baseret på emissionsdata for konventionelle motorcykler beregnet i de danske emissionsopgørelser for vejtransport (Winther, 2022a).

Beregningsmetode

Brændstofforbruget og emissionerne beregnes for hver maskintype, år og emissionstrin som produktet af antal maskiner, motorstørrelse (kW), gennemsnitlig motorbelastning (%), årlige driftstimer og brændstof- eller emissionsfaktor (g/kWh). Beregningerne af brændstofforbrug og emissioner tager også hensyn til effekterne af motorslid, varierende motorbelastning og andelen af maskiner med præinstalleret partikelfilter.

Bestande og driftstimer for non-road maskiner i 2021

Tabel S.1 viser det totale antal maskiner og årlige driftstimer samt specifikke årlige driftstimer (timer pr. maskine) for non-road maskiner i 2021 opdelt pr. non-road sektor, brændstof- og motortype.

Tabel S.1 Antal maskiner og årlige driftstimer samt specifikke årlige driftstimer (timer pr. maskine) for non-road maskiner i 2021 opdelt pr. non-road sektor, brændstof- og motortype.

	Total	Diesel	Benzin 2-takt	Benzin 4-takt	Benzin Total	LPG	El
				Antal maskiner			
Landbrug	96.618	78.532	-	18.036	18.036	-	50
Skovbrug	2.754	854	1.800	-	1.800	-	100
Bygge og anlæg	110.474	59.263	5.414	45.430	50.844	-	367
Industri	20.293	10.788	-	-	-	1.723	7.781
Handel og service	164.412	14.837	37.802	20.171	57.972	1.126	90.476
Husholdninger	2.290.198	-	254.249	448.382	702.631	-	1.587.567
Grand total	2.684.750	164.274	299.265	532.019	831.284	2.849	1.653.404
				Årlige driftstimer (mio. timer)			
Landbrug	19,08	15,90	-	3,13	3,13	-	0,04
Skovbrug	2,06	0,59	1,44	-	1,44	-	0,03
Bygge og anlæg	36,19	27,69	0,43	7,89	8,32	-	0,18
Industri	12,73	6,97	-	-	-	1,53	4,23
Handel og service	32,36	6,62	3,61	5,89	9,50	0,98	15,25
Husholdninger	125.75.	-	4.72	6.90	11.62		114.13.
Grand total	228.17.	57.78	10.20	23.82	34.02	2.51	133.86.
				Specifikke årlige driftstimer (timer pr. maskine)			
Landbrug	197	202	-	174	174	-	800
Skovbrug	747	693	800	-	800	-	250
Bygge og anlæg	328	467	80	174	164	-	482
Industri	627	646	-	-	-	890	544
Handel og service	197	447	96	292	164	868	169
Husholdninger	55	-	19	15	17	-	72

Der er flest dieselmaskiner indenfor landbrug, efterfulgt af bygge og anlæg, handel og service og industri. Det samlede antal driftstimer er dog lavere for landbrugsmaskiner end for bygge- og anlægsmaskiner, fordi det vægtede specifikke antal driftstimer for maskiner indenfor landbruget er lavt sammenlignet med de øvrige sektorer.

LPG-drevne gaffeltrucks bruges indenfor handel og service og indenfor industri.

Langt den største bestand af benzinmaskiner udgøres af private maskiner indenfor husholdninger. På grund af forholdsvis lave specifikke driftstimer er det samlede antal driftstimer for benzinmaskiner indenfor husholdninger dog kun lidt højere end for de professionelle benzinmaskiner indenfor handel og service samt bygge og anlæg.

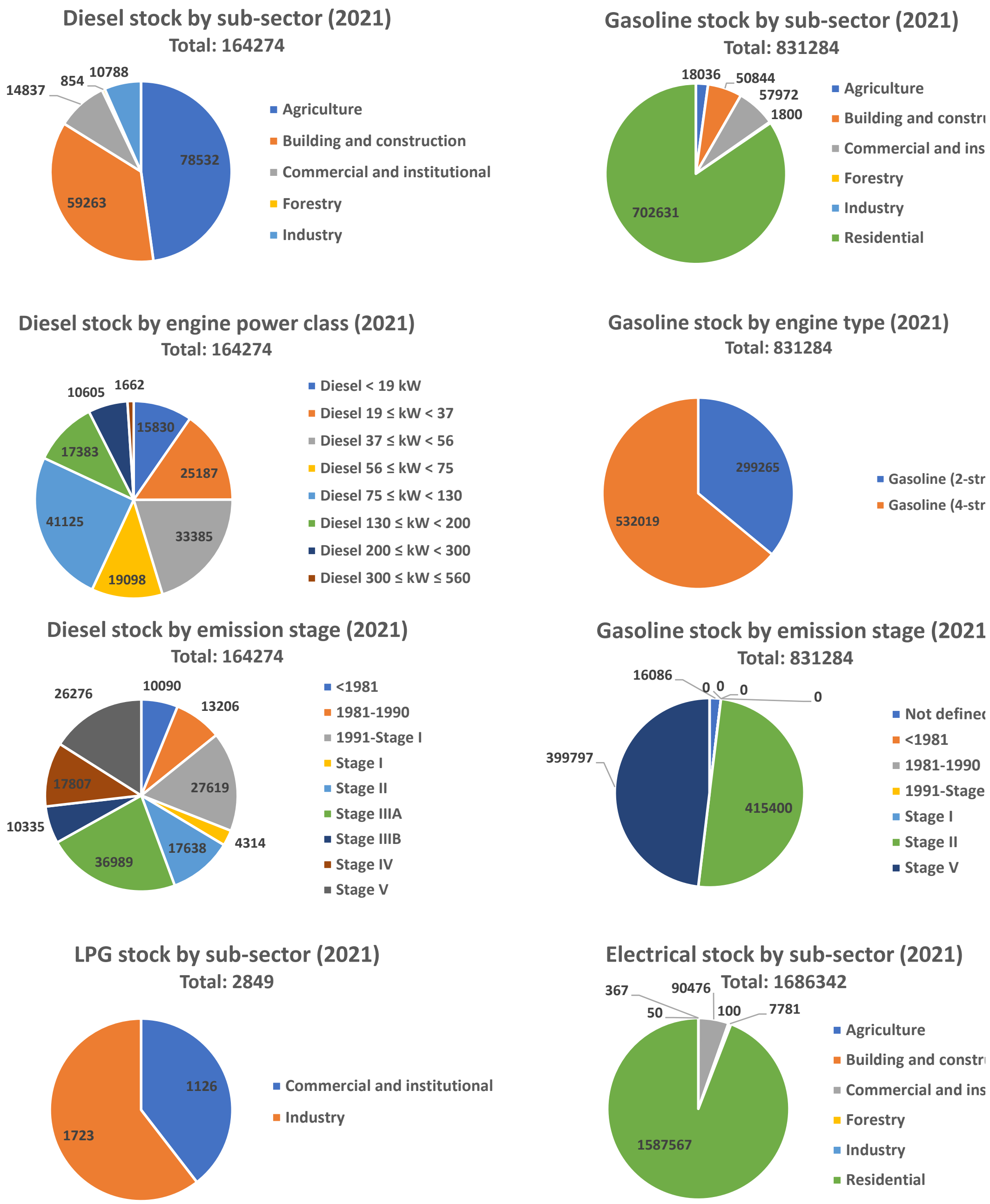
Også for elektriske maskiner er langt den største bestand indenfor husholdninger. En stor del af det samlede antal driftstimer indenfor husholdninger udføres af robotplæneklippere, og derfor ville det gennemsnitlige specifikke antal driftstimer være noget lavere for husholdninger, hvis materiellet kun bestod af manuelt betjente maskiner. Det samme gælder indenfor handel og service, hvor robotplæneklipperes driftstimer også udgør en stor andel af de samlede driftstimer.

For andre typer af eldrevne maskiner og udstyr, er gaffeltrucks, der bruges indenfor bygge- og anlæg samt handel og service, den mest almindelige type.

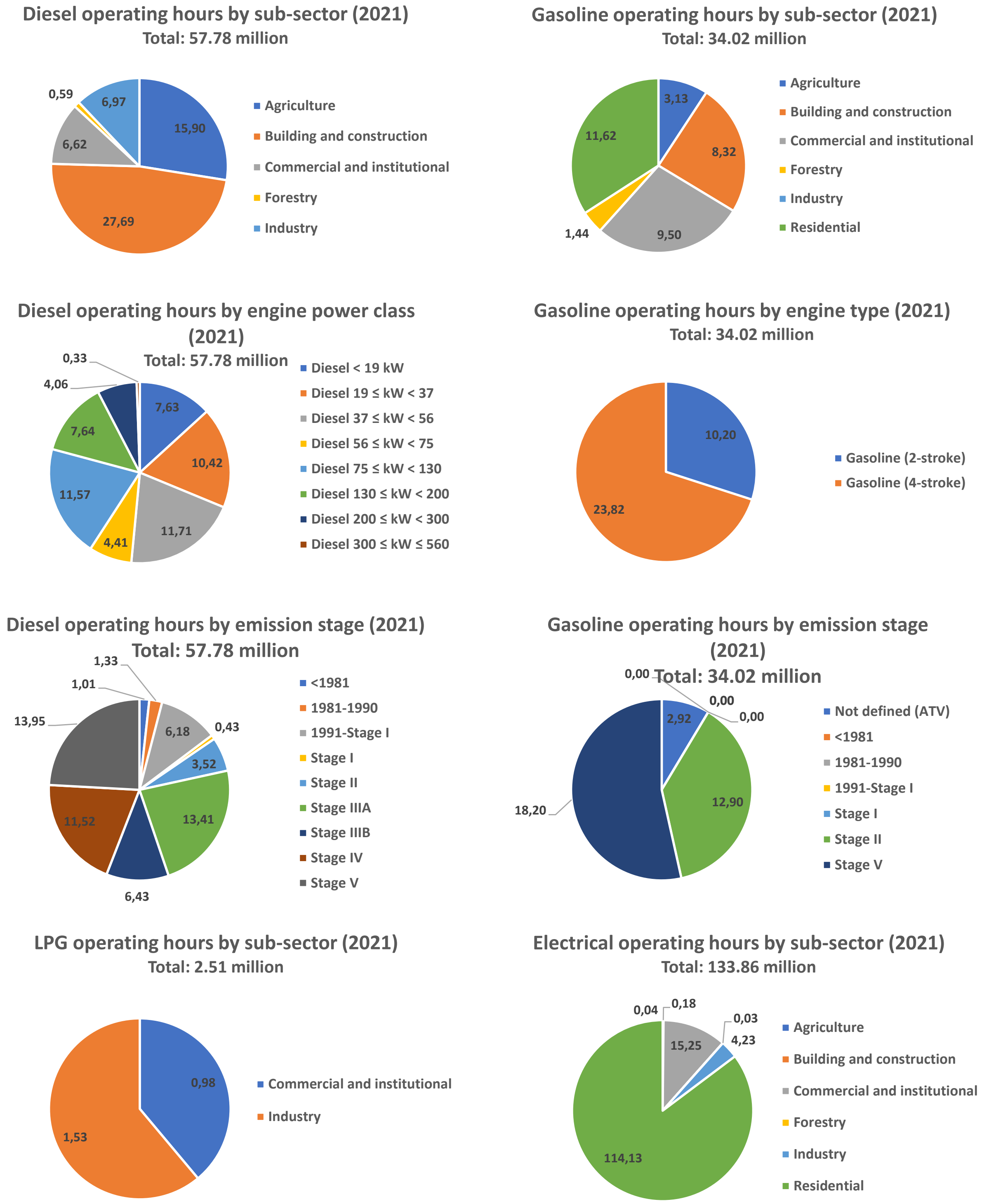
Gummihjulslæssere og gravemaskiner på bånd (< 5,1 tons) er dog begyndt at indgå i bestanden af bygge- og anlægsmaskiner fra 2021.

I 2021 er den samlede bestand af dieselmotorer bredt fordelt indenfor de forskellige motoreffektklasser og emissionstrin i 2021 (figur S.1). For dieselmaskiner som helhed bliver andelene af de samlede driftstimer (figur S.2) i stigende grad højere end bestandsandelene (figur S.2) for nyere og nyere emissionsstandarder og stigende motoreffektklasser.

For benzinmaskiner, er 4-taktsmotorer den mest almindelige motortype, og bortset fra ATV-maskiner, hvor emissionsfaktorerne er baseret på emissionsdata for konventionelle motorcykler, er der kun trin II- og trin V-motorer tilbage i bestanden i 2021 (figur S.1). Også for benzinmaskiner er andelene af de samlede driftstimer (figur S.2) højere end deres bestandsandele (figur S.1) for stadig nyere emissionsstandarder.



Figur S.1 Total bestand af non-road maskiner i 2021 fordelt på brændstoftype, sektor, motorstørrelseskategori og emissionstrin.



Figur S.2 Totale årlige driftstimer for non-road maskiner i 2021 fordelt på brændstoftype, sektor, motorstørrelses-kategori og emissionstrin.

Bestande og driftstimer for non-road maskiner i perioden 1980-2040

Udviklingen i bestanden og de totale årlige driftstimer for non-road maskiner i perioden 1980-2040, fordelt på brændstoftype, sektor, motorstørrelseskategori og emissionstrin er vist i henholdsvis figur S.3 og figur S.4.

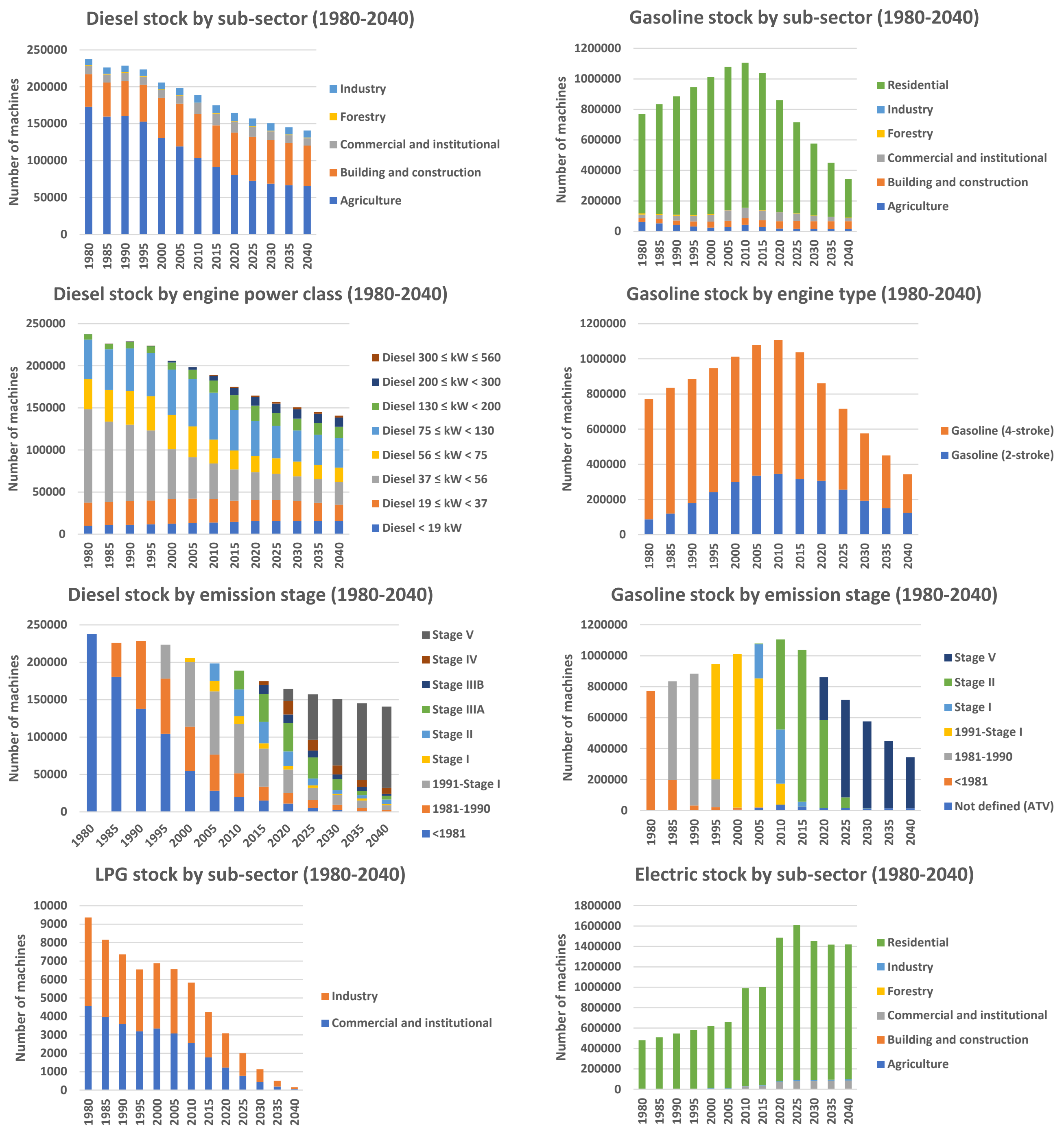
Udviklingen i den samlede bestand af dieselmaskiner er særligt påvirket af bestandsudviklingen indenfor landbrug, hvor antallet af traktorer er faldet markant i årene frem mod 2021. Nedgangen i bestanden af dieselmaskiner forventes at flade ud mod 2040, ikke mindst fordi den totale bestand af traktorer forventes at være konstant i fremtiden.

Der har været en stor vækst i bestanden af benzinmaskiner indenfor husholdninger frem til 2010, hvorefter den samlede bestand af benzinmaskiner er begyndt at falde som følge af et øget skifte fra benzin til el for nogle af maskintyperne.

Antallet af elektriske maskiner indenfor husholdninger er steget meget i den historiske periode frem til 2021, og denne stigning i bestanden forventes at fortsætte indtil 2025.

Antallet af elektriske gaffeltrucks, der anvendes indenfor handel og service samt industri forventes at stige i fremtiden, som følge af den grønne omstilling i salget indenfor dette maskinsegment, hvor salget af diesel- og LPG-drevne gaffeltrucks forventes at overgå helt til elektrisk frem mod 2030.

Det fremgår også tydeligt af figur S.3 og S.4, hvordan nye emissionsstandarder for diesel og benzin gradvist implementeres i bestanden og bliver mere og mere dominerende frem mod 2040.



Figur S.3 Total bestand af non-road maskiner i perioden 1980-2040, fordelt på brændstoftype, sektor, motorstørrelseskategori og emissionstrin.

I de fleste tilfælde følger udviklingen i de samlede driftstimer (Figur S.4) det samme mønster som bestandsudviklingen i perioden 1980-2040 (Figur S.3). Det er dog værd at bemærke følgende. En væsentlig årsag til, at det samlede antal driftstimer for diesel stiger en smule frem mod 2010, i modsætning til udviklingen i den samlede bestand, skyldes udviklingen inden for størrelseskategorien 37-56 kW, hvor især mange ældre landbrugstraktorer med lave specifikke driftstimer udgår af bestanden.

For benzinmaskiner falder det samlede antal driftstimer mindre end det samlede antal maskiner fra 2010 og frem, fordi de specifikke driftstimer for de maskintyper der ikke erstattes af elektriske maskiner, generelt er højere end de gennemsnitlige specifikke driftstimer for den samlede bestand. Dette gælder især for maskiner indenfor husholdninger.

For elektriske maskiner fra 2015 og frem har robotplæneklippere en stor andel af de samlede antal driftstimer indenfor handel og service og husholdninger. Antallet af robotplæneklippere er vokset markant i de senere år, og for robotplæneklippere er de maskinspecifikke årlige driftstimer meget høje.

For diesel- og benzinmaskiner for alle år i perioden 1980-2040, bliver andelene af de samlede driftstimer (figur S.4) i stigende grad højere end bestandsandelene af maskiner (figur S.3) for stadig nyere emissionsstandarder og stadig større motoreffektklasser.

Figur S.4 Totale årlige driftstimer for non-road maskiner i perioden 1980-2040, fordelt på brændstoftype, sektor, motorstørrelseskategori og emissionstrin.

Energiforbrug og emissioner i 2021

Tabel S.2 viser resultaterne for energiforbrug for non-road maskiner i 2021, opdelt pr. non-road sektor, brændstof- og motortype.

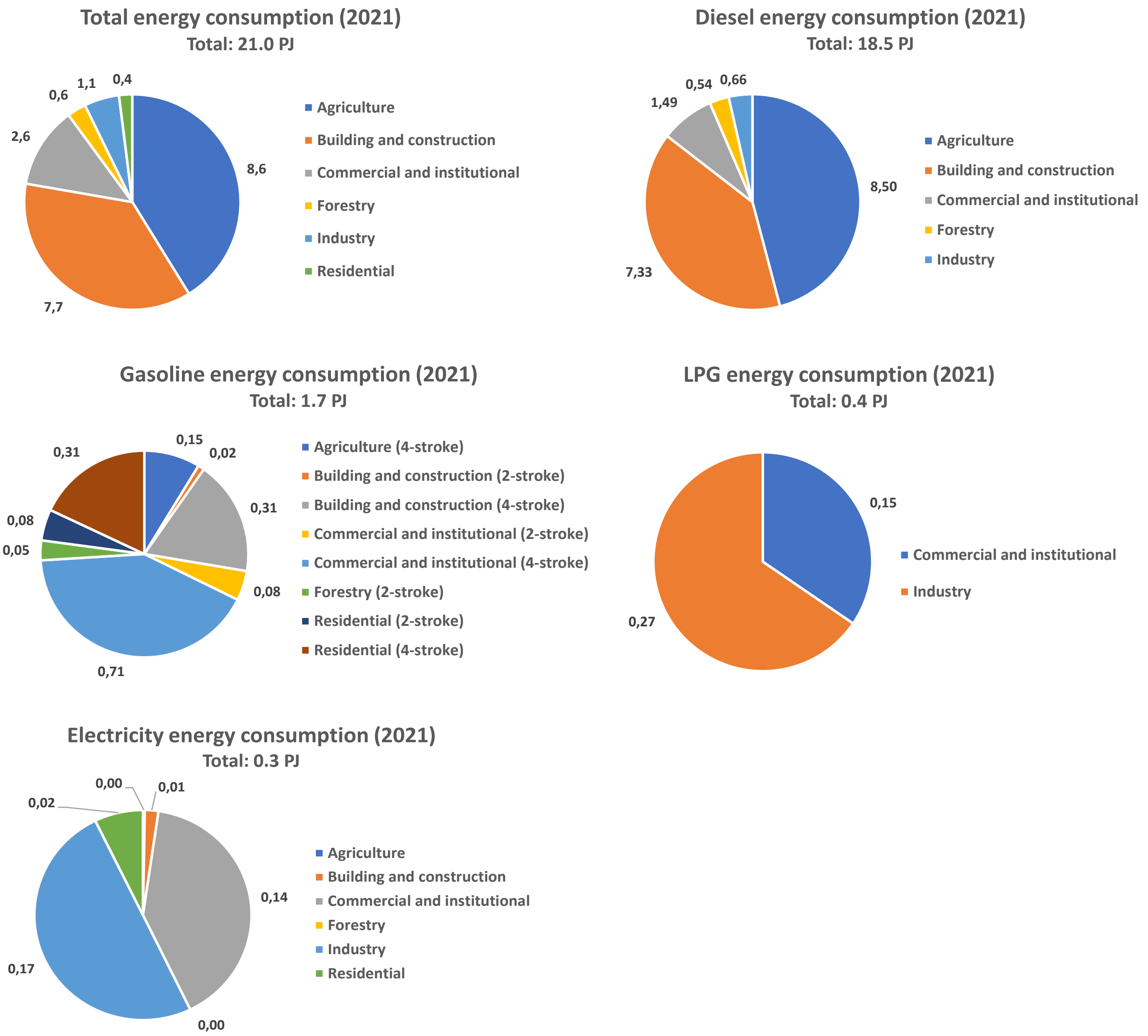
Tabel S.2 Resultater for energiforbrug for non-road maskiner i 2021 opdelt pr. non-road sektor, brændstof- og motortype.

	Total	Diesel	Benzin 2-takt	Benzin 4-takt	Benzin Total	LPG	El
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
Landbrug	8,64	8,50	-	0,15	0,15	-	0,00
Skovbrug	0,59	0,54	0,05	-	0,05	-	0,00
Bygge og anlæg	7,66	7,33	0,02	0,31	0,32	-	0,01
Industri	1,10	0,66	-	-	0,00	0,27	0,17
Handel og service	2,56	1,49	0,08	0,71	0,79	0,15	0,14
Husholdninger	0,41	-	0,08	0,31	0,39	-	0,01
Grand total	20,97	18,51	0,23	1,47	1,71	0,42	0,33
				% af total			
Landbrug	41	46	0	10	9	0	0
Skovbrug	3	3	23	0	3	0	0
Bygge og anlæg	37	40	7	21	19	0	2
Industri	5	4	0	0	0	65	50
Handel og service	12	8	34	48	46	35	41
Husholdninger	2	0	36	21	23	0	7
Grand total	100	100	100	100	100	100	100

I 2021 var forbrugsandelene for hhv. diesel-, benzin-2-takts-, benzin-4-takts-, LPG- (gaffeltrucks) og elektriske motorer hhv. 88 %, 1 %, 7 %, 2 % og 2 % af det samlede energiforbrug (afledt af tabel S.2).

I 2021 beregnes det største energiforbrug for maskinerne indenfor landbrug (41 %) og bygge og anlæg (37 %). Mindre forbrugsandele beregnes for maskinerne inden for handel og service (12 %), industri (5 %), skovbrug (3 %) og husholdninger (2 %).

For diesel i 2021 beregnes de største energiforbrug for non-road sektorerne landbrug (46 %), bygge og anlæg (40 %) og handel og service (12 %). Størstedelen af benzinforbruget sker indenfor handel og service (46 %), husholdninger (23 %) og bygge og anlæg (19 %). LPG anvendes af gaffeltrucks indenfor industri (65 %) og handel og service (35 %), mens størstedelen af elforbruget sker indenfor industri (50 %), handel og service (41 %) samt husholdninger (7 %).



Figur S.5 Totale energiforbrug fordelt på brændstoftyper og sektorer for non-road maskiner i 2021.

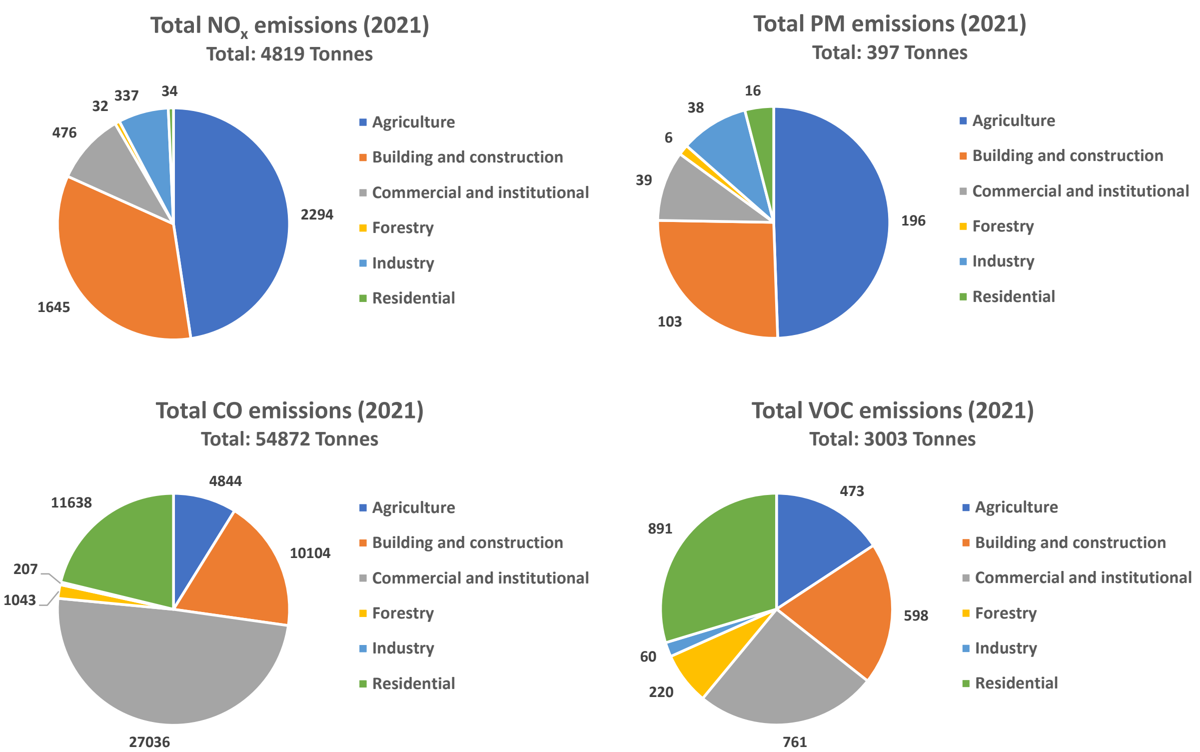
Tabel S.3 viser emissionerne for non-road maskiner i 2021, både som totaler og fordelt på non-road sektorer. Tabellen viser også non-road sektorernes procentvise andele af den samlede non-road emission.

Tabel S.3 Totale emissioner pr. non-road sektor i 2021 og sektorernes procentandele af den samlede non-road emission.

	SO_2	NO_x	PM	CO	VOC	CO_2	NMVOC	CH_4	N_2O	BC
	Tons	Tons	Tons	Tons	Tons	ktons	Tons	Tons	Tons	Tons
Landbrug	4,04	2294,0	196,4	4843,7	472,6	639,7	443,1	29,5	30,6	115,7
Skovbrug	0,28	32,2	5,7	1043,4	219,8	43,6	206,9	13,0	2,0	1,2
Bygge og anlæg	3,57	1645,0	102,5	10104,1	597,7	565,3	578,8	18,9	26,1	72,2
Industri	0,31	337,3	37,8	206,8	60,4	66,0	58,7	1,7	3,1	22,7
Handel og service	1,04	476,5	38,8	27035,8	761,5	173,8	731,6	29,9	6,7	18,8
Husholdninger	0,17	34,4	15,9	11638,1	891,4	26,7	871,0	20,4	0,5	0,8
Grand total	9,40	4819,4	397,1	54872,0	3003,5	1515,1	2890,0	113,4	69,1	231,4
					Emissions (% af total)					
Landbrug	43	48	49	9	16	42	15	26	44	50
Skovbrug	3	1	1	2	7	3	7	11	3	1
Bygge og anlæg	38	34	26	18	20	37	20	17	38	31
Industri	3	7	10	0	2	4	2	1	5	10
Handel og service	11	10	10	49	25	11	25	26	10	8
Husholdninger	2	1	4	21	30	2	30	18	1	0
Grand total	100	100	100	100	100	100	100	100	100	100

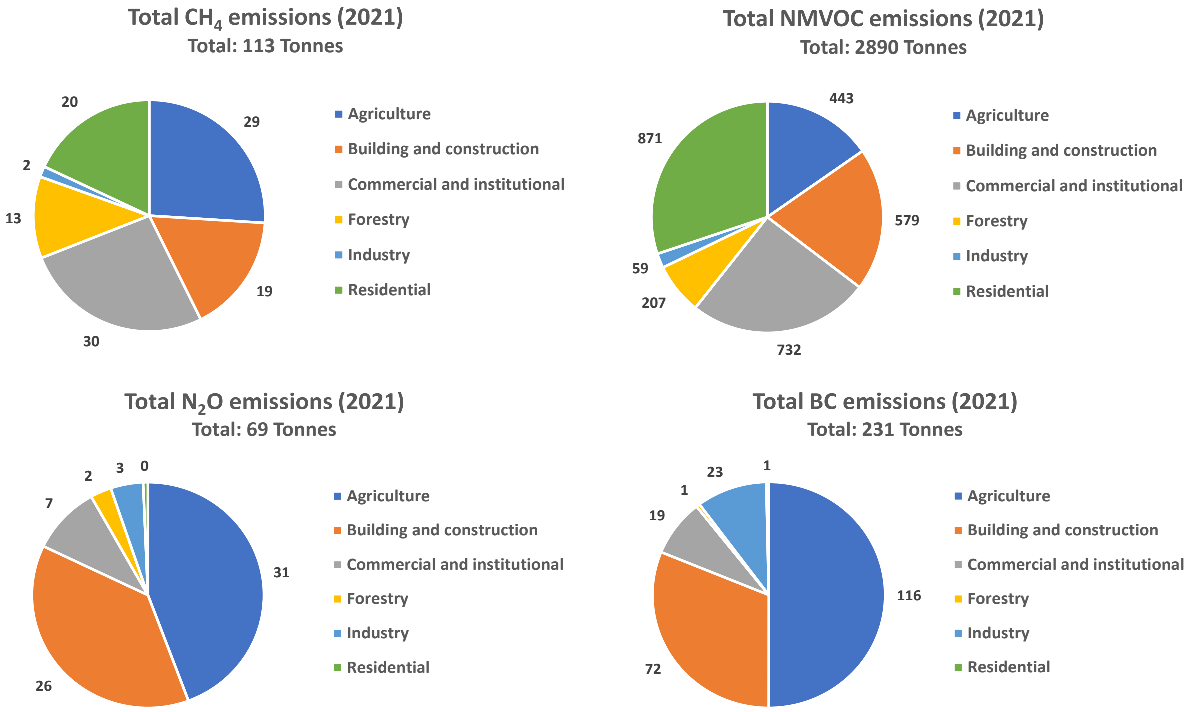
For NO_x, PM, CO_2, SO_2, N_2O og BC beregnes de største emissioner i 2021 for non-road sektorerne landbrug og bygge og anlæg.

De vigtigste grunde til de høje beregnede emissionsbidrag i de to ovennævnte non-road sektorer er det store dieselbrændstofforbrug og de høje dieselrelaterede emissionsfaktorer for NO_x, N_2O og BC. For PM, CO_2 og SO_2 skyldes de høje emissionsbidrag primært det høje energiforbrug, der beregnes for disse sektorer.



Figur S.6 NO_x-, PM-, CO- og VOC-emissioner fordelt på sektorer for non-road maskiner i 2021.

For CO, VOC, NMVOC, CH_4 beregnes de største emissioner i 2021 for non-road maskinerne i husholdninger og handel og service, efterfulgt af byggeri og anlæg. Dette skyldes det relativt store benzinforbrug i disse sektorer og høje brændstofrelaterede emissionsfaktorer for benzin.



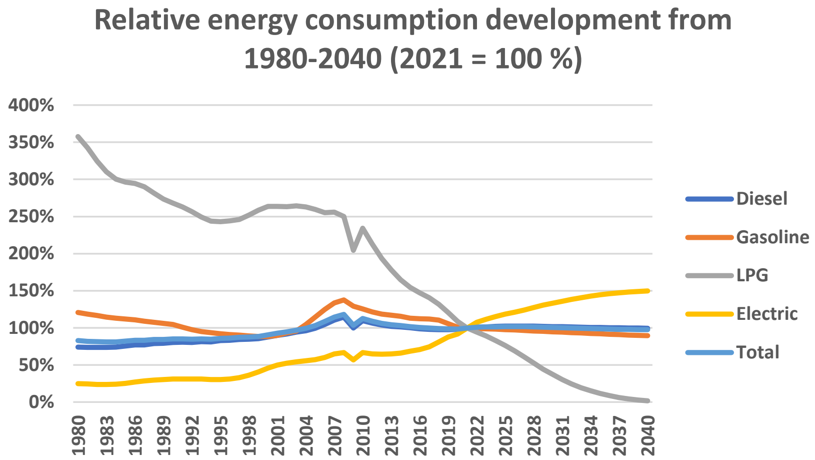
Figur S.7 CH_4-, NMVOC-, N_2O- og BC-emissioner fordelt på sektorer for non-road maskiner i 2021.

Energiforbrug og emissioner i perioden 1980-2040

Figur S.8 viser udviklingen i det relative energiforbrug pr. brændstoftype og samlet for non-road maskiner i 1980-2040.

Det samlede energiforbrug er steget med 21 % fra 1980 til 2021. For diesel, benzin, LPG og elektricitet har brændstofforbruget ændret sig med henholdsvis 35 %, -17 %, -72 % og 303 % fra 1980 til 2021 (afledt af figur S.8).

Fra 2021 til 2040 beregnes et mindre fald på 2 % for det samlede energiforbrug. For diesel, benzin, LPG og elektricitet beregnes energiforbrugsændringer på hhv. -1 %, -11 %, -98 % og 50 % (figur S.8).



Figur S.8 Udviklingen i det relative energiforbrug pr. brændstoftype og samlet for non-road maskiner i 1980-2040.

Figur S.9 viser udviklingen i energiforbruget som totaler og pr. brændstoftype pr. non-road sektor fra 1980-2040.

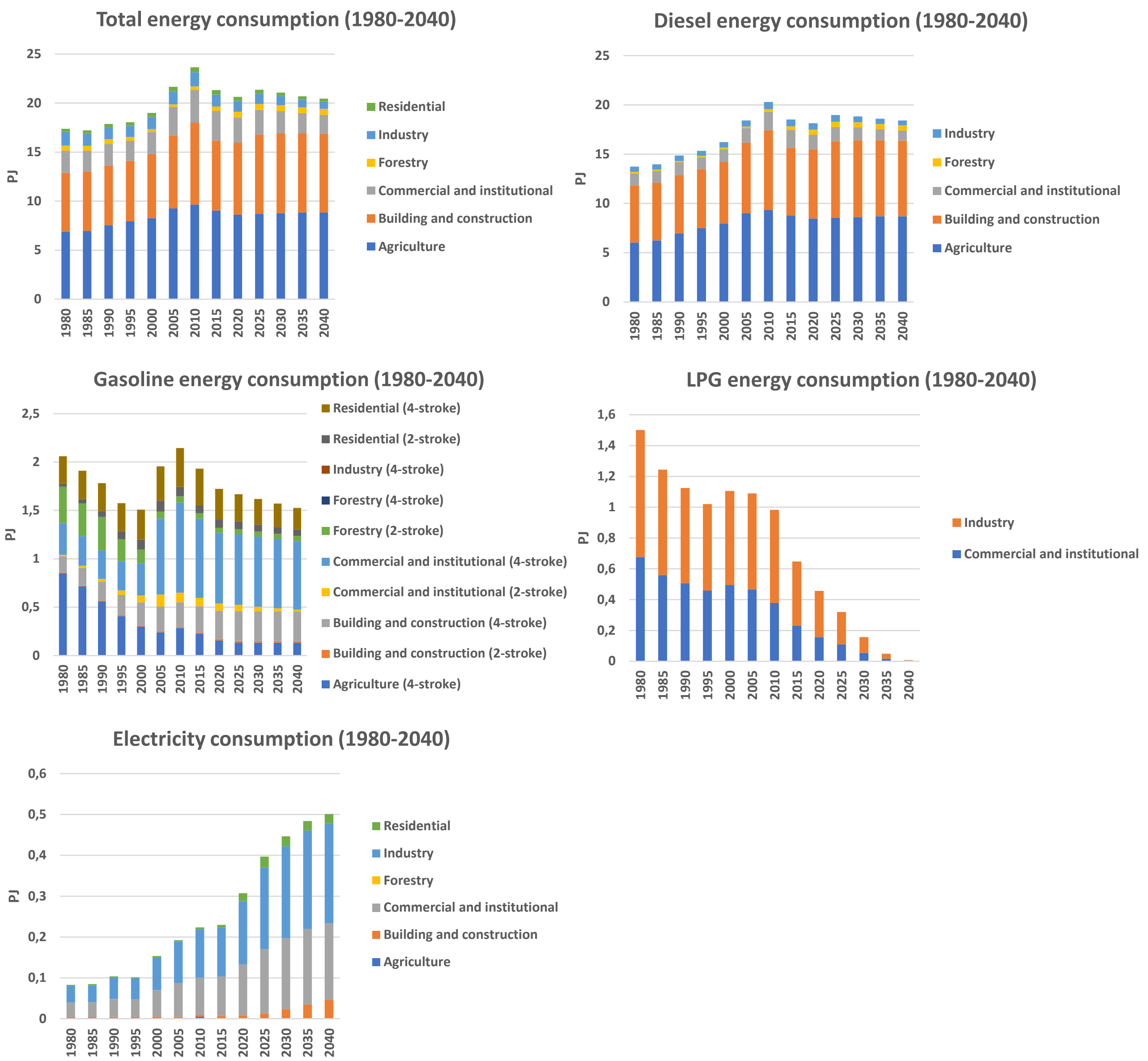
Udviklingen i landbrugets non-road energiforbrug i perioden 1980-2040 har stor betydning for udviklingen i det samlede non-road energiforbrug og for udviklingen i det samlede dieselforbrug separat.

For benzin påvirkes udviklingen i brændstofforbruget i den historiske periode fra 1980 til 2021 især af de følgende tendenser. Benzinforbruget er faldet i land- og skovbrug frem mod 2005 som følge af henholdsvis udfasningen af benzindrevne traktorer og mindre brug af motorsave. Antallet af benzindrevne maskiner i handel og service og husholdninger er også steget betydeligt fra 2000 til 2010, hvorefter bestanden af benzinmaskiner begynder at falde på grund af et skifte i nysalget fra benzindrevne til elektriske maskiner.

Antallet af benzindrevne maskiner og det afledte benzinforbrug forventes at falde i fremtiden som følge af en yderligere stigning frem mod 2040 i salgsandelen og de samlede driftstimer for eldrevne maskiner.

Som en følge af udviklingen i bestanden og aktiviteterne for elektriske maskiner stiger det beregnede elforbrug væsentligt fra 1980 til 2021, og det beregnede elforbrug forventes at stige yderligere frem til 2040.

Fra 1980 til 1995 er forbruget af LPG faldet på grund af et fald i antallet af LPG-gaffeltrucks og det heraf afledte samlede antal driftstimer i denne periode. Der ses et betydeligt fald i det samlede LPG-forbrug fra 2010 og fremefter, og dette fald i LPG-forbruget forventes at fortsætte i fremtiden frem mod 2040 som en følge af skiftet i nysalget af gaffeltruck til rent elektriske maskiner fra 2030 og frem.



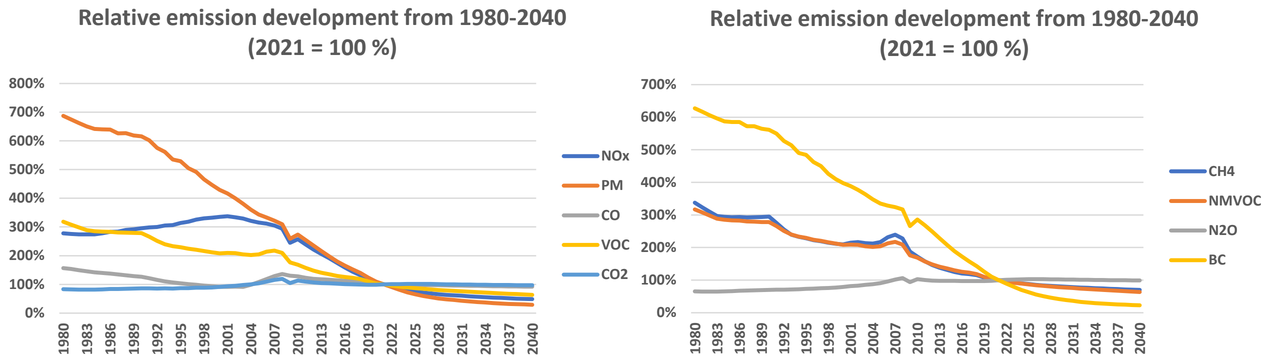
Figur S.9 Udvikling i energiforbruget som totaler og pr. brændstoftype pr. non-road sektor fra 1980-2040.

Figur S.10 viser den relative udvikling i emissionerne af NO_x, PM, CO, VOC og CO_2 (venstre delfigur) og emissionerne af CH_4, NMVOC, N_2O og BC (højre delfigur) for non-road maskiner i 1980-2040.

De samlede emissioner af NO_x, PM, CO og VOC er faldet med hhv. 64 %, 85 %, 36 % og 69 % fra 1980 til 2021 (afledt af figur S.10). De samlede CO_2 -emissioner er steget med 20 % i samme periode (afledt af figur S.10).

