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Key Indicators of Climate Change and the Energy Sector in 2025.

Special Topic: The Role of Grid-scale Battery Storage in the Energy Transition

Bernhard Kasberger, Daniela Kletzan-Slamanig, Ina Meyer, Asjad Naqvi, Thomas Neier, Franz Sinabell, Mark Sommer

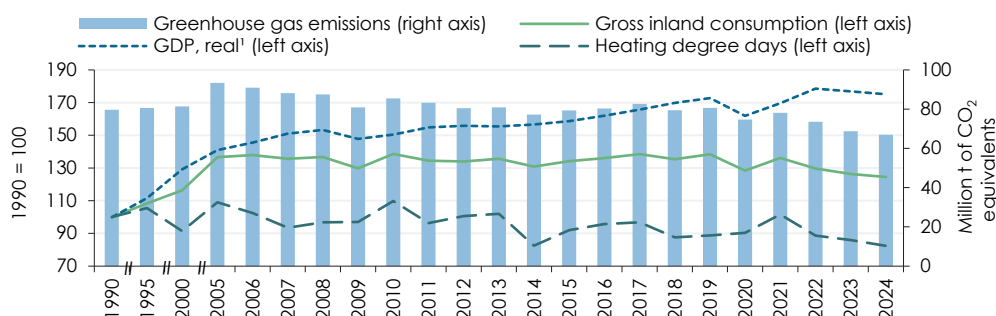
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- In 2023, the Austrian economy shrank (real GDP –1.0 percent); energy consumption (–3.0 percent) and greenhouse gas emissions (–6.6 percent) also continued to fall.
- The reduction in emissions can be attributed to persistently high energy prices, mild weather, climate protection measures (expansion of renewable energy, heating replacement, CO₂ pricing) and declining economic growth.
- For 2024, the Environment Agency Austria is forecasting a further decrease in emissions of 2.6 percent. In addition to climate protection measures, the continued recession (–1.0 percent in real terms) had a dampening effect.
- Since 1990, the cultivated arable land in Austria has decreased by around 85,600 hectares (6 percent). The steady decline in agricultural land is jeopardising food security in the face of stagnating yields per hectare and population growth.
- Battery storage and photovoltaic systems complement each other and make the energy transition more cost-efficient. A cleverly designed regulatory framework maximises the potential of batteries and makes it possible to limit or postpone grid expansion in a targeted manner.

Greenhouse gas emissions, energy consumption, gross value added at basic prices and heating degree days in Austria



"The reduction in greenhouse gas emissions in recent years was not exclusively due to efficiency gains and structural changes in the energy system, but also to the recession."

In 2023, in addition to climate protection measures and mild weather, the recession curbed energy consumption and greenhouse gas emissions. According to preliminary data, this trend continued in 2024, although the decline in emissions slowed (Source: Environment Agency Austria; Statistics Austria; WDS – WIFO Data System, Macrobond. 2024: Statistics Austria, preliminary energy balance 2024; Environment Agency Austria, near-term forecast 2024. – ¹ Reference year 2015).

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October 2025

Key Indicators of Climate Change and the Energy Sector in 2025. Special Topic: The Role of Grid-scale Battery Storage in the Energy Transition

The year 2023 was marked by inflation and recession. Austria again emitted significantly less greenhouse gases than in the previous year (–6.6 percent), and energy consumption also declined (–2.5 percent). This development was partly due to the economic downturn and, in addition, due to persistently high energy prices as a result of the war in Ukraine, mild weather, the expansion of renewable energy technologies, and improvements in the energy efficiency of capital stocks. Greenhouse gas emissions reached their lowest level since 1990 (68.7 million t of CO₂ equivalents). Nevertheless, there is still a great need for action to achieve Austria's goal of climate neutrality by 2040, especially as preliminary data for 2024 indicate a significant slowdown in emission reductions. This year's special topic deals with the potential of grid-scale battery storage to contribute to the energy transition through its complementarity with renewable generation technologies, especially photovoltaics. In a smart regulatory environment, the combination of battery storage and photovoltaics can smooth and reduce electricity prices and reduce the need for grid expansion.