Fra 2021 til 2040, forventes de samlede NO_x -, PM-, CO-, VOC- og CO_2 -emissioner at falde med henholdsvis 51 %, 71 %, 8 %, 36 % og 3 % (figur S.10). De samlede emissioner af CH_4, NMVOC, BC og SO_2 er faldet med henholdsvis 70 %, 68 %, 84 % og 99,7 % fra 1980 til 2021, hvorimod de samlede N_2O -emissioner er steget med 53 % i samme periode (afledt af figur S.10).

Fra 2021 til 2040, er de samlede emissioner af CH_4, NMVOC, N_2O, BC og SO_2 faldet med hhv. 30 %, 37 %, 1 %, 77 % og 1 % (Figur S.10).



Figur S.10 Relativ udvikling i emissionerne af NO_x, PM, CO, VOC og CO_2 (venstre delfigur) og emissionerne af CH_4, NMVOC, N_2O og BC (højre delfigur) for non-road maskiner fra 1980-2040.

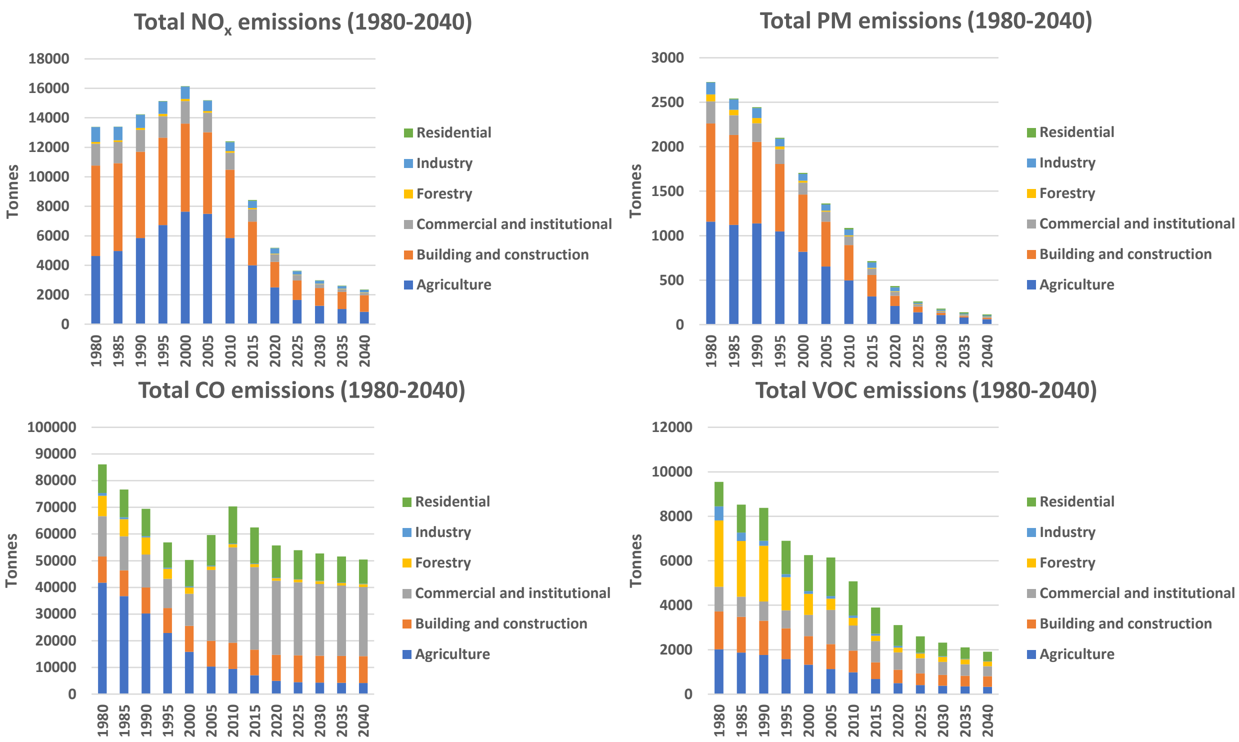
Figur S.11 viser udviklingen i NO_x -, PM-, CO- og VOC-emissionerne pr. delsektor for non-road maskiner i 1980-2040.

I hele perioden 1980-2040 kommer størstedelen af NO_x - og PM-emissionerne fra dieselmaskiner, der anvendes i landbrug og byggeri.

De fleste NO_x - og PM-emissioner kommer fra dieselmaskiner, der blev anvendt i landbrug og byggeri i perioden 1980-2040.

NO_x-emissionerne er steget fra 1980 til 2000, hovedsagelig på grund af en stigning i landbrugets non-road emissioner. Fra 2000 er NO_x-emissionerne reduceret kraftigt frem mod 2021 på grund af det gradvise skift til nyere emissionstrin i for nysolgte dieselmaskiner, som det ses i fordelingen af bestande og de samlede driftstimer i alle delsektorer, og som igen reducerer NO_x-emissionsfaktorerne. Af samme årsager forventes NO_x-emissionerne at falde yderligere frem mod 2040.

De samlede PM-emissioner er faldet kraftigt fra begyndelsen af 1990'erne og frem til 2021, og emissionerne forventes også at falde yderligere frem mod 2040. Denne emissionsudvikling for PM kan forklares ved ændringer i fordelingen af bestande og totale driftstimer for dieselmotorer henimod nyere motorteknologier. Især på grund af dieselmotorernes skifte til Euro V-motorer forventes PM-emissionerne at falde yderligere frem mod 2040.



Figur S.11 NO$_x$-, PM-, CO- og VOC-emissioner pr. delsektor for non-road maskiner fra 1980-2040.

Faldet i de samlede CO-emissioner fra 1980 til 2000 skyldes i vid udstrækning udfasningen af gamle benzindrevne traktorer indenfor landbrug. Fra 2000 til 2010 steg de samlede CO-emissioner betydeligt, hovedsagelig på grund af en stor stigning i aktiviteterne fra benzinmaskiner indenfor handel og service, hvor emissionerne fra 4-taktsmotorer er meget dominerende. Derefter reduceres CO-emissionerne gradvist, hovedsageligt på grund af emissionsfaktorreduktioner og på grund af det stigende skifte fra benzin til elektriske maskiner inden for mange typer af maskiner. Der forventes moderate fald i CO -emissionerne fra 2021 til 2040.

De samlede VOC-emissioner er faldet betydeligt fra 1990 til 2005, hovedsageligt pga. udfasningen af landbrugets gamle benzindrevne traktorer og pga. den store reduktion i bestanden og de samlede driftstimer for de benzindrevne kædesave med 2-taktsmotorer, der anvendes i skovbrug. VOC-emissionerne falder i alle non-road sektorer fra 2005 og fremefter, hovedsagelig på grund af emissionsfaktorreduktioner og det stigende skifte fra benzin til elektriske maskiner inden for mange typer af maskiner.

1 Introduction

The Danish emission inventories and projections for non-road mobile machinery (NRMM) are calculated with the DEMOS (Danish Emission model system for Mobile Sources) model[3], developed at the Department of Environmental Science (ENVS)/Danish Centre for Environment and Energy (DCE) at Aarhus University.

In the DEMOS sub-model for non-road (DEMOS-NRMM), time series of stock and activity data are modelled each year, and output emission results are calculated that automatically feeds into the total Danish atmospheric emission inventories annually prepared by ENVS/DCE at Aarhus University.

The Danish greenhouse gas emissions are reported to the EU and the UNFCCC (United Nations Framework Convention on Climate Change) Convention, and air pollutant emissions are reported to the UNECE LRTAP (United Nations Economic Commission for Europe Long Range Transboundary Pollution) Convention. In addition, each year national emission projections of greenhouse gases are prepared for the Danish Climate Status and Outlook published by the Danish Energy Agency, and bi-annually projections of air pollutant emissions are made for the EU and the UNECE.

The grouping of the non-road sectors in DEMOS-NRMM are the same as those used to group the inventory results according to the UNFCCC Common Reporting Format (CRF) and UNECE National Format for Reporting (NFR) nomenclature. However, for better overview, the non-road sector Manufacturing industries/Construction in CRF/NMR are treated in two separate non-road sectors, building and construction and industry, in DEMOS-NRMM.

The DEMOS-NRMM sectors and the corresponding non-road sector codes used for the UNFCCC and UNECE Conventions is shown in Table 1.1.

Table 1.1 SNAP – CRF/NFR correspondence table for transport.

DEMOS non-road sector	CRF/NFR classification
Agriculture	1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry
Forestry	1A4cii Agriculture/Forestry/Fishing: Off-road agriculture/forestry
Building and construction	1A2gvii Manufacturing industries/Construction (mobile)
Industry	1A2gvii Manufacturing industries/Construction (mobile)
Commercial and institutional	1A4aii Commercial/Institutional: Mobile
Residential	1A4bii Residential: Household and gardening (mobile)

The DEMOS-NRMM model uses annual data for stock numbers and operating hours for different types of non-road machinery, split according to fuel type, engine type, engine size and engine age. The machine specific stock numbers and operating hours are further stratified into model layers by fuel type, engine type, engine power class (grouping of engine size) and emission

[3] The DEMOS model consists of separate database models for each mode of transport (road, rail, air, navigation), and for the non-road mobile machinery (NRMM) used in agriculture, forestry, building and construction, industry, commercial and institutional, and residential.

stage (grouping of engine age) that match the resolution of fuel consumption and emission factors in the model.

The fuel consumption and emissions are calculated for each machinery type, year and emission stage in DEMOS-NRMM as the product of the number of machines, engine size (kW), engine load factor (%), annual operating hours and fuel consumption or emission factor (g/kWh). The calculations also take into account the emission effects of engine aging (deterioration effects due to engine wear) and transient engine operation.

The first comprehensive documentation report of the Danish emission inventories for non-road machinery was published by Winther and Nielsen (2006). The report described the basis of the DEMOS-NRMM model in terms of model setup, input data for stock and activities, emission factors and model calculation method. In the report national emission estimates were presented for the historical period 1985-2005 and emission projections were presented for the forecast period 2005-2030.

The DEMOS-NRMM model has subsequently been updated over the years. In this way, the list of machinery types has been expanded in the model, new sales statistics and tractor registry data has been incorporated in input data, and fuel consumption and emission factors updates have been made in some parts of the model.

Other important update elements are an improved description of maximum lifetime and operational behavior for the different equipment types, as well as stock numbers and working hours as a function of machinery age; all information obtained in data meetings with branch experts and collaboration with large machinery manufacturers, and importers and sellers of non-road machinery in Denmark (see Annex 7).

The national emission inventories for non-road machinery with updated model elements are more briefly documented in sector reports for mobile sources (e.g. Winther, 2022a), and in the Danish NIR and IIR reports (Nielsen et al., 2023a, b).

Outside national emission reporting, DEMOS-NRMM has been used in different impact assessment studies e.g. to assess the air pollution caused by non-road machinery in urban areas (Olesen et al., 2013), and to calculate the emission consequences of possible environmental zones for non-road working machines (Lansø et al., 2023; Winther et al., 2023) and the mapping of national emissions for non-road machinery until 2030 made in a partnership project with research and industry (Pedersen et al., 2019).

As discussed above, the many updates of the DEMOS-NRMM model and the Danish emission inventories made in the recent years have only been briefly documented, and therefore there is a need for a more thorough model description and a detailed overview of the development in energy consumption and emissions in the individual non-road sectors and in total for non-road for historical years and in projections.

This report documents the Danish emission inventories for non-road machinery calculated with DEMOS-NRMM in the period from 1980 to 2040 for the following emission components NO_x (nitrogen oxides), PM (particulate matter), CO (carbon monoxide), VOC (volatile organic compounds), NMVOC (non-methane volatile organic compounds), CH_4 (methane), CO_2 (carbon dioxide), SO_2 (sulphur dioxide), N_2O (nitrous oxide), and BC (black carbon).

Chapter 2 explains the sources of stock data, annual operating hours, machinery lifetimes and average engine loads used in DEMOS-NRMM to model the stock. Chapter 3 provides an overview of the existing emission limit values for non-road engines. Chapter 3 also documents the emission factors used in the inventory model and the adjustment factors for engine wear, transient engine load and the proportion of engines with pre-installed particulate filters. Chapter 4 explains the calculation method for energy consumption and emissions.

Chapter 5 presents the aggregated results for stock data and operating hours per non-road sector, calculated in the model for 2021 and for the period 1980-2040. Chapter 6 presents stock data and operating hours in greater details per non-road sector for 2021 and for the period 1980-2040.

Chapter 7 presents detailed results for energy consumption and emissions by non-road sector calculated in the model for 2021 and for the period 1980-2040. Chapter 8 presents aggregated results for energy consumption and emissions per non-road sector for 2021 and for the period 1980-2040.

The energy consumption of electric machines and the upstream emissions from the generation of electricity are not included under non-road in the national emission inventories, because there is no direct emission from these machines. Despite this, the energy consumption of electric machines is included in this report, because it is important to know how the consumption of electricity has developed in the years until now, and because it is important to obtain an estimate of the electricity consumption for non-road machinery in the future.

The projected electricity consumption presented in this report is regarded as conservative in the sense that electricity projections in DEMOS-NRMM are made only for electric machines, which are present in the stock in 2021. For these machines, the necessary data for stock and operating hours are generated as input for the model based on branch expectations.

2 Stock and activity data

In order to model the stock and activities for non-road machinery, sales data and total stock numbers, operation hours, engine lifetimes and engine load factors are collected from many different data sources, and in some cases data assumptions are made to account for missing data.

The data sources and assumptions are described in the following paragraph 2.1, for the different non-road mobile machinery types used in each non-road sector.

For the different non-road sectors, the stock and activity data are collected on a machine type and engine type level for each year in the inventory period covered by the model. Additional information on machine age, engine size (and the corresponding engine size class) and engine load factors are gathered in order to split the machinery stock into the relevant engine power class and emission stage for each year in the model.

The corresponding data for number of machines, annual working hours, engine size, engine load factor and emission factors are necessary input data for the subsequent calculation of the emissions for each of the machines in the model, as explained in Chapter 4.

The inventory stock numbers, and operating hours collected for the inventory are very comprehensive and will therefore not be shown in full in this report.

Data for total stock and operating hours is shown in Chapter 5 per non-road sector, fuel type and engine type for 2021 and for the 1980-2040 period. Total stock and operating hours are also shown per engine power class and emission stage for total non-road in 2021 and for the 1980-2040 period.

Per non-road sector, Chapter 6 shows data for total stock and operating hours per machinery type, fuel type and engine type for 2021. Total stock and operating hours are also shown per engine power class and emission stage for each non-road sector in 2021 and for the 1980-2040 period.

Annex 1 comprises a list of the machinery types in the model, sorted by sector, fuel type and engine type. In addition, Annex 1 shows the aggregated data for engine size, engine load factors, total operating hours, specific operating hours and average machinery age used in 2021.

In Annex 2, aggregated data for stock numbers and total operating hours is shown per machinery type for 1980-2040.

In Annex 3 aggregated data for stock numbers and total operating hours is shown per non-road sector, per engine type and engine power class (diesel only) and total non-road for 1980-2040.

In Annex 4 aggregated data for stock numbers and total operating hours is shown per non-road sector, per fuel type and emission stage and total non-road for 1980-2040.

In Annex 5 fuel consumption and emission results are shown per machinery type for 2021, sorted by sector, fuel type and engine type.

Annex 6 shows aggregated fuel consumption and emission results per non-road sector for 1980-2040. Annex 6 also shows fuel consumption results grouped into fuel type, non-road sector and engine type.

2.1 Collection of data for stock, operation hours, lifetimes and load factors

Agricultural machinery

The stock for tractors is distributed into branch, age, engine size and fuel type by combining various data sources. Tractors are predominantly used in agriculture, but a small number of tractors are also used in the industry, building and construction and commercial sectors.

Detailed tractor stock data for 2003-2020 taken from the Danish motor register makes up a complete stock matrix with branch code, fuel type, new sales year, vehicle weight and engine size for these years (Statistics Denmark (2021a).

A stock distribution key is derived for the year 2003 and used in combination with total tractor numbers for years before 2003 (Statistics Denmark; 1989, 2021b) and supplementary stock numbers for gasoline tractors in the separate years 1974, 1990 and 2005 (see Statistics Denmark, 1974; Dansk Teknologisk Institut, 1992; Høy, 2005), to model the stock distribution for the years 1980-2002.

Supplementary new sales data in kW classes provided by the Association of Danish Agricultural Machinery Dealers for sales years before 2003 are used to adjust the engine sizes by average in the modelled stock for 1980-2002.

For harvesters a lifetime of 25 years is assumed for all machines (Høy, 2005). This is used together with new sales data for the years 1980-2019[4] (Fasting, 2022) and total stock numbers for 1982-2000, 2005 and 2013[5] (Statistics Denmark, 2021b) to distribute the stock of harvesters into engine size and age in the model.

New sales figures are given in numbers per harvester platform width (ft) and are related to engine sizes (kW) based on information from Høy (2005)[6].

An adjustment ratio between total harvester stock (Statistics Denmark) and estimated stock (based on new sales and lifetime) is calculated in the model, and this ratio is used to scale each inventory year's stock-engine size distribution.

For tractors, the stock distribution into engine age and engine size for the last historical year (2020) makes up the stock distribution for the projection years.

[4] For 2020, the average of new sales data for 2015-2019 is used.
[5] Total stock numbers for 2001-2004 and 2006-2012 are estimated by interpolation. Total stock numbers for 2014-2020 are estimated by expert judgement of the evolution of the total stock.
[6] For 1985 and 2004, respectively, kW:ft ratios of 5 and 10 are assumed. For the years 1986-2003, kW:ft ratio's are estimated by interpolation. For 2005 onwards, the kW:ft ratio for 2004 is used.

This enables the calculation of an unadjusted total power output (GWh) for each of the projection years.

For harvesters, the stock distribution is projected in the model in the following way. New sales data for the projection years are estimated as averages of the new sales in 2015-2020. The sales distribution into engine age and engine size, and the lifetime of 25 years for harvesters, enables the modelling of an unadjusted stock distribution and calculated total power output (GWh) for the projection years.

Next, it is assumed that the total power output (GWh) in each projection year equals the total power output in the last historical year. Finally, the unadjusted fleet is estimated by scaling the engine age and size specific fleet numbers equally with the ratio between the total power output for last historical year and the total power output for the projection year.

Engine load factors come from Ingledew (2023) for tractors in different engine power categories and for harvesters. Annual working hours for tractors and harvesters as a function of machinery age come from Bak et al. (2003). The annual working hours for tractors and harvesters are shown in Figure 2.1.1[7].

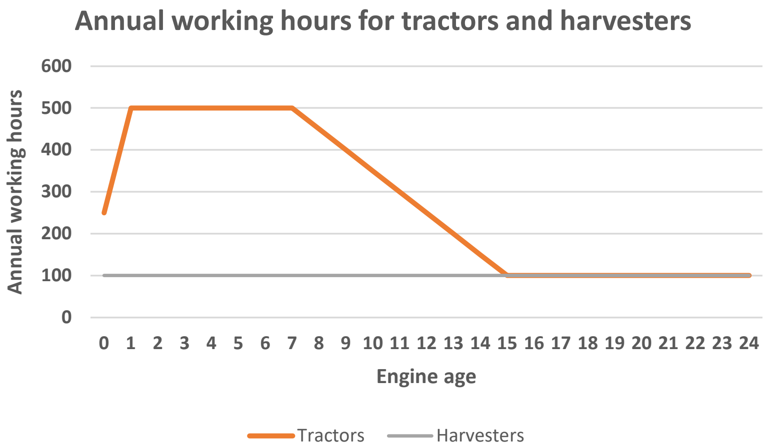


Figure 2.1.1 Annual working hours for tractors and harvesters as a function of engine age.

All terrain vehicles (ATV's) are used mainly in the agricultural sector for different working tasks and smaller hobby ATV's are used by privates. New sales data for 1992-2021 for ATV's, annual hours of operation for new machines and maximum lifetimes are provided by VNH (2022). New sales data for the projection years are estimated as averages of the new sales in 2018-2021.

For other agricultural machinery types with no specific new sales information available, information on the number of different types of machines, their respective engine load factors, engine sizes, average engine lifetime and annual

[7] Engine load factor, tractors = 0.6 for engine size > 118 kW and age = 0-3 year. Engine load factor = 0.5 for all other diesel tractors. Engine load factor = 0.4 for gasoline tractors.
Annual hours, machine pool tractors = 375 (age = 0 year), 750 (age 1-7 year), (15-age)*75+150 (age 8-14 year), 150 (age > 14 year).
Annual hours, gasoline tractors = 100 (certified tractors), 50 (non-certified tractors).
Engine load factor = 0.8 for harvesters.
Annual hours, harvesters = 150 for engine size > 116 kW and age = 0-1 year. Annual hours = 100 for all other harvesters.

working hours has been provided by Ingledew (2023) and Winther et al. (2006). The data obtained for 2021 are used to model the stock for the projection years 2022-2040 also.

For other agricultural machinery, the average lifetimes are used to distribute the total stock into stock numbers by engine age. For a given type of machinery it is assumed that the percentage share of the total stock is the same for all engine ages. Furthermore, average operating hours per year for the specific machinery type is used for all machines regardless of age.

Forestry machinery

The number of forestry machines, engine size, annual working hours and average lifetimes are provided by KVL (2005) for 1980-2004, and by the Danish Forest Association (Clemmensen, 2022) for 2005-2021. For forestry machinery, the data obtained for 2021 are used to model the stock for the projection years 2022-2040 also.

For forestry machinery, the average lifetimes are used to distribute the total stock into stock numbers by engine age. For a given type of machinery it is assumed that the percentage share of the total stock is the same for all engine ages. Furthermore, average operating hours per year for the specific machinery type is used for all machines regardless of age.

Construction machinery

For the most important types of building and construction machinery annual new sales data for 1996-2021 has been provided by the Association of Danish Agricultural Machinery Dealers (Fasting, 2022).

Due to lack of data, new sales data for years before 1996 has been roughly estimated as averages of the new sales in 1996-1999. New sales data for the projection years are estimated as averages of the new sales in 2017-2021.

From 2021 0-5 tonnes battery electric wheel loaders and track type excavators has picked up in new sales, and the shift towards battery electric machines is expected to continue with gradually larger sales shares for these machinery types in the future. This technology shift is also reflected in the projected stock in the model.

Engine load factors based on electronic engine power registrations, and data for engine size and annual working hours for new machines has been provided by branch experts (Sjøgren 2016; Mikkelsen 2016), see also Annex 7.

Telescopic loaders are predominantly used in the building and construction sector, but these machines are, however, also quite commonly used in agriculture, manufacturing industries and in the commercial sector. Data for engine size, engine load factors and annual working hours for new engines was provided by Scantruck (Jensen, 2016). Branch distribution information for telescopic loaders has been provided by Scantruck (Faurby, 2021).

To calculate the stock numbers and operating hours for each machinery type and each year in the model, equipment survival rates and annual working hours as a function of machinery age is used in the model. The functions have been established by IFEU (2014) and regarded as fit by Danish branch experts to model the evolution of the Danish non-road machinery stock (Sjøgren 2016; Mikkelsen 2016; Brun 2018; Christensen 2018). The shape of the age dependant functions for survival rate and working hours are shown in the Figures 2.2.1 and 2.3.1.

For a remaining group of building and construction mobile machinery types with low emission contributions (e.g. pumps, generators, compressors), total stock numbers from 1990 to 2021 has been estimated based on 1990 stock numbers from Dansk Teknologisk Institut (1992, 1993) and a proportional development of the stock numbers with GDP. For these machinery types, load factors, engine sizes and annual working hours have been gathered by Winther et al. (2006), and the data obtained for 2021 are used to model the stock for the projection years 2022-2040 also.

For these machinery types, the average lifetimes are used to distribute the total stock into stock numbers by engine age. For each machinery type it is assumed that the percentage share of the total stock is the same for all engine ages. Furthermore, average operating hours per year for the specific machinery type is used for all machines regardless of age.

Industrial machinery

Forklifts are mainly being used in the commercial sector and in manufacturing industries, and to a smaller extent in the building and construction sector. Forklift sales per fuel type and lifting capacity has been provided by the Association of Producers and Distributors of Forklifts in Denmark for 1976-2019. Further, WITS (World Industrial Truck Sales) and FEM (Federation European Material) forklift sales figures per fuel type for Denmark in 2000-2021 has been provided by Toyota Material Handling (Christensen, 2022). The latter data source has provided information of branch distribution of forklifts per fuel type and lifting capacity.

The lifting capacity for forklifts is related to engine size (kW) based on information from the Producers and Distributors of Forklifts in Denmark. Engine load factors come from Bak et al. (2003), and annual working hours for new machines are obtained from Toyota Material Handling (Brun, 2018).

Forklift new sales data for the projection years are estimated as averages of the new sales in 2017-2021. A phase out of internal combustion engines is expected towards 2030 for forklifts and this market shift towards battery electric forklifts is included in the projection of the sales figures in the model.

To calculate the stock numbers and operating hours for forklifts for each year in the model, survival rate and annual working hour functions are used as described before for building and construction machinery.

The total number of refrigerating units for long distance transport trucks has been estimated for 1990 and 2021 by Dansk Teknologisk Institut (1992, 2022). Based on these data, a linear development in the number of refrigerating units from 1990 to 2021 has been assumed. For distribution lorries, the total number of refrigerating units for distribution lorries has been estimated for 1990 by Dansk Teknologisk Institut (1992), and a proportional increase in the number of units has been assumed based on the development in the number of Danish inhabitants from 1990 to 2021. For refrigerating units, the data obtained for 2021 are used to model the stock for the projection years 2022-2040 also.

For refrigerating units, the average lifetimes are used to distribute the total stock into stock numbers by engine age. It is assumed that the percentage share of the total stock is the same for all engine ages. Furthermore, average operating hours per year is used for all refrigerating units regardless of age.

Telescopic loaders and tractors are also frequently used in the industry. Data descriptions for telescopic loaders and tractors are given in the previous paragraphs related to building and construction and agriculture, respectively.

Commercial and institutional machinery

The number of handling machines in airports and seaports, engine sizes, annual working hours and average lifetimes are taken from Winther et al. (2006). The data are used to model the stock for all years in the time period.

For handling machines, the average lifetimes are used to distribute the total stock into stock numbers by engine age. For a given type of handling machinery it is assumed that the percentage share of the total stock is the same for all engine ages. Furthermore, average operating hours per year for the specific machinery type is used for all machines regardless of age.

Forklifts, telescopic loaders and tractors are also frequently used in the commercial and institutional sector. Data descriptions for forklifts, telescopic loaders and tractors are given in the previous paragraphs related to industrial machinery, building and construction and agriculture, respectively.

In addition, the commercial and institutional sector is the most important sector for greenkeeping activities. Data descriptions for these machines are given in the following paragraph under residential machinery.

Residential machinery

Household and gardening equipment are used for greenkeeping purposes by privates in the residential sector and by professionals in the commercial and institutional sector.

For the most important household and gardening machinery types, annual new sales data for 2006 onwards is provided by the Association for Industrial Technics, Tools and Automation (BITVA: Brancheforeningen for industriel teknik, værktøj og automation), see Gade (2022). Until 2018 new sales data was provided by the Dealers Association of Electric Tools and Gardening Machinery (LTEH: Leverandørforeningen for Transportabelt Elværktøj og Havebrugsmaskiner).

Engine size, annual working hours for new machines and maximum lifetimes has been provided by LTEH (Nielsen and Schösser, 2016) and by Nielsen (2022) and Schösser (2022), see also Annex 7. Supplementary data for engine load factors, engine sizes and annual working hours has been provided by Winther et al. (2006).

To calculate the stock numbers and operating hours for each year in the model, survival rate and annual working hour functions is used for professional equipment as described before for building and construction machinery.

For equipment used by privates, average lifetimes are used to distribute the total stock into stock numbers by engine age. For a given type of machinery it is assumed that the percentage share of the total stock is the same for all engine ages. Furthermore, average operating hours per year for the specific machinery type is used for all machines regardless of age.

New sales of gasoline fuelled machinery are expected to gradually phase out and be fully replaced by battery electric machinery towards 2030 for hedge cutters, trimmers, blowers, cutters, 2035 for vertical cutters and 2040 for lawn mowers and chain saws. This technology shift is included in the projected sales figures used in the model.

2.2 Stock numbers by age

Figure 2.2.1 shows the general survival rate function for non-road mobile machinery used in DEMOS-NRMM for machinery types where new sales data are collected. The survival rate function is normalized by maximum lifetime. The maximum lifetimes are shown in Annex 1 for the relevant non-road machinery types.

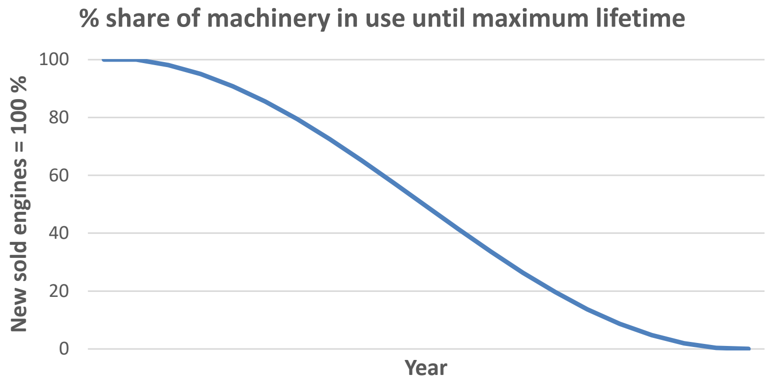


Figure 2.2.1 Percentage share of machinery in use until maximum lifetime.

2.3 Operating hours by age

Figure 2.3.1 depicts the function that correlates annual working hours between old engines and new engines. The function is established by IFEU (2014) and is utilized in DEMOS-NRMM to compute the annual working hours for non-road machinery categories where new sales data is gathered. The annual working hours for the relevant machinery types are shown in Annex 1.

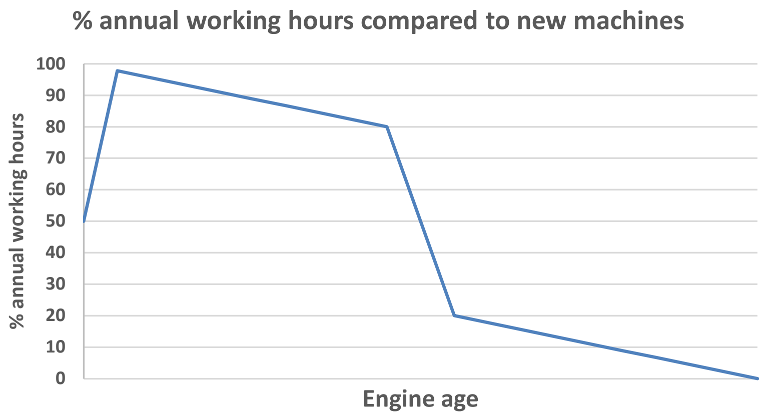


Figure 2.3.1 Annual working hours compared to new machines as a function of engine age.

3 Emission fundamentals

3.1 Emission limit values

For non-road machinery as well as and recreational craft and railway locomotives/motor cars, the engines must comply with the emission legislation limits agreed by the EU in terms of NO_x, CO, VOC and TSP emissions and fuel sulphur content. In terms of greenhouse gases, the emission legislation requirements for VOC influence the emissions of CH_4, the latter emission component forming a part of total VOC.

The emission directives list specific emission limit values (g per kWh) for CO, VOC, NO_x (or VOC + NO_x) and TSP, depending on engine size (kW for diesel, ccm for gasoline) and date of implementation (referring to engine market date).

For diesel, the directives 97/68 and 2004/26 (Table 3.1.1) relate to Stage I-IV non-road machinery other than agricultural and forestry tractors and the directives have different implementation dates for machinery operating under transient and constant loads. For Stage I-IV agricultural and forestry tractors the relevant directives are 2000/25 and 2005/13 (Table 3.1.1).

For emission approval of the EU Stage I, II and IIIA engine technologies, emissions (and fuel consumption) measurements are made using the steady state test cycle ISO 8178 C1, referred to as the Non-Road Steady Cycle (NRSC), see e.g. www.dieselnet.com. In addition to the NRSC test, the newer Stage IIIB, IV and V (and optionally Stage IIIA) engine technologies are tested under more realistic operational conditions using the new Non-Road Transient Cycle (NRTC).

For gasoline, the directive 2002/88 distinguished between Stage I and II hand-held (SH) and non-hand-held (NS) types of machinery (Table 3.1.2). Emissions are tested using one of the specific constant load ISO 8178 test cycles (D2, G1, G2, G3) depending on the type of machinery.

For Stage V machinery, EU directive 2016/1628 relates to non-road machinery other than agricultural tractors and railways machinery (Table 3.1.1) and non-road gasoline machinery (Table 3.1.2). EU directive 167/2013 relates to Stage V agricultural and forestry tractors (Table 3.1.1).

Table 3.1.1 Overview of EU emission directives and emission limit values relevant for diesel fuelled non-road mobile machinery other than agricultural and forestry tractors and for agricultural and forestry tractors.

Stage	Engine size	CO	VOC	NO_x	VOC+NO_x	PM	Other machinery than agricultural and forestry tractors			Agricultural and forestry tractors	
								Implement. date		EU	Implement.
	[kW]			[g/kWh]			EU Directive	Transient	Constant	Directive	Date
Stage I											
A	130<=P<560	5	1.3	9.2	-	0.54	97/68	1/1 1999	-	2000/25	1/7 2001
B	75<=P<130	5	1.3	9.2	-	0.7		1/1 1999	-		1/7 2001
C	37<=P<75	6.5	1.3	9.2	-	0.85		1/4 1999	-		1/7 2001
Stage II											
E	130<=P<560	3.5	1	6	-	0.2	97/68	1/1 2002	1/1 2007	2000/25	1/7 2002
F	75<=P<130	5	1	6	-	0.3		1/1 2003	1/1 2007		1/7 2003
G	37<=P<75	5	1.3	7	-	0.4		1/1 2004	1/1 2007		1/1 2004
D	18<=P<37	5.5	1.5	8	-	0.8		1/1 2001	1/1 2007		1/1 2002
Stage IIIA											
H	130<=P<560	3.5	-	-	4	0.2	2004/26	1/1 2006	1/1 2011	2005/13	1/1 2006
I	75<=P<130	5	-	-	4	0.3		1/1 2007	1/1 2011		1/1 2007
J	37<=P<75	5	-	-	4.7	0.4		1/1 2008	1/1 2012		1/1 2008
K	19<=P<37	5.5	-	-	7.5	0.6		1/1 2007	1/1 2011		1/1 2007
Stage IIIB											
L	130<=P<560	3.5	0.19	2	-	0.025	2004/26	1/1 2011	-	2005/13	1/1 2011
M	75<=P<130	5	0.19	3.3	-	0.025		1/1 2012	-		1/1 2012
N	56<=P<75	5	0.19	3.3	-	0.025		1/1 2012	-		1/1 2012
P	37<=P<56	5	-	-	4.7	0.025		1/1 2013	-		1/1 2013
Stage IV											
Q	130<=P<560	3.5	0.19	0.4	-	0.025	2004/26	1/1 2014	1/1 2014	2005/13	1/1 2014
R	56<=P<130	5	0.19	0.4	-	0.025		1/10 2014	1/10 2014		1/10 2014
Stage V[A]											
NRE-v/c-7	P>560	3.5	0.19	3.5		0.045	2016/1628		2019	167/2013[B]	2019
NRE-v/c-6	130≤P≤560	3.5	0.19	0.4		0.015			2019		2019
NRE-v/c-5	56≤P<130	5.0	0.19	0.4		0.015			2020		2020
NRE-v/c-4	37≤P<56	5.0			4.7	0.015			2019		2019
NRE-v/c-3	19≤P<37	5.0			4.7	0.015			2019		2019
NRE-v/c-2	8≤P<19	6.6			7.5	0.4			2019		2019
NRE-v/c-1	P<8	8.0			7.5	0.4			2019		2019
Generators	P>560	3.5	0.19	0.67		0.035			2019		2019

A = For selected machinery types, Stage V includes emission limit values for particle number.

B = Article 63 in 2016/1628 revise Article 19 in 167/2013 to include Stage V limits as described in 2016/1628.

Table 3.1.2 Overview of the EU emission directives and emission limit values relevant for gasoline fuelled non-road machinery.

	Category	Engine size	CO	HC	NO_X	$HC+NO_X$	Implement.
		[ccm]	[g pr kWh]	[g pr kWh]	[g pr kWh]	[g pr kWh]	date
EU Directive 2002/88	Stage I						
Hand-held	SH1	S<20	805	295	5.36	-	1/2 2005
	SH2	20≤S<50	805	241	5.36	-	1/2 2005
	SH3	50≤S	603	161	5.36	-	1/2 2005
Non-hand-held	SN3	100≤S<225	519	-	-	16.1	1/2 2005
	SN4	225≤S	519	-	-	13.4	1/2 2005
	Stage II						
Hand-held	SH1	S<20	805	-	-	50	1/2 2008
	SH2	20≤S<50	805	-	-	50	1/2 2008
	SH3	50≤S	603	-	-	72	1/2 2009
Non-hand-held	SN1	S<66	610	-	-	50	1/2 2005
	SN2	66≤S<100	610	-	-	40	1/2 2005
	SN3	100≤S<225	610	-	-	16.1	1/2 2008
	SN4	225≤S	610	-	-	12.1	1/2 2007
EU Directive 2016/1628	Stage V						
Hand-held (<19 kW)	NRSh-v-1a	S<50	805	-	-	50	2019
	NRSh-v-1b	50≤S	603		-	72	2019
Non-hand-held (P<19 kW)	NRS-vr/vi-1a	80≤S<225	610	-	-	10	2019
	NRS-vr/vi-1b	S≥225	610	-	-	8	2019
Non-hand-held (19=<P<30 kW)	NRS-v-2a	S≤1000	610	-	-	8	2019
	NRS-v-2b	S>1000	4.40*	-	-	2.70*	2019
Non-hand-held (30=<P<56 kW)	NRS-v-3	any	4.40*	-	-	2.70*	2019
ATV	ATS-v-1	P > 0	400			8	2019

* Or any combination of values satisfying the equation $(HC+NO_x) \times CO^{0.784} \leq 8.57$ and the conditions $CO \leq 20.6$ g/kWh and $(HC+NO_x) \leq 2.7$ g/kWh.

3.2 Emission stages and emission factors

The core data source for fuel consumption and emission factors in the Danish non-road model DEMOS-NRMM is the German TREMOD NRMM model (IFEU, 2004, 2009). In model updates made over the years, the DEMOS-NRMM emission factor base has expanded to include new emission stages and sources and has included supplementary emission information when necessary. A description of the fuel consumption and emission factors is given in the following.

Diesel machinery baseline emission factors

For diesel engines, the emission factors are grouped in the following emission stages: < 1981, 1981–1990, 1991–Stage I, Stage I, II, IIIA, IIIB, IV and V. The emission factors for each of these emission stages are divided into engine size classes, which correspond to the engine size classifications made in the EU emission directives for NRMM.

Up to Stage II: The factors for fuel consumption and NO_x, VOC, CO and PM emissions for technology levels up to and including Stage II are reported in the TREMOD NRMM model (IFEU, 2009). These are based on measured data from a range of different studies and data suggested from literature reviews.

Stage IIIA Onwards: Apart from PM Stage IIIB, IV and V, no measurement data have been sourced that allow the determination of emission factors for the emission stages IIIA, IIIB, IV and V. Consequently, the emission factors for these technology levels are estimated based on expert knowledge from measurement experts (IFEU, 2009), actual measured Stage II emission factors and the EU emission limits in place for newer emission stages. The following principles are used to formulate the emission factors.

For stage levels/power class combinations for which NO_x and VOC emissions are regulated by a total (NO_x + VOC) emission limit in the EU emission regulations, an emission factor sum is calculated as the (NO_x + VOC) emission limit value minus 10 %. The emissions are largely attributed to NO_x (90 %) and the remaining 10 % is attributed to VOC (IFFEU, 2009). For VOC, however, the deducted Stage IIIA EF is considerably higher than the Stage II EF based on measurements, and the emission factor value for Stage II is used in this case.

For Stage IIIB (P >= 56 kW) the NO_x emission factor is set to the EU emission limit value minus 10 % based on expert assumptions (IFEU, 2009). For Stage IV (all engine sizes) and Stage V (P >= 56 kW) the NO_x emission factor is set to the EU emission limit value based on expert assumptions (IFEU, 2009).

For Stage IIIB and V (P >= 56 kW) and Stage IV (all engine sizes) the VOC emission factor is set to the EU emission limit value minus 30 % based on expert assumptions (IFEU, 2009).

For CO, the EU emission limits for Stage IIIA, IIIB, IV and V are considerably higher than the Stage II EF based on measurements, and hence the emission factor value for Stage II is used in these cases[8].

[8] In IFEU (2009) the CO emission factors are taken as the EU emission limit value minus 40 %, for the emission stages IIIA, IIIB and IV and all engine power classes.

For PM the EU emission limit for Stage IIIA is considerably higher than the Stage II EF derived from measurements, and hence the emission factor value for Stage II is used in this situation. For the emission stages IIIB, IV and V, PM emission factors for engines with and without particle filters are taken from ICCT (2016).

BC emission factors are calculated from PM emission factors using BC-fractions of PM listed in the EMEP/EEA Emissions Inventory Guidebook (2023).

Fuel consumption factors for Stage IIIA onwards engine technologies are provided by Sjøgren (2016).

Table 3.2.1 provides an overview of the emission factor sources and principles used to establish emission factors for NO_x, VOC, CO and PM for Stage IIIA, IIIB, IV and V diesel NRMM engines.

Table 3.2.1 Overview of the emission factor sources and principles used to establish emission factors for NO_x, VOC, CO and PM for Stage IIIA, IIIB, IV and V diesel NRMM engines.

Emission stage	NO_x	VOC	PM	CO
Stage IIIA	EF = 90 % of the EU (NO_x+HC) limit value minus 10%	EF = Stage II EF	EF = Stage II EF	EF = Stage II EF
Stage IIIB	For P < 56 kW: EF = 90 % of the EU (NO_x +HC) limit value minus 10% For P >= 56 kW: NO_x limit value – 10 %	For P < 56 kW: EF = 90 % of the EU (NO_x +HC) limit value minus 10% For P >= 56 kW: VOC limit value – 30 %.	ICCT (2016)	EF = Stage II EF
Stage IV	NO_x limit value	VOC limit value – 30 %	ICCT (2016)	EF = Stage II EF
Stage V	For P < 56 kW: EF = 90 % of the EU (NO_x +HC) limit value minus 10% For P >= 56 kW: NO_x limit value	For P < 56 kW: EF = 90 % of the EU (NO_x +HC) limit value minus 10% For P >= 56 kW: VOC limit value – 30 %	ICCT (2016)	EF = Stage II EF

N_2O emission factors comes from the EMEP/EEA Emissions Inventory Guidebook (2023). CH_4 is assumed to be 2.4% of total VOC (IFEU, 2009).

Table 3.2.2 Baseline emission factors and fuel consumption (FC) for diesel non-road engines (g/kWh).

Engine power class	Emission stage	NO_x (g/kWh)	PM	PM (DPF)	CO	VOC	NMVOC	CH_4	N_2O	BC	BC (DPF)	FC
P<8	<1981	12	2.8	-	7	5	4.88	0.12	0.035	1.54	-	300
P<8	1981-1990	11.5	2.3	-	6	3.8	3.71	0.09	0.035	1.265	-	285
P<8	1991-Stage I	11.2	1.6	-	5	2.5	2.44	0.06	0.035	0.88	-	270
P<8	Stage V	6.075	0.4	-	4.8	0.675	0.659	0.016	0.035	0.32	-	270
8<=P<19	<1981	12	2.8	-	7	5	4.88	0.12	0.035	1.54	-	300
8<=P<19	1981-1990	11.5	2.3	-	6	3.8	3.71	0.09	0.035	1.265	-	285
8<=P<19	1991-Stage I	11.2	1.6	-	5	2.5	2.44	0.06	0.035	0.88	-	270
8<=P<19	Stage V	6.075	0.4	-	3.96	0.675	0.659	0.016	0.035	0.32	-	270
19<=P<37	<1981	18	2	-	6.5	2.5	2.44	0.06	0.035	1.1	-	300
19<=P<37	1981-1990	18	1.4	-	5.5	2.2	2.15	0.05	0.035	0.77	-	281
19<=P<37	1991-Stage I	9.8	1.4	-	4.5	1.8	1.76	0.04	0.035	0.77	-	262
19<=P<37	Stage II	6.5	0.4	-	2.2	0.6	0.59	0.01	0.035	0.32	-	262
19<=P<37	Stage IIIA	6.075	0.4	-	2.2	0.6	0.59	0.01	0.035	0.32	-	262
19<=P<37	Stage V	3.807	0.0035	0.0035	2.2	0.423	0.413	0.010	0.035	0.0005	0.0005	262
37<=P<56	<1981	7.7	1.8	-	6	2.4	2.34	0.06	0.035	0.99	-	290
37<=P<56	1981-1990	8.6	1.2	-	5.3	2	1.95	0.05	0.035	0.66	-	275
37<=P<56	1991-Stage I	11.5	0.8	-	4.5	1.5	1.46	0.04	0.035	0.44	-	260
37<=P<56	Stage I	7.7	0.4	-	2.2	0.6	0.59	0.01	0.035	0.32	-	260
37<=P<56	Stage II	5.5	0.2	-	2.2	0.4	0.39	0.01	0.035	0.16	-	260
37<=P<56	Stage IIIA	3.807	0.2	-	2.2	0.4	0.39	0.01	0.035	0.16	-	240
37<=P<56	Stage IIIB	3.807	0.019	0.0035	2.2	0.423	0.413	0.010	0.035	0.015	0.0005	240
37<=P<56	Stage V	3.807	0.0035	0.0035	2.2	0.423	0.413	0.010	0.035	0.0005	0.0005	240
56<=P<75	<1981	7.7	1.8	-	6	2.4	2.34	0.06	0.035	0.99	-	290
56<=P<75	1981-1990	8.6	1.2	-	5.3	2	1.95	0.05	0.035	0.66	-	275
56<=P<75	1991-Stage I	11.5	0.8	-	4.5	1.5	1.46	0.04	0.035	0.44	-	260
56<=P<75	Stage I	7.7	0.4	-	2.2	0.6	0.59	0.01	0.035	0.32	-	260
56<=P<75	Stage II	5.5	0.2	-	2.2	0.4	0.39	0.01	0.035	0.16	-	260
56<=P<75	Stage IIIA	3.807	0.2	-	2.2	0.4	0.39	0.01	0.035	0.16	-	230
56<=P<75	Stage IIIB	2.97	0.017	0.004	2.2	0.133	0.130	0.003	0.035	0.014	0.0006	230
56<=P<75	Stage IV	0.4	0.017	0.004	2.2	0.133	0.130	0.003	0.035	0.014	0.0006	230
56<=P<75	Stage V	0.4	0.004	0.004	2.2	0.133	0.130	0.003	0.035	0.0006	0.0006	230
75<=P<130	<1981	10.5	1.4	-	5	2	1.95	0.05	0.035	0.77	-	280
75<=P<130	1981-1990	11.8	1	-	4.3	1.6	1.56	0.04	0.035	0.55	-	268
75<=P<130	1991-Stage I	13.3	0.4	-	3.5	1.2	1.17	0.03	0.035	0.22	-	255
75<=P<130	Stage I	8.1	0.2	-	1.5	0.4	0.39	0.01	0.035	0.16	-	255
75<=P<130	Stage II	5.2	0.2	-	1.5	0.3	0.29	0.01	0.035	0.16	-	255
75<=P<130	Stage IIIA	3.24	0.2	-	1.5	0.3	0.29	0.01	0.035	0.16	-	225
75<=P<130	Stage IIIB	2.97	0.017	0.004	1.5	0.133	0.130	0.003	0.035	0.014	0.0006	225
75<=P<130	Stage IV	0.4	0.017	0.004	1.5	0.133	0.130	0.003	0.035	0.014	0.0006	225
75<=P<130	Stage V	0.4	0.004	0.004	1.5	0.133	0.130	0.003	0.035	0.0006	0.0006	225
130<=P<560	<1981	17.8	0.9	-	2.5	1.5	1.46	0.04	0.035	0.45	-	270
130<=P<560	1981-1990	12.4	0.8	-	2.5	1	0.98	0.02	0.035	0.4	-	260
130<=P<560	1991-Stage I	11.2	0.4	-	2.5	0.5	0.49	0.01	0.035	0.2	-	250
130<=P<560	Stage I	7.6	0.2	-	1.5	0.3	0.29	0.01	0.035	0.14	-	250
130<=P<560	Stage II	5.2	0.1	-	1.5	0.3	0.29	0.01	0.035	0.07	-	250
130<=P<560	Stage IIIA	3.24	0.1	-	1.5	0.3	0.29	0.01	0.035	0.07	-	220
130<=P<560	Stage IIIB	1.8	0.017	0.004	1.5	0.133	0.130	0.003	0.035	0.012	0.0006	220
130<=P<560	Stage IV	0.4	0.017	0.004	1.5	0.133	0.130	0.003	0.035	0.012	0.0006	220
130<=P<560	Stage V	0.4	0.004	0.004	1.5	0.133	0.130	0.003	0.035	0.0006	0.0006	220

Gasoline machinery baseline emission factors

Emission factors for gasoline engines are divided into 2-stroke and 4-stroke engine types, for both hand-held (SH) and non-hand-held (SN) equipment. The emission factors are further grouped into the engine size classes (ccm) corresponding to the engine size classifications made in the EU emission directive 2002/88 for gasoline fuelled non-road machinery.

The fuel consumption and emission factors for each engine type and size class are divided into the following emission stages: < 1981, 1981–1990, 1991–Stage I, Stage I, Stage II and Stage V.

The fuel consumption and emission factors for NO_x, VOC, CO and TSP (2-stroke only) emissions are provided by IFEU (2004) up to Stage II. They are based on expert judgement, taking into account specific measurement data, type approval values, and estimated emission increases for the engines originating from 1990 and earlier (see IFEU, 2004).

Stage II emission factors are used for Stage V machinery, in the cases where the Stage V emission limit values exceed the measured emission factors for Stage II. In other cases, the ratio between NO_x and VOC emission factors for Stage II is used to split Stage V NO_x +VOC limit values into emission factor values for NO_x and VOC.

The 4-stroke PM emission factors from IFEU (2004) originates from USEPA (USEPA, 1999). N_2O emission factors come from the EMEP/EEA Emissions Inventory Guidebook (2023). CH_4 is assumed to be 7.0 % and 3.4 % of VOC for 2-stroke and 4-stroke engines respectively (IFEU, 2009).

Table 3.2.3 Emission factors and fuel consumption (FC) for gasoline 2 stroke non-road engines (g/kWh).

Equipment code	Engine power class	Emission stage	NO_x	TSP	CO	VOC	NMVOC	CH_4	N_2O	BC	FC
							(g/kWh)				
SH2	20<=S<50	<1981	1.00	7.00	695	305	284	21.35	0.01	0.350	882
SH2	20<=S<50	1981-1990	1.00	5.30	579	300	279	21.00	0.01	0.265	809
SH2	20<=S<50	1991-Stage I	1.10	3.50	463	203	189	14.21	0.01	0.175	735
SH2	20<=S<50	Stage I	1.50	3.50	379	188	175	13.16	0.01	0.175	720
SH2	20<=S<50	Stage II	1.50	3.50	379	44	41	3.08	0.01	0.175	500
SH2	20<=S<50	Stage V	1.50	3.50	379	44	41	3.08	0.01	0.175	500
SH3	S>=50	<1981	1.10	3.60	510	189	176	13.23	0.01	0.180	665
SH3	S>=50	1981-1990	1.10	2.70	425	158	147	11.06	0.01	0.135	609
SH3	S>=50	1991-Stage I	1.20	1.80	340	126	117	8.82	0.01	0.090	554
SH3	S>=50	Stage I	2.00	1.80	340	126	117	8.82	0.01	0.090	529
SH3	S>=50	Stage II	1.20	1.80	340	64	60	4.48	0.01	0.090	500
SH3	S>=50	Stage V	1.20	1.80	340	64	60	4.48	0.01	0.090	500
SN1	S<66	<1981	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN1	S<66	1981-1990	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN1	S<66	1991-Stage I	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN1	S<66	Stage I	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN1	S<66	Stage II	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN1	S<66	Stage V	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN2	66<=S<100	<1981	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN2	66<=S<100	1981-1990	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN2	66<=S<100	1991-Stage I	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN2	66<=S<100	Stage I	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN2	66<=S<100	Stage II	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN2	66<=S<100	Stage V	0.03	2.60	418	10	9.3	0.70	0.01	0.130	652
SN3	100<=S<225	<1981	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN3	100<=S<225	1981-1990	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN3	100<=S<225	1991-Stage I	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN3	100<=S<225	Stage I	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN3	100<=S<225	Stage II	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN3	100<=S<225	Stage V	0.03	2.60	418	10	9.3	0.70	0.01	0.130	652
SN4	S>=225	<1981	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN4	S>=225	1981-1990	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN4	S>=225	1991-Stage I	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN4	S>=225	Stage I	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN4	S>=225	Stage II	0.50	2.60	418	155	144	10.85	0.01	0.130	652
SN4	S>=225	Stage V	0.03	2.60	418	8	7.4	0.56	0.01	0.130	652

Table 3.2.4 Emission factors and fuel consumption (FC) for gasoline 4 stroke non-road engines (g/kWh).

Equipment code	Engine power class	Emission stage	NO_x	TSP	CO	VOC	NMVOC (g/kWh)	CH_4	N_2O	BC	FC
SH2	20<=S<50	<1981	2.40	0.08	198	33	31.9	1.12	0.03	0.004	496
SH2	20<=S<50	1981-1990	3.50	0.08	165	27.5	26.6	0.94	0.03	0.004	474
SH2	20<=S<50	1991-Stage I	4.70	0.08	132	22	21.3	0.75	0.03	0.004	451
SH2	20<=S<50	Stage I	4.70	0.08	132	22	21.3	0.75	0.03	0.004	406
SH2	20<=S<50	Stage II	4.70	0.08	132	22	21.3	0.75	0.03	0.004	406
SH2	20<=S<50	Stage V	4.70	0.08	132	22	21.3	0.75	0.03	0.004	406
SH3	S>=50	<1981	2.40	0.08	198	33	31.9	1.12	0.03	0.004	496
SH3	S>=50	1981-1990	3.50	0.08	165	27.5	26.6	0.94	0.03	0.004	474
SH3	S>=50	1991-Stage I	4.70	0.08	132	22	21.3	0.75	0.03	0.004	451
SH3	S>=50	Stage I	4.70	0.08	132	22	21.3	0.75	0.03	0.004	406
SH3	S>=50	Stage II	4.70	0.08	132	22	21.3	0.75	0.03	0.004	406
SH3	S>=50	Stage V	4.70	0.08	132	22	21.3	0.75	0.03	0.004	406
SN1	S<66	<1981	1.20	0.08	822	26.9	26.0	0.91	0.03	0.004	603
SN1	S<66	1981-1990	1.80	0.08	685	22.5	21.7	0.77	0.03	0.004	603
SN1	S<66	1991-Stage I	2.40	0.08	548	18	17.4	0.61	0.03	0.004	603
SN1	S<66	Stage I	4.30	0.08	411	16.1	15.6	0.55	0.03	0.004	475
SN1	S<66	Stage II	4.30	0.08	411	16.1	15.6	0.55	0.03	0.004	475
SN1	S<66	Stage V	4.30	0.08	411	16.1	15.6	0.55	0.03	0.004	475
SN2	66<=S<100	<1981	2.30	0.08	822	10.5	10.1	0.36	0.03	0.004	627
SN2	66<=S<100	1981-1990	3.50	0.08	685	8.7	8.4	0.30	0.03	0.004	599
SN2	66<=S<100	1991-Stage I	4.70	0.08	548	7	6.8	0.24	0.03	0.004	570
SN2	66<=S<100	Stage I	4.70	0.08	467	7	6.8	0.24	0.03	0.004	450
SN2	66<=S<100	Stage II	4.70	0.08	467	7	6.8	0.24	0.03	0.004	450
SN2	66<=S<100	Stage V	4.02	0.08	467	5.98	5.8	0.20	0.03	0.004	450
SN3	100<=S<225	<1981	2.60	0.08	525	19.1	18.5	0.65	0.03	0.004	601
SN3	100<=S<225	1981-1990	3.80	0.08	438	15.9	15.4	0.54	0.03	0.004	573
SN3	100<=S<225	1991-Stage I	5.10	0.08	350	12.7	12.3	0.43	0.03	0.004	546
SN3	100<=S<225	Stage I	5.10	0.08	350	11.6	11.2	0.39	0.03	0.004	546
SN3	100<=S<225	Stage II	5.10	0.08	350	9.4	9.1	0.32	0.03	0.004	546
SN3	100<=S<225	Stage V	3.52	0.08	350	6.48	6.3	0.22	0.03	0.004	546
SN4	S>=225	<1981	1.30	0.08	657	11.1	10.7	0.38	0.03	0.004	539
SN4	S>=225	1981-1990	2.00	0.08	548	9.3	9.0	0.32	0.03	0.004	514
SN4	S>=225	1991-Stage I	2.60	0.08	438	7.4	7.1	0.25	0.03	0.004	490
SN4	S>=225	Stage I	2.60	0.08	438	7.4	7.1	0.25	0.03	0.004	490
SN4	S>=225	Stage II	2.60	0.08	438	7.4	7.1	0.25	0.03	0.004	490
SN4	S>=225	Stage V	2.08	0.08	438	5.92	5.7	0.20	0.03	0.004	490

LPG machinery baseline emission factors

The emission factors for CO, VOC, NO_x and PM are taken from Notter and Schmied (2015). The factors are split into four different degrees of retrofitting (without aftertreatment, with oxidation catalysers, 50 % with 3-way catalysers and 100 % with 3-way catalysers) according to new sales year.

The fuel consumption factors come from IFEU (2004) and N_2O emission factors are taken from the EMEP/EEA Emissions Inventory Guidebook (2023). CH_4 is assumed to be 5 % of VOC (USEPA, 2004).

The fuel consumption and emission factors for LPG fuelled machinery are shown in Table 3.2.5.

Table 3.2.5 Emission factors and fuel consumption (FC) for LPG fuelled non-road machinery (g/kWh).

Sales year	Technology level	NO_x	TSP	CO	VOC	NMVOC	CH_4	N_2O	BC	FC
						(g/kWh)				
<1980	Without aftertreatment	10	0.02	10	8	7.6	0.400	0.05	0.0010	311
1980-1993	With oxidation catalysers	10	0.01	0.2	0.5	0.475	0.025	0.05	0.0005	311
1994-1999	50 % with 3-way catalysers	6	0.01	0.2	0.5	0.475	0.025	0.05	0.0005	311
2000-	100 % with 3-way catalysers	2	0.01	0.2	0.5	0.475	0.025	0.05	0.0005	311

Emission factors for ATV's

Due to lack of data, the emission factors for ATV's are based on emission data for conventional technology motorcycles for the engine sizes <250 cc (private ATV's) and 250-750 cc (professional ATV's), derived from the Danish emission inventories (Winther, 2022a). Fuel consumptions per hour for the ATV's are provided by VNH (2022).

Table 3.2.6 Fuel consumption (kg/h) and emission factors (g/MJ) for ATV's.

Machine type	FC	NO_x	TSP	CO	VOC	NMVOC	CH_4	N_2O	BC
	kg/h				(g/MJ)				
ATV (professional)	1.125	108	32	16306	1077	917	160	2	1.6
ATV (private)	0.75	128	39	22043	1527	1330	197	2	2.0

Efficiency factors for electric machinery

For large machinery, the efficiency factor is a measure of how much electric energy the battery provides, per unit of electricity taken from the grid. For garden machinery, the efficiency factor expresses how much electric energy is transformed into mechanical energy, per unit of electricity taken from the grid.

The efficiency factors for large machinery are provided by Toyota (2021) and efficiency factors for garden machinery is taken from Notter and Schmied (2015).

Table 3.2.7 Efficiency factors for electric machinery.

Equipment type	1980	1990	2000	2010	2020	2030	2040
Large machinery (battery)	0.66	0.66	0.66	0.75	0.85	0.85	0.85
Garden (battery)	0.4	0.44	0.52	0.6	0.64	0.66	0.68
Garden (cable)	0.73	0.73	0.76	0.79	0.81	0.81	0.81

CO_2 and SO_2 emission factors

Diesel non-road machines use neat diesel with a lower heating value of 42.7 MJ/kg and a CO_2 emission factor of 74.1 gCO_2/MJ. The sulphur content of non-road diesel has been greatly reduced from 1980, when the sulphur content was 5000 ppm, until 2005, when the sulphur content was reduced to 10 ppm.

The gasoline non-road machines use gasoline bought from ordinary gas stations. Neat gasoline has a calorific value of 43.8 MJ/kg and a CO_2 emission factor of 73 gCO_2/MJ. The sulphur content of neat gasoline has been 50 ppm from 1980 until 2005, when the sulphur content was reduced to 10 ppm.

From 2006 onwards, ethanol has been added to the gasoline sold from gas stations. Ethanol has a lower heating value of 26.7 MJ/kg, is without sulfur and is considered CO_2 neutral according to the UNFCCC guidelines for national emission reporting. As a consequence of that, the resulting lower heating values, and CO_2 and SO_2 emission factors for gasoline at gas stations are slightly lower than for neat gasoline.

The lower heating values and CO_2 and SO_2 emission factors for the gasoline, diesel and LPG used by non-road machinery in 2021 are shown in Table 3.2.8.

Table 3.2.8 Emission factors and fuel consumption (FC) for LPG fuelled non-road machinery (g/kWh).

Fuel type	LHV	Emission factors(g/MJ)	
	MJ/kg	CO_2	SO_2
Diesel	42.7	74.1	0.468
Gasoline	42.1	68.5	0.428
LPG	46	63.1	0

3.3 Adjustment factors for engine deterioration

The emission factors increase over time due to engine wear. The emission deterioration effects for NO_x, PM, CO and VOC are incorporated in the emission calculations in the following way.

Diesel and 2-stroke gasoline engines

The deterioration factor for a given machinery type, engine size and engine age in year X depends on the engine-size class (only for gasoline), y, and the emission level, z. The deterioration factors for diesel and gasoline 2-stroke engines are found from:

$$DF_{i,j,k}(X) = \frac{K_{i,j,k}}{LT_i} \cdot DF_{y,z} \tag{1}$$

DF = deterioration factor,

K = engine age,

LT = lifetime,

i = machinery type,

j = engine size,

k = engine age,

y = engine-size class,

z = emission level.

As can be derived from Equation 1, for diesel and gasoline 2-stroke engines younger than average engine lifetime a linear interpolation is made between zero and the maximum deterioration factor. For engines older than average engine lifetime, the maximum deterioration factor is used.

The deterioration factors come from IFEU (2004) and Winther (2022a) and are shown in the Tables 3.3.1 and 3.3.2 below for diesel engines and gasoline 2-stroke engines, respectively. The values express $DF_{y,z}$ i.e. the ratio representing the maximum emission increase for any specific type of equipment and technology level compared to the emissions from the engine as new.

As an example, from Table 3.3.1, the TSP emissions from a diesel engine becomes 47.3 % higher as the engine age reach average lifetime compared to the emissions from the engine as new. Reversely the NO_x emissions from 2-stroke SN1 engines up to Stage I decrease by 60 % compared to new engines when average engine lifetime is reached (Table 3.3.2).

Table 3.3.1 Deterioration factors for diesel machinery relative to average engine lifetime.

Emission stage	NO_x	VOC	CO	TSP
< Stage I	0.024	0.047	0.185	0.473
Stage I	0.024	0.036	0.101	0.473
Stage II	0.009	0.034	0.101	0.473
Stage IIIA, IIIB, IV, V	0.008	0.027	0.151	0.473

Table 3.3.2 Deterioration adjustment factors for gasoline 2-stroke engines relative to average engine lifetime.

Engine	Engine power class	Emission stage	Technology Level	NO_x	VOC	CO	TSP
2-stroke	SH1	S<20	<1981	0	0.2	0.2	0
2-stroke	SH1	S<20	1981-1990	0	0.2	0.2	0
2-stroke	SH1	S<20	1991-Stage I	0	0.2	0.2	0
2-stroke	SH1	S<20	Stage I	0	0.24	0.24	0
2-stroke	SH1	S<20	Stage II	0	0.24	0.24	0
2-stroke	SH1	S<20	Stage V	0	0.24	0.24	0
2-stroke	SH2	20<=S<50	<1981	0	0.2	0.2	0
2-stroke	SH2	20<=S<50	1981-1990	0	0.2	0.2	0
2-stroke	SH2	20<=S<50	1991-Stage I	0	0.2	0.2	0
2-stroke	SH2	20<=S<50	Stage I	0	0.29	0.24	0
2-stroke	SH2	20<=S<50	Stage II	0	0.29	0.24	0
2-stroke	SH2	20<=S<50	Stage V	0	0.29	0.24	0
2-stroke	SH3	S>=50	<1981	-0.031	0.2	0.2	0
2-stroke	SH3	S>=50	1981-1990	-0.031	0.2	0.2	0
2-stroke	SH3	S>=50	1991-Stage I	-0.031	0.2	0.2	0
2-stroke	SH3	S>=50	Stage I	0	0.266	0.231	0
2-stroke	SH3	S>=50	Stage II	0	0.266	0.231	0
2-stroke	SH3	S>=50	Stage V	0	0.266	0.231	0
2-stroke	SN1	S<66	<1981	-0.6	0.201	0.9	1.1
2-stroke	SN1	S<66	1981-1990	-0.6	0.201	0.9	1.1
2-stroke	SN1	S<66	1991-Stage I	-0.6	0.201	0.9	1.1
2-stroke	SN1	S<66	Stage I	-0.33	0.266	1.109	5.103
2-stroke	SN1	S<66	Stage II	-0.33	0	1.109	5.103
2-stroke	SN1	S<66	Stage V	-0.33	0	1.109	5.103
2-stroke	SN2	66<=S<100	<1981	-0.6	0.201	0.9	1.1
2-stroke	SN2	66<=S<100	1981-1990	-0.6	0.201	0.9	1.1
2-stroke	SN2	66<=S<100	1991-Stage I	-0.6	0.201	0.9	1.1
2-stroke	SN2	66<=S<100	Stage I	-0.33	0.266	1.109	5.103
2-stroke	SN2	66<=S<100	Stage II	-0.33	0	1.109	5.103
2-stroke	SN2	66<=S<100	Stage V	-0.33	0	1.109	5.103
2-stroke	SN3	100<=S<225	<1981	-0.6	0.201	0.9	1.1
2-stroke	SN3	100<=S<225	1981-1990	-0.6	0.201	0.9	1.1
2-stroke	SN3	100<=S<225	1991-Stage I	-0.6	0.201	0.9	1.1
2-stroke	SN3	100<=S<225	Stage I	-0.33	0.266	1.109	5.103
2-stroke	SN3	100<=S<225	Stage II	-0.33	0	1.109	5.103
2-stroke	SN3	100<=S<225	Stage V	-0.33	0	1.109	5.103
2-stroke	SN4	S>=225	<1981	-0.6	0.201	0.9	1.1
2-stroke	SN4	S>=225	1981-1990	-0.6	0.201	0.9	1.1
2-stroke	SN4	S>=225	1991-Stage I	-0.6	0.201	0.9	1.1
2-stroke	SN4	S>=225	Stage I	-0.274	0	0.887	1.935
2-stroke	SN4	S>=225	Stage II	-0.274	0	0.887	1.935
2-stroke	SN4	S>=225	Stage V	-0.274	0	0.887	1.935

4-Stroke gasoline engines

For gasoline 4-stroke engines the deterioration factors are calculated as:

$$DF_{i,j,k}(X) = \sqrt{\frac{K_{i,j,k}}{LT_i}} \cdot DF_{y,z} \qquad (2)$$

DF = deterioration factor,

K = engine age,

LT = lifetime,

i = machinery type,

j = engine size,

k = engine age,

y = engine-size class,

z = emission level.

As explained in Equation 2, for gasoline 4-stroke engines younger than average engine lifetime the square root of a linear interpolation is made between zero and the maximum deterioration factor. For engines older than average engine lifetime the maximum deterioration factor is used.

The deterioration factors for gasoline 4-stroke engines come from IFEU (2004) and Winther (2022a) and are shown Table 3.3.3 below (IFEU, 2004; Winther, 2022a). The values express $DF_{y,z}$ i.e. the ratio representing the maximum emission increase for any specific type of equipment and technology level.

Table 3.3.3 Deterioration adjustment factors for gasoline 4-stroke engines relative to average engine lifetime.

Engine	Size code	Size class	Emission Level	NO_x	VOC	CO	TSP
4-stroke	SN1	S<66	<1981	-0.6	1.1	0.9	1.1
4-stroke	SN1	S<66	1981-1990	-0.6	1.1	0.9	1.1
4-stroke	SN1	S<66	1991-Stage I	-0.6	1.1	0.9	1.1
4-stroke	SN1	S<66	Stage I	-0.3	1.753	1.051	1.753
4-stroke	SN1	S<66	Stage II	-0.3	1.753	1.051	1.753
4-stroke	SN1	S<66	Stage V	-0.3	1.753	1.051	1.753
4-stroke	SN2	66<=S<100	<1981	-0.6	1.1	0.9	1.1
4-stroke	SN2	66<=S<100	1981-1990	-0.6	1.1	0.9	1.1
4-stroke	SN2	66<=S<100	1991-Stage I	-0.6	1.1	0.9	1.1
4-stroke	SN2	66<=S<100	Stage I	-0.3	1.753	1.051	1.753
4-stroke	SN2	66<=S<100	Stage II	-0.3	1.753	1.051	1.753
4-stroke	SN2	66<=S<100	Stage V	-0.3	1.753	1.051	1.753
4-stroke	SN3	100<=S<225	<1981	-0.6	1.1	0.9	1.1
4-stroke	SN3	100<=S<225	1981-1990	-0.6	1.1	0.9	1.1
4-stroke	SN3	100<=S<225	1991-Stage I	-0.6	1.1	0.9	1.1
4-stroke	SN3	100<=S<225	Stage I	-0.3	1.753	1.051	1.753
4-stroke	SN3	100<=S<225	Stage II	-0.3	1.753	1.051	1.753
4-stroke	SN3	100<=S<225	Stage V	-0.3	1.753	1.051	1.753
4-stroke	SN4	S>=225	<1981	-0.6	1.1	0.9	1.1
4-stroke	SN4	S>=225	1981-1990	-0.6	1.1	0.9	1.1
4-stroke	SN4	S>=225	1991-Stage I	-0.6	1.1	0.9	1.1
4-stroke	SN4	S>=225	Stage I	-0.599	1.095	1.307	1.095
4-stroke	SN4	S>=225	Stage II	-0.599	1.095	1.307	1.095
4-stroke	SN4	S>=225	Stage V	-0.599	1.095	1.307	1.095
4-stroke	SH1	S<20	<1981	0	0	0	0
4-stroke	SH1	S<20	1981-1990	0	0	0	0
4-stroke	SH1	S<20	1991-Stage I	0	0	0	0
4-stroke	SH1	S<20	Stage I	0	0	0	0
4-stroke	SH1	S<20	Stage II	0	0	0	0
4-stroke	SH1	S<20	Stage V	0	0	0	0
4-stroke	SH2	20<=S<50	<1981	0	0	0	0
4-stroke	SH2	20<=S<50	1981-1990	0	0	0	0
4-stroke	SH2	20<=S<50	1991-Stage I	0	0	0	0
4-stroke	SH2	20<=S<50	Stage I	0	0	0	0
4-stroke	SH2	20<=S<50	Stage II	0	0	0	0
4-stroke	SH2	20<=S<50	Stage V	0	0	0	0
4-stroke	SH3	S>=50	<1981	0	0	0	0
4-stroke	SH3	S>=50	1981-1990	0	0	0	0
4-stroke	SH3	S>=50	1991-Stage I	0	0	0	0
4-stroke	SH3	S>=50	Stage I	0	0	0	0
4-stroke	SH3	S>=50	Stage II	0	0	0	0
4-stroke	SH3	S>=50	Stage V	0	0	0	0

No deterioration is assumed for fuel consumption (all fuel types) or for LPG engine emissions and hence, DF = 1 in these situations.

3.4 Adjustment factors for transient engine load

The adjustment factors for transient engine loads come from IFEU (2014)[9] and Winther (2022a) and are shown in Table 3.4.1.

Table 3.4.1 Transient operation adjustment factors for diesel engines.

Technology Level	Engine load	Engine load factor	NO_x	VOC	CO	TSP	FC
<= Stage II	High	>0.45	0.95	1.05	1.53	1.23	1.01
Stage IIIA	High	>0.45	1.04	1.05	1.53	1.47	1.01
Stage IIIB-V	High	>0.45	1	1	1	1	1
<= Stage II	Middle	0.25≤LF≤0.45	1.025	1.67	2.05	1.6	1.095
Stage IIIA	Middle	0.25≤ LF≤0.45	1.125	1.67	2.05	1.92	1.095
Stage IIIB-V	Middle	0.25≤ LF≤0.45	1	1	1	1	1
<= Stage II	Low	<0.25	1.1	2.29	2.57	1.97	1.18
Stage IIIA	Low	<0.25	1.21	2.29	2.57	2.37	1.18
Stage IIIB-V	Low	<0.25	1	1	1	1	1

No transient corrections are made for gasoline and LPG engines and, hence, $TF_z = 1$ for these fuel types.

3.5 Preinstalled particle filters

As a part of some engine manufacturer's emission reduction strategy, some of the Stage IIIB and IV non-road machines used in building and construction are equipped with preinstalled diesel particle filters, and hence have low particle emissions. This particle filter effect on particle emissions must be taken into account in the calculations, since the baseline emission factors for TSP more aligns with EU emission legislation limits, and these emission limits do not necessarily require particulate filters in order to be met.

There is no Danish register of non-road machinery and hence a full overview of engine technologies and exhaust emission aftertreatment system is not readily available. The share of Stage IIIB and IV diesel engines used in the building and construction sector with preinstalled diesel particle filters is therefore based on questionnaire data received from the most important mobile machinery manufacturers and Danish machinery importers (Winther, 2022b).

The percentage share of diesel engines with preinstalled particulate filters are shown in Table 3.6.

Tabel 3.4.2 Percentage of stage IIIB og IV non-road diesel engines with preinstalled particulate filters.

Engine power class	Stage IIIB	Stage IV
	% preinstalled DPF	
19<=P<37	0	0
37<=P<56	30	80
56<=P<75	35	70
75<=P<130	90	70
130<=P<560	100	65
P>560	0	0

9 Based on measurements for high and low engine loads from USEPA (2010) and supplementary emission information from TU Graz.

The particle reduction factor, F_{dpf}, for any given machinery type, engine size and engine age in year X, depends on the share of engines with preinstalled particle filters, in the different size classes and emission levels:

$$F_{dpf,i,j,k}(X) = \frac{(1-S_{y,z})\cdot EF_{y,z} + S_{y,z}\cdot EF_{dpf,y,z}}{EF_{y,z}} \quad (3)$$

F_{dpf} = particle reduction factor,

S = share of engines with preinstalled filters,

i = machinery type,

j = engine size,

k = engine age.

This emission reduction factor only relates to particle emissions from Stage IIIB and IV diesel engines with preinstalled filters[10].

[10] The particle emission adjustment relating to Stage IIIB and IV engines equipped with particle filters also significantly affects BC emissions, since particle filters very efficiently reduce BC from the exhaust.

4 Calculation method

The fuel consumption and emissions in year X, for a given machinery type, engine size and engine age, are calculated as:

$$E(X)_{i,j,k} = N_{i,j,k} \cdot HRS_{i,j,k} \cdot P \cdot LF_i \cdot EF_{Basis,y,z} \cdot (1 + DF(X)_{i,j,k}) \cdot TF(X)_{i,j,k} \cdot F_{dpf,i,j,k}(X)) \qquad (4)$$

E = fuel consumption or emissions (g),
N = number of engines (from stock model),
HRS = annual working hours (from stock model),
P = average rated engine size in kW (from stock model),
LF = load factor,
EF_{Basis} = basis fuel consumption and emission factors in g/kWh (shown in paragraph 3.2).
DF = deterioration factor (eq. 1 and 2 in paragraph 3.3)
TF = transient engine operation factor (Table 3.4.1),
F_{dpf} = particle filter share factor (eq. 3 in paragraph 3.5; relevant for PM and BC only),
i = machinery type,
j = engine size,
k = engine age,
y = engine power class,
z = emission level.

The fuel consumption (g) is transformed into energy consumption (MJ) in the following way:

$$E(MJ) = E(g) \cdot LHV_k/1000 \qquad (5)$$

E (MJ) = energy consumption (MJ),

E (g) = Fuel consumption (g), calculated with eq. 4,

LHV = lower heating value (MJ/kg), see paragraph 3.2,

The CO_2 and SO_2 emissions are calculated in the following way:

$$E_i = E_i(MJ) \cdot EF_f \qquad (6)$$

Hvor E = emission (g),

E (MJ) = energiforbrug (MJ), beregnet med formel 5),

EF = emission factor (CO_2, SO_2) in g/MJ, see paragraph 3.2,

i = machinery type,

f = fuel type (diesel, gasoline, LPG).

The evaporative hydrocarbon emissions from gasoline fueling are calculated as:

$$E_{Evap,fueling,i} = FC_i \cdot EF_{Evap,fueling} \quad (7)$$

Where $E_{Evap,fueling}$, = hydrocarbon emissions from fueling, i = machinery type, FC = fuel consumption in kg, $EF_{Evap,fueling}$ = emission factor in g NMVOC pr kg fuel.

For gasoline tank evaporation, the hydrocarbon emissions are found from:

$$E_{Evap,tan\,k,i} = N_i \cdot EF_{Evap,tan\,k,i} \quad (8)$$

Where $E_{Evap,tank,i}$ = hydrocarbon emissions from tank evaporation, N = number of engines, i = machinery type and $EF_{Evap,fueling}$ = emission factor in g NMVOC pr year.

The electricity consumption in a given year, X, is calculated as:

$$E(X)_i = N_i \cdot HRS_i \cdot P \cdot LF_i \cdot / eff_{i,j,k} \quad (9)$$

E = Electricity consumption (MJ),

N = number of engines (from stock model),

HRS = annual working hours (from stock model),

P = average rated engine size in kW (from stock model),

LF = load factor,

i = machinery type,

In the case of electric forklifts, excavators and loaders, P x LF equals average electric consumption in kW taken from the battery during operation.

5 Total Stock and operating hours

The aggregated results for stock and operating hours in 2021 and for the period 1980-2040 are presented in this chapter.

For each non-road sector, the data for stock and operating hours are presented for 2021 and for the 1980-2040 period, split by fuel type.

For total non-road, the data for stock and operating hours are shown for 2021 and for the 1980-2040 period, split by engine type, engine power class and emission stage.

In Annex 3, aggregated data for stock numbers and total operating hours is shown for total non-road, per engine type and engine power class (diesel only) for 1980-2040.

In Annex 4, aggregated data for stock numbers and total operating hours is shown for total non-road, per fuel type and emission stage for 1980-2040.

Stock numbers, total operating hours, and specific operating hours for non-road machinery in 2021 per non-road sector, fuel type and engine type are shown in Table 5.1.

The stock numbers and total operating hours are also displayed in the Figures 5.1 and 5.2 and in addition engine power class and emission level distributions are shown.

Table 5.1 Stock numbers, total operating hours, and specific operating hours for non-road machinery in 2021 per non-road sector, fuel type and engine type.

	Total	Diesel	Gasoline 2-stroke	Gasoline 4-stroke	Gasoline Total	LPG	El
				Stock numbers			
Agricultural machinery	96,618	78,532	-	18,036	18,036	-	50
Forestry machinery	2,754	854	1,800	-	1,800	-	100
Building and construction machinery	110,474	59,263	5,414	45,430	50,844	-	367
Industrial machinery	20,293	10,788	-	-	-	1,723	7,781
Commercial and institutional machinery	164,412	14,837	37,802	20,171	57,972	1,126	90,476
Residential machinery	2,290,198	-	254,249	448,382	702,631		1,587,567
Grand total	2,684,750	164,274	299,265	532,019	831,284	2,849	1,653,404
				Operating hours (million hours)			
Agricultural machinery	19.08	15.90	-	3.13	3.13	-	0.04
Forestry machinery	2.06	0.59	1.44	-	1.44	-	0.03
Building and construction machinery	36.19	27.69	0.43	7.89	8.32	-	0.18
Industrial machinery	12.73	6.97	-	-	-	1.53	4.23
Commercial and institutional machinery	32.36	6.62	3.61	5.89	9.50	0.98	15.25
Residential machinery	125.75	-	4.72	6.90	11.62	-	114.13
Grand total	228.17	57.78	10.20	23.82	34.02	2.51	133.86
				Specific operating hours (hours per machine)			
Agricultural machinery	197	202	-	174	174	-	800
Forestry machinery	747	693	800	-	800	-	250
Building and construction machinery	328	467	80	174	164	-	482
Industrial machinery	627	646	-	-	-	890	544
Commercial and institutional machinery	197	447	96	292	164	868	169
Residential machinery	55	-	19	15	17	-	72

The largest number of diesel machines are used in agriculture, followed by construction, commercial and institutional and industry. However, the total number of operating hours is lower for agricultural machinery than for construction machinery, because the weighted number of operating hours per machine (specific operating hours) for agriculture is low compared to the other sectors.

LPG fuelled forklifts are used in commercial and institutional, and industrial non-road.

In terms of numbers, by far the largest stock of gasoline machines is in residential. However, due to rather low specific operating hours, the total number of operating hours for private gasoline machines is only slightly higher than for gasoline machines in commercial and institutional and building and construction.

Also for electric machines the largest stock is by far in residential. Robotic lawn mowers has a very high share of the total number of operating hours, and thus the average specific number of operating hours will be somewhat higher for residential than if the stock consisted only of manually operated machines. The same tendency applies to commercial and institutional, where robotic lawn mowers also play a major role in terms of total hours in use.

For other types of electric equipment, forklifts used in building and construction, commercial and institutional and industry is the most common type. However, track type excavators and wheel loaders (< 5,1 tonnes) have begun to enter the stock of building and construction machinery from 2021.

In 2021, the total stock of diesel engines is widely distributed over the different engine power classes and emission levels in 2021 (Figure 5.1). For diesel machinery as a whole, the shares of total operating hours (Figure 5.2) are higher than stock shares of machinery (Figure 5.2) for increasingly newer emission standards and increasingly larger engine power classes.

For gasoline machinery in total, 4-stroke engines are the most numerous engine type, and apart from agricultural ATV’s not covered by EU emission standards, only Stage II and Stage V engines are present in the stock in 2021 (Figure 5.1). Also, in the case of gasoline machinery, the shares of total operating hours (Figure 5.2) are higher than stock shares of machinery (Figure 5.1) for increasingly newer emission standards.

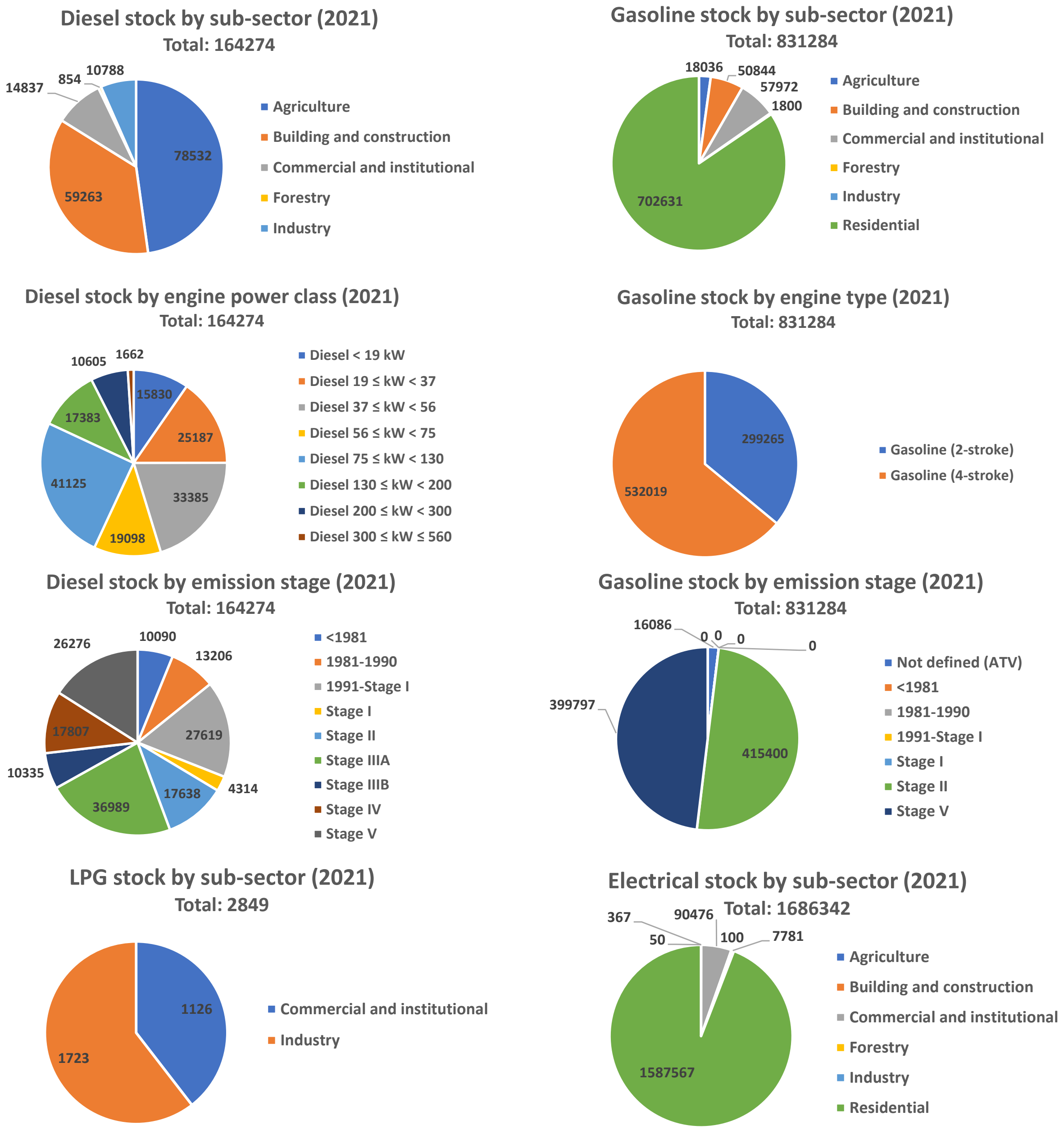


Figure 5.1 Total stock by fuel type, sub-sector, rated engine power class and emission stage for non-road machinery in 2021

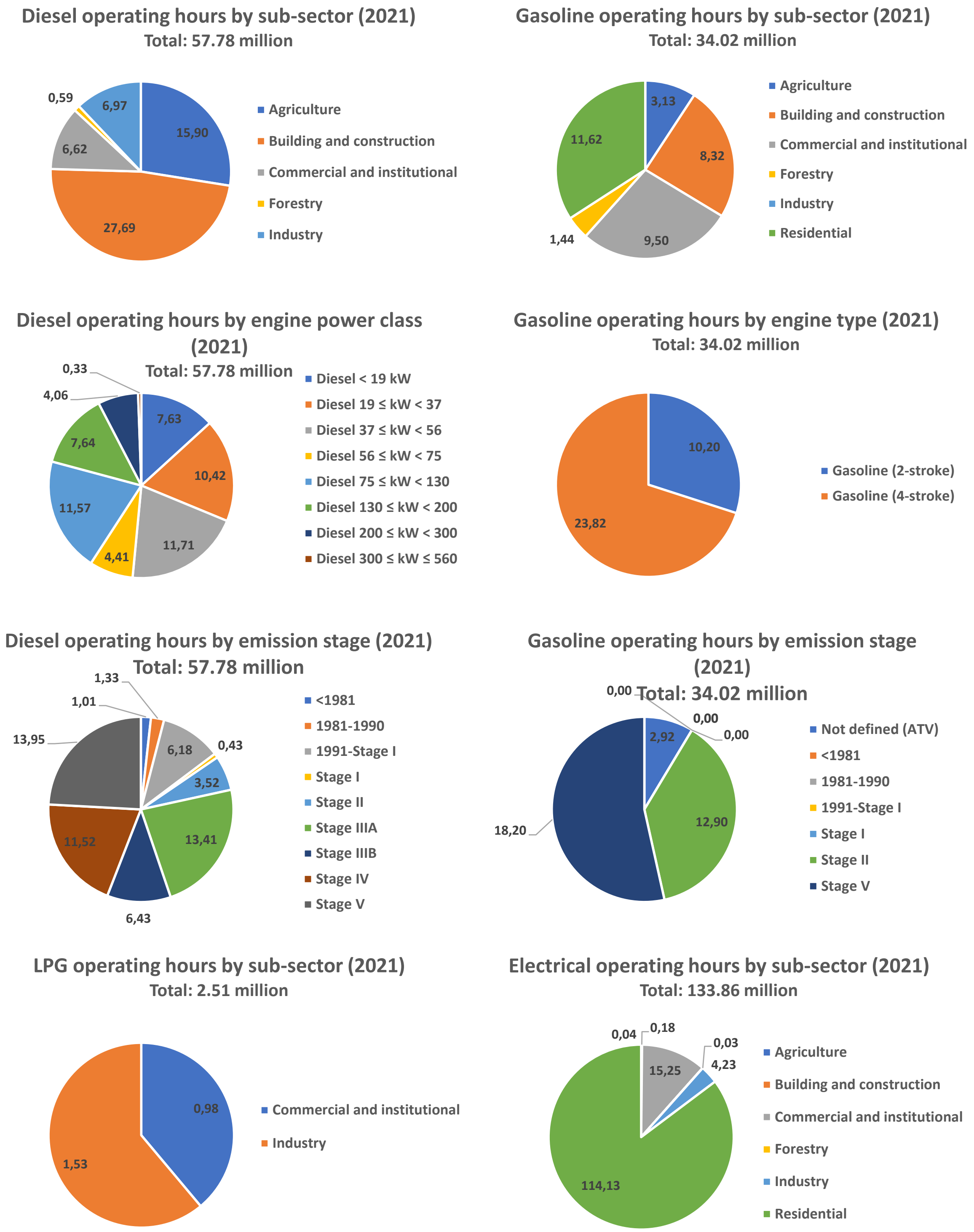


Figure 5.2 Total operating hours by fuel type, sub-sector, rated engine power class and emission stage for non-road machinery in 2021.