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This 18th WIFO report on the key indicators of climate change and the energy sector documents and analyses their development in 2023 and – if the relevant figures are already available – in 2024, based on current data on greenhouse gas emissions in Austria (Environment Agency Austria, 2025a, 2025b, 2025c) and energy flows according to the energy balance (Statistics Austria, 2024c, 2025).

The year 2023 was economically characterised by inflation and recession in Austria. Energy consumption and greenhouse gas emissions fell again, although the decline slowed compared to the previous year.

Developments in the areas of energy consumption, energy supply and greenhouse gas emissions are analysed below for Austria's total economy and its sectors with regard to climate policy targets. This year's special topic is dedicated to the potential of battery storage systems to contribute to the energy transition by supplementing renewable energy generation as a complementary technology, particularly via photovoltaics. The use of battery storage systems enables a smoothing or reduction in electricity prices and, subject to an adequate regulatory framework, allows the necessary grid expansion to be limited or postponed.

1. Climate and energy indicators

1.1 Gross domestic energy consumption in the EU 27 continued to fall in 2023

In 2023, GDP in the EU 27 increased by 0.4 percent compared to the previous year. In contrast, energy input fell by 4.0 percent to 54,427 PJ, the lowest level since 1990. The decline was due to the continued relatively high energy prices, the mild winter, measures to increase energy efficiency, and the increasing share of renewable energy sources. The use of fossil fuels continued to fall compared to the previous year – the average decline in natural gas in the EU 27 was 15 percent – while the share of renewable energy sources increased again and, at 24.5 percent of gross final energy consumption in the EU 27, was 1.5 percentage points

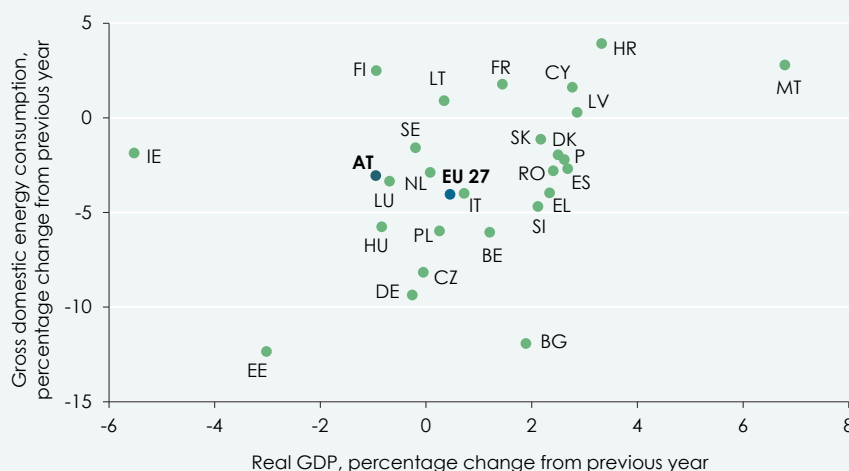
higher than in 2022. The progress made in the last three years has further narrowed the gap to the energy efficiency targets set for 2030.

A comparison of economic development and energy input at country level shows a differentiated picture (Figure 1): in 2023, economic output increased in two thirds of EU countries and shrank in one third – including Austria. In addition to Malta (+6.8 percent), Croatia, Cyprus and Latvia also recorded significant GDP growth. A reduction in gross domestic energy consumption was achieved by 20 member countries, led by Estonia, Bulgaria, Germany and the Czech Republic.

The EU 27 economy grew only slightly in 2023, with energy consumption reaching its lowest level since 1990 at –4 percent compared to the previous year.

Figure 1: Development of gross domestic energy consumption in relation to GDP development in the EU countries

2023



Source: Eurostat.

1.2 Austria: high inflation, recession and climate policy measures curbed emissions in 2023

Austria once again emitted significantly fewer greenhouse gases in 2023 compared to the previous year (–6.6 percent). Across all sectors, emissions totalled 68.7 million t of CO₂ equivalents (CO₂ emissions: 56.9 million t; Figure 2). This corresponds to a decrease of 13.7 percent relative to the 1990 level.