For stock trends in the total period 1980-2040, the following are generally noted.

The development of the total stock of diesel machinery is particularly affected by agriculture, where the number of tractors has decreased significantly in years up to 2021. The decline in the stock will level off towards 2040, not least because the future stock of tractors is expected to be constant.

There has been a large growth in the stock of residential gasoline machines until 2010, after which the total stock of gasoline machinery decreases due to an increased switch to electricity for some of the machine types.

The number of electric machines in residential has increased a lot in the historical period up to 2021, and this stock increase is expected to continue until 2025. The number of electric forklifts used in the commercial and institutional and industrial sectors is expected to increase in the future due to the green transition in machine sales, where sales of diesel and LPG fuelled forklifts is expected to switch completely to electric towards 2030.

In addition, it is clear how new emission standards for diesel and gasoline are gradually being implemented in the stock and will become more and more dominant towards 2040.

Figure 5.3 Total stock by fuel type, sub-sector, rated engine power class and emission stage for non-road machinery (1980-2040).

In most cases, the development in the total operating hours follows the same pattern as the stock development in the period 1980-2040. However, it is worth noting the following. A major reason why the total number of operating hours for diesel increases slightly towards 2010, in contrast to the development in the total stock, is due to the development within the size category 37-56 kW, where especially many older agricultural tractors with few specific operating hours are leaving the stock.

For gasoline machines, the total number of operating hours decreases less than the total stock numbers from 2010 onwards, because the specific operating hours for the machine types not being replaced by electric machines are generally higher than the average specific operating hours for the total stock. This is particularly true for the residential sector.

For all years throughout the 1980-2040 period for diesel and gasoline machinery, the shares of total operating hours (Figure 5.4) are higher than stock shares of machinery (Figure 5.3) for increasingly newer emission standards and increasingly larger engine power classes.

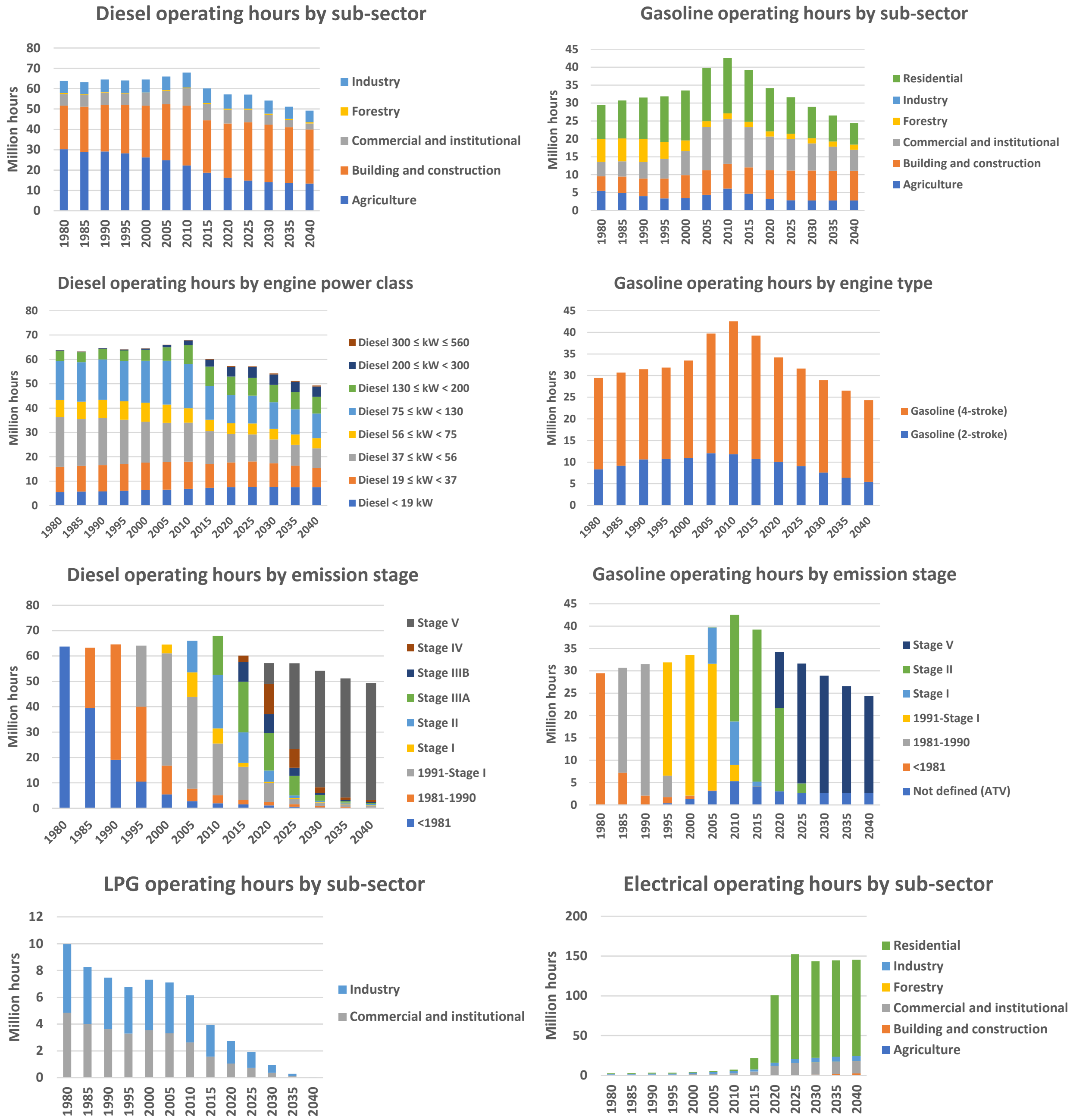


Figure 5.4 Total operating hours by fuel type, sub-sector, rated engine power class and emission stage for non-road machinery 1980-2040.

6 Stock and operating hours by sub-sector

The results for stock and operating hours in 2021 and for the period 1980-2040 are presented in the following sub-chapters for each non-road sector.

For each non-road sector, the data for stock and operating hours are presented for 2021 for the different machine types split by fuel type, engine type, engine power class and emission stage. For the period 1980-2040 stock and operating hours are shown per fuel type, engine type, engine power class and emission stage.

In Annex 3, aggregated data for stock numbers and total operating hours is shown per non-road sector and total non-road, per engine type and engine power class for 1980-2040.

In Annex 4 aggregated data for stock numbers and total operating hours is shown per non-road sector and total non-road, per fuel type and emission stage for 1980-2040.

6.1 Agricultural machinery

6.1.1 Stock

Agricultural tractors have the highest share of the total stock numbers for diesel fuelled agricultural machinery in 2021, followed by harvesters and machine pool tractors (Figure 6.1.1).

The stock of diesel engines in the agricultural sector in 2021 is widely distributed across the different engine size categories. There are most diesel machines within the engine size range 75-130 kW, but also significant stock shares appear in the four size categories within 37-75 kW and 130-300 kW.

The stock of diesel engines in 2021 is also widely distributed over the different emission levels. As previously mentioned, a large part of the stock consists of agricultural tractors, which are typically used for many years in agriculture before they are replaced.

In terms of gasoline, professional ATV's, private ATV's and fodder trucks, in this consecutive order, are the most numerous machinery types in 2021. All the gasoline machinery types are equipped with 4-stroke engines.

The emission levels represented in the stock of gasoline machinery in 2021 are Stage II, Stage V and a "constructed" emission level for ATV's. For ATV's emission factors are not readily available and therefore has been derived from motorcycle emission data, as explained in section 3.2.

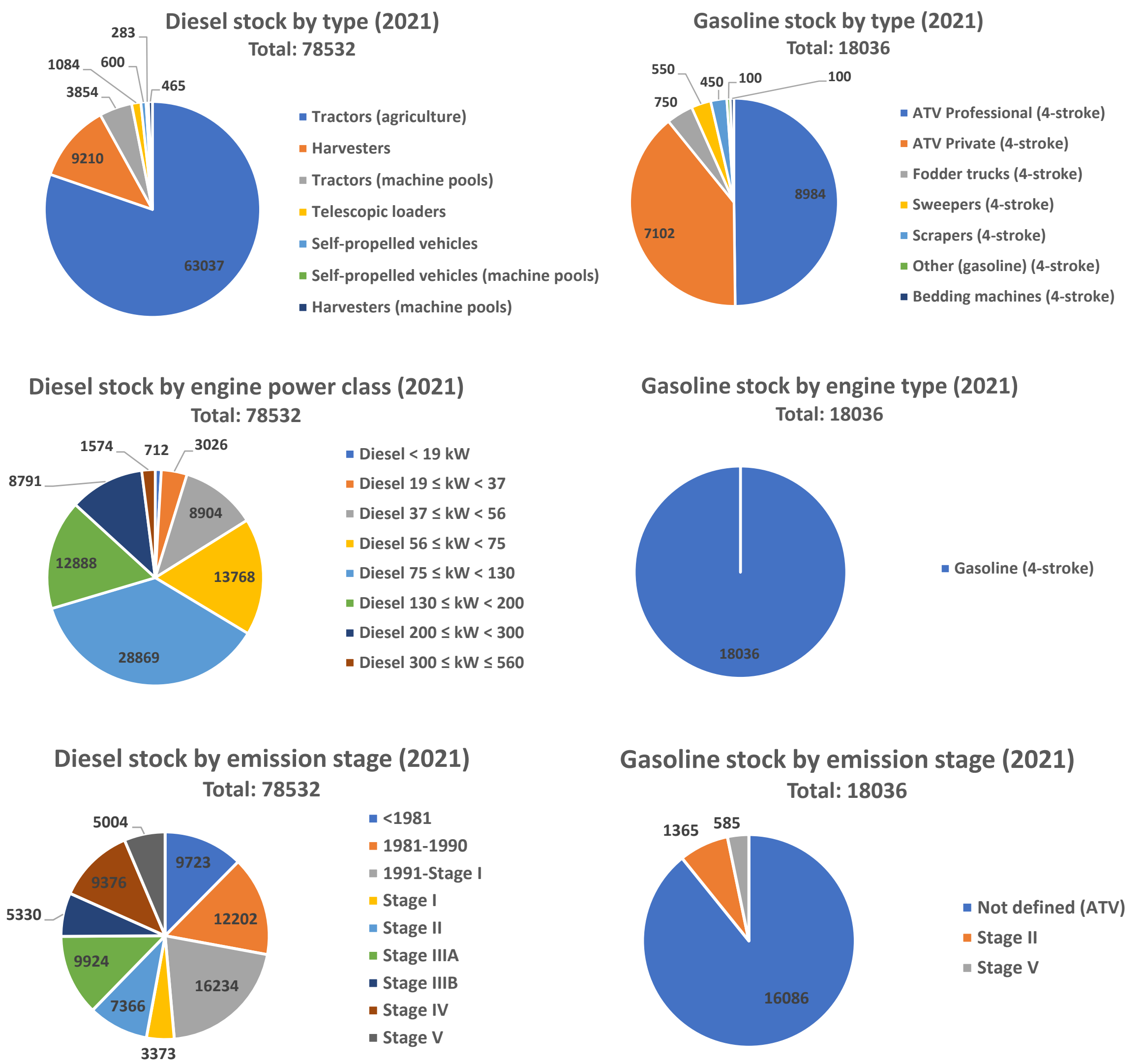


Figure 6.1.1 Stock by fuel type, machine type, engine power class and emission stage for agricultural non-road machinery in 2021.

For diesel engines in the engine size categories 37-56 kW and 56-75 kW, a significant decrease in stock numbers is noted in the historical years from 1980 leading up to 2021 (Figure 6.1.2). This stock development is due to structural changes in the agricultural sector towards a smaller number of tractors with larger engine sizes overall being used, as described in activity data (section 2.1).

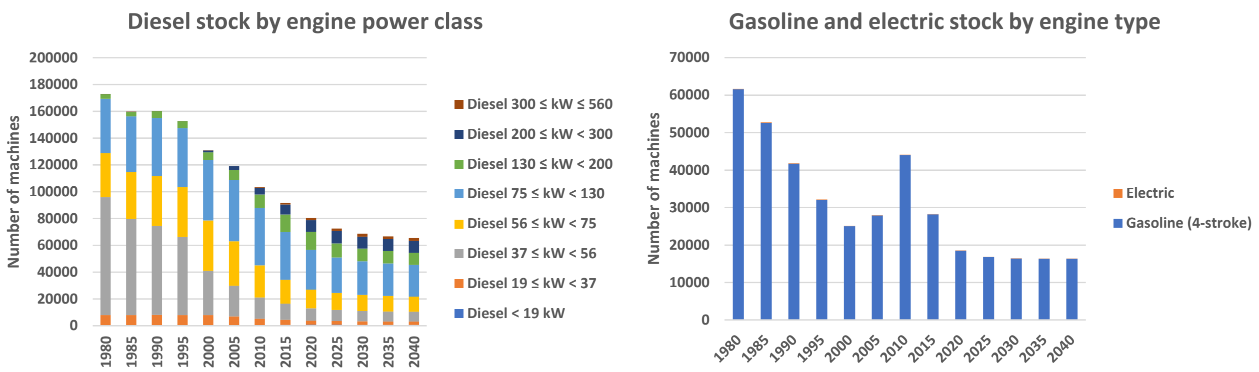


Figure 6.1.2 Stock by engine power class/engine type for agricultural non-road machinery 1980-2040.

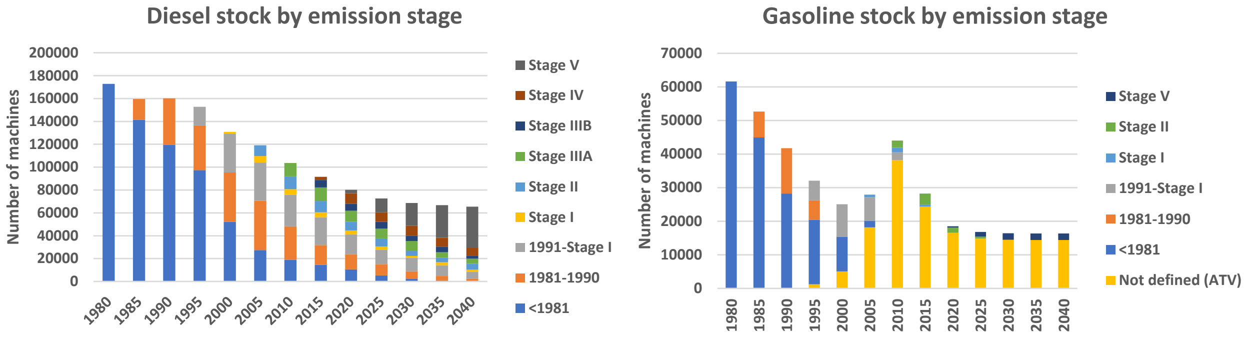


Figure 6.1.3 Stock by emission stage for diesel and gasoline fuelled agricultural non-road machinery 1980-2040.

For the stock of agricultural non-road diesel machinery taken as a whole, the penetration of the different pre-Euro engine stages, and engine stages complying with the gradually stricter EU stage I-V emission limits from 1980-2040 is very visible from Figure 6.1.3. The EU emission directive stage implementation years differ for the different engine power classes, and new sales also fluctuate from the year to year, and hence the emission level shares into specific engine power classes (not shown) will differ slightly from the total picture shown in Figure 6.1.3.

The development of the stock of gasoline-powered agricultural machinery is composed of a phasing out of vintage tractors until 2005, and a substantial decline of other equipment types in the period up to 2021, except for ATV machines, where new sales picked up from the mid 1990's and caused a significant growth of the total stock of ATV's until 2010 (Figure 6.1.3). A small number of electrical tractors are used in agriculture.

6.1.2 Operating hours

The development of the total number of operating hours for diesel and gasoline fuelled agricultural machinery from 1980-2040 is by large similar with the development in stock data, both by engine power class, engine type, and emission levels.

The annual operating hours from 1980-2040 are shown by engine power class and engine type in Figure 6.1.4, and by emission level for diesel and gasoline machinery in Figure 6.1.5.

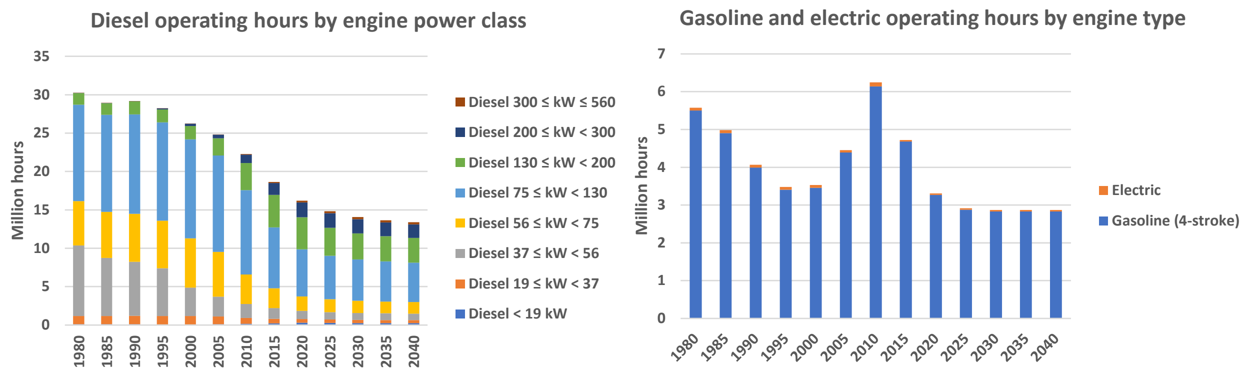


Figure 6.1.4 Operating hours by engine power class/engine type for agricultural non-road machinery 1980-2040.

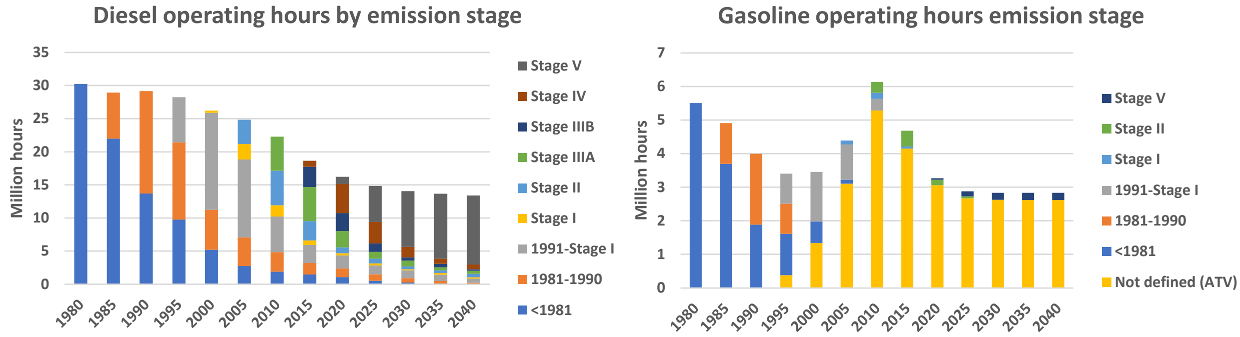


Figure 6.1.5 Operating hours by emission stage for diesel and gasoline fuelled agricultural non-road machinery 1980-2040.

6.2 Forestry machinery

6.2.1 Stock

Tractors (forestry, silvicultural and other tractors) are the most numerous diesel machinery types used in forestry, followed by different types of chippers and the harvester machinery type (Figure 6.2.1). Gasoline 2-stroke and a small number of electric chain saws are also used in the forestry sector; electric chain saws from 2020.

The stock of forestry diesel engines in 2021 is widely distributed across the different engine size categories. Most of the diesel machines are in the engine power class 75-130 kW, but also a significant number of machines are in the two engine size categories 19-37 kW and 130-200 kW. The stock of diesel engines in 2021 is also widely distributed over the different emission levels.

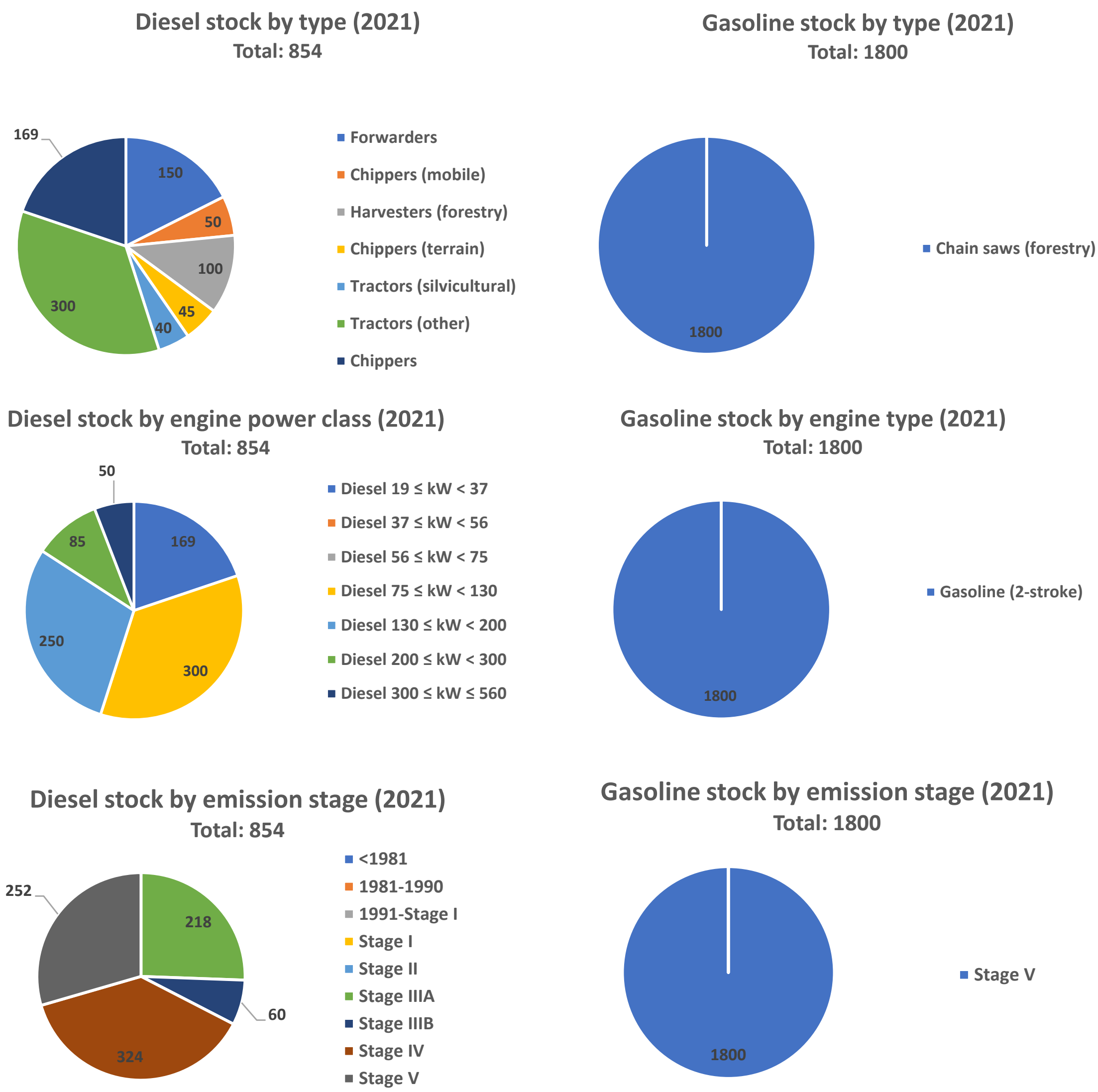


Figure 6.2.1 Stock by fuel type, machine type, engine power class and emission stage for forestry non-road machinery in 2021.

For diesel machinery the total stock has slightly declined from 1980 to 2005, followed by a stock growth until 2021, due to an increased production of wood chips used as a fuel for power and heat production in Denmark.

A gradual increase in engine size is noted for forestry machinery in general. In the period up to 2005, machines in the engine size categories 37-56 kW and 56-75 kW are being replaced by 75-130 kW machinery. From 2005 onwards, 75-130 kW machinery decrease in numbers, whereas stock increases are noted for engine sizes larger than 130 kW (Figure 6.2.2).

From 1990 until 2005, the number of gasoline-powered chainsaws has significantly reduced, and a decrease in the total number of forestry diesel machinery are also noted during this period (Figure 6.2.1). From 2005 until 2021, the number of diesel machinery has increased, after which the total number of diesel machines flattens out at a slightly lower level until 2040.

The diesel engines used in forestry tend to increase in engine power, where a shift from 37-56 kW to 56-75 kW is noted during the 1990s and a shift from 56-75 kW to 75-130 kW is noted in the 2000s in the overall stock (Figure 6.2.2).

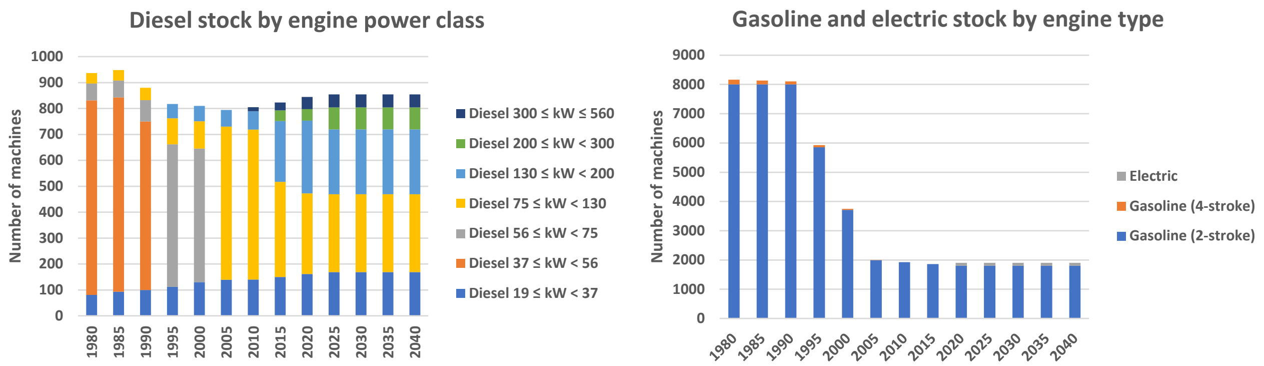


Figure 6.2.2 Stock by engine power class/engine type for forestry non-road machinery 1980-2040.

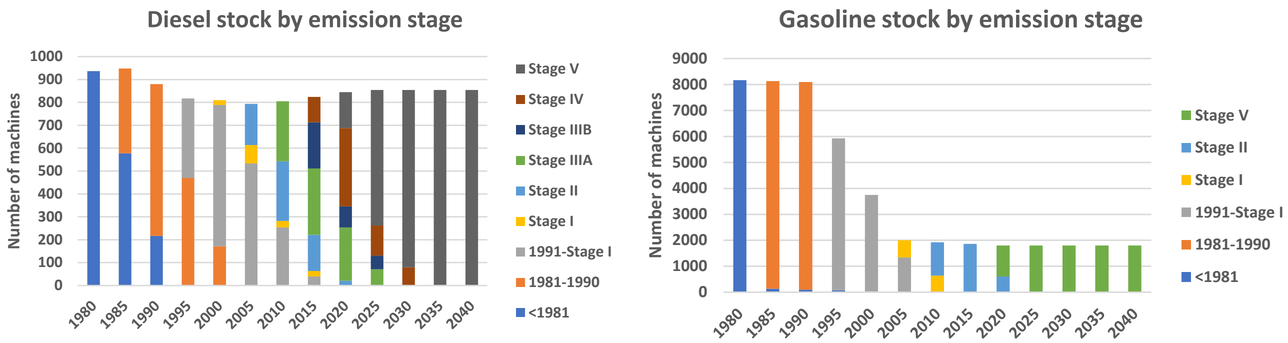


Figure 6.2.3 Stock by emission stage for diesel and gasoline fuelled forestry non-road machinery 1980-2040.

The composition of the diesel (and gasoline chain saws) machinery stock into the different pre-Euro engine stages, and EU stage I-V emission limits from 1980-2040, and the gradual development towards newer emission standards are shown in Figure 6.2.3.

6.2.1 Operating hours

For diesel machinery the total number of operating hours has slightly declined from 1980 to 2005, followed by a significant stock growth until 2021, due to an increased production of wood chips used as a fuel for power and heat production in Denmark (Figure 6.2.4).

The development of the total number of operating hours for gasoline fuelled forestry machinery from 1980-2040 is by large similar with the development in stock data, both by engine power class, engine type, and emission levels.

The annual operating hours from 1980-2040 is shown by engine power class and engine type in Figure 6.2.4, and by emission level for diesel and gasoline machinery in Figure 6.2.5.

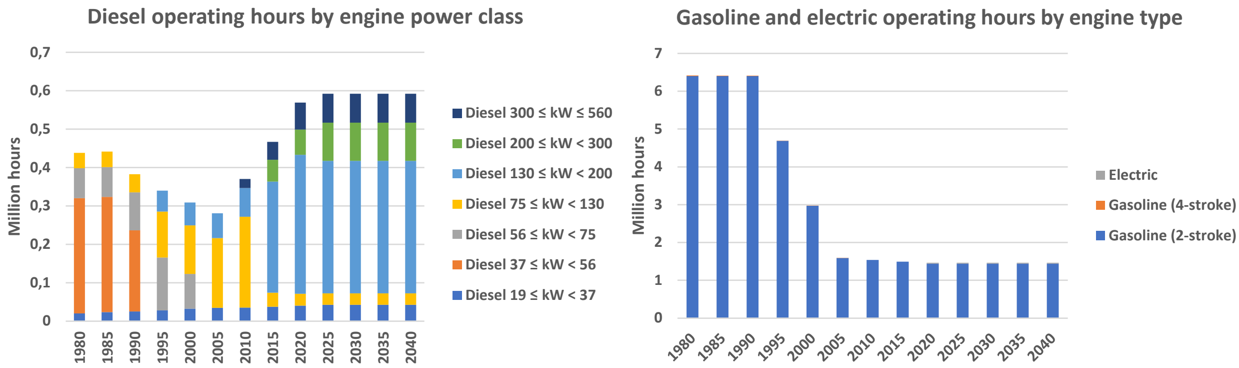


Figure 6.2.4 Operating hours by engine power class/engine type for forestry non-road machinery 1980-2040.

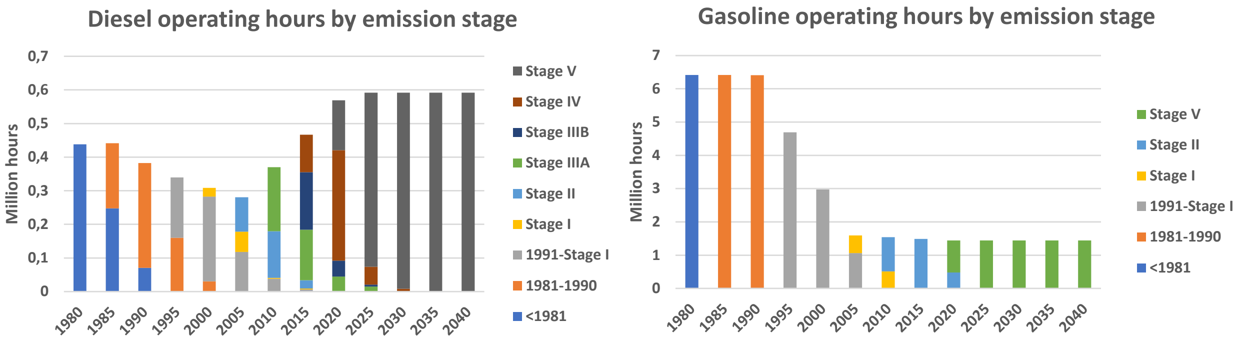


Figure 6.2.5 Operating hours by emission stage for diesel and gasoline fuelled forestry non-road machinery 1980-2040.

6.3 Construction machinery

6.3.1 Stock

Numerous types of diesel machinery are used in the building and construction sector, with quite large shares of the total stock. For gasoline machinery 4-stroke engines are the most dominant engine type, and pumps and generators are most frequent in numbers. In terms of electric equipment, forklifts are the most common type, however, track type excavators and wheel loaders (< 5,1 tonnes) have begun to enter the machinery stock from 2021 (Figure 6.3.1).

In 2021, most of the diesel machines used in the building and construction sector are in the engine power class 37-56 kW and 56- 75 kW, and the stock of diesel engines is widely distributed over the different emission levels in 2021.

For gasoline machinery in 2021 Stage II and Stage V engines are present in the stock.

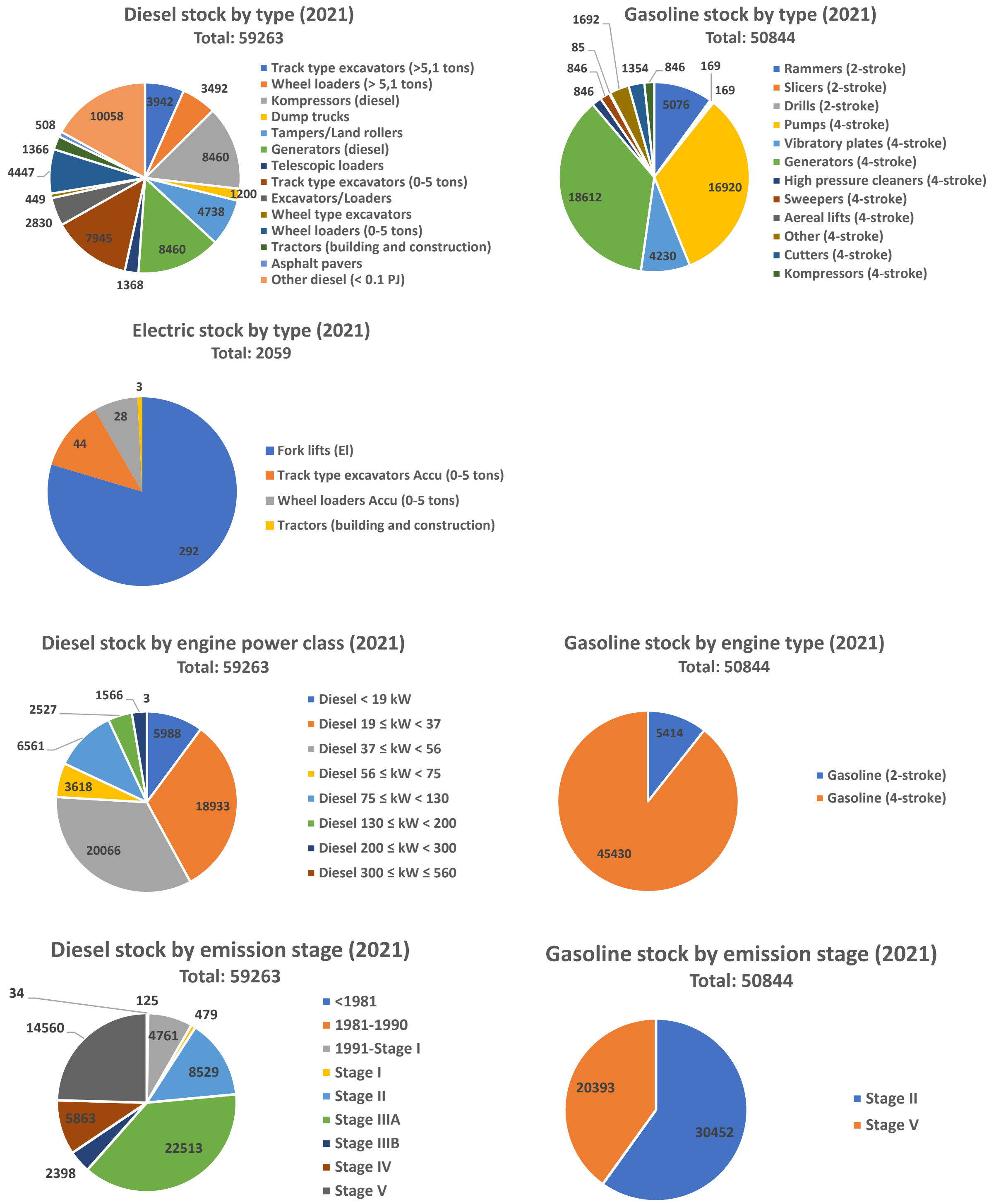


Figure 6.3.1 Stock by fuel type, machine type, engine power class and emission stage for building and construction non-road machinery in 2021.

Most significantly, the number of diesel machinery has increased until 2010. A small stock decline is expected from 2025 to 2040, mainly due to the increasing number of track type excavators and wheel loaders (< 5,1 tonnes) shifting to electricity.

For diesel, there has been a slight shift towards larger engines during the period. Most notable, the number of 19-56 kW engines decreases while on the other hand the number of 200-300 kW engines increases.

The number of gasoline engines has increased until 2021 due to the economic growth in the historical years. From 2021 onwards the stock of electric forklifts, track type excavators and wheel loaders (< 5,1 tonnes) are expected to increase due to the transition towards zero emission machinery that has already begun.

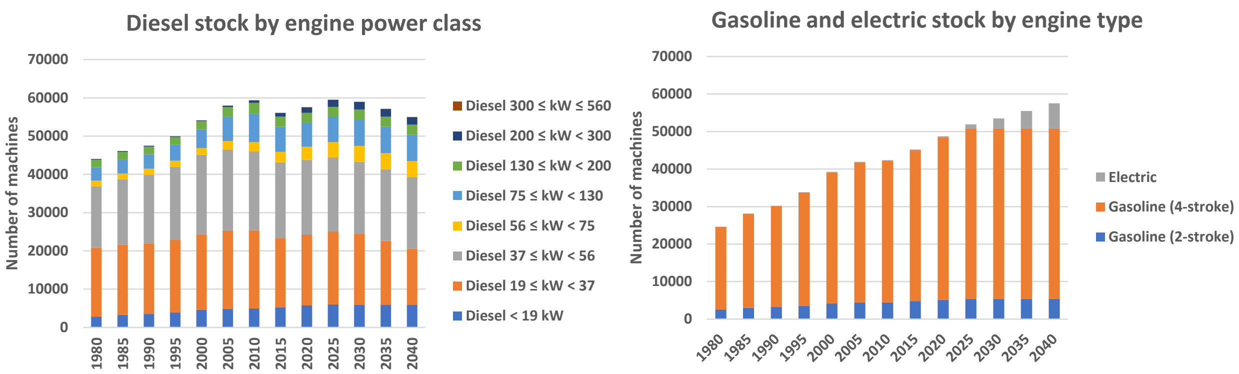


Figure 6.3.2 Stock by engine power class/engine type for building and construction non-road machinery 1980-2040.

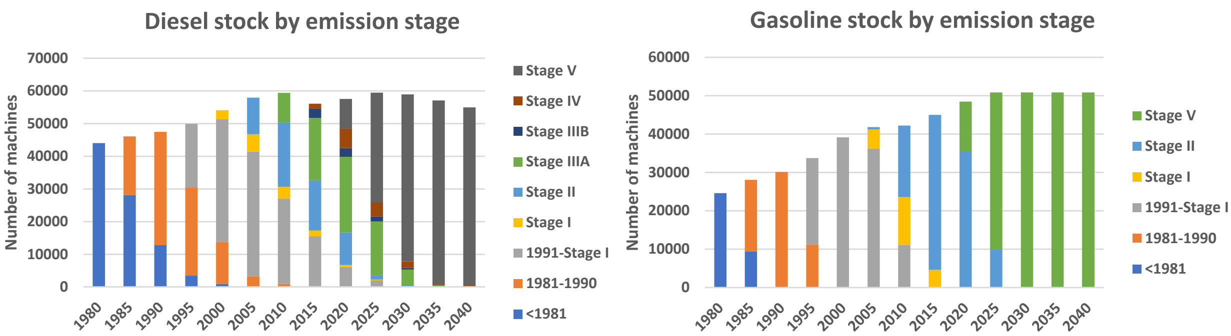


Figure 6.3.3 Stock by emission stage for diesel and gasoline fuelled building and construction non-road machinery 1980-2040.

6.3.2 Operating hours

The development of the total number of operating hours for diesel, gasoline and electric fuelled building and construction machinery from 1980-2040 is by large similar with the development in stock data, both by engine power class, engine type, and emission levels.

In each year, however, the share of operating hours for the most modern EU emission standards are higher than their stock number shares, given that annual operating hours gradually reduce by machinery age (Figure 2.3.1).

The annual operating hours from 1980-2040 are shown by engine power class and engine type in Figure 6.3.4, and by emission level for diesel and gasoline machinery in Figure 6.3.5.

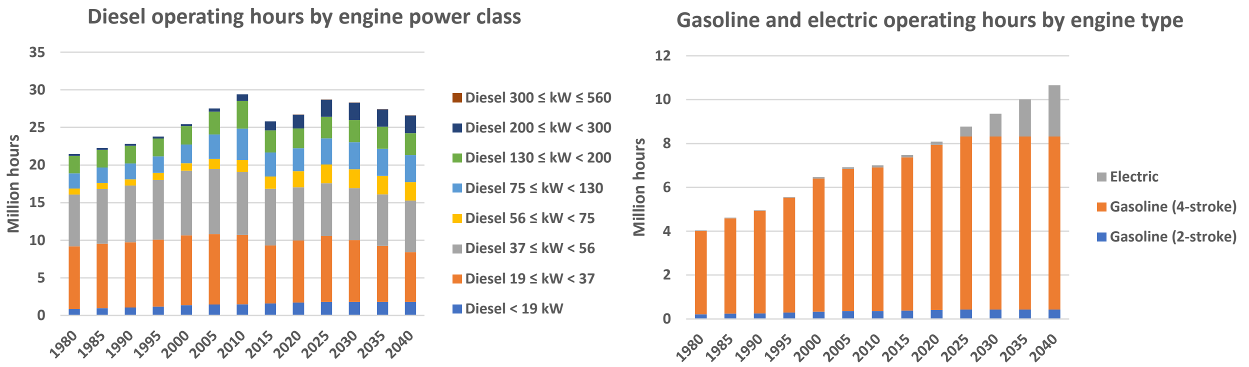


Figure 6.3.4 Operating hours by engine power class/engine type for building and construction non-road machinery 1980-2040.