The main reasons for the year-on-year reduction were the lively inflation and the recession, which reduced emissions in the industrial sector in particular. The lower number of heating degree days, the reduced consumption of fossil fuels in the building sector (heating replacement) and a decline

in diesel consumption in the transport sector also had a dampening effect.

For the sectors outside the EU emissions trading system, national caps apply for the period 2021 to 2030 in accordance with the Effort Sharing Regulation 2018/842/EU (European Commission, 2018). In 2023, the relevant cap for Austria was 45.2 million t of CO₂ equivalents. At 44.3 million t of CO₂ equivalents, actual emissions were below the target value. Emissions in the emissions trading sector also fell significantly compared to 2022 (–2.2 million t of CO₂ equivalents or –8.3 percent) and reached 24.4 million t, of which 6 million t were attributable to energy generation and 18.4 million t to industry. The reduction was mainly due to a decrease in industrial production (primarily in the areas of steel and pig iron, paper, chemical products and cement) and lower fuel

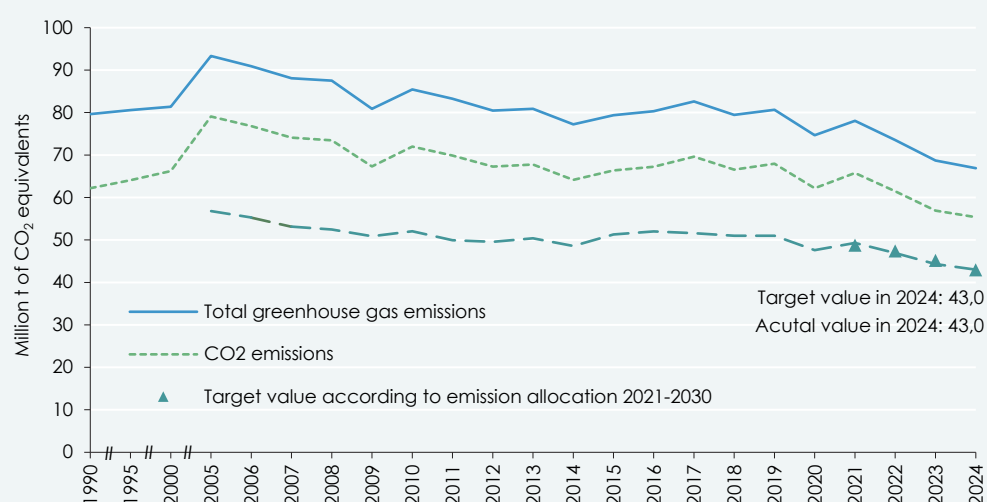
In 2023, Austria emitted fewer greenhouse gases than in the previous year, both in the EU emissions trading system and in the sectors regulated by the Climate Protection Act.

consumption in electricity, gas, steam and air conditioning supply.

In 2024, Austria's greenhouse gas emissions fell by 2.6 percent according to the latest data from the Environment Agency Austria's near-term forecast (Nowcast). Although the decline observed in previous years thus continued, it slowed noticeably¹.

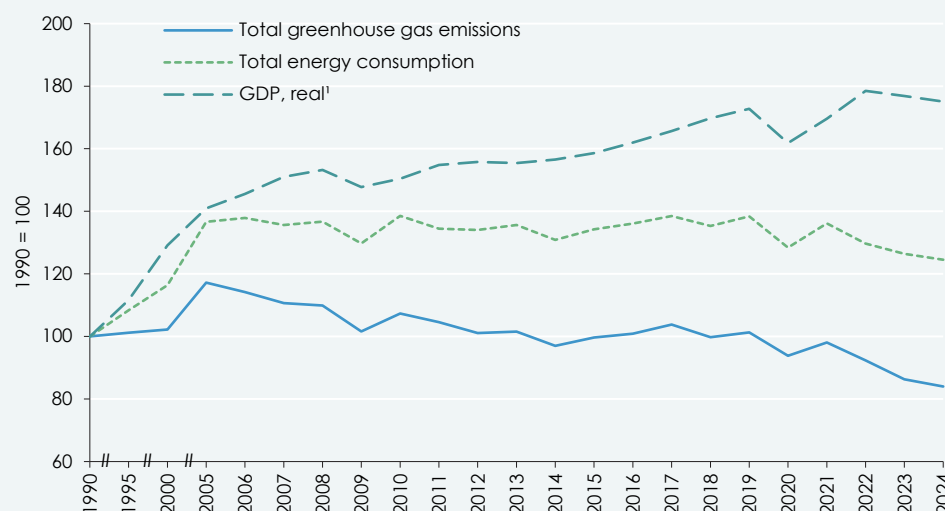
The same applies to emissions under the Climate Protection Act. According to Nowcast data, at 43 million t of CO₂ equivalents, these were exactly in line with the target set for 2024. However, at -2.9 percent, the decline here was also much lower than in the two previous years (2022 -4.9 percent and 2023 -5.5 percent).