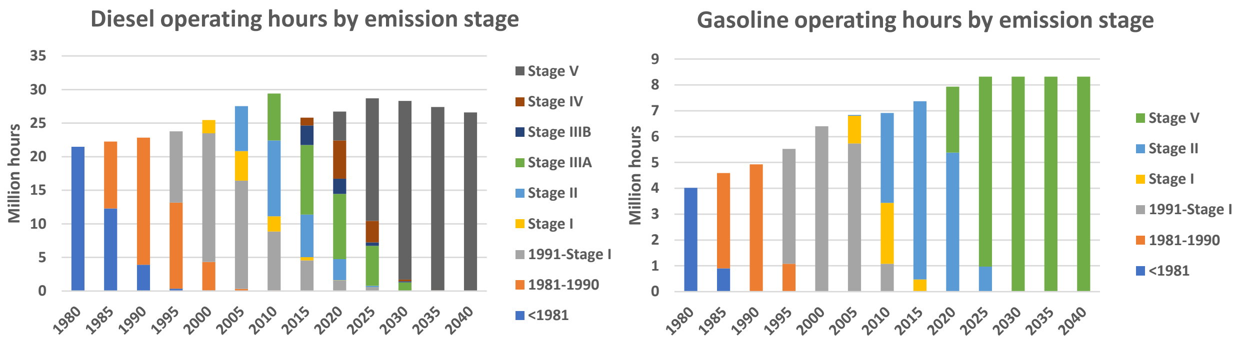


Figure 6.3.5 Operating hours by emission stage for diesel and gasoline fuelled building and construction non-road machinery 1980-2040.

6.4 Industrial machinery

6.4.1 Stock

The stock of industrial diesel non-road machinery consists of a few different machinery types, namely refrigerating units (onboard distribution and long range road transportation lorries and trucks), forklifts, tractors and telescopic loaders (Figure 6.4.1). LPG and electric forklifts and very few electric tractors are also used in the industrial sector.

The distribution of diesel engines by engine power class and emission stage is largely influenced by the numbers of refrigerating units. For the latter machinery types the engine sizes are below 19 kW, and in this case, Stage V is the first EU emission stage to comply with (Table 3.1.1).

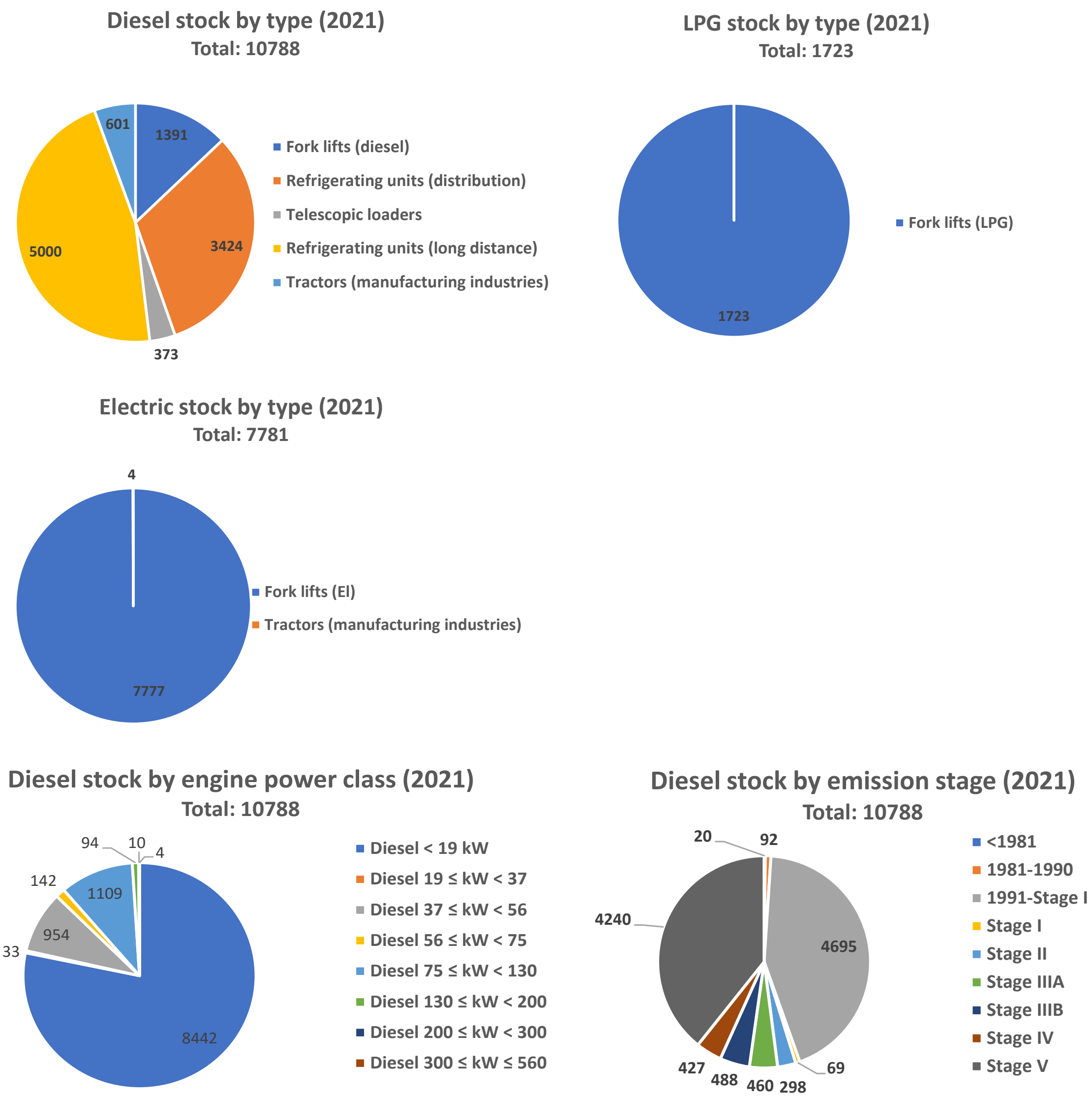


Figure 6.4.1 Stock by machine type, engine power class and emission stage for diesel fuelled industrial non-road machinery in 2021.

The number of refrigerating units has increased until 2021, proportional to population growth. For diesel, the engine power class 37-56 kW mainly consists of forklifts, and a decline in the number of forklifts, also in the case of LPG, is expected in the future years towards 2040, due to transition in new sales from fossil fuelled to entirely electric forklifts from 2030 onwards (Figure 6.4.2).

A small number of gasoline-powered tractors were present in the stock until they were completely phased out in 2005.

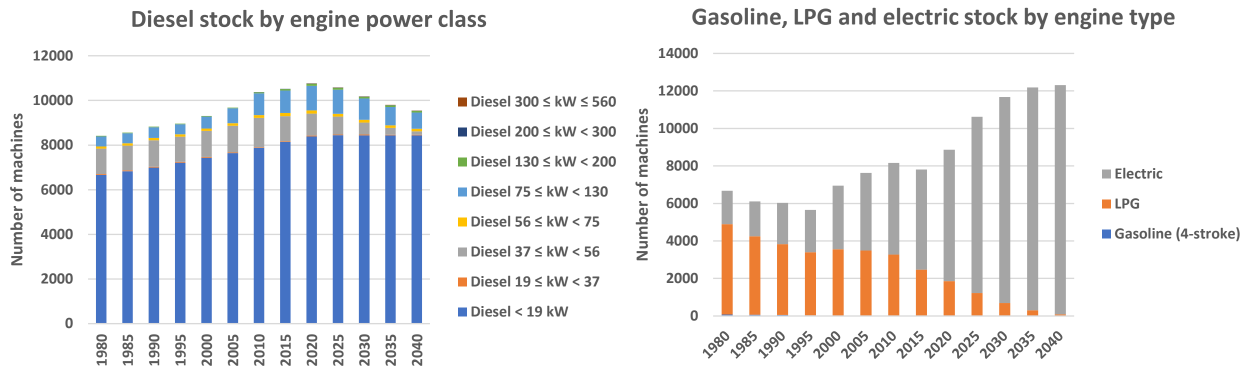


Figure 6.4.2 Stock by engine power class/engine type for industrial non-road machinery 1980-2040.

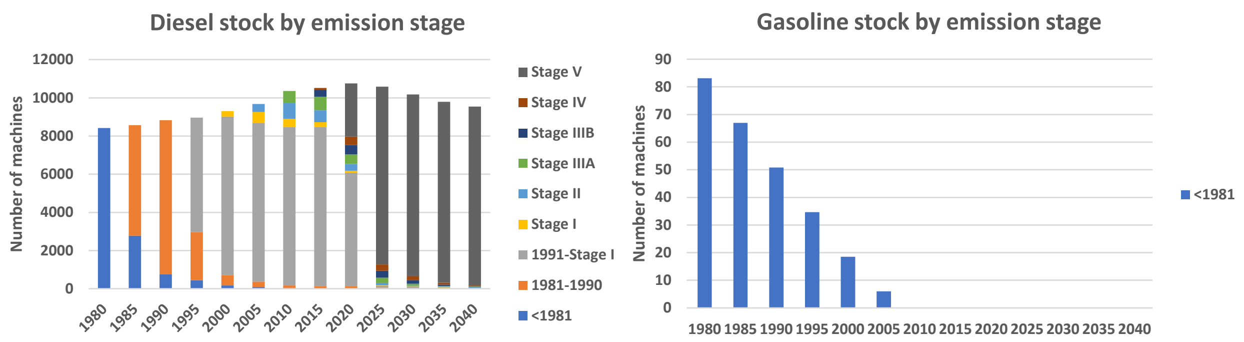


Figure 6.4.3 Stock by emission stage for diesel and gasoline fuelled industrial non-road machinery 1980-2040.

6.4.2 Operating hours

The development of the total number of operating hours for diesel, LPG and electric fuelled industrial machinery from 1980-2040 is by large similar with the development in stock data, both by engine power class, engine type, and emission levels.

In each year, however, the share of operating hours for the most modern EU emission standards is higher than their stock number shares, given that annual operating hours gradually reduce by machinery age (Figure 2.3.1).

The annual operating hours from 1980-2040 are shown by engine power class and engine type in Figure 6.4.4, and by emission level for diesel and gasoline machinery in Figure 6.4.5.

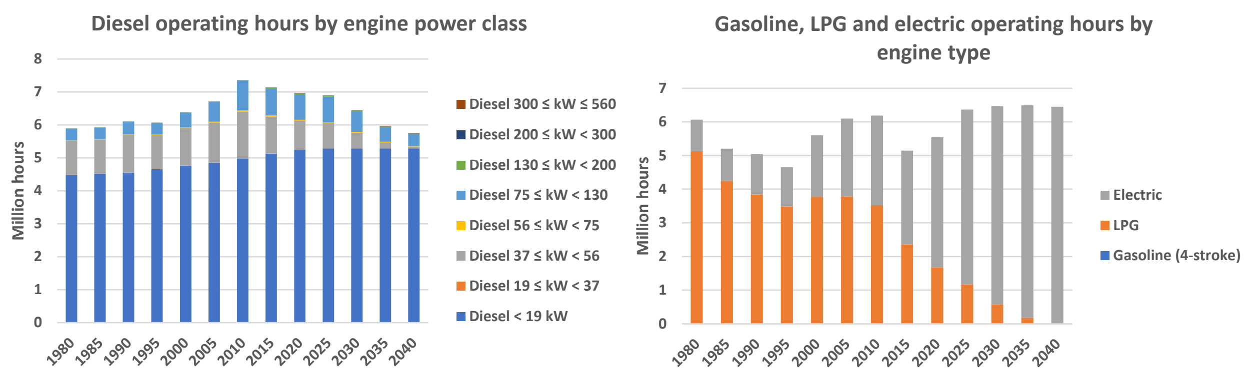


Figure 6.4.4 Operating hours by engine power class/engine type for industrial non-road machinery 1980-2040.

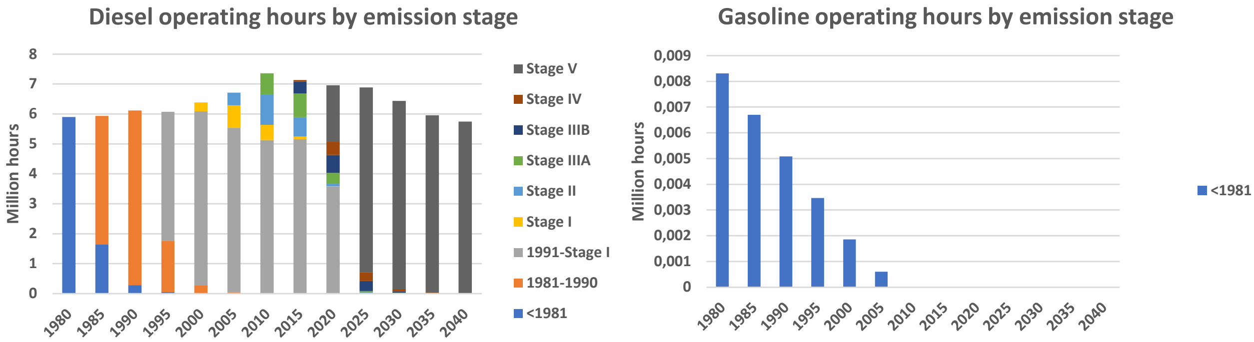


Figure 6.4.5 Operating hours by emission stage for diesel and gasoline fuelled industrial non-road machinery 1980-2040.

6.5 Commercial and institutional machinery

6.5.1 Stock

The stock of diesel machinery in the commercial and institutional sector consists of tractors, forklifts, telescopic loaders and ground support equipment (GSE) in ports and airports. LPG forklifts are used in this sector as well.

Many different gasoline fuelled machinery types are also used in the commercial and institutional sector. For gasoline 2-stroke engines the highest stock numbers are counted for chain saws, shrub clearers and blowers. In the case of 4-stroke engines, riders and lawn mowers are the most numerous types of machinery (Figure 6.5.1).

Also many, mainly battery electric (accu), types of equipment are used in the commercial and institutional sector. Trimmers is the most numerous equipment type, followed by robotic lawn mowers, blowers and hedge cutters. A large group of other types of electrical equipment is also part of the stock.

The stock of commercial and institutional diesel engines in 2021 is widely distributed across the different engine size categories and emission levels. For gasoline machinery, Stage II and Stage V engines are present in the stock in 2021.

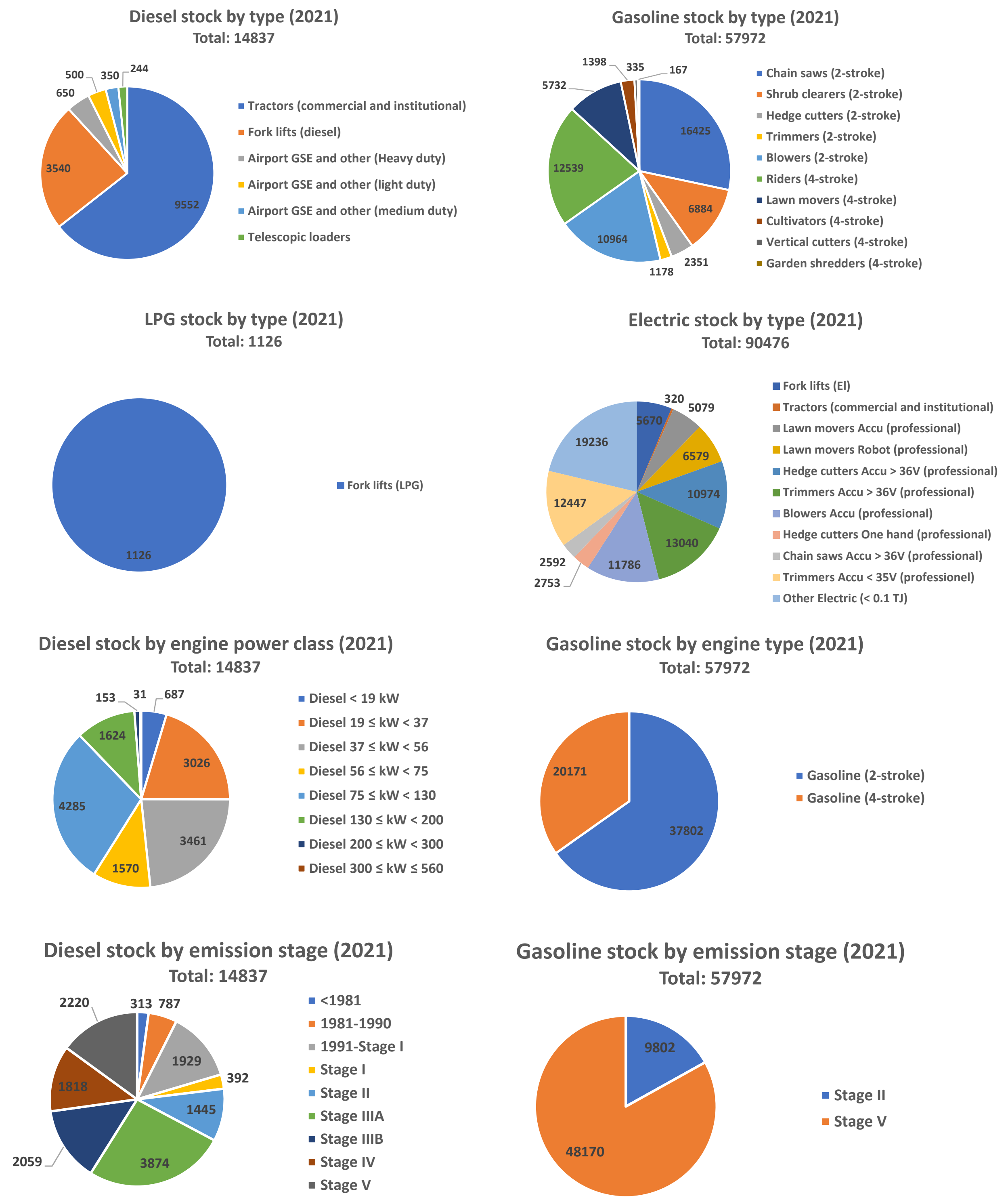


Figure 6.5.1 Stock by fuel type, machine type, engine power class and emission stage for commercial and institutional non-road machinery in 2021.

Most significantly, the number of diesel machinery has increased until 2015. For diesel, the engine power class 37-56 kW primarily consists of forklifts, and a decline in the number of diesel and LPG fuelled forklifts is, as previously explained, expected in the future years towards 2040, due to the complete shift in new sales from fossil fuelled to electric from 2030 onwards (Figure 6.5.2).

A large increase in the number of gasoline machinery is noted from 1980 to 2005, due to a steady rise in new sales during that period, especially for 2-stroke engines.

The increase in the number of electric machines has mainly occurred from 2005 until 2021. In the most recent years, for some machinery types, electric powered machinery more and more frequently replaces gasoline fuelled counterparts, which have declined in total numbers during the same period.

The trend towards an increasing share of electric machines is expected to continue towards 2040. Branch expectations are that new sales will be exclusively electrical machinery for trimmers, hedge cutters and blowers in 2030, for vertical cutters in 2035 and for chain saws and lawn mowers in 2040.

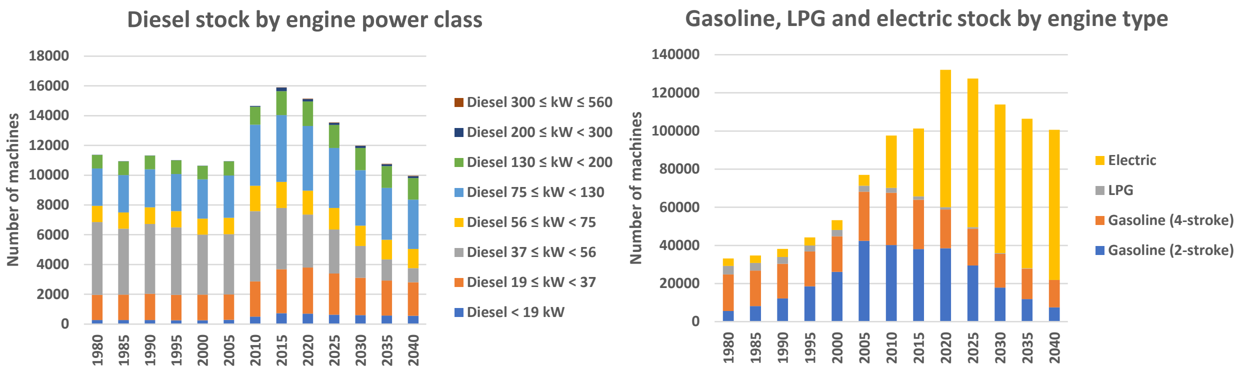


Figure 6.5.2 Stock by engine power class/engine type for commercial and institutional non-road machinery 1980-2040.

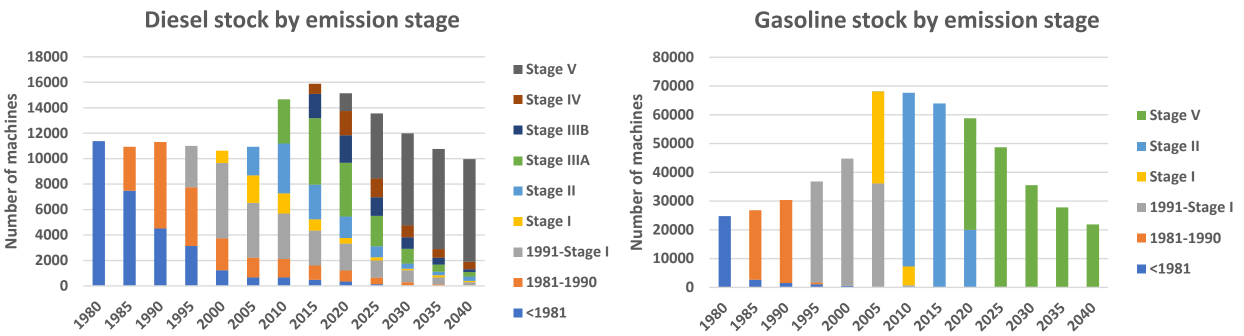


Figure 6.5.3 Stock by emission stage for diesel and gasoline fuelled type commercial and institutional non-road machinery 1980-2040.

6.5.2 Operating hours

The development of the total number of operating hours for diesel, gasoline and LPG fuelled commercial and institutional non-road machinery from 1980-2040 is by large similar with the development in stock data, both by engine power class, engine type, and emission levels. In each year, however, the share of operating hours for the most modern EU emission standards are higher than their stock number shares, given that annual operating hours gradually reduce by machinery age (Figure 2.3.1).

For electrical machinery many of the total number of operating hours are delivered by robotic lawn mowers, very visible from 2020 onwards. The annual operating hours per machine are estimated to be 2000, and total operating hours for professional robotic lawn mowers hence sums up to 7.5 and 14.5 million hours, respectively, in 2020 and 2021.

The annual operating hours from 1980-2040 are shown by engine power class and engine type in Figure 6.5.4, and by emission level for diesel and gasoline machinery in Figure 6.5.5.

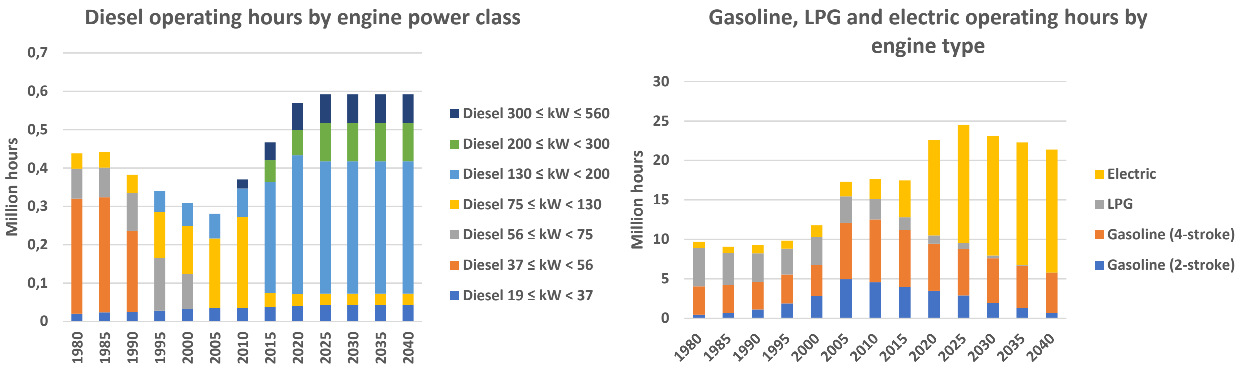


Figure 6.5.4 Operating hours by engine power class/engine type for commercial and institutional non-road machinery 1980-2040.

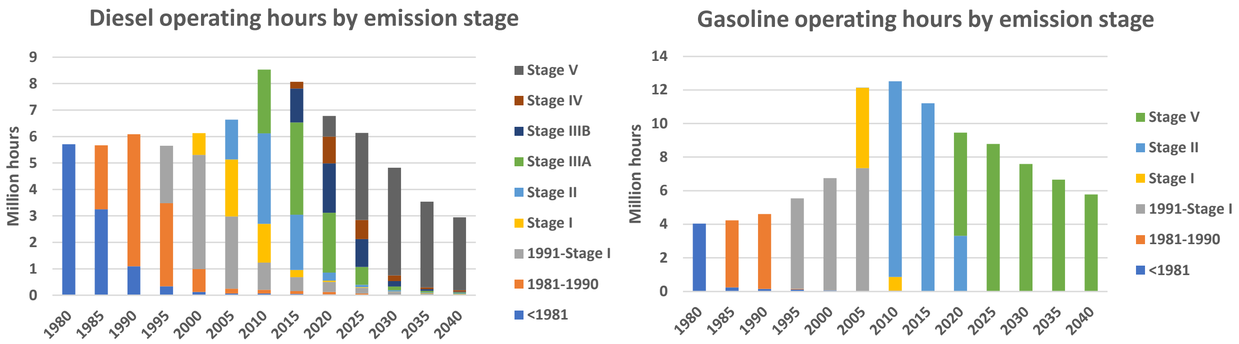


Figure 6.5.5 Operating hours by emission stage for diesel and gasoline fuelled commercial and institutional non-road machinery 1980-2040.

6.6 Residential machinery

6.6.1 Stock

Many different gasoline fuelled machinery types are used for residential purposes. For gasoline 2-stroke engines, the highest stock numbers are counted for shrub clearers, chain saws and hedge cutters. In the case of 4-stroke engines, lawn mowers, riders and cultivators are the most numerous types of machinery.

Also many, mainly battery electric (accu), types of equipment are used in the residential sector. Trimmers is the most numerous equipment type, followed by hedge cutters, robotic and battery electric lawn mowers. A large group of other types of electrical equipment is also part of the stock (Figure 6.6.1).

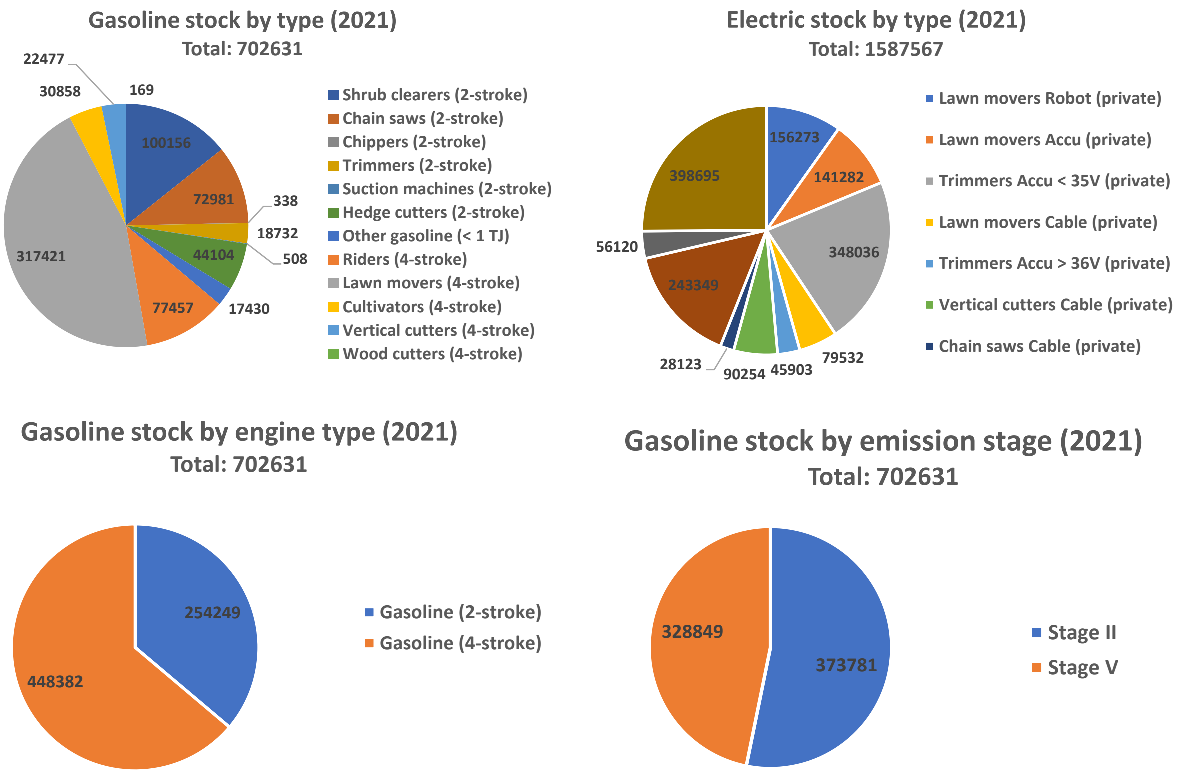


Figure 6.6.1 Stock by fuel type, machine type, engine power class and emission stage for residential non-road machinery in 2021.

A large increase in the number of gasoline machinery is noted from 1980 to 2005, due to a steady rise in new sales during that period, especially for 2-stroke engines (Figure 6.6.2).

The increase in the number of electric machines has mainly occurred from 2005 until 2021. In the most recent years, for some machinery types, electric powered machinery more and more frequently replaces gasoline fuelled counterparts, which have declined in total numbers during the same period.

The share of electric machines is expected to continue to grow towards 2040. Branch expectations are that new sales will be exclusively electrical machinery for trimmers, hedge cutters and blowers in 2030, for vertical cutters in 2035 and for chain saws and lawn mowers in 2040.

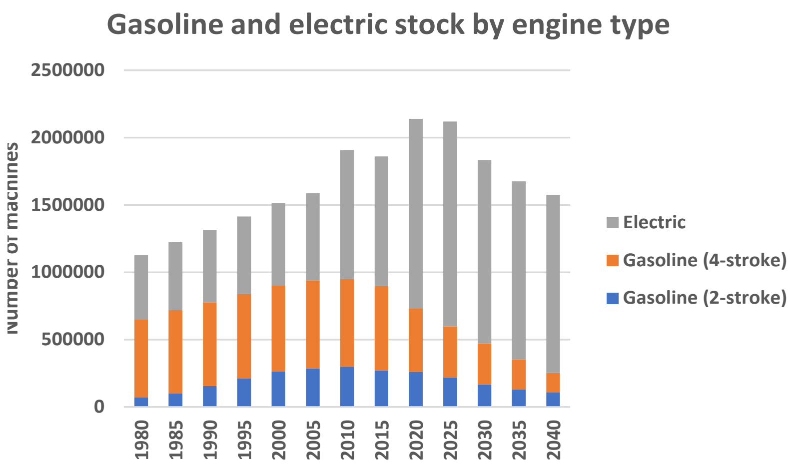


Figure 6.6.2 Stock by engine type for residential non-road machinery 1980-2040.

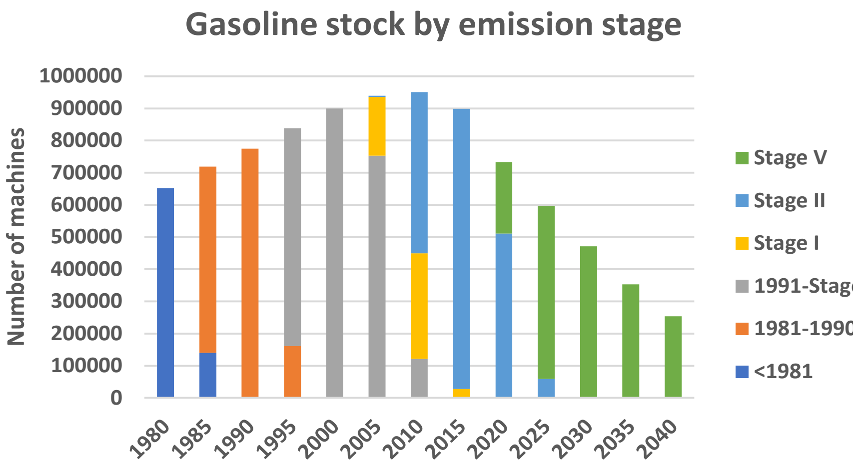


Figure 6.6.3 Stock by emission stage for gasoline fuelled type residential non-road machinery 1980-2040.

6.6.2 Operating hours

The development of the total number of operating hours for gasoline fuelled residential non-road machinery is largely similar to the development in stock data. For electrical machinery robotic lawn mowers has a very high share of the total number of operating hours, very visible from 2020 onwards. The annual operating hours per machine are estimated to be 700, and total operating hours for robotic lawn mowers in private hence sums up to more than 81.7 and 110.8 million hours, respectively, in 2020 and 2021.

The annual operating hours from 1980-2040 are shown by engine type in Figure 6.6.4 and by emission level for gasoline machinery in Figure 6.6.5.

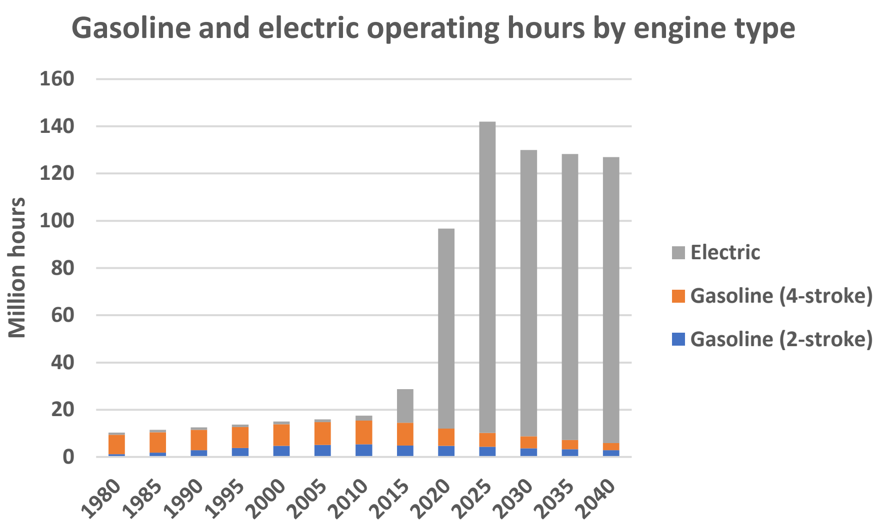


Figure 6.6.4 Operating hours by engine type for residential non-road machinery 1980-2040.

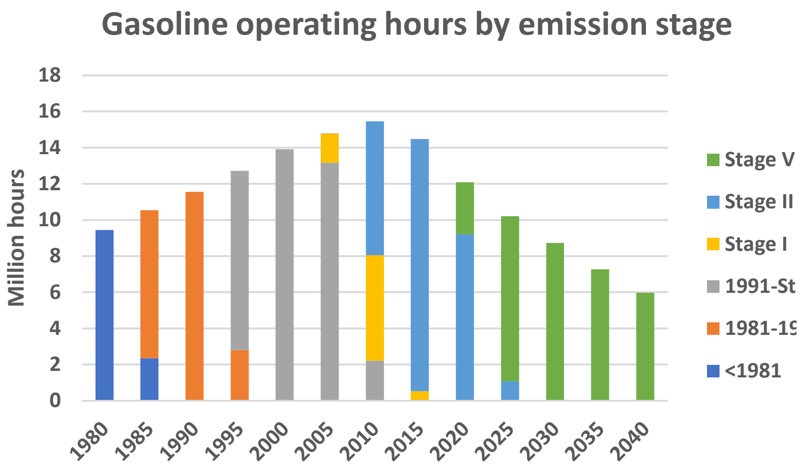


Figure 6.6.5 Operating hours by emission stage for gasoline fuelled residential non-road machinery 1980-2040.

7 Energy consumption and emissions by sub-sector

The results for energy consumption and emissions in 2021 and for the period 1980-2040 are presented in the following sub-chapters for each non-road sector.

For each non-road sector, the energy consumption and emission results are presented for 2021 for the different machine types split by fuel type and engine type. For the period 1980-2040 aggregated energy consumption and emissions are presented split by fuel type and engine type.

In Annex 5, fuel consumption and emission results are shown for all machinery types in 2021, sorted by sector, fuel type and engine type.

Annex 6 shows aggregated fuel consumption and emission results per non-road sector for 1980-2040. Annex 6 also shows fuel consumption results grouped into fuel type, non-road sector and engine type.

7.1 Agricultural machinery

The energy consumption and emission results for agricultural machinery in 2021 are shown in Table 7.1 per fuel type and engine type.

Table 7.1 Energy consumption and emission results for agricultural machinery in 2021 per fuel type and engine type.

Fuel type	Energy	SO_2	NO_x	PM	CO	VOC	CO_2	NMVOC	CH_4	N_2O	BC
	PJ	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes
Diesel	8.50	3.98	2277.9	191.8	2071	287	629.5	280.1	6.9	30.4	115.5
Gasoline (4-stroke)	0.15	0.06	16.1	4.6	2773	186	10.2	163.0	22.6	0.2	0.2
El	0.00	0.00	0.0	0.0	0	0	0.0	0.0	0.0	0.0	0.0
Total	8.6	4.0	2294.0	196.4	4844	473	639.7	443.1	29.5	30.6	115.7
					Emissions (% of total)						
Diesel	98	98	98	98	43	61	98	63	23	99	100
Gasoline (4-stroke)	2	2	2	2	57	39	2	37	77	1	0
El	0	0	0	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100	100	100
					Emission factors (g/GJ)						
Diesel		0.47	268	22.6	244	34	74.1	33.0	0.8	3.6	13.6
Gasoline (4-stroke)		0.43	108	30.6	18632	1247	68.5	1095.1	151.9	1.6	1.5

7.1.1 Energy consumption

Diesel is by far the most dominant fuel type for agricultural machinery. In 2021 the energy consumption shares for diesel and gasoline where 98 % and 2 % respectively (Table 7.1).

Agricultural tractors have the highest share of diesel energy consumption for agricultural machinery in 2021, followed by harvesters and machine pool tractors (Figure 7.1.1). For gasoline, professional ATV's, private ATV's and fodder trucks, in this consecutive order, have the highest energy consumption shares in 2021. The miniscule amount of electric energy in 2021 is used by agricultural and machine pool tractors.

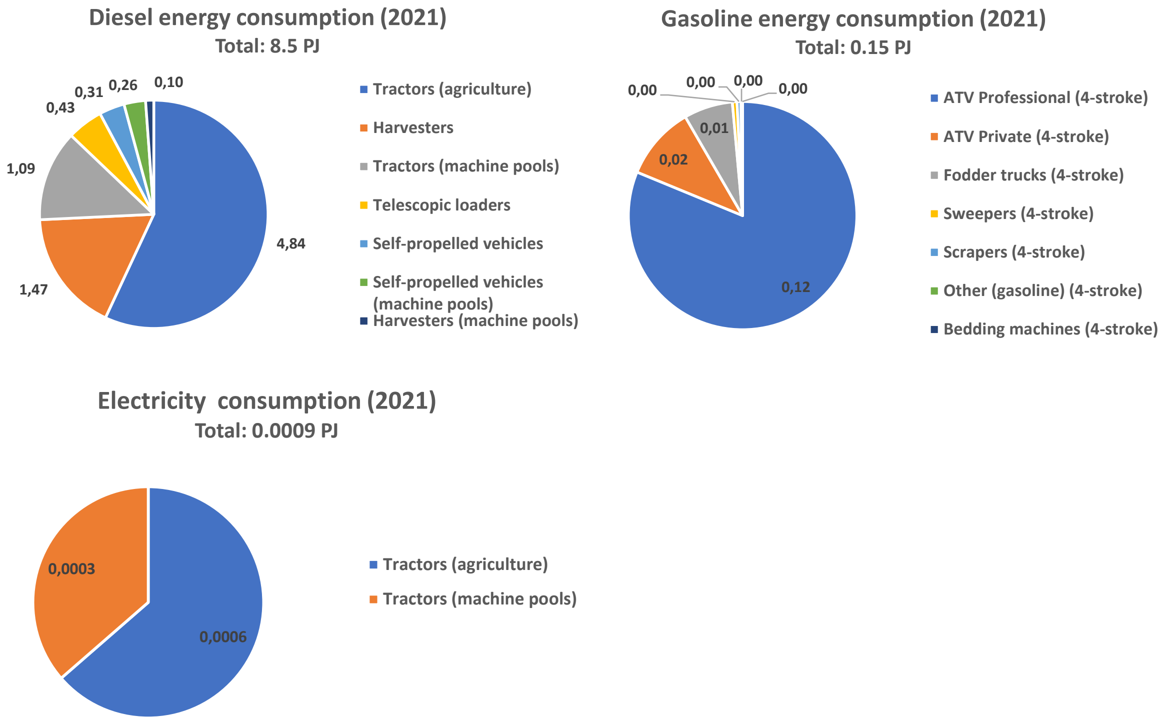


Figure 7.1.1 Energy consumption by fuel type and machine type for agricultural non-road machinery in 2021.

The total energy consumption has increased from 1980 until 2010, after which the energy consumption has fallen slightly to a lower level, where it is expected to remain until 2040.

The energy consumption development per fuel type and engine type in different engine size categories from 1980-2040 is determined by the development of the number of machines, annual operating hours, engine size and the specific energy consumption.

The energy consumption of diesel for the engine size categories 75-130 kW, 130-200 kW and 200-300 kW in particular, represents large shares of the total energy consumption in the period 1980-2040, and the larger the engine size category, the greater the energy consumption shares become compared with the share of total stock and operating hours for the engine size category (Figure 6.1.2 and 6.1.4) during the period.

For diesel engines in the engine size categories 37-56 kW and 56-75 kW, a significant decrease in energy consumption is noted in the historical years leading up to 2021. The development in energy consumption is due to structural changes in the agricultural sector towards a smaller number of tractors with larger engine sizes, as described in activity data (section 2.1) and as shown in Figure 6.1.2.

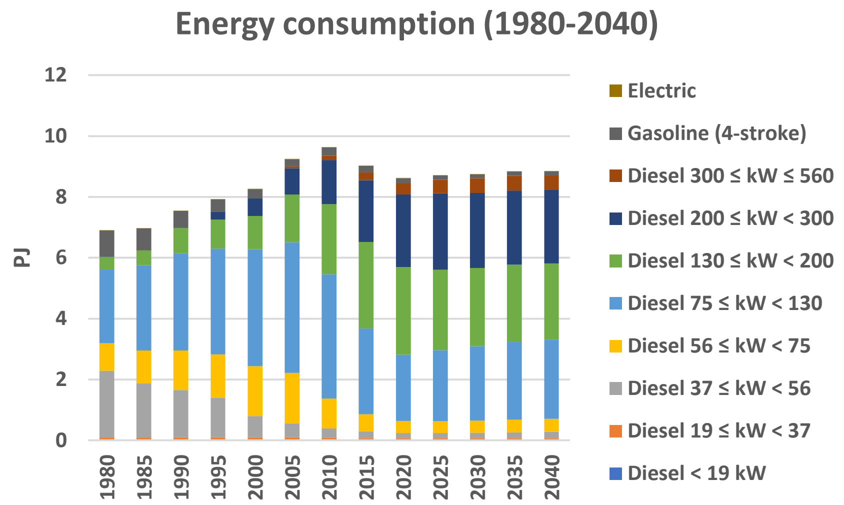


Figure 7.1.2 Energy consumption by engine type for agricultural non-road machinery 1980-2040.

7.1.2 Emissions

In 2021 the NO_x*[PM, CO, VOC]* emission shares for diesel engines and 4-stroke gasoline engines were 98 %*[98 %, 43 %, 61 %]* and 2 %*[2 %, 57 %, 39 %]*, respectively (Table 7.1).

For diesel engines, most of the emissions come from agricultural tractors in 2021, followed by harvesters and machine pool tractors (Figure 7.1.3). For gasoline 4-stroke engines, the highest emitters are professional ATV's, private ATV's and fodder trucks, in this consecutive order.

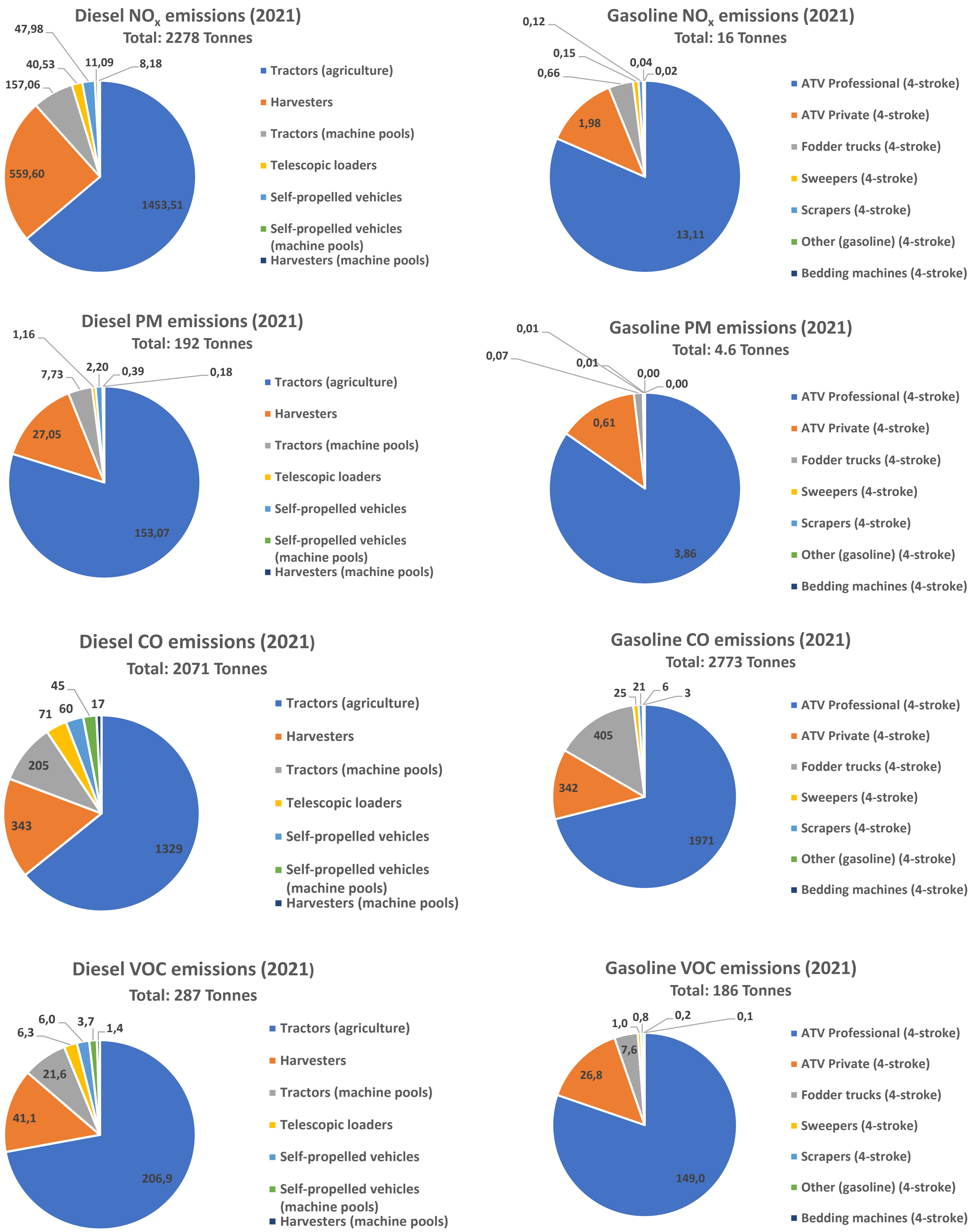


Figure 7.1.3 NO_x, PM, CO and VOC emissions by fuel type and machine type for agricultural non-road machinery in 2021.

In 2021 the NMVOC*[CH_4, N_2O, BC]* emission shares for diesel engines and 4-stroke gasoline engines were 63 %*[23 %, 99 %, 100 %]* and 37 %*[77 %, 1 %, 0 %]*, respectively (Table 7.1).

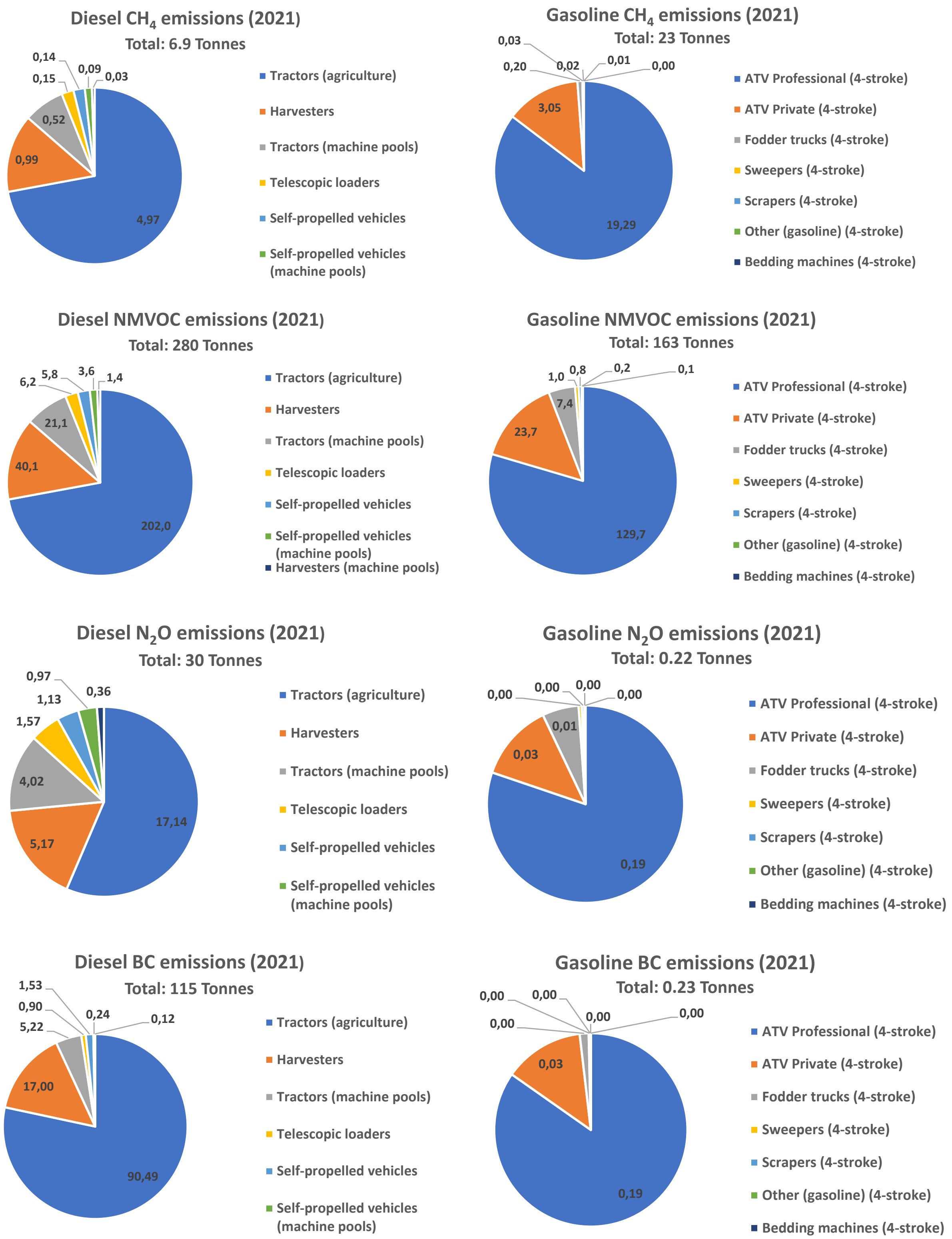


Figure 7.1.4 Emissions of CH_4, NMVOC, N_2O and BC by fuel type and machine type for agricultural non-road machinery in 2021.

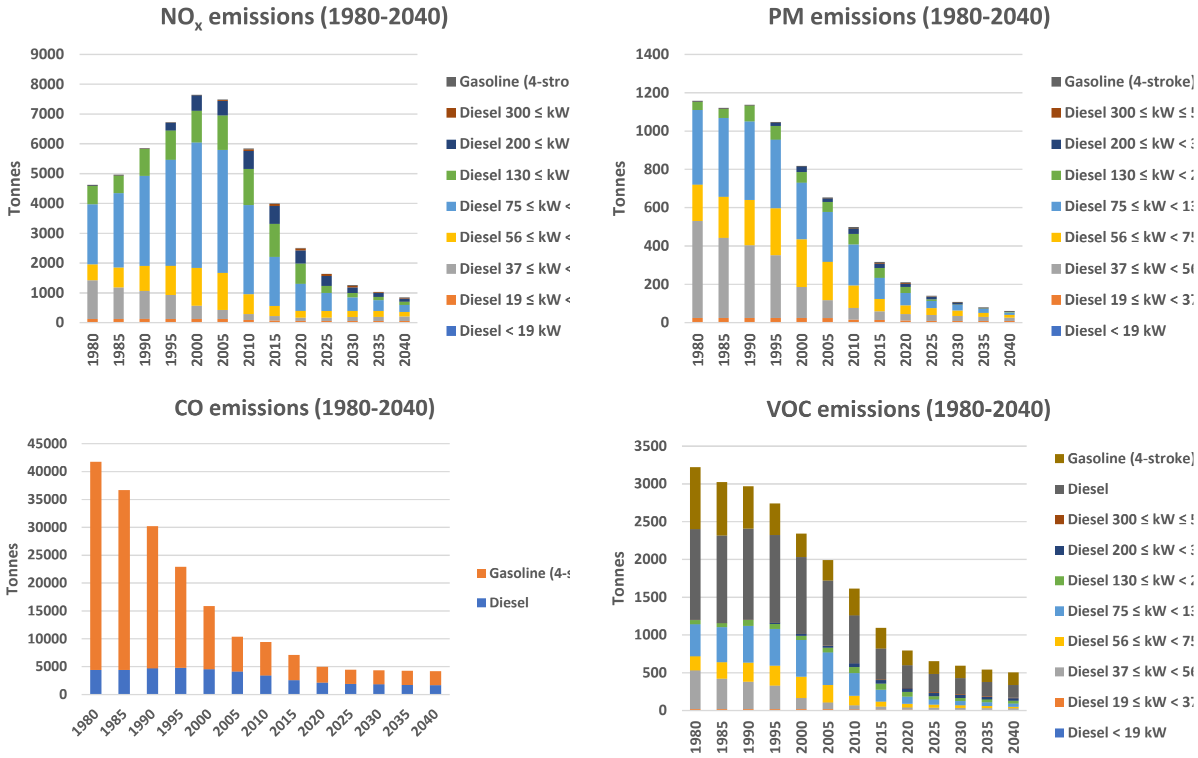


Figure 7.1.5 NO_x, PM, CO and VOC emissions by engine type for agricultural non-road machinery 1980-2040.

The development in the total NO_x and PM emissions for agricultural machinery is largely dominated by the emission development for diesel machinery.

For NO_x, the emissions have increased from 1980 until 2000 due to an increase in the diesel fuel consumption, after which emissions reduced sharply towards 2021. This latter emission decrease is mainly due to the gradual shift towards newer EU emission stage levels in new sales during the period, which is visible in the stock composition (Figure 6.1.2) and in the distribution of the operating hours (Figure 6.1.4). This in turn reduces the NO_x emission factors. For the same reasons, the NO_x emissions are expected to decline further towards 2040.

The PM emissions have fallen sharply from the early 1990s until 2021, and the emissions are also expected to decline further towards 2040. This emission development for PM can be explained by the distribution changes in the stock and operating hours towards newer engine technologies for diesel engines (Figures 6.1.2 and 6.1.4). Predominantly due to the continuous shift of the diesel engines towards Euro V standards, the emissions of PM for agricultural machinery are expected to decline further towards 2040.

For agricultural machinery, the CO emissions are dominated by the emission contributions from gasoline engines, whereas most of the VOC is emitted by diesel machinery. The CO and VOC emissions have decreased significantly from 1980 to 2021.

For VOC the emission decrease is mainly caused by the shift towards newer EU emission stage levels in the machinery stock and consequently higher shares of operating hours for these machines. This explanation goes for CO as well, and in addition the phasing out of gasoline fuelled vintage tractors until

2005 played a major role for CO in this period. The emissions of CO and VOC are expected to continue to decrease slightly in the future towards 2040.

7.2 Forestry machinery

The energy consumption and emission results for forestry machinery in 2021 are shown in Table 7.2 per fuel type and engine type.

Table 7.2 Energy consumption and emission results for agricultural machinery in 2021 per fuel type and engine type.

Engine type	Energy	SO_2	NO_x	PM	CO	VOC	CO_2	NMVOC	CH_4	N_2O	BC
	PJ	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes
Diesel	0.54	0.25	29.2	1.4	94	8.1	39.9	7.9	0.2	2.0	0.9
Gasoline (2-stroke)	0.05	0.02	2.9	4.4	949	211.7	3.6	198.9	12.8	0.0	0.2
El	0.00	0.00	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.59	0.28	32.2	5.7	1043	219.8	43.6	206.9	13.0	2.0	1.2
					Emissions (% of total)						
Diesel	91	92	91	24	9	4	92	4	2	99	81
Gasoline (2-stroke)	9	8	9	76	91	96	8	96	98	1	19
El	0	0	0	0	0	0	0	0	0	0	0
Total	91	92	91	24	9	4	92	4	2	99	81
					Emission factors (g/GJ)						
Diesel		0.47	54	2.5	175	15	74.1	14.7	0.4	3.7	1.8
Gasoline (2-stroke)		0.43	55	82.2	17916	3996	68.5	3754.8	240.8	0.5	4.1

7.2.1 Energy consumption

Diesel engines account for most of the energy consumption by forestry machinery. In 2021 the energy consumption shares for diesel engines and 2-stroke gasoline engines (chain saws) were 91 % and 9 % respectively (Table 7.2).

A number of different diesel engine types, e.g. forwarders, harvesters and different types of chippers and tractors, have relatively large consumption shares of the total diesel consumption in forestry (Figure 7.2.1).

A miniscule amount of electric energy in 2021 is used by chain saws.

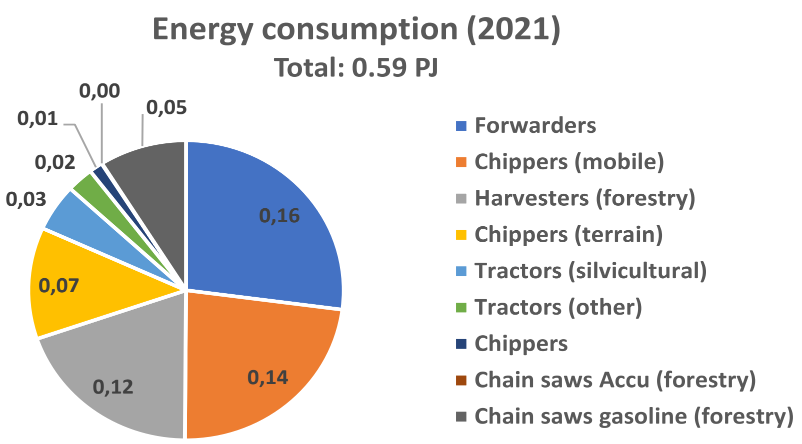


Figure 7.2.1 Energy consumption by fuel type and machine type for forestry non-road machinery in 2021.

From 1990 until 2005, the energy consumption in forestry has decreased significantly due to a large decrease in the number of gasoline-powered chainsaws (Figure 6.2.2) and hence reductions in total operating hours (Figure 6.2.4), during this period. After 2005, the energy consumption has increased significantly until 2021, due to a large increase in the stock and total operating hours for diesel engines larger than 130 kW (Figure 6.2.2 and 6.2.4), within this time period. A small growth in the energy consumption is expected in the future in the first years up to 2040.

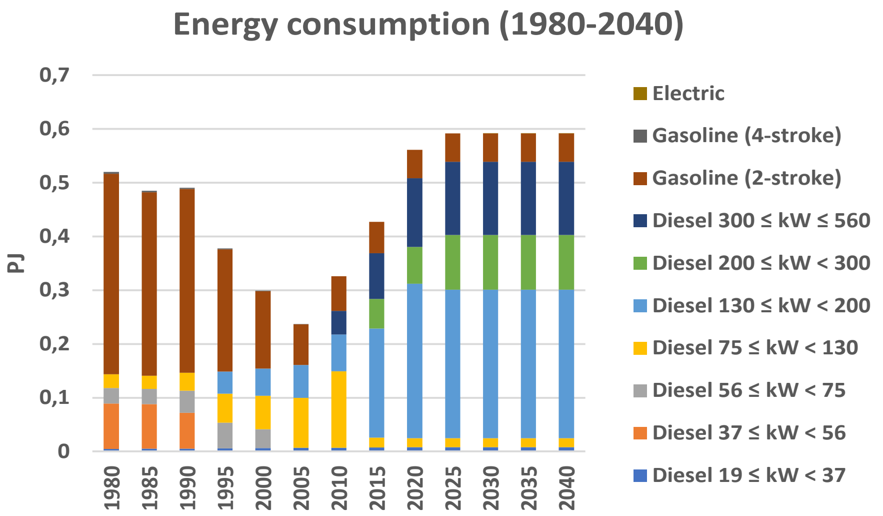


Figure 7.2.2 Energy consumption by engine type for forestry non-road machinery 1980-2040.

7.2.2 Emissions

In 2021, the NO_x*[PM, CO, VOC]* emission shares for diesel engines and 2-stroke gasoline engines were 91 %*[24 %, 9 %, 4 %]* and 9 %*[76 %, 91 %, 96 %]*, respectively (Table 7.2).

The major diesel engine emission sources for NO_x and PM in 2021 is forwarders, harvesters and different types of chippers. In overall, gasoline chain saws are, however, the largest emission source for PM, CO and VOC in forestry (Figure 7.2.3).

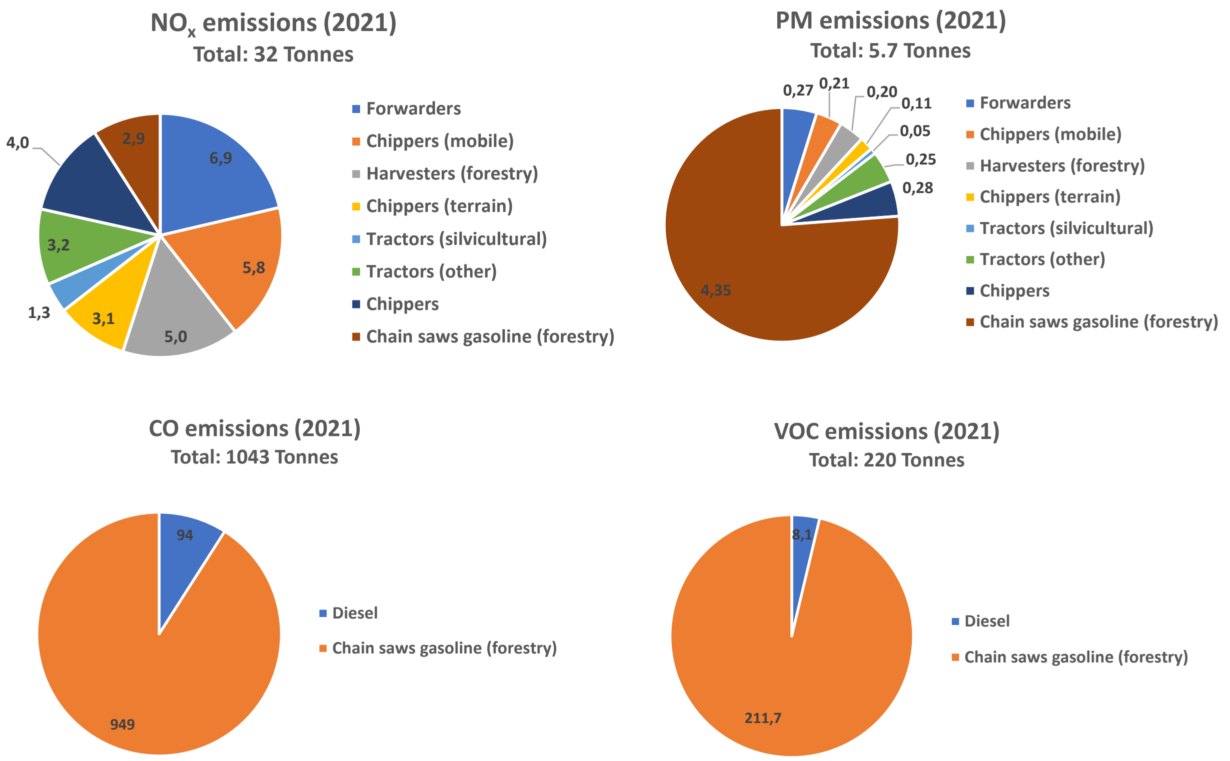


Figure 7.2.3 NO_x, PM, CO and VOC emissions by fuel type and machine type for forestry non-road machinery in 2021.

In 2021 the NMVOC*[CH_4, N_2O, BC]* emission shares for diesel engines and 4-stroke gasoline engines were 4 %*[2 %, 99 %, 81 %]* and 96 %*[98 %, 1 %, 19 %]*, respectively (Table 7.2).

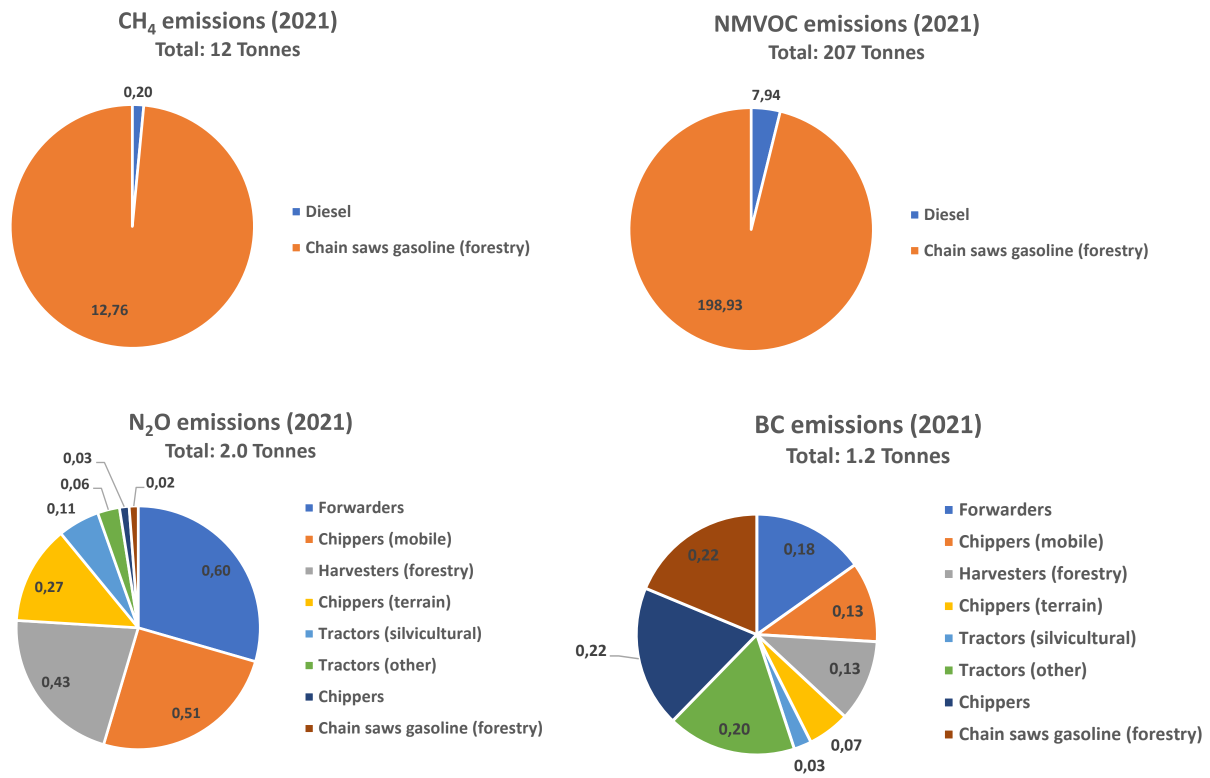


Figure 7.2.4 Emissions of CH_4, NMVOC, N_2O and BC by fuel type and machine type for forestry non-road machinery in 2021.

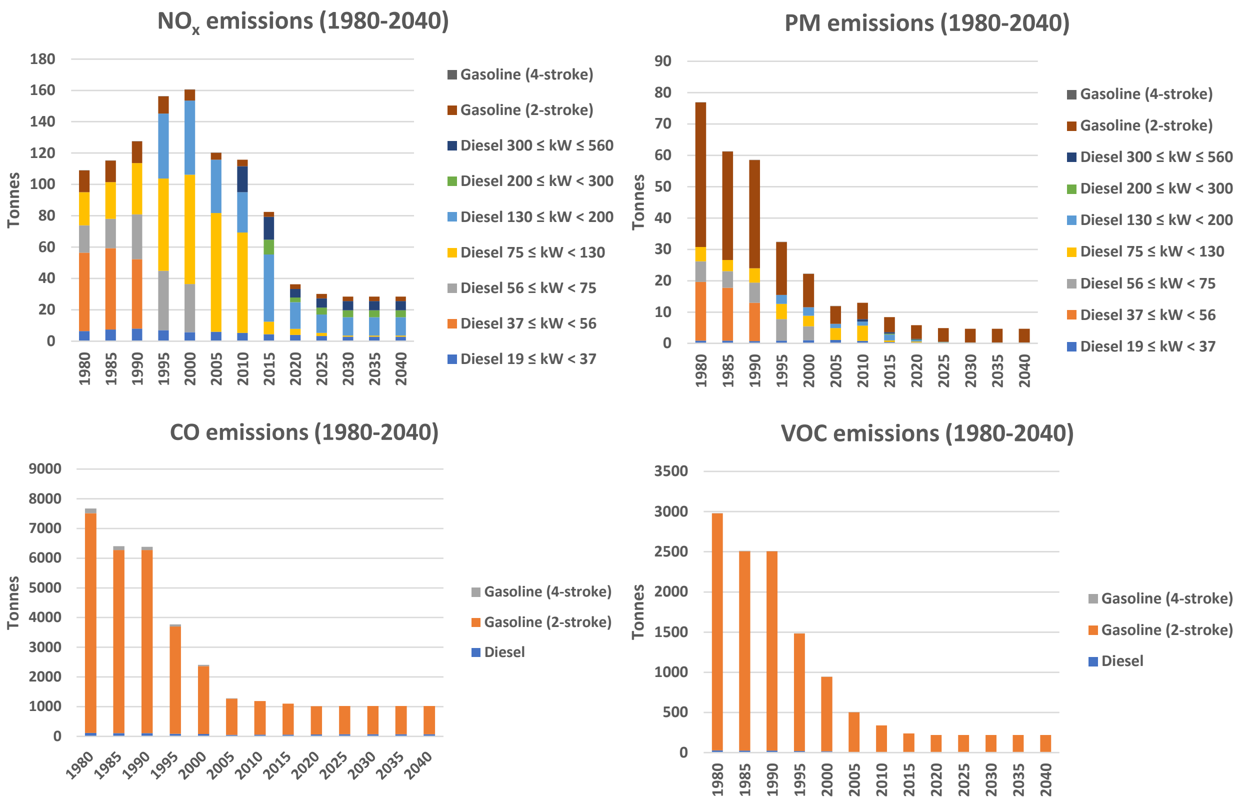


Figure 7.2.5 NO_x, PM, CO and VOC emissions by engine type for forestry non-road machinery 1980-2040.

For NO_x, the emissions for forestry machinery have increased from 1980 until 2000. Hereafter, major emission reductions have been achieved until 2021. This is mainly due to the gradual shift towards newer EU emission stage levels in new sales during the period, which is visible in the stock composition (Figure 6.2.2) and in the distribution of the operating hours (Figure 6.2.4), which in turn reduces the NO_x emission factors. For the same reasons, the emissions of NO_x are expected to decline further towards 2040.

For PM, the emission development up to 2021 can be explained by the distribution changes in the stock and operating hours towards newer engine technologies for diesel engines, and total stock and operating hour reductions in conjunction with the implementation of newer and cleaner EU emission standards for gasoline 2-stroke engines (Figures 6.2.2 and 6.2.4). Mainly due to the continuous shift of the diesel engines towards Euro V standards, the emissions of PM for forestry machinery are expected to decline further towards 2040.

The forestry emissions of CO and VOC have decreased significantly from 1990 to 2021 due to the significant decline in stock and total operating hours for gasoline 2-stroke engine chain saws and the general implementation of newer EU CO and VOC emission standards for gasoline 2-stroke engines in this time period. The total CO and VOC emissions are expected to be relatively constant from 2021 until 2040.

7.3 Building and construction machinery

The energy consumption and emission results for building and construction machinery in 2021 are shown in Table 7.3 per fuel type and engine type.

Table 7.3 Energy consumption and emission results for building and construction machinery in 2021 per fuel type and engine type.

Engine type	Energy	SO_2	NO_x	PM	CO	VOC	CO_2	NMVOC	CH_4	N_2O	BC
	PJ	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes
Diesel	7.33	3.43	1603.4	95.2	1513	210	543.2	204.5	5.0	25.7	71.8
Gasoline (2-stroke)	0.02	0.01	0.2	5.0	385	99	1.1	92.7	5.8	0.0	0.2
Gasoline (4-stroke)	0.31	0.13	41.3	2.3	8206	290	21.0	281.6	8.1	0.4	0.1
Gasoline total	0.32	0.14	41.5	7.3	8592	388	22.1	374.3	13.9	0.4	0.4
El	0.01	0.00	0.0	0.0	0	0	0.0	0.0	0.0	0.0	0.0
Total	7.66	3.57	1645.0	102.5	10104	598	565.3	578.8	18.9	26.1	72.2
					Emissions (% of total)						
Diesel	95.7	96	97	93	15	35	96	35	27	98	99
Gasoline (2-stroke)	0.2	0	0	5	4	16	0	16	31	0	0
Gasoline (4-stroke)	4.0	4	3	2	81	48	4	49	43	1	0
Gasoline total	4.2	4	3	7	85	65	4	65	73	2	1
El	0	0	0	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100	100	100
					Emission factors (g/GJ)						
Diesel		0.47	219	13	206	29	74.1	27.9	0.7	3.5	9.8
Gasoline (2-stroke)		0.43	13	298	23023	5891	68.5	5543.7	346.8	0.4	14.9
Gasoline (4-stroke)		0.43	135	8	26781	945	68.5	919.0	26.3	1.3	0.4
Gasoline total		0.43	129	23	26586	1201	68.5	1158.4	42.9	1.2	1.1

7.3.1 Energy consumption

Diesel is by far the most dominant fuel type for building and construction machinery. In 2021 the energy consumption shares for diesel, gasoline 2-stroke and gasoline 4-stroke engines where 96 % and 0.2 % and 4 % respectively in rounded figures (Table 7.3).

Numerous types of diesel machinery are used in the building and construction sector, of which excavators and wheel loaders (5,1 tonnes) and compressors are the top consumers of diesel in 2021. For gasoline machinery 4-stroke engines use, the major part of the fuel, and pumps are the top consumer, followed by vibratory plates and generators. In 2021 the electricity in building and construction is predominantly used by forklifts.

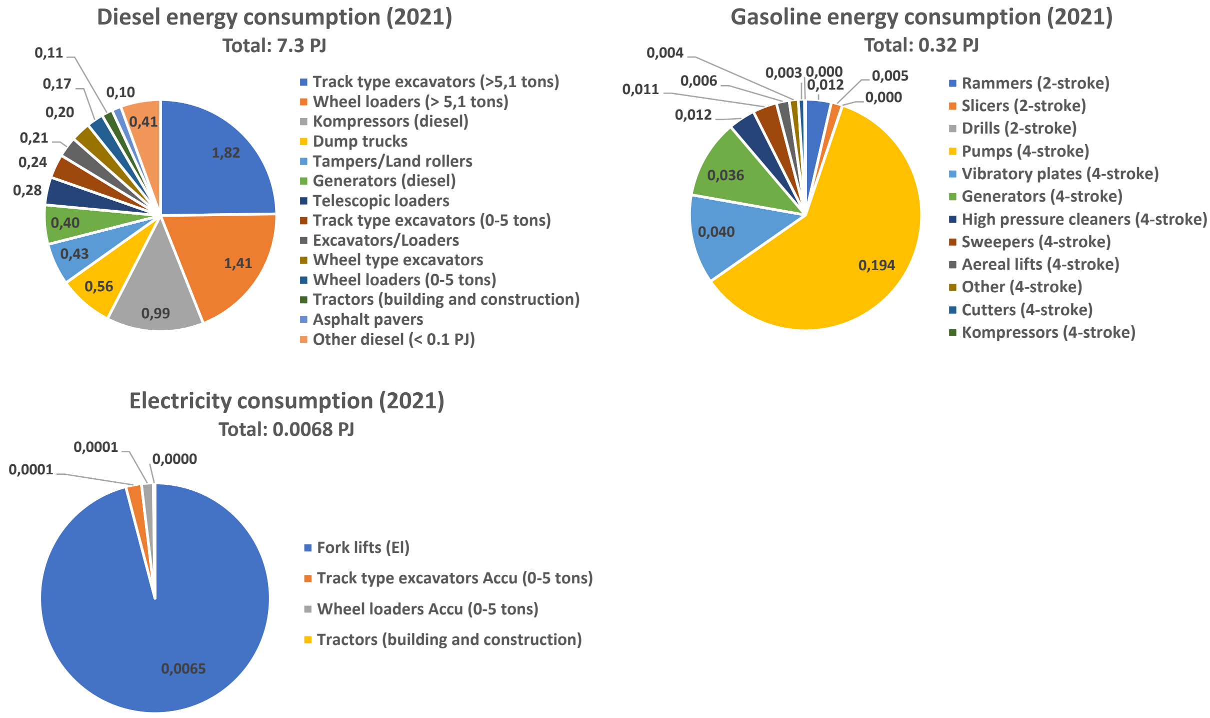


Figure 7.3.1 Energy consumption by fuel type and machine type for building and construction non-road machinery in 2021.

The total energy consumption has increased from 1980 until 2010, after which the energy consumption has fallen slightly to a lower level in 2020. A small growth in the energy consumption is expected in the future in the first years up to 2040.

The energy consumption development per fuel type and engine type in different engine size categories from 1980-2040 is determined by the development of the number of machines, annual operating hours, engine size and the specific energy consumption.

For diesel engines between 200-300 kW considerable energy consumption increases are noted in the historical years leading up to 2021, and fuel consumption increases are further expected up to 2040, due to a growth in stock numbers (Figure 6.3.2) and total operating hours (Figure 6.3.4).

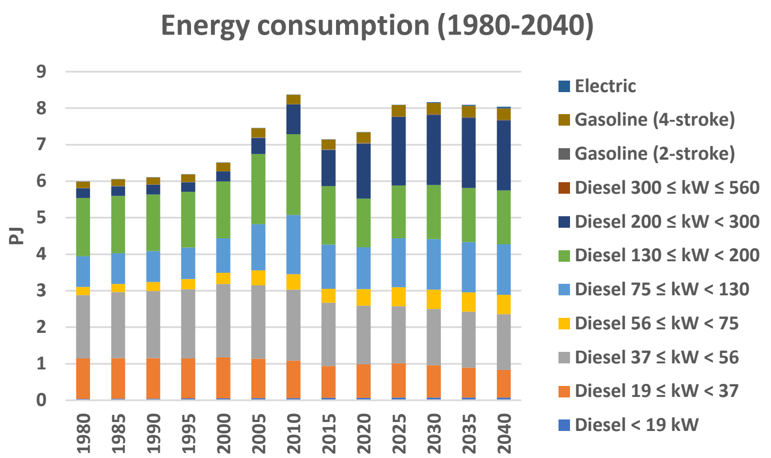


Figure 7.3.2 Energy consumption by engine type for building and construction non-road machinery 1980-2040.

7.3.2 Emissions

In 2021 the NO_x*[PM, CO, VOC]* emission shares for diesel engines and 2-stroke gasoline engines were 97 %*[93 %, 15 %, 35 %]* and 3 %*[7 %, 85 %, 65 %]*, respectively (Table 7.3).

In the case of diesel, numerous different machinery types contribute with fair emission shares to the emission total in 2021.

For gasoline in 2021, pumps are by far the largest emission source for NOx, CO and VOC, and 2-stroke rammers, slicers and drills are the largest emission sources for PM due to high PM emission factors for 2-stroke engines in general.

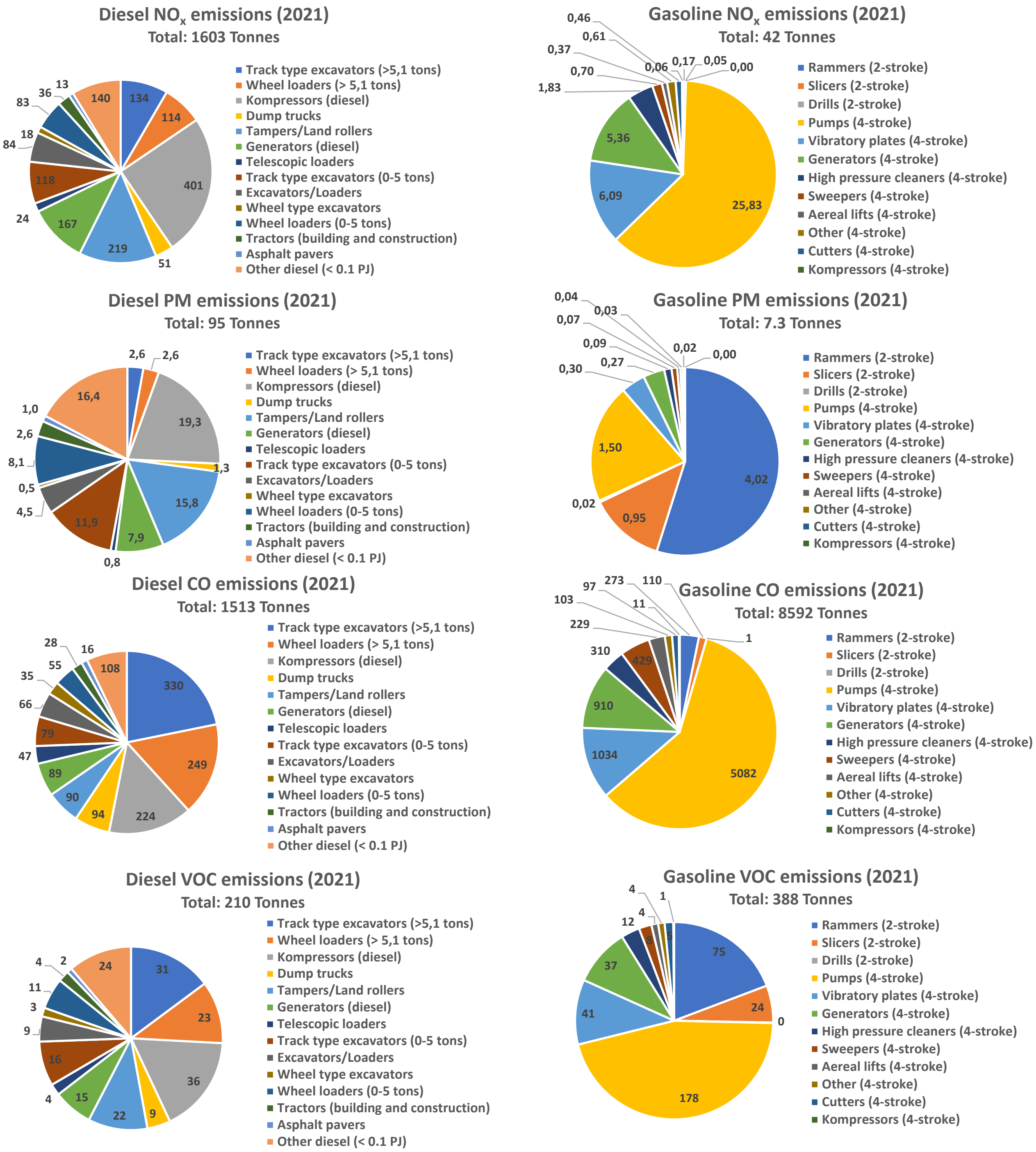


Figure 7.3.3 NO_x, PM, CO and VOC emissions by fuel type and machine type for building and construction non-road machinery in 2021.

In 2021 the NMVOC*[CH$_4$, N$_2$O, BC]* emission shares for diesel engines and 4-stroke gasoline engines were 35 %*[27 %, 98 %, 99 %]* and 65 %*[73 %, 2 %, 1 %]*, respectively (Table 7.3).

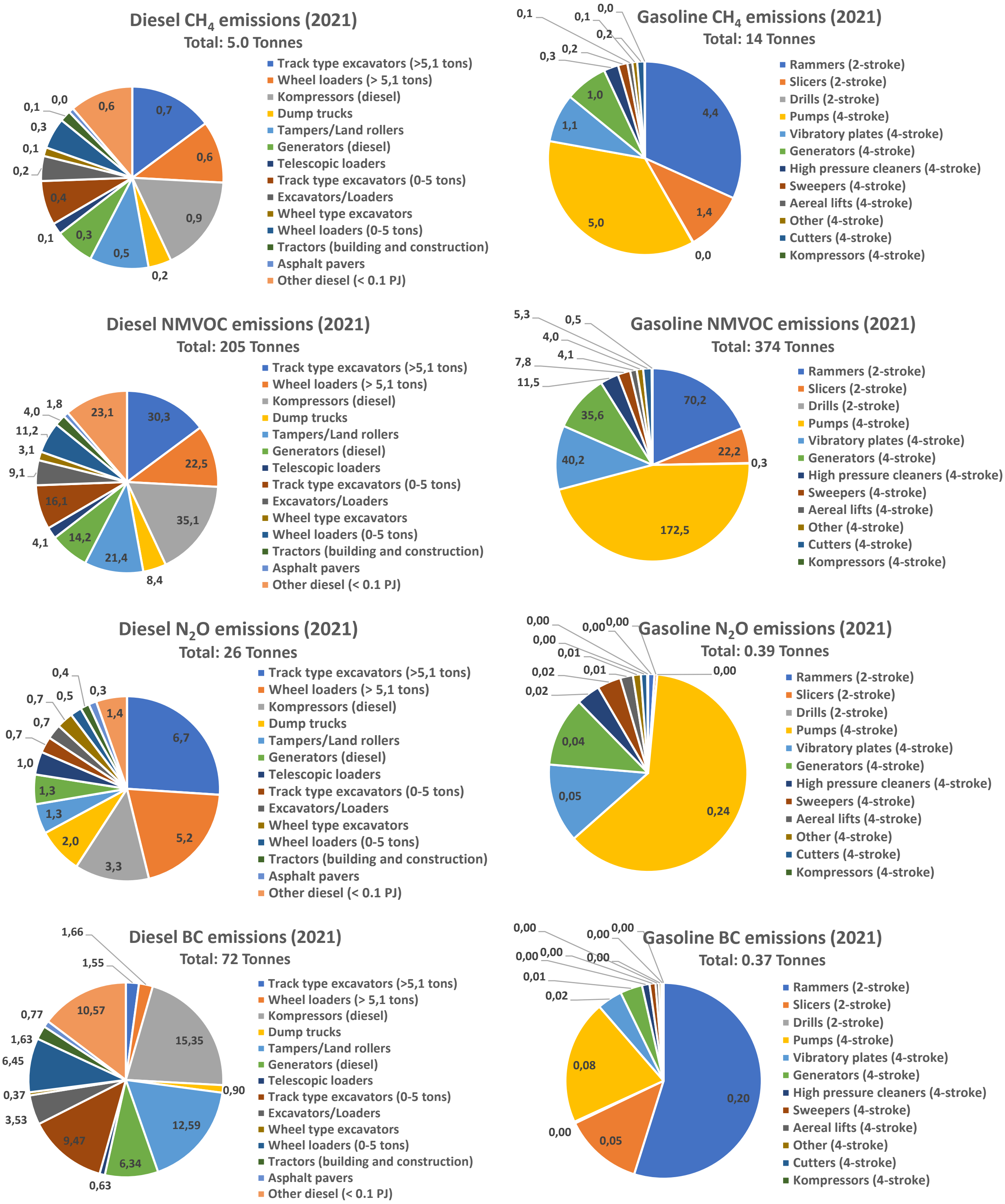


Figure 7.3.4 CH$_4$, NMVOC, N$_2$O and BC emissions by fuel type and machine type for building and construction non-road machinery in 2021.