Figure 2: Greenhouse gas emissions in Austria and Kyoto target



Source: Environment Agency Austria, greenhouse gas inventory 1990-2023. 2024: Environment Agency Austria, near-term forecast 2024.

Figure 3: Greenhouse gas emissions and growth in Austria



Source: Environment Agency Austria; Statistics Austria; WDS – WIFO Data System, Macrobond. 2024: Statistics Austria, preliminary energy balance 2024; Environment Agency Austria, near-term forecast 2024. – ¹ Reference year 2015.

¹ This is also reflected in WIFO's forecast of greenhouse gas emissions for the years 2024 to 2026 (Glocker & Ederer, 2025).

As the Austrian gross domestic product also shrank by 1 percent in 2024, the reduction in greenhouse gas emissions is not exclusively due to efficiency gains and the structural change in the energy system, but also to the weaker economic development. Energy consumption also fell only moderately by –1.5 percent in 2024 (2023 –2.5 percent; Figure 3). This is reflected in a slight decrease in energy-related emissions of 1 percent, a decline in process-related emissions of 2.4 percent and lower emissions from the transport sector (–2.7 percent). Compared to 2023, the decline in emissions intensity in relation to the total economy and in terms of energy consumption has therefore slowed.

1.3 Moderate decline in greenhouse gas emissions in most sectors

Greenhouse gas emissions fell in all sectors in 2023 (Figure 4). The highest relative decline was recorded in small-scale consumption (buildings and services) at 12.6 percent, which corresponds to a reduction of 1.0 million t of CO₂ equivalents to 10.6 percent of total emissions. The energy sector was also able to significantly reduce its emissions by –10.8 percent compared to the previous year. In absolute terms, emissions from

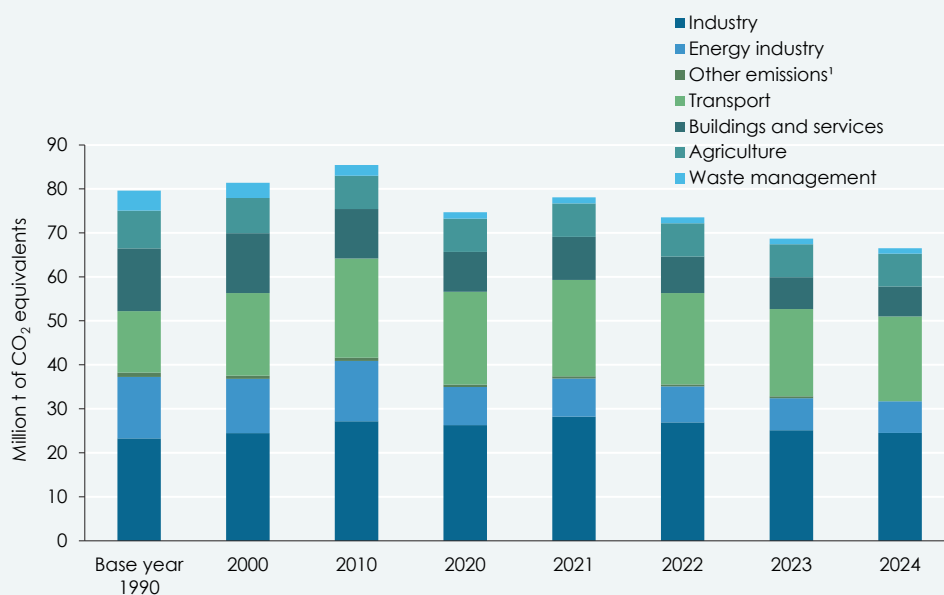
industry fell the most (–1.8 million t of CO₂ equivalents or –6.7 percent), although it remained the largest emitter with a share of over 36 percent. Emissions from the transport sector decreased by 0.9 million t of CO₂ equivalents (–4.4 percent) and accounted for 28.9 percent of total emissions. Since 1990, there has been an increase in emissions in industry (+8.0 percent) and transportation (+42.2 percent). By contrast, the other sectors have been able to reduce their emissions, in some cases significantly.

The sectoral picture is likely to be similar in 2024. According to the Environment Agency Austria's Nowcast data, however, the energy sector only recorded a decrease of 1 percent to 7.2 million t of CO₂ equivalents, increasing its share to 10.8 percent of total emissions. Small-scale consumption (–6.0 percent), industry (–2.4 percent) and the transport sector (–2.7 percent) were able to reduce their greenhouse gas emissions more significantly. Agriculture accounted for 11.1 percent of total emissions, with a slight upward trend, and waste management for 1.9 percent. Emissions in these sectors fell by 0.6 percent and 3.5 percent respectively compared to the previous year.

Although emissions continue to fall, the decline is slowing.

Small-scale consumption and transportation recorded the sharpest declines in emissions in 2024. Greenhouse gas emissions hardly fell at all in the energy sector.

Figure 4: Sources of greenhouse gas emissions in Austria



Source: Environment Agency Austria, Greenhouse Gas Inventory 1990-2023. 2024: Environment Agency Austria, Short-Term Forecast 2024. – ¹ Military, fluorinated greenhouse gases, CO₂ transport and storage.

1.4 Industrial emissions fall as production declines

Domestic industry once again emitted significantly fewer greenhouse gases in 2023 than in the previous year (–6.7 percent). However, their share of total emissions remained

almost stable at 36.5 percent (–0.1 percentage points). The decrease in emissions was due not least to the 4.6 percent decline in industrial gross value added at basic prices. Of the total of 25.1 million t of CO₂ equivalents, around 15.5 million t were attributable to process emissions, which fell by

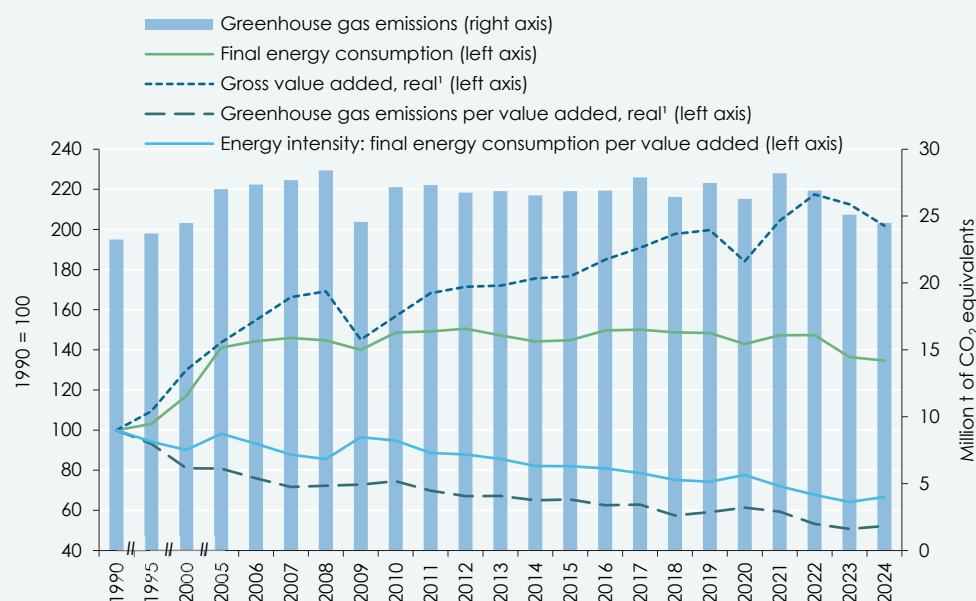
In industry, the decline in emissions continues, but is increasingly based on lower value added.