The emissions from diesel machinery dominates the development of the total NO$_x$ and PM emissions for building and construction machinery.

For NO$_x$, the emissions have been quite stable from 1980 until 2000, after which emissions reduced sharply towards 2021. This is mainly due to the gradual shift towards newer EU emission stage levels in new sales during the period, which is visible in the stock composition (Figure 6.3.2) and in the distribution of the operating hours (Figure 6.3.4). This in turn reduces the NO_x emission factors. For the same reasons, the NO_x emissions are expected to decline further towards 2040.

The PM emissions have fallen sharply from the early 1990s until 2021, and the emissions are also expected to decline further towards 2040. This emission development for PM can be explained by the distribution changes in the stock and operating hours towards newer engine technologies for diesel engines (Figures 6.3.2 and 6.3.4). Predominantly due to the continuous shift of the diesel engines towards Euro V standards, the emissions of PM for building and construction machinery are expected to decline further towards 2040.

For building and construction machinery in the 1980-2040 period, the CO emissions are dominated by the emission contributions from 4-stroke gasoline engines, and for VOC the emission contributions from 4-stroke gasoline engines are also quite high. In both cases the emission factors are very high for engines at all EU emission stage levels.

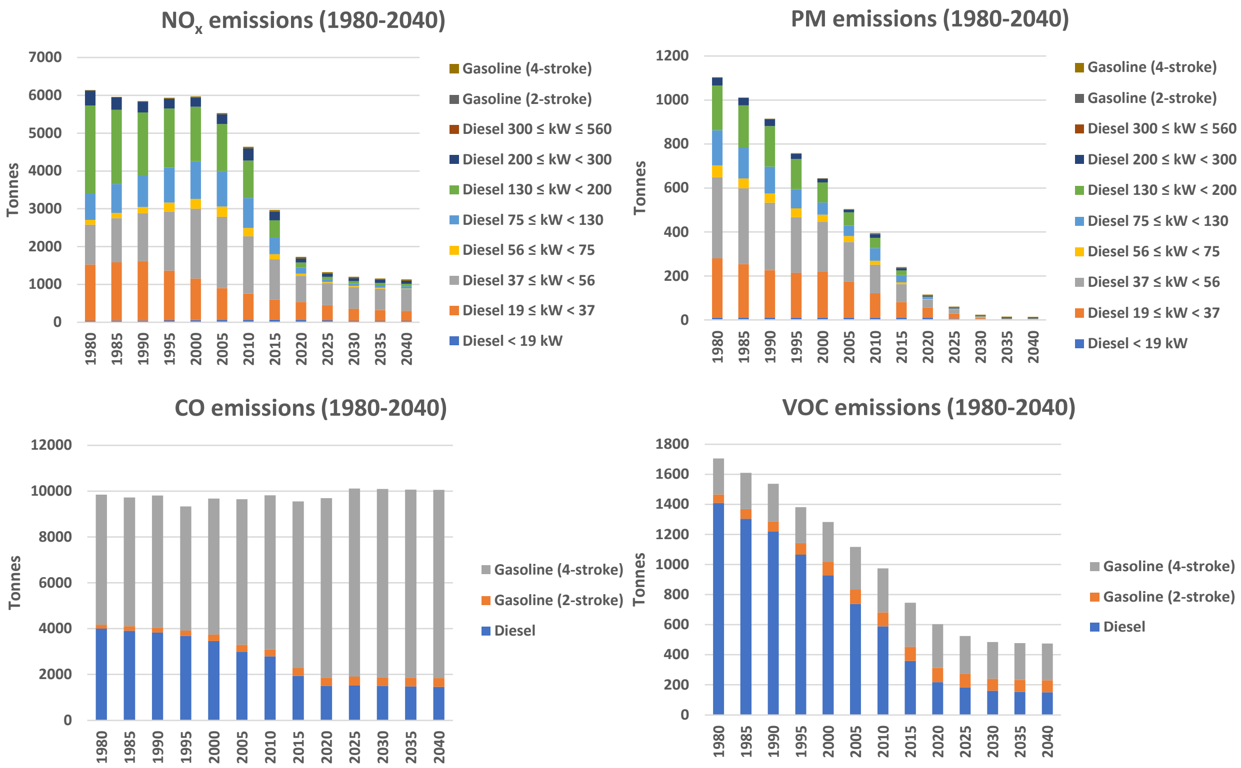


Figure 7.3.5 NO_x, PM, CO and VOC emissions by engine type for building and construction non-road machinery 1980-2040.

7.4 Industrial machinery

The energy consumption and emission results for industrial machinery in 2021 are shown in Table 7.4 per fuel type and engine type.

Table 7.4 Energy consumption and emission results for industrial machinery in 2021 per fuel type and engine type.

Engine type	Energy	SO_2	NO_x	PM	CO	VOC	CO_2	NMVOC	CH_4	N_2O	BC
	PJ	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes
Diesel	0.66	0.31	298.9	37.6	203	50.8	48.7	49.5	1.2	2.2	22.7
LPG	0.27	0.00	38.4	0.2	4	9.6	17.3	9.1	0.5	1.0	0.0
El	0.17	0.00	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	1.10	0.31	337.3	37.8	207	60.4	66.0	58.7	1.7	3.1	22.7
						Emissions (% of total)					
Diesel	60	100	89	99	98	84	74	84	72	69	100
LPG	25	0	11	1	2	16	26	16	28	31	0
El	15	0	0	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100	100	100
						Emission factors (g/GJ)					
Diesel		0.47	455	57.2	309	77	74.1	75.4	1.9	3.3	34.6
LPG		0.00	140	0.7	14	35	63.1	33.2	1.7	3.5	0.0

7.4.1 Energy consumption

In 2021 the energy consumption shares for diesel engines, LPG (forklifts) and electric engines (forklifts and very few tractors) where 60 %, 25 % and 15 %, respectively (Table 7.4).

A handful of different diesel engine types, namely forklifts, refrigerating units, telescopic loaders and tractors make up the total diesel consumption in the industrial sector (Figure 7.4.1).

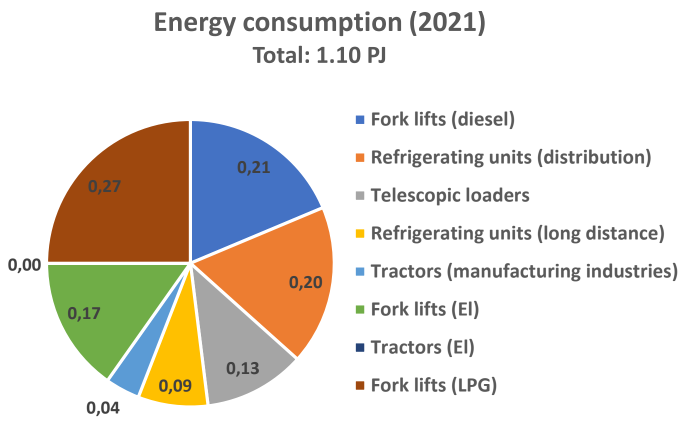


Figure 7.4.1 Energy consumption by machine type for industrial non-road machinery in 2021.

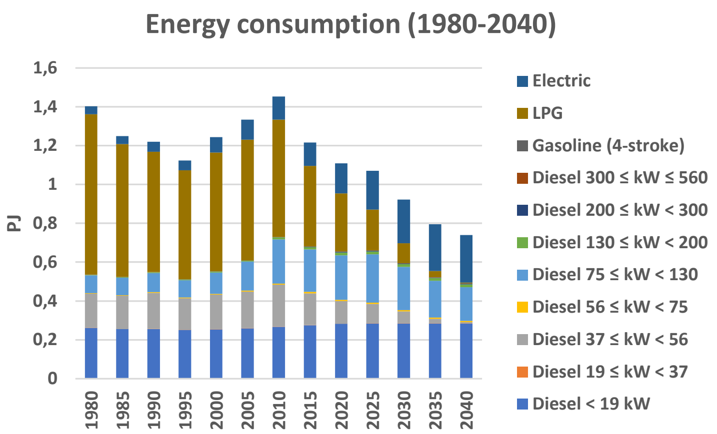


Figure 7.4.2 Energy consumption by engine type for industrial non-road machinery 1980-2040.

From 1980 until 1995, the energy consumption for industrial machinery decreased due to a decrease in the number of LPG forklifts (Figure 6.4.2) and hence reductions in total operating hours (Figure 6.4.4), during this period. After 1995, the energy consumption has increased until 2010, mainly due to an increase in the stock and total operating hours for diesel engines between 75-130 kW (Figure 6.4.2 and 6.4.4), within this time period. A decline in the energy consumption is expected in the future towards 2040, mainly due to transition in new sales for forklifts, for which new sold machines is expected to be purely electric from 2030 onwards.

7.4.2 Emissions

In 2021, the NO_x*[PM, CO, VOC]* emission shares for diesel and LPG engines were 89 %*[99 %, 98 %, 74 %]* and 11 %*[1 %, 2 %, 26 %]*, respectively (Table 7.4).

Refrigeration units in distribution and long-distance transport and forklifts are the largest diesel engine emission sources for NO_x, PM, CO and VOC in 2021. The NO_x and VOC emissions from LPG forklifts are also quite big in 2021.

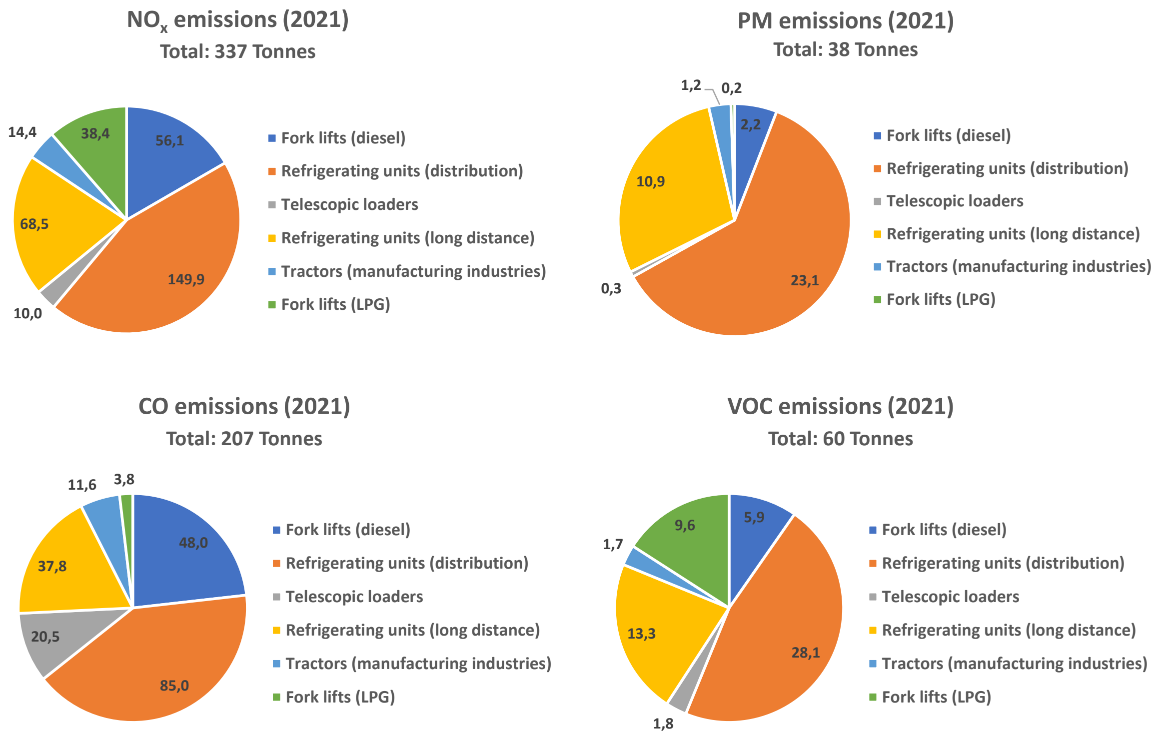


Figure 7.4.3 NO_x, PM, CO and VOC emissions by fuel type and machine type for industrial non-road machinery in 2021.

In 2021 the NMVOC*[CH_4, N_2O, BC]* emission shares for diesel engines and LPG engines were 84 %*[72 %, 69 %, 100 %]* and 16 %*[28 %, 31 %, 0 %]*, respectively (Table 7.4).

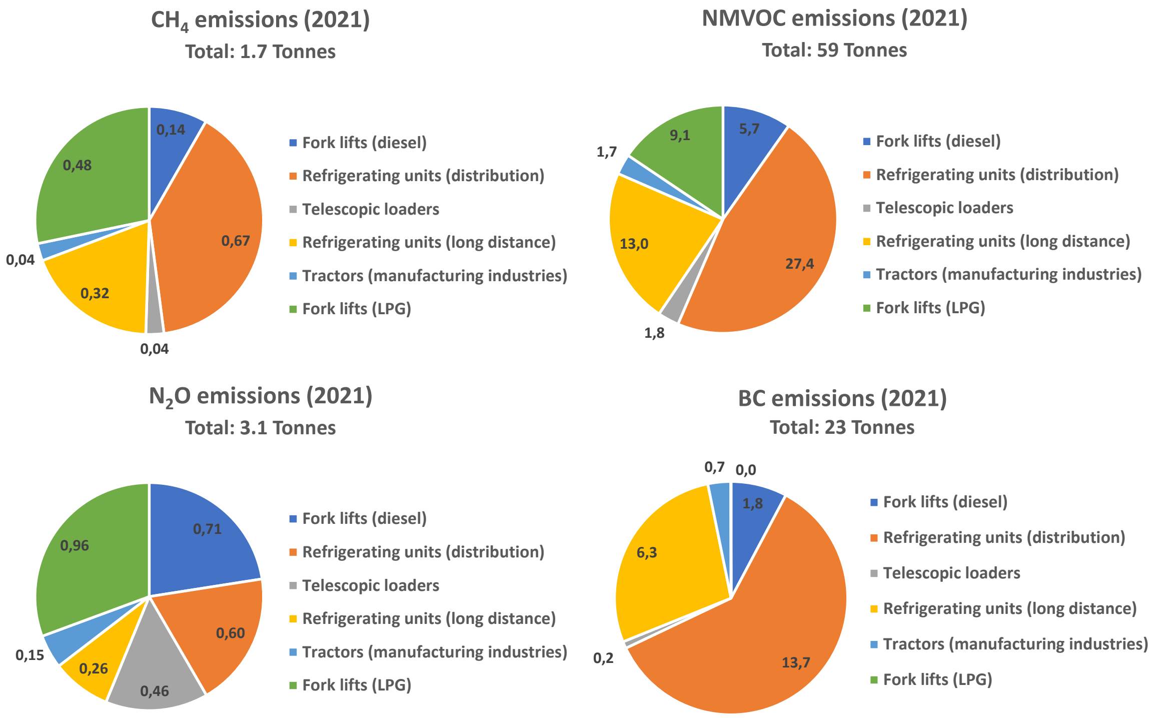


Figure 7.4.4 CH_4, NMVOC, N_2O and BC emissions by fuel type and machine type for industrial non-road machinery in 2021.

The NO_x emissions for industrial non-road machinery decrease during the entire period from 1980-2040. For diesel engines the NO_x emissions remain at a high level until 2000. This is mainly because refrigerating units are equipped with small diesel engines < 19 kW, that do not have to meet comply with EU emission standards until Stage V enter into force.

The emissions from LPG forklifts significantly reduce from 1980-2020 mainly due to emission factor improvements, and further emission reductions until 2040 are envisaged, due to the transition in new sales to 100 % electric for forklifts from 2030.

The PM emissions for industrial non-road machinery almost solely comes from diesel engines, and the emissions significantly reduces until 2025 due to the modernization of the stock complying with newer EU emission stage levels during the period, which in turn reduces the PM emission factors. The changes in the stock composition and in the distribution of the operating hours are visible from Figure 6.4.2 and 6.4.4.

The future PM emissions almost solely comes from diesel engines < 19 kW, for which stage V emission limits are more relaxed and PM emission limits can be met without the use of particle filters.

For CO, VOC and to a large extent for NO_x, the emissions from LPG engines more or less drop to zero in the time period from 1980 to 2021. For gasoline 4-stroke engines, emissions no longer occur from 2005, by the time when the last gasoline fuelled tractors exit the machinery stock.

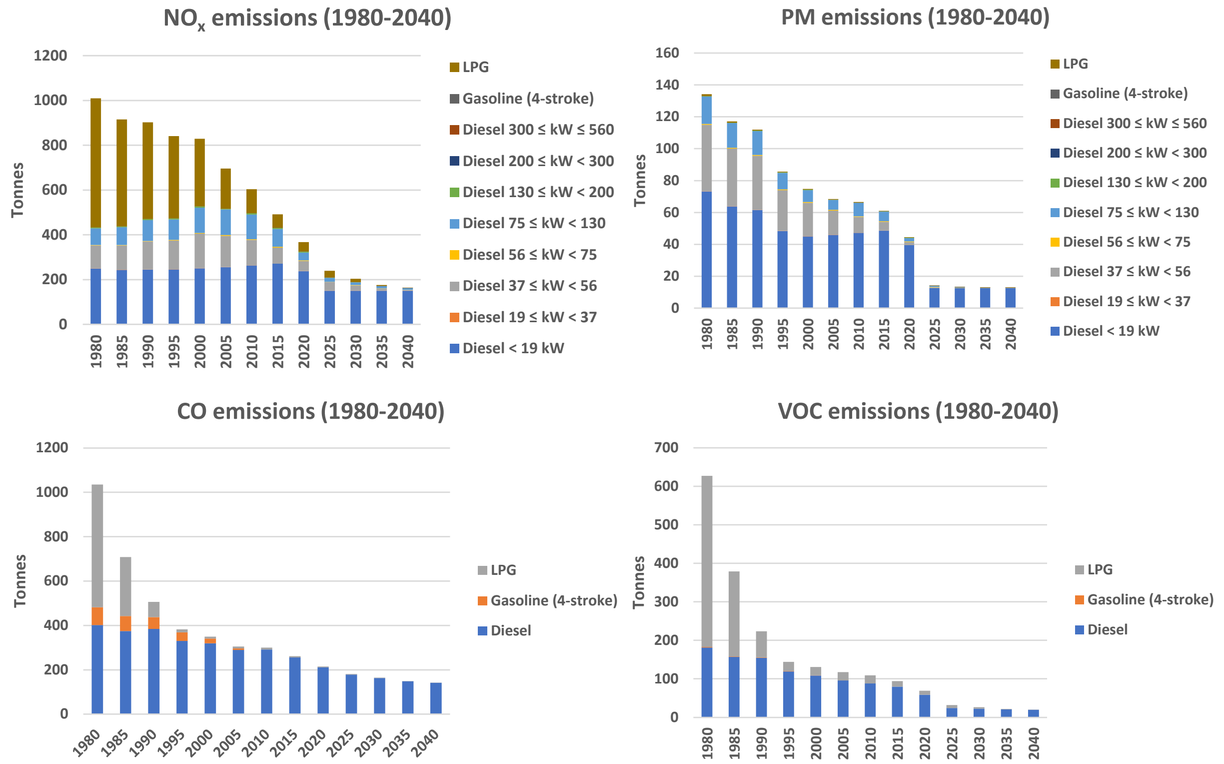


Figure 7.4.5 NO$_x$, PM, CO and VOC emissions by engine type for industrial non-road machinery 1980-2040.

7.5 Commercial and institutional machinery

The energy consumption and emission results for commercial and institutional non-road machinery in 2021 are shown in Table 7.5 per fuel type and engine type.

Table 7.5 Energy consumption and emission results for commercial and institutional non-road machinery in 2021 per fuel type and engine type.

Engine type	Energy	SO_2	NO_x	PM	CO	VOC	CO_2	NMVOC	CH_4	N_2O	BC
	PJ	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes
Diesel	1.49	0.70	402.0	26.1	354	48	110.4	46.9	1.2	5.2	18.2
Gasoline (2-stroke)	0.08	0.03	4.6	8.3	1397	288	5.4	271.7	16.5	0.0	0.4
Gasoline (4-stroke)	0.71	0.31	49.5	4.4	25282	420	48.8	408.1	12.0	1.0	0.2
Gasoline total	0.79	0.34	54.1	12.6	26680	708	54.2	679.8	28.5	1.0	0.6
LPG	0.15	0.00	20.3	0.1	2	5	9.2	4.8	0.3	0.5	0.0
El	0.14	0.00	0.0	0.0	0	0	0.0	0.0	0.0	0.0	0.0
Total	2.56	1.04	476.5	38.8	27036	761	173.8	731.6	29.9	6.7	18.8
					Emissions (% of total)						
Diesel	58	67	84	67	1	6	64	6	4	77	97
Gasoline (2-stroke)	3	3	1	21	5	38	3	37	55	1	2
Gasoline (4-stroke)	28	29	10	11	94	55	28	56	40	15	1
Gasoline total	31	33	11	33	99	93	31	93	95	15	3
LPG	6	0	4	0	0	1	5	1	1	8	0
El	5	0	0	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100	100	100
					Emission factors (g/GJ)						
Diesel		0.47	269.8	17.5	238	32	74.1	31.5	0.8	3.5	12.2
Gasoline (2-stroke)		0.43	58.7	104.3	17639	3638	68.5	3430.1	208.3	0.5	5.2
Gasoline (4-stroke)		0.43	69.5	6.1	35501	590	68.5	573.0	16.9	1.4	0.3
Gasoline total		0.43	68.4	16.0	33713	895	68.5	859.0	36.0	1.3	0.8
LPG		0.00	139.9	0.7	14	35	63.1	33.2	1.7	3.5	0.0

7.5.1 Energy consumption

For the commercial and institutional non-road machinery in 2021 the energy consumption shares for diesel, gasoline 2-stroke, gasoline 4-stroke, LPG (forklifts) and electrical engines where 58 %, 3 %, 28 %, 6 % and 5%, respectively (Table 7.5).

Only a few types of diesel machinery are used in the commercial and institutional sector. Tractors and forklifts are the largest consumers of diesel in 2021.

For gasoline machinery, 4-stroke engines, in particular riders, use a major part of the gasoline fuel. A comprehensive list of 2-stroke and 4-stroke engines contribute with small consumptions of gasoline in 2021.

In 2021 the electricity is predominantly used by forklifts in the commercial and institutional sector. The remaining part of the electricity is consumed by a large group of different equipment types in 2021.

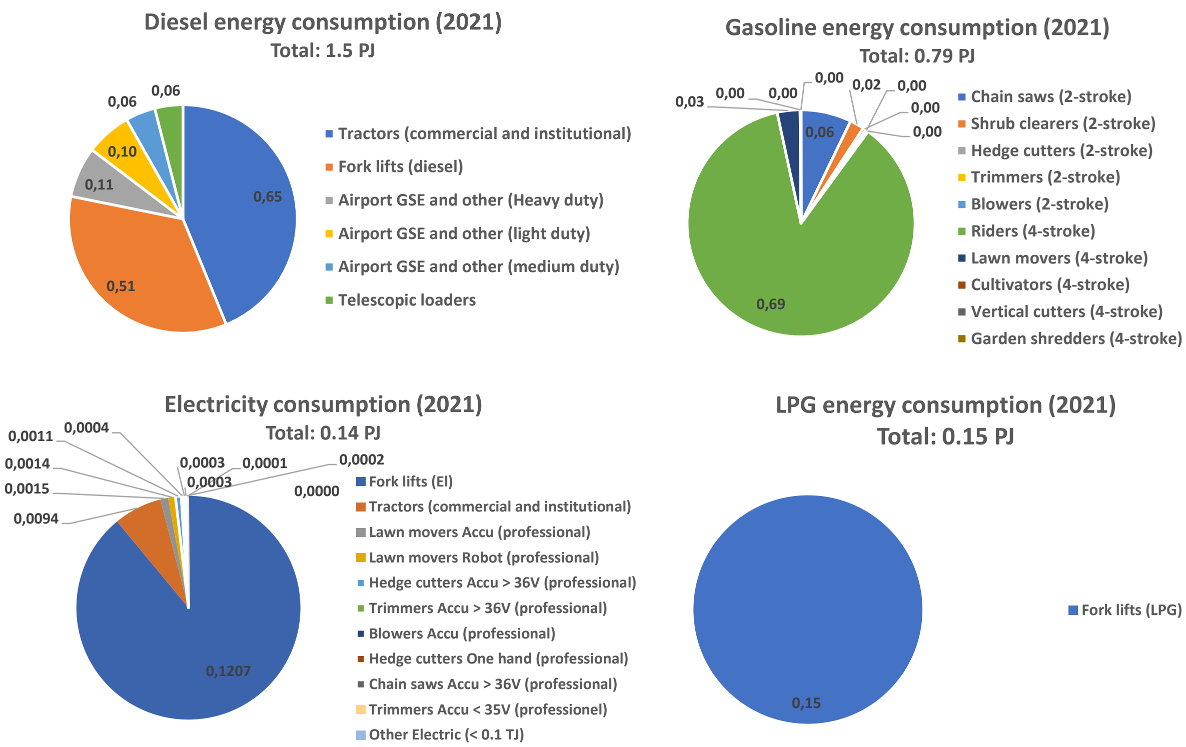


Figure 7.5.1 Energy consumption by fuel type and machine type for Commercial and institutional non-road machinery in 2021.

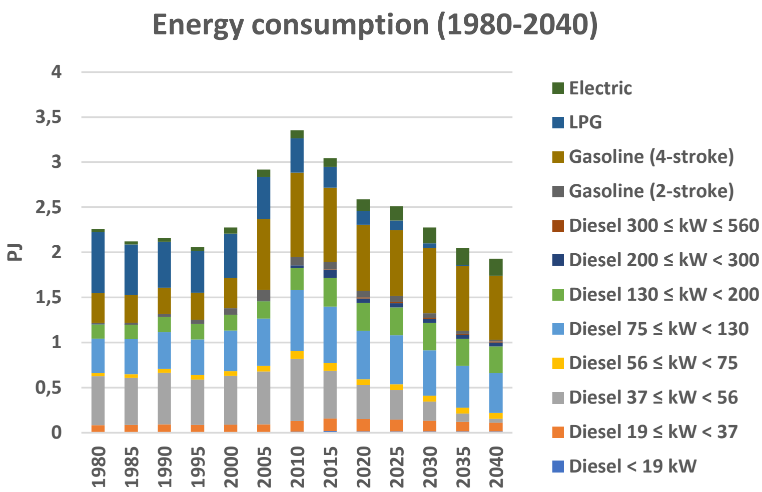


Figure 7.5.2 Energy consumption by engine type for Commercial and institutional non-road machinery 1980-2040.

After 1995, the energy consumption increased until 2010, mainly due to an increase in the stock and total operating hours for diesel engines between 75-130 kW and 4-stroke gasoline engines (Figure 6.5.2 and 6.5.4) within this time period. A decline in the energy consumption is expected in the future towards 2040, mainly due to transition in new sales for forklifts, for which new sold machines is expected to be purely electric from 2030 onwards.

7.5.2 Emissions

In 2021, the NO_x*[PM, CO, VOC]* emission shares for diesel, gasoline 2-stroke, gasoline 4-stroke and LPG engines were 84 %*[67 %, 1 %, 6 %]*, 1 %*[21 %, 5 %, 38 %]*, 10 %*[11 %, 94 %, 55 %]* and 4 %*[0 %, 0 %, 1 %]*, respectively (Table 7.5).

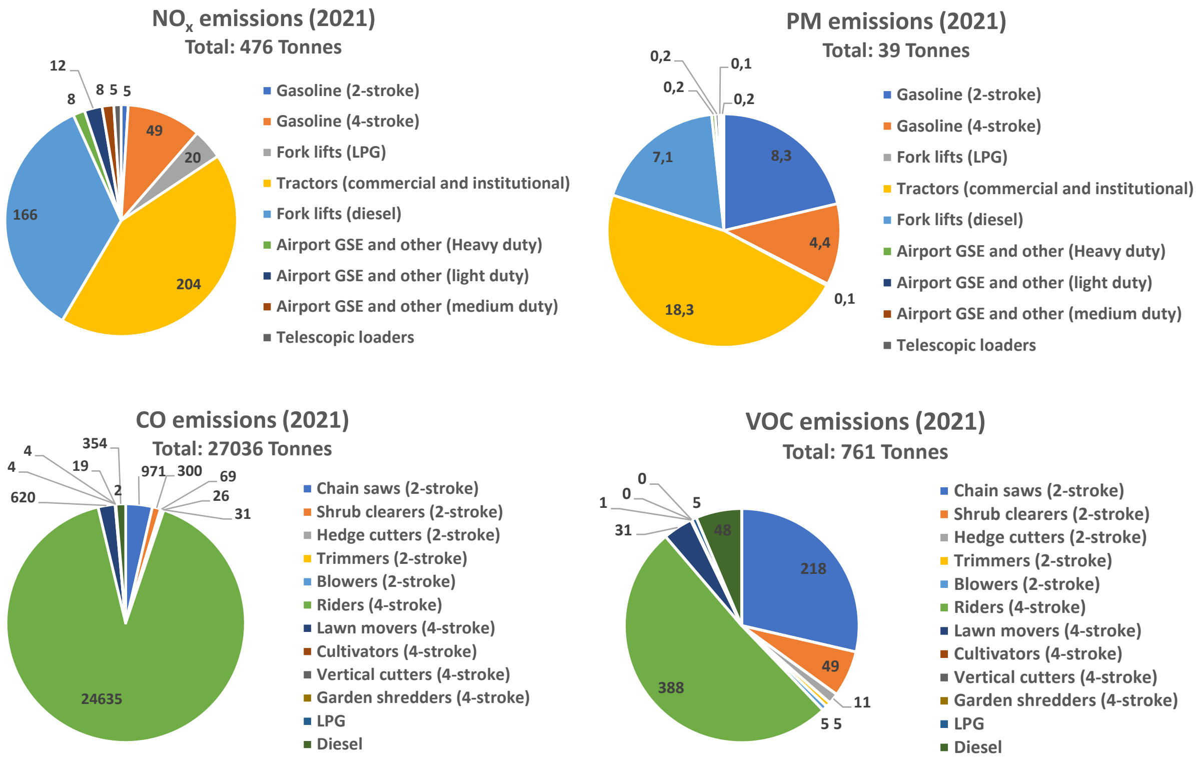


Figure 7.5.3 NO$_x$, PM, CO and VOC emissions by fuel type and machine type for Commercial and institutional non-road machinery in 2021.

In 2021, the NMVOC*[CH_4, N_2O, BC]* emission shares for diesel, gasoline 2-stroke, gasoline 4-stroke and LPG engines were 6 %*[4 %, 77 %, 97 %]*, 37 %*[55 %, 1 %, 2 %]*, 56 %*[40 %, 15 %, 1 %]*, and 1 %*[1 %, 8 %, 0 %]*, respectively (Table 7.5).

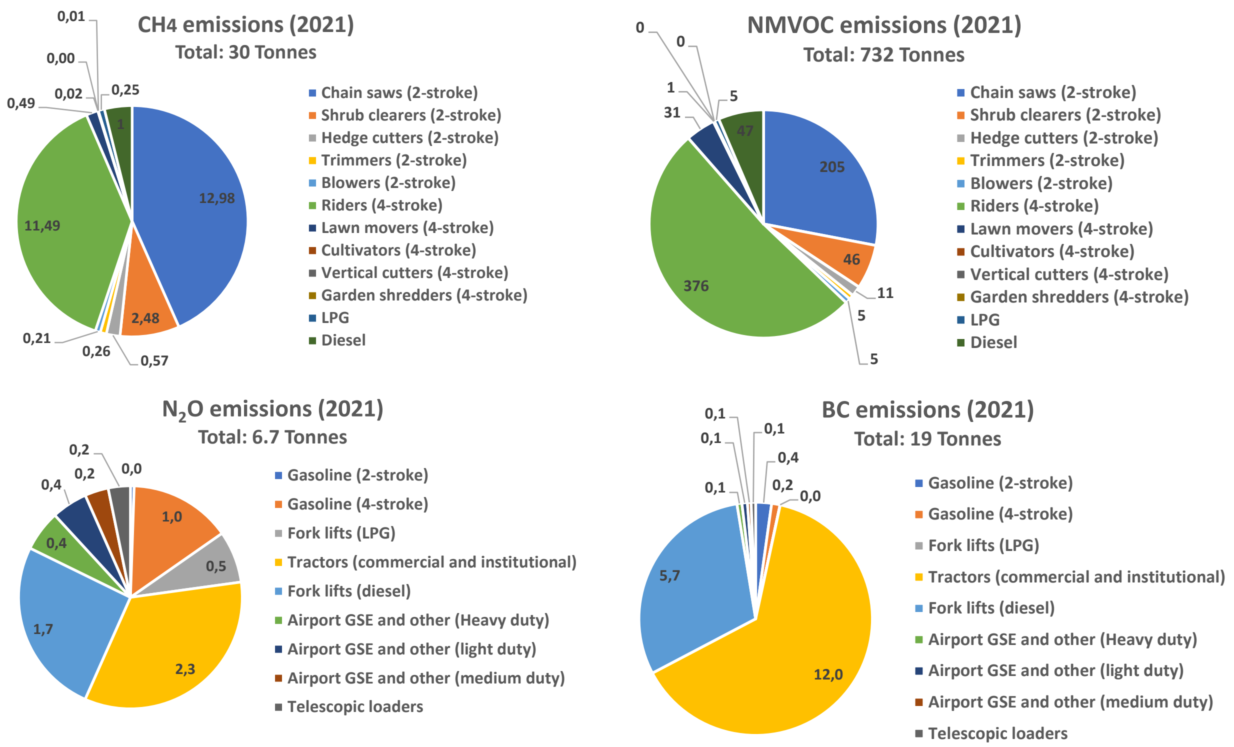


Figure 7.5.4 CH_4, NMVOC, N_2O and BC emissions by fuel type and machine type for Commercial and institutional non-road machinery in 2021.

The total NO$_x$ emissions for commercial and institutional machinery have been quite stable from 1980 until 2000, after which emissions reduced sharply towards 2021. This is mainly due to the gradual shift towards newer EU emission stage levels in new sold machines during the period, which is visible in the stock composition (Figure 6.5.2) and in the distribution of the operating hours (Figure 6.5.4), which in turn reduces the NO_x emission factors. For the same reasons, the NO_x emissions are expected to decline further towards 2040.

The PM emissions have fallen sharply from the early 1990s until 2021, and the emissions are also expected to decline further towards 2040. This emission development for PM can be explained by the distribution changes in the stock and operating hours towards newer engine technologies for diesel engines (Figures 6.5.2 and 6.5.4). Predominantly due to the continuous shift of the diesel engines towards Euro V with preinstalled particle filters, the emissions of PM for forestry machinery are expected to decline further towards 2040.

The emissions from LPG forklifts significantly reduce from 1980-2020 mainly due to emission factor improvements, and further emission reductions until 2040 are envisaged, due to the transition in new sales to 100 % electric for forklifts from 2030.

In the 1980-2040 period, the CO emissions are dominated by the emission contributions from 4-stroke gasoline engines, for which riders are the major emission source. The CO and VOC emissions from 4-stroke gasoline engines and the VOC emissions from 2-stroke gasoline engines increase sharply from 2000 to 2010 due to a large increase in stock numbers and total operating hours (Figure 6.5.2 and 6.5.4). In both cases the emission factors are very high for engines at all EU emission stage levels.

From 2010 onwards, a large decrease in the VOC emissions is noted for gasoline 2-stroke engines and a small VOC emissions decline is noted for gasoline 4-stroke engines, in both cases similar with the development in stock numbers and total operating hours during the same period. The main reason for these emission decreases is the ongoing shift towards electrical equipment, and all new sold machines are expected to be electrical in 2030 for trimmers, hedge cutters and blowers, in 2035 for vertical cutters and in 2040 for chain saws.

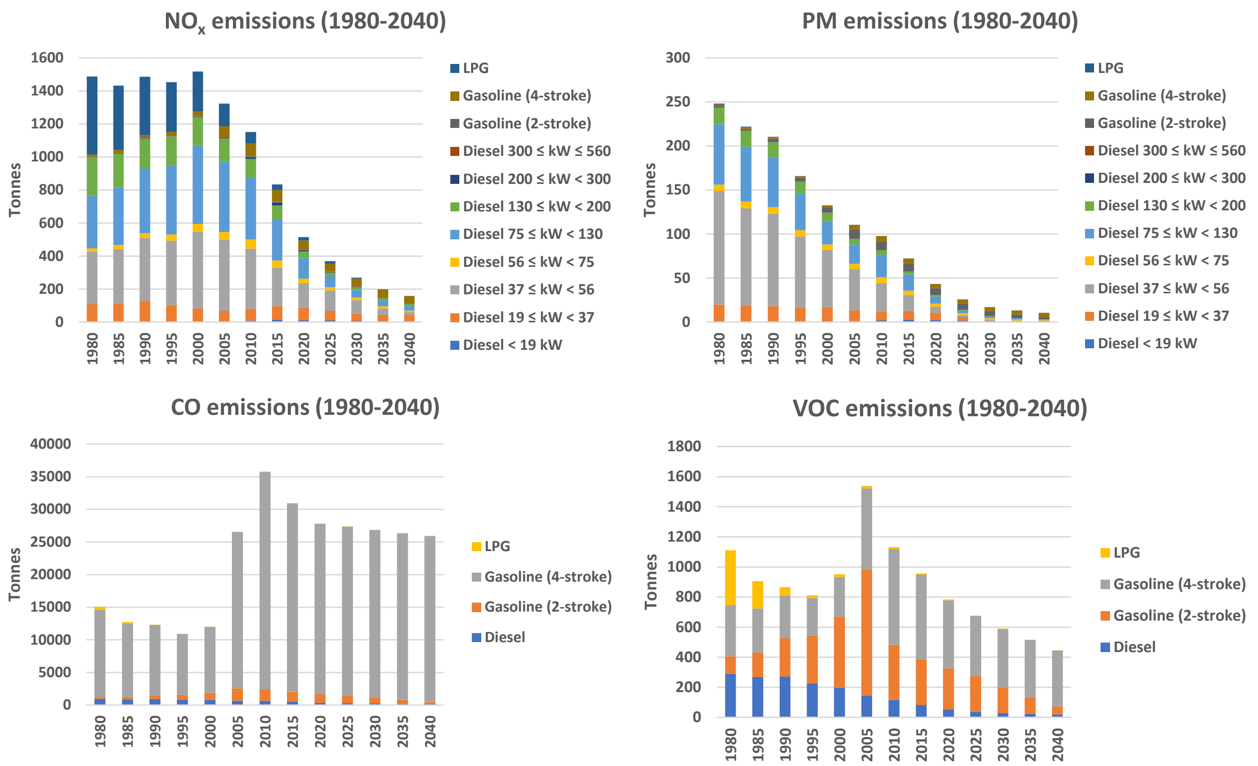


Figure 7.5.5 NO_x, PM, CO and VOC emissions by engine type for Commercial and institutional non-road machinery 1980-2040.

7.6 Residential machinery

The energy consumption and emission results for residential non-road machinery in 2021 are shown in Table 7.6 per fuel type and engine type.

Table 7.6 Energy consumption and emission results for residential non-road machinery in 2021 per fuel type and engine type.

Engine type	Energy	SO_2	NO_x	PM	CO	VOC	CO_2	NMVOC	CH_4	N_2O	BC
	PJ	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes
Gasoline (2-stroke)	0.08	0.04	5.2	13.9	1615	291	5.7	277.3	14.2	0.0	0.7
Gasoline (4-stroke)	0.31	0.13	29.3	2.0	10024	600	21.0	593.7	6.3	0.4	0.1
Gasoline total											
El	0.02	0.00	0.0	0.0	0	0	0.0	0.0	0.0	0.0	0.0
Total	0.41	0.17	34.4	15.9	11638	891	26.7	871.0	20.4	0.5	0.8
					Emissions (% of total)						
Gasoline (2-stroke)	20	21	15	88	14	33	21	32	69	8	88
Gasoline (4-stroke)	74	79	85	12	86	67	79	68	31	92	12
Gasoline total											
El	6	0	0	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100	100	100
					Emission factors (g/GJ)						
Gasoline (2-stroke)		0.43	62	167.3	19375	3497	68.5	3327.2	170.0	0.4	8.4
Gasoline (4-stroke)		0.43	95	6.4	32641	1954	68.5	1933.4	20.4	1.4	0.3
Gasoline total		0.43	88	40.8	29810	2283	68.5	2230.9	52.4	1.2	2.0

7.6.1 Energy consumption

For the residential non-road machinery in 2021 the energy consumption shares for gasoline 2-stroke, gasoline 4-stroke and electrical engines where 20 %, 74 % and 6 %, respectively (Table 7.6).

For gasoline 4-stroke engine machinery, riders and lawn mowers are the big fuel consumers in residential, and most of the fuel for 2-stroke engine machinery is consumed by chain saws. Apart from this, many different 2-stroke and 4-stroke engines contribute with small consumptions of gasoline in 2021.

In 2021, robotic lawn mowers are by far the biggest consumer of electricity in residential. Quite large contributions are also noted for lawn mowers by battery or cable and trimmers. The remaining part of the electricity in residential is consumed by a large group of different equipment types in 2021.

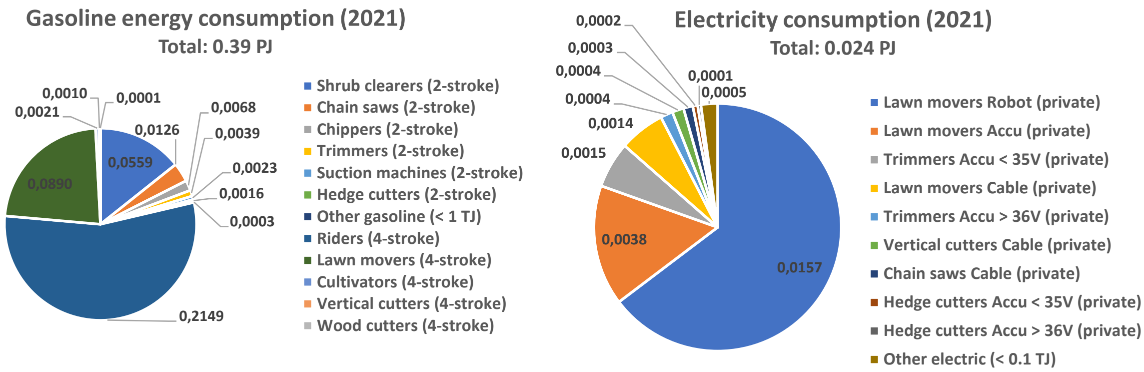


Figure 7.6.1 Energy consumption by fuel type and machine type for residential non-road machinery in 2021.

A large increase in the fuel consumption is noted from 1980 to 2010 for 4-stroke engines, and from 1980 to 2005 for 2-stroke engines due to a steady rise in the activities for these machines during that period.