4.6 percent compared to the previous year – in particular due to lower steel production. Energy consumption in industry fell by 7.4 percent to around 291 PJ. This underlines the decoupling of energy consumption and emissions in the industrial sector, with emissions intensity decreasing by 4.5 percent and energy intensity by 5.3 percent in 2023 (Figure 5).

According to the Environment Agency Austria, industrial greenhouse gas emissions fell

by a further 2.4 percent to 24.5 million t of CO₂ equivalents in 2024, while gross value added at basic prices is likely to have shrunk more than twice as much at –5.0 percent. Energy consumption went down only slightly by 1.3 percent to around 287 PJ. As a result, both emissions intensity (+2.7 percent) and energy intensity (+3.9 percent) increased again. This indicates that the reduction in emissions in 2024 was driven more by weaker industrial activity than by efficiency gains.

Figure 5: Greenhouse gas emissions, energy consumption and gross value added of industry



Source: Environment Agency Austria; Statistics Austria; WDS – WIFO Data System, Macrobond. 2024: Statistics Austria, preliminary energy balance 2024; Environment Agency Austria, near-term forecast 2024. – ¹ Manufacturing companies including mining, at basic prices, reference year 2015.

1.5 Decrease in transport-related emissions continues

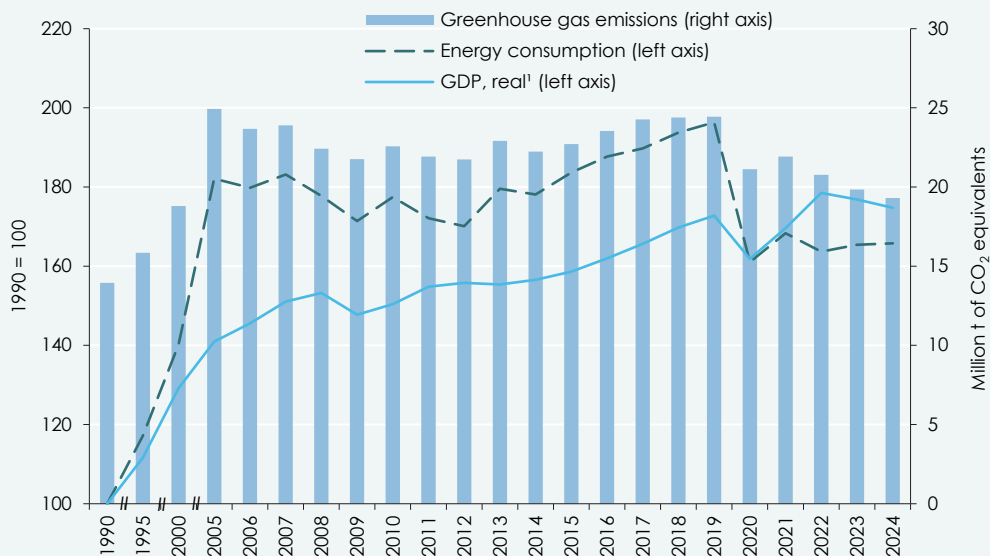
In 2023, emissions from the transport sector fell, while its final energy consumption increased slightly. These trends are likely to have continued in 2024.

Transport-related emissions fell by 4.4 percent to 19.8 million t of CO₂ equivalents in 2023, mainly due to the reduction in road traffic. Sales of diesel fuel decreased, particularly in exports with heavy commercial vehicles, while petrol sales gained slightly compared to 2022 (Environment Agency Austria, 2025a). The share of transportation in total emissions increased by 0.6 percentage points to 28.9 percent. At 345 PJ, final energy consumption in the transport sector was 1.1 percent higher than in the previous

year. The discrepancy between the development of emissions and final energy consumption continues to result from the fact that the consumption data includes international air traffic, while the emissions data does not.

A further decrease in transport-related emissions of 2.7 percent to 19.3 million t of CO₂ equivalent is forecast for 2024. Final energy consumption, on the other hand, is likely to have risen slightly by 0.2 percent to around 346 PJ. As a result, transportation's share of total emissions is expected to increase to 28.8 percent.

Figure 6: Greenhouse gas emissions and energy consumption of the transport sector and growth in Austria



Source: Environment Agency Austria; Statistics Austria; WDS – WIFO Data System, Macrobond. 2024: Statistics Austria, preliminary energy balance 2024; Environment Agency Austria, near-term forecast 2024. – ¹ Reference year 2015.

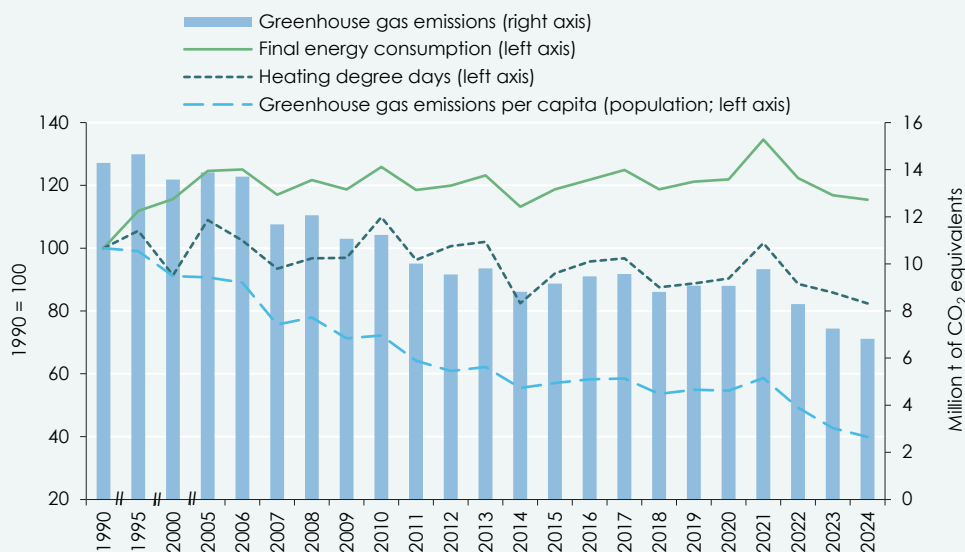
1.6 Greenhouse gas emissions from small-scale consumption continue to fall

In the private households, services and agriculture sectors, both final energy consumption and greenhouse gas emissions fell significantly in 2023. Final energy consumption was 4 percent lower than in the previous year. The majority of the reduction in consumption was attributable to space heating, for which, due to the lower number of

heating degree days, less energy was used (–3 percent), and price-related reductions in consumption. In the energy mix, the proportion of gas oil fell noticeably from 10 percent to 8 percent and that of natural gas moderately from 16.3 to 16 percent. The replacement of heating systems is likely to have played a role in this. As a result, direct greenhouse gas emissions from fossil sources dropped by 13 percent.

The share of gas oil used for heating purposes in small-scale consumption fell significantly in 2024.

Figure 7: Greenhouse gas emissions of buildings, energy consumption of private households, services and agriculture as well as the number of heating degree days



Source: Environment Agency Austria; Statistics Austria. 2024: Statistics Austria, preliminary energy balance 2024; Environment Agency Austria, near-term forecast 2024.

In 2024, final energy consumption and greenhouse gas emissions fell for the third year in a row. At 393 PJ, final energy consumption was 5 PJ (1.2 percent) lower than in 2023. This decline is unexpectedly weak, especially as the number of heating degree days was over 4 percent lower and the majority of energy (2023: 77 percent) is used to generate space heating. Lower energy prices may have played a role here.

In terms of energy sources, the use of gas oil for heating purposes (–5 PJ), biomass (–3 PJ), natural gas (–0.3 PJ) and district heating (–0.2 PJ) in particular decreased. An increase was recorded in the area of ambient heat (+1.8 PJ). The use of gas oil thus declined significantly by over 16 percent, while the use of natural gas decreased moderately by 0.5 percent. As a result, direct greenhouse gas emissions from fossil sources fell by 6 percent to 6.8 million t of CO₂ equivalents; per capita emissions shrank by 6.5 percent (Figure 7).