Although a few machinery types remain fully gasoline fuelled (most importantly riders and shrub clearers), the fuel consumption for gasoline residential machinery taken as a whole is expected to decrease from 2010 onwards. This is due to the gradual shift in new sales from gasoline to electric, which is expected to continue towards 2040. Branch expectations are that new sales will be exclusively electrical machinery for trimmers, hedge cutters and blowers in 2030, for vertical cutters in 2035 and for chain saws and lawn mowers in 2040.

The shares of electricity consumption of total fuel consumption are very low compared with the shares of total operating hours for electric machinery. This is due to the fact that the electric machines generally have small engine sizes, are very energy efficient compared with gasoline-powered counterparts, and that robotic lawn mowers have a low total electricity consumption despite a very high number of operating hours due to their very low relative electricity consumption.

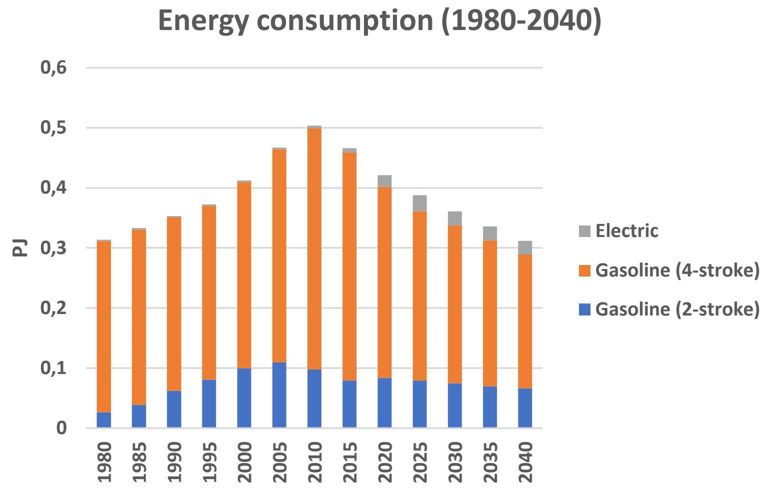


Figure 7.6.2 Energy consumption by engine type for residential non-road machinery 1980-2040.

7.6.2 Emissions

In 2021, the NO$_x$*[PM, CO, VOC]* emission shares for gasoline 2-stroke and gasoline 4-stroke engines were 15 %*[88 %, 14 %, 33]* and 85 %*[12 %, 86 %, 67 %]*, respectively (Table 7.6).

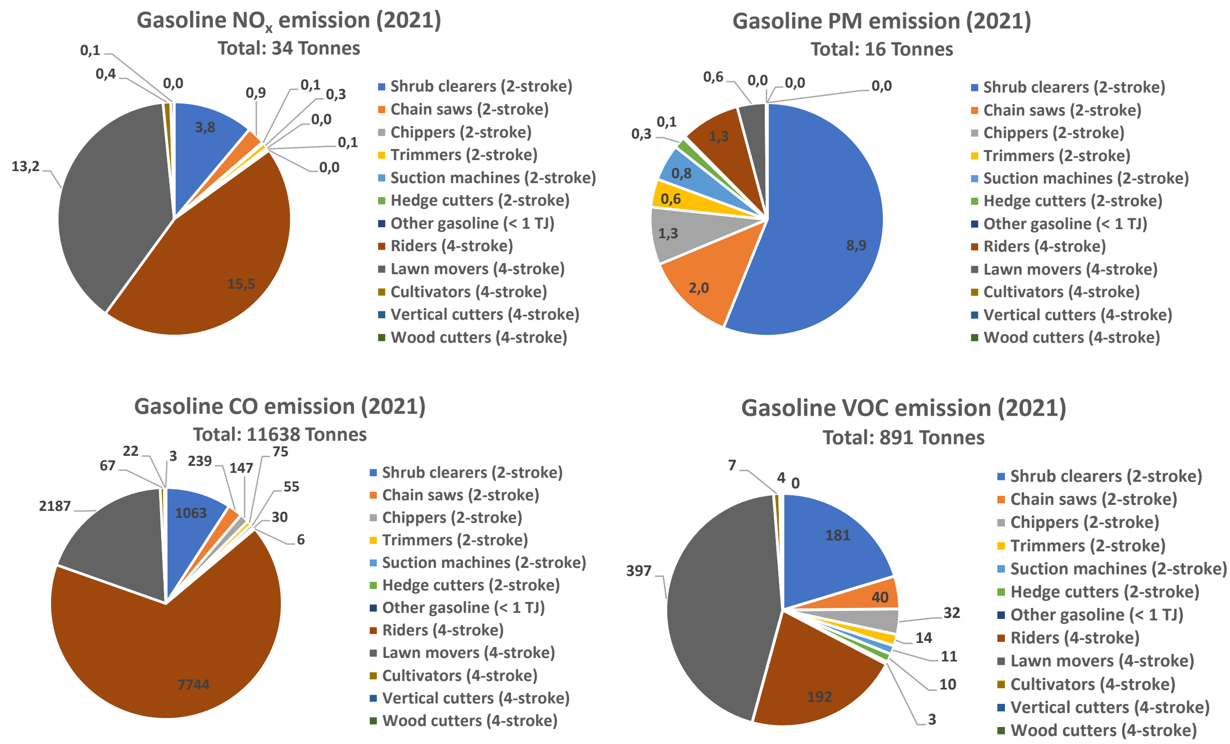


Figure 7.6.3 NO$_x$, PM, CO and VOC emissions by machine type for residential non-road machinery in 2021.

In 2021, the NMVOC*[CH$_4$, N$_2$O, BC]* emission shares for gasoline 2-stroke and gasoline 4-stroke engines were 32 %*[69 %, 8 %, 88* and 68 %*[31 %, 92 %, 12 %]*, respectively (Table 7.6).

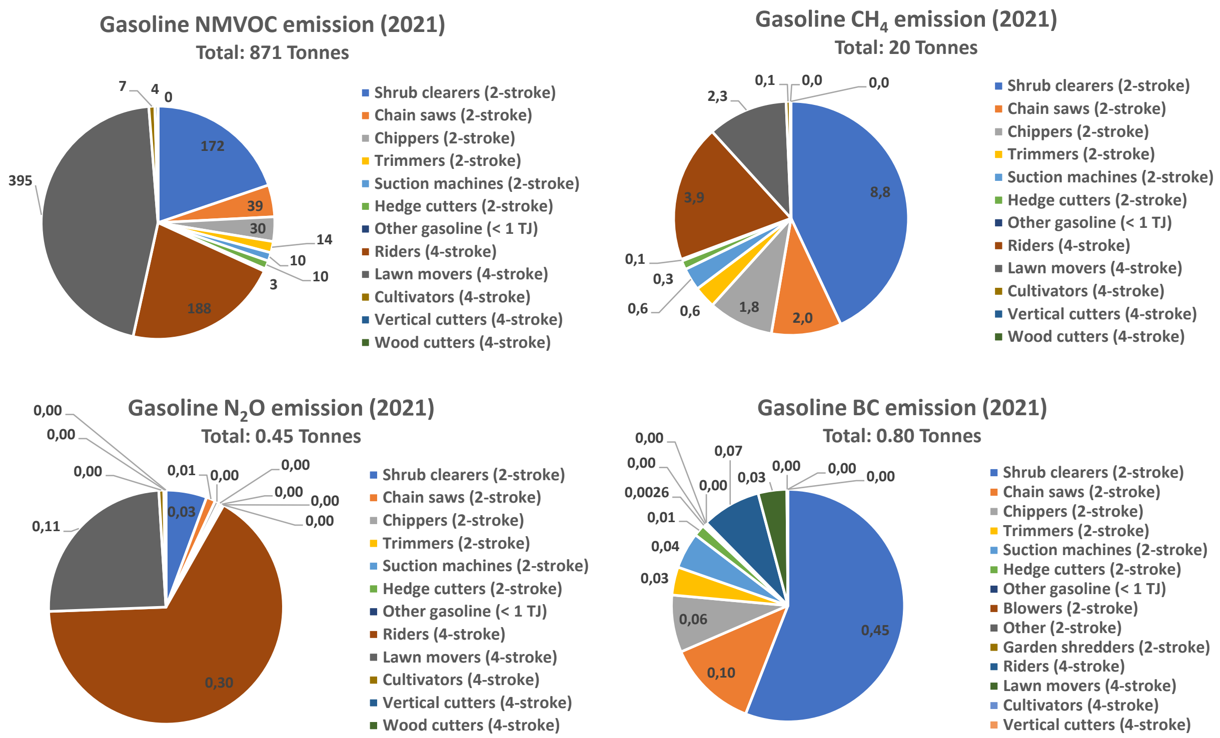


Figure 7.6.4 CH_4, NMVOC, N_2O and BC emissions by machine type for residential non-road machinery in 2021.

In the 1980-2040 period, the CO and NO_x emissions are dominated by the emission contributions from 4-stroke gasoline engines, for which riders are the major emission source. For PM the emissions predominantly come from 2-stroke gasoline engines, of which shrub clearers continue to play a major emission role throughout the 19980-2040 period.

The sharp CO emissions increase for 4-stroke gasoline engines from 2000 to 2010 and from 1980 to 2005 in the case of VOC emissions from 2-stroke gasoline engines are mainly due to a large increase in stock numbers and total operating hours (Figure 6.6.2 and 6.6.4). In both cases the emission factors are very high for engines at all EU emission stage levels.

For VOC, large emission decreases are noted for gasoline 2-stroke and 4-stroke engines from 2005 onwards and 2015 onwards, respectively. The emission reductions are in both cases similar with the development in stock numbers and total operating hours during the same period. The main reason for these emission decreases is the ongoing shift towards electrical equipment, so that all new sold machines are expected to be electrical in 2030 for trimmers, hedge cutters and blowers, in 2035 for vertical cutters and in 2040 for chain saws.

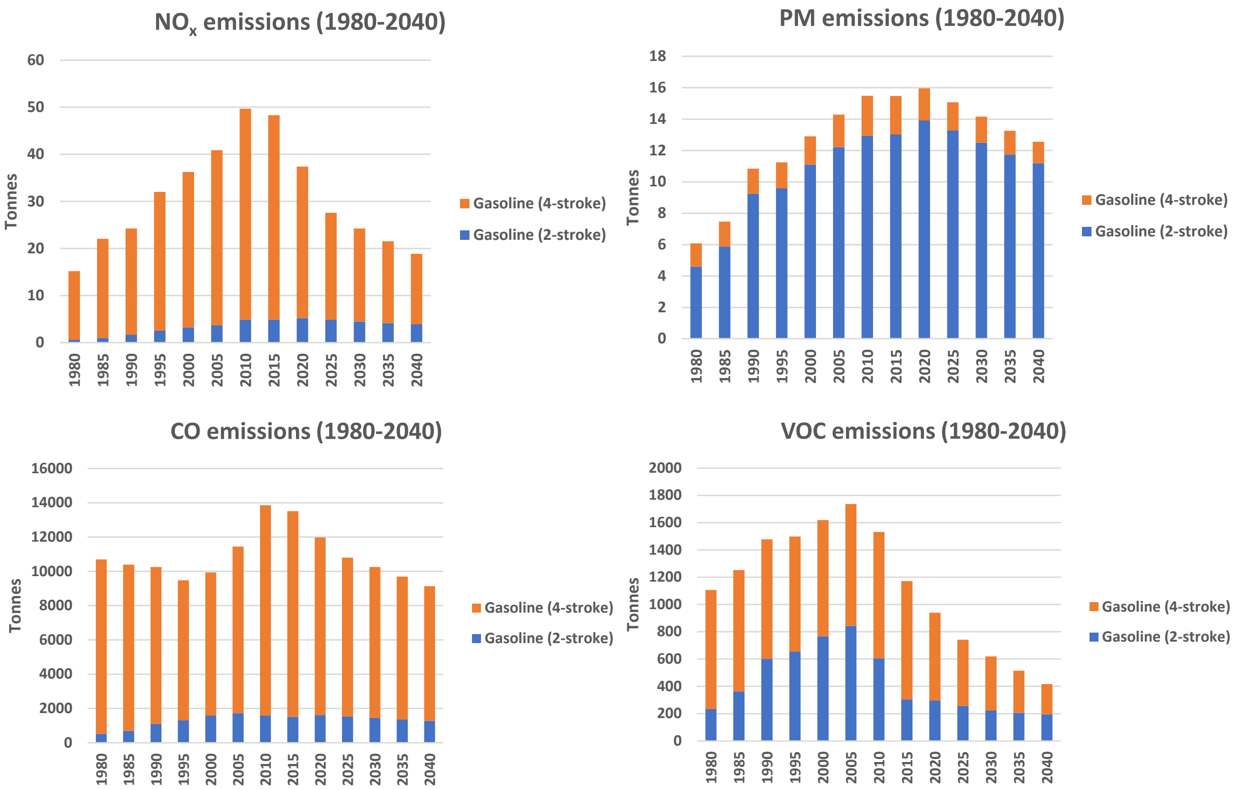


Figure 7.6.5 NO_x, PM, CO and VOC emissions by engine type for residential non-road machinery 1980-2040.

8 Total Energy consumption and emissions

The aggregated results for fuel consumption and emissions in 2021 and for the period 1980-2040 are presented in this chapter.

For each non-road sector, the fuel consumption results are presented for 2021 and for the 1980-2040 period, split by fuel type and engine type, and aggregated emission results are presented for each non-road sector.

Annex 6 shows aggregated fuel consumption and emission results per non-road sector for 1980-2040. Annex 6 also shows fuel consumption results grouped into fuel type, non-road sector and engine type.

8.1 Total Energy consumption

The energy consumption results for non-road machinery in 2021 per non-road sector, fuel type and engine type are shown in Table 8.1.

Table 8.1 Energy consumption results for non-road machinery in 2021 per non-road sector, fuel type and engine type.

	Total	Diesel	Gasoline 2-stroke	Gasoline 4-stroke	Gasoline Total	LPG	El
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
Agricultural machinery	8.64	8.50	-	0.15	0.15	-	0.00
Forestry machinery	0.59	0.54	0.05	-	0.05	-	0.00
Building and construction machinery	7.66	7.33	0.02	0.31	0.32	-	0.01
Industrial machinery	1.10	0.66	-	-	0.00	0.27	0.17
Commercial and institutional machinery	2.56	1.49	0.08	0.71	0.79	0.15	0.14
Residential machinery	0.41	-	0.08	0.31	0.39	-	0.01
Grand total	20.97	18.51	0.23	1.47	1.71	0.42	0.33
			% of total				
Agricultural machinery	41	46	0	10	9	0	0
Forestry machinery	3	3	23	0	3	0	0
Building and construction machinery	37	40	7	21	19	0	2
Industrial machinery	5	4	0	0	0	65	50
Commercial and institutional machinery	12	8	34	48	46	35	41
Residential machinery	2	0	36	21	23	0	7
Grand total	100	100	100	100	100	100	100

For non-road machinery in total in 2021 the energy consumption shares for diesel, gasoline 2-stroke, gasoline 4-stroke, LPG (forklifts) and electrical engines where 88 %, 1 %, 7 %, 2 % and 2 %, respectively (derived from Table 8.1).

In total for 2021, most of the fuel is used by the machines in agriculture (41 %) and building and construction (37 %), whereas smaller fuel consumption shares are calculated for the machines in commercial and institutional (12 %), industrial (5 %), forestry (3 %) and residential (2 %).

The most prominent sectors of diesel consumption are agriculture (46 %), building and construction (40 %) and commercial and institutional (12 %) in 2021. In the case of gasoline, most of the fuel is used in the sectors commercial and institutional (46 %), residential (23 %) and building and construction (19

%). The LPG is used in the industrial (65 %) and commercial and institutional (35 %) sectors, whereas most of the electricity is used in the industrial (50 %) and commercial and institutional (41 %) sectors and by residential machinery (7 %).

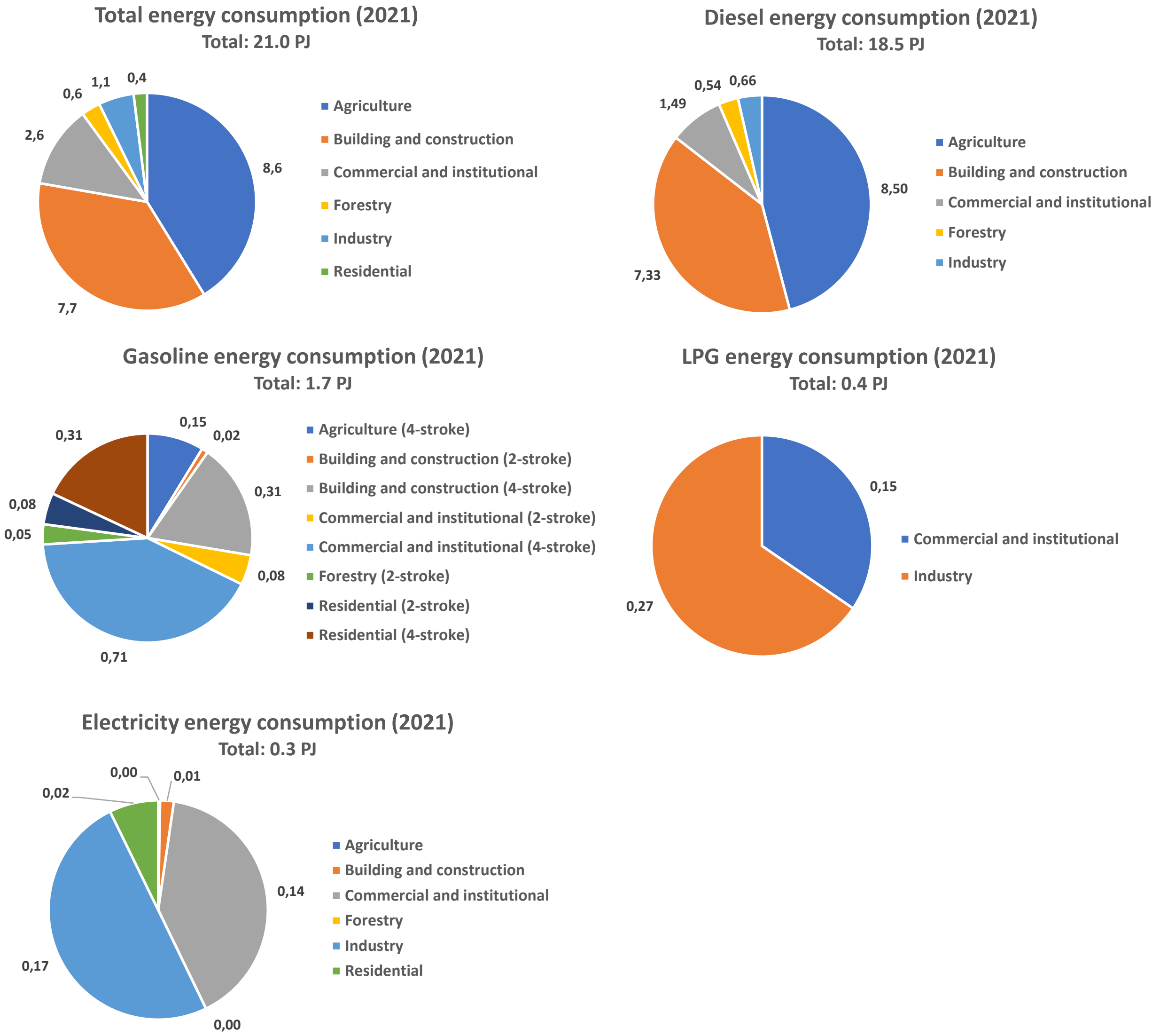


Figure 8.1 Energy consumption by fuel type and sub-sector for non-road machinery in 2021.

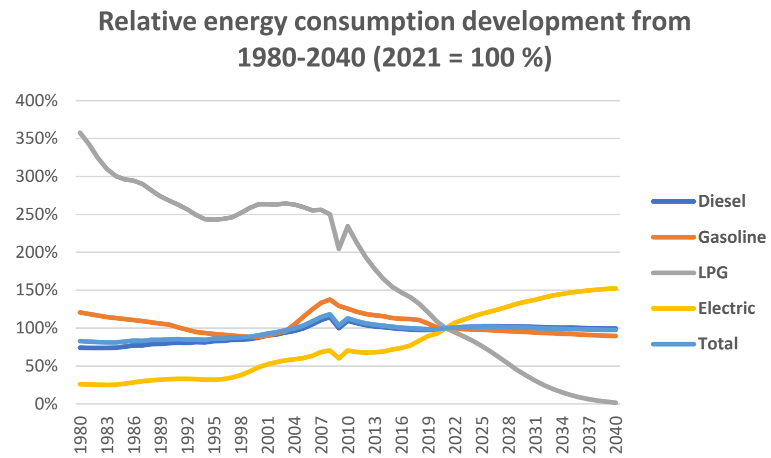


Figure 8.2 Relative energy consumption development per fuel type and total for non-road machinery 1980-2040.

The total non-road fuel consumption increased by 21 % from 1980 to 2021. For diesel, gasoline, LPG and electricity the fuel consumption has changed by 35 %, -17 %, -72 % and 303 %, respectively (derived from Figure 8.2).

From 2021 to 2040, a minor decrease of 2 % is calculated for the total non-road fuel consumption. For diesel, gasoline, LPG and electricity the calculated fuel consumption is expected to change by -1 %, -11 %, -98 % and 50 %, respectively (Figure 8.2).

The development of the agricultural energy consumption throughout the period 1980-2040 has a major impact on the development in the total energy consumption and for the total diesel consumption separately during the period.

For gasoline, the fuel consumption development in the historical period from 1980 to 2021 was mostly influenced by the following trends. The gasoline consumption has decreased in agriculture and forestry towards 2005 due to the phasing out of gasoline-powered tractors and less use of chainsaws, respectively. Also, the number of gasoline-powered machines in commercial and institutional and residential increased significantly from 2000 to 2010, after which the stock of gasoline machines decrease due to a shift in new sales towards electric machinery.

The number of gasoline-powered machines and thus gasoline consumption are expected to decrease in the future, due to a further increase towards 2040 in the new sales share and total operating hours for electric powered machines.

Because of the development of the stock and activities for electric machinery, the calculated consumption of electricity increased substantially from 1980 to 2021, and the calculated electricity consumption is expected to increase further until 2040.

From 1980 until 1995, the consumption of LPG have decreased due to a decrease in the number of LPG forklifts and hence total operating hours during this period. A significant decline in the total LPG consumption is noted from 2010 onwards, and this LPG consumption decrease is expected to continue in the future towards 2040, due to the transition in forklift new sales towards purely electric machinery from 2030 onwards.

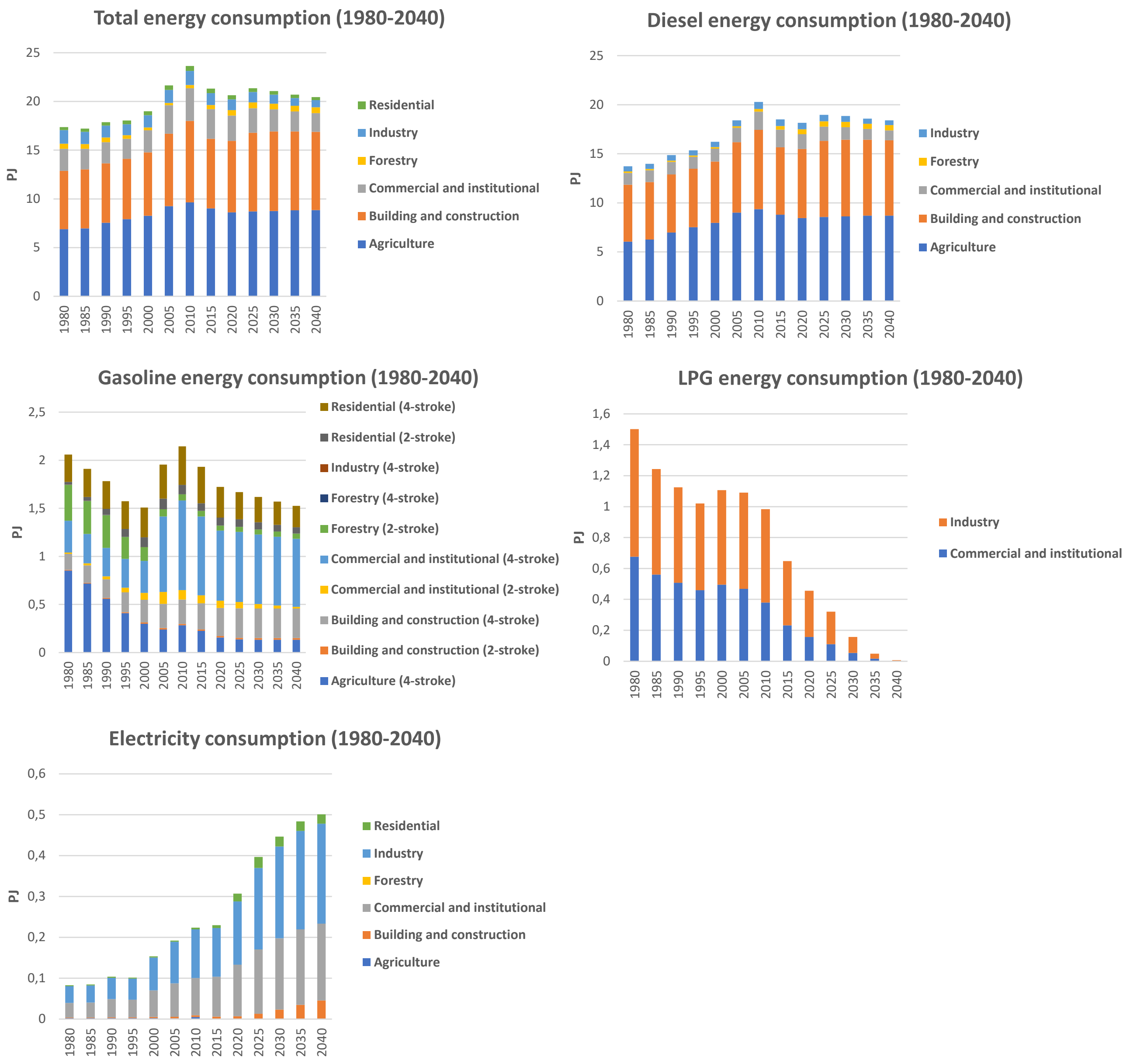


Figure 8.3 Energy consumption by fuel type and sub-sector for non-road machinery 1980-2040.

8.2 Total Emissions

In Table 8.2 the aggregated emission results per non-road sector, fuel type and engine type are shown for 2021.

Table 8.2 Emission results for non-road machinery in 2021 per non-road sector, fuel type and engine type.

	SO_2	NO_x	PM	CO	VOC	CO_2	NMVOC	CH_4	N_2O	BC
	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	kTonnes	Tonnes	Tonnes	Tonnes	Tonnes
Agricultural machinery	4.04	2294.0	196.4	4843.7	472.6	639.7	443.1	29.5	30.6	115.7
Forestry machinery	0.28	32.2	5.7	1043.4	219.8	43.6	206.9	13.0	2.0	1.2
Building and construction machinery	3.57	1645.0	102.5	10104.1	597.7	565.3	578.8	18.9	26.1	72.2
Industrial machinery	0.31	337.3	37.8	206.8	60.4	66.0	58.7	1.7	3.1	22.7
Commercial and institutional machinery	1.04	476.5	38.8	27035.8	761.5	173.8	731.6	29.9	6.7	18.8
Residential machinery	0.17	34.4	15.9	11638.1	891.4	26.7	871.0	20.4	0.5	0.8
Grand total	9.40	4819.4	397.1	54872.0	3003.5	1515.1	2890.0	113.4	69.1	231.4
					Emissions (% of total)					
Agricultural machinery	43	48	49	9	16	42	15	26	44	50
Forestry machinery	3	1	1	2	7	3	7	11	3	1
Building and construction machinery	38	34	26	18	20	37	20	17	38	31
Industrial machinery	3	7	10	0	2	4	2	1	5	10
Commercial and institutional machinery	11	10	10	49	25	11	25	26	10	8
Residential machinery	2	1	4	21	30	2	30	18	1	0
Grand total	100	100	100	100	100	100	100	100	100	100

The largest emissions of NO_x, PM, CO_2, SO_2, N_2O and BC in 2021 are calculated for agricultural non-road and building and construction.

The primary reasons for the high emission contributions in the two above mentioned non-road sectors are the large fuel consumption of primarily diesel and the high diesel related emission factors, in the case of NO_x, N_2O and BC. For PM, CO_2 and SO_2 the high emission contributions are primarily due to the high fuel consumption calculated for these sectors.

For CO, VOC, NMVOC and CH_4, the largest emissions in 2021 are calculated for residential non-road and commercial and institutional, followed by building and construction. This is due to relatively large gasoline consumptions in these sectors, and high fuel related emission factors for gasoline.

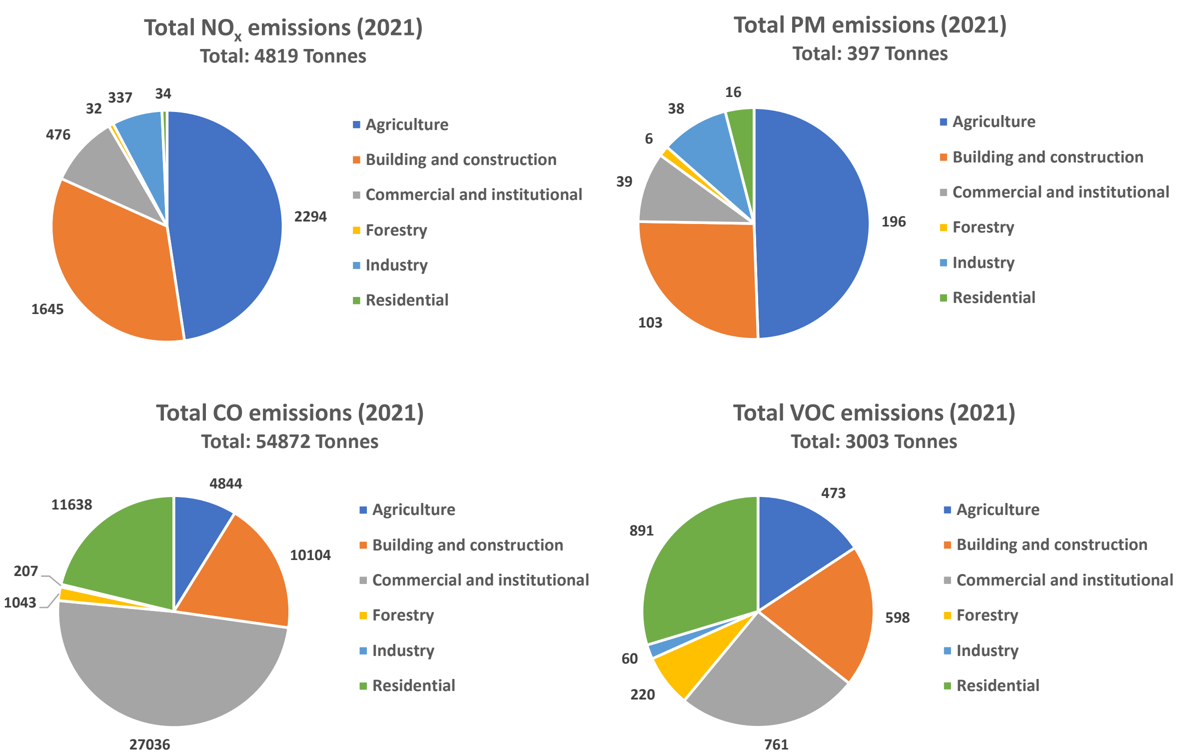


Figure 8.4 Emissions of NO_x, PM, CO and VOC per sub-sector for non-road machinery in 2021.

For CO, VOC, NMVOC and CH_4, the largest emissions in 2021 are calculated for residential non-road and commercial and institutional, followed by building and construction. This is due to relatively large gasoline consumptions in these sectors, and high fuel related emission factors for gasoline.

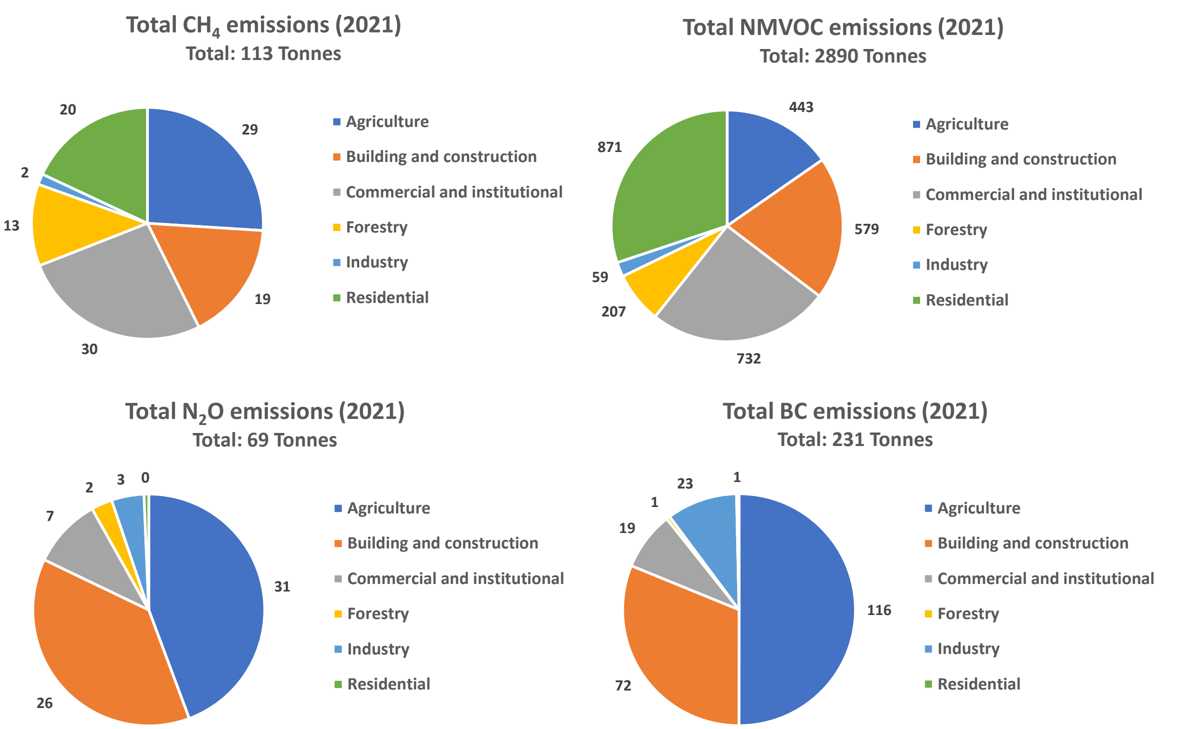


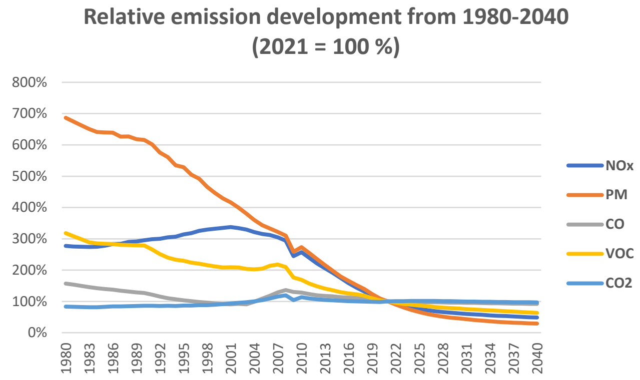
Figure 8.5 Emissions of CH_4, NMVOC, N_2O and BC per sub-sector for non-road machinery in 2021.

The total emissions of NO_x, PM, CO and VOC have decreased by 64 %, 85 %, 36 % and 69 %, respectively, from 1980 to 2021 (derived from Figure 8.6). The total CO_2 emissions increased by 20 % in the same period (derived from Figure 8. 6).

From 2021 to 2040 the total of NO_x, PM, CO, VOC and CO_2 emissions are expected to decrease by 51 %, 71 %, 8 %, 36 % and 3 %, respectively (Figure 8. 6).

The total emissions of CH_4, NMVOC, BC and SO_2 decreased by 70 %, 68 %, 84 % and 99.7 %, respectively, from 1980 to 2021 (derived from Figure 8. 6). The total N_2O emissions increased by 53 % in the same period (derived from Figure 8. 6).

From 2021 to 2040 the total emissions of CH_4, NMVOC, N_2O, BC and SO_2 decreased by 30 %, 37 %, 1 %, 77 % and 1 %, respectively (Figure 8. 6).



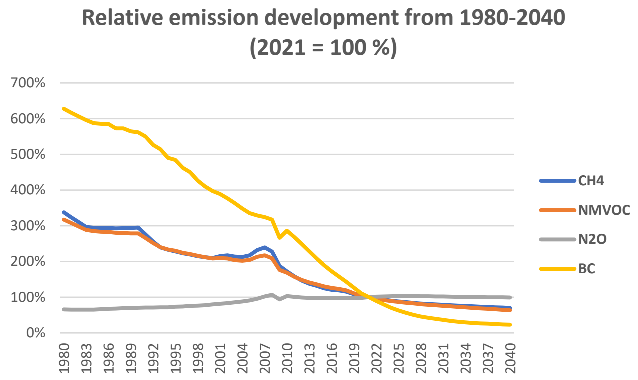


Figure 8.6 Relative development of the emissions of NO_x, PM, CO, VOC and CO_2 (left) and CH_4, NMVOC, N_2O and BC (right) for non-road machinery 1980-2040.

During the period 1980-2040, most of the NO_x and PM emissions come from the diesel machinery used in agriculture and building and construction.

For NO_x, the emissions increased from 1980 until 2000 mainly due to an increase in the emissions from agriculture. From 2000, the emissions reduced sharply towards 2021 due to the gradual shift towards newer EU emission stage levels in new sales for diesel machinery, which is visible in the distribution of the stock and total operating hours in all sub-sectors, and in turn reduces the NO_x emission factors. For the same reasons, the NO_x emissions are expected to decline further towards 2040.

The total PM emissions have fallen sharply from the early 1990s until 2021, and the emissions are also expected to decline further towards 2040. This emission development for PM can be explained by the distribution changes in the stock and operating hours towards newer engine technologies for diesel engines (Figures 6.1.2 and 6.1.4). Predominantly due to the continuous shift of the diesel engines towards Euro V standards, the emissions of PM for agricultural machinery are expected to decline further towards 2040.

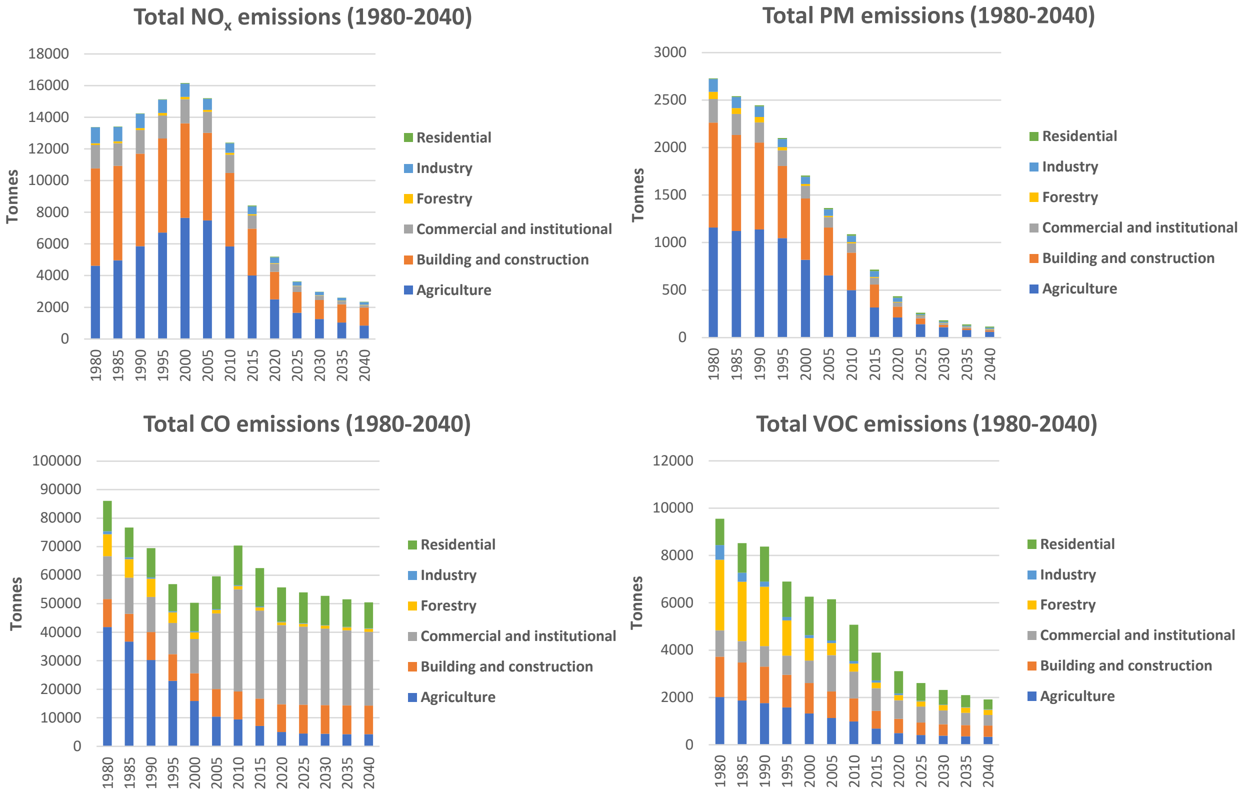


Figure 8.7 Emissions of NO_x, PM, CO and VOC per sub-sector for non-road machinery 1980-2040.

The decline in the total CO emissions from 1980 to 2000 is by large caused by the phasing out of gasoline fuelled vintage tractors. From 2000 to 2010 the total CO emissions increase significantly mainly due to a large increase in the activities made by gasoline machinery in the commercial and institutional sector, for which the emissions from 4-stroke engines play a dominant role. After that, the CO emissions gradually reduce mainly due to emission factor reductions and because of the increasing shift from gasoline to electric machinery in many machinery cases. Slight decreases in the CO emissions are expected from 2021 towards 2040.

The total emissions of VOC decreased significantly from 1990 to 2005 mainly due to the phasing out of gasoline fuelled vintage tractors in agriculture and the large reduction of the stock and total operating hours for gasoline 2-stroke engine chain saws used in forestry. The VOC emissions reduce in all non-road sectors from 2005 onwards mainly due to emission factor reductions and the increasing shift from gasoline to electric machinery in many machinery cases.

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Annexes

All annexes are available at:
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List of content

ENERGY CONSUMPTION AND EMISSIONS FROM NON-ROAD MACHINERY IN DENMARK

Time series from 1980-2040

This report documents the Danish emission inventories and forecasts for non-road machinery used in the agriculture, forestry, building and construction, industry, commercial and institutional and residential sectors calculated with the DEMOS-NRMM model. Stock and activity data are shown for the period 1980-2040, and energy consumption and emission results are presented for the following emission components NOx (nitrogen oxides), PM (particulate matter), CO (carbon monoxide), VOC (volatile organic compounds), NMVOC (non-methane volatile organic compounds), CH_4 (methane), CO_2 (carbon dioxide), SO_2 (sulphur dioxide), N_2O (nitrous oxide), and BC (black carbon). The total emissions of NOx, PM, CO and VOC have decreased by 64 %, 85 %, 36 % and 69 %, respectively, from 1980 to 2021, whereas the total CO2 emissions have increased by 20 % in the same period. From 2021 to 2040 the total of NOx, PM, CO, VOC and CO_2 emissions are expected to decrease by 51 %, 71 %, 8 %, 36 % and 3 %, respectively. The total emissions of CH_4, NMVOC, BC and SO_2 have decreased by 70 %, 68 %, 84 % and 99.7 %, respectively, from 1980 to 2021, whereas the total N_2O emissions have increased by 53 % in the same period. From 2021 to 2040 the total emissions of CH_4, NMVOC, N_2O, BC and SO_2 are expected to decrease by 30 %, 37 %, 1 %, 77 % and 1 %, respectively.

ISBN: 978-87-7156-822-6
ISSN: 2244-9981