1.7 Greenhouse gas emissions from public electricity and district heating generation stagnate

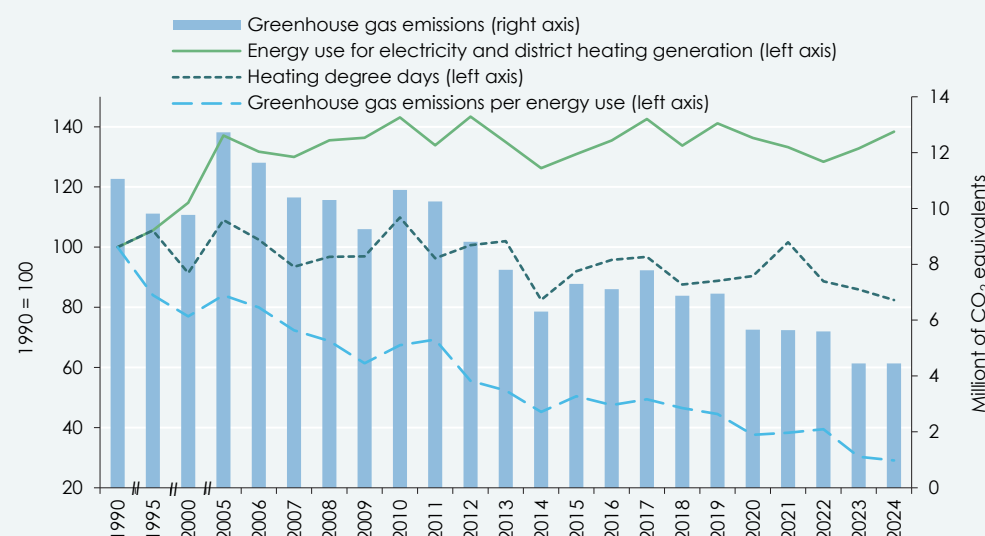
Public electricity generation in Austria rose to 228 PJ (+22 PJ) in 2023, with hydropower contributing in particular (+17 percent or +22 PJ) after the below-average previous year. More electricity was also generated from photovoltaics (+69 percent or +9 PJ) and wind power (+11 percent or +3 PJ), while the generation of electricity from natural gas fell by 33 percent (–11 PJ). Public

district heating generation totalled 67 PJ in 2023 and fell by 7 percent (–5 PJ) compared to the previous year, more significantly than the number of heating degree days (–3 percent). Price-related savings are also likely to have played a role here.

In 2024, domestic public electricity generation reached a new high of 282 PJ (+28 PJ) according to the preliminary energy balance. Increases in the areas of hydropower (+18 PJ or +11 percent), wind power (+4.4 PJ or +13 percent) and photovoltaics (+4.5 PJ or +16 percent) in particular contributed to this. A large part of the increase was channelled into net exports (+24 PJ), as domestic demand only grew slightly (+3 PJ or +1.5 percent compared to the previous year). In contrast, the generation of electricity from natural gas by public electricity, gas, steam and air conditioning supply declined slightly by –5 percent (–1 PJ; ENTSO-E). District heating generation totalled 79 PJ in 2024 and was therefore only slightly below the previous year's level (–0.8 percent), although the number of heating degree days fell by over 4 percent. One possible explanation is lower price-related savings than in 2023. As a result of the significant increase in electricity generation, aggregated domestic energy input increased by an estimated 4 percent. Greenhouse gas emissions from public electricity and district heating generation stagnated at the previous year's level in 2024, presumably due to a slightly higher use of natural gas and oil in district heating generation (Figure 8).

Electricity production from renewable sources increased significantly in 2024.

Figure 8: Greenhouse gas emissions and energy use for electricity and district heating generation by energy supply companies



Source: Environment Agency Austria; Statistics Austria; WDS – WIFO Data System, Macrobond. 2024: Energy input according to WIFO estimate based on the preliminary energy balance; emissions according to Environment Agency, 2024 near-term forecast.

1.8 Austria was once again a net exporter of electricity in 2024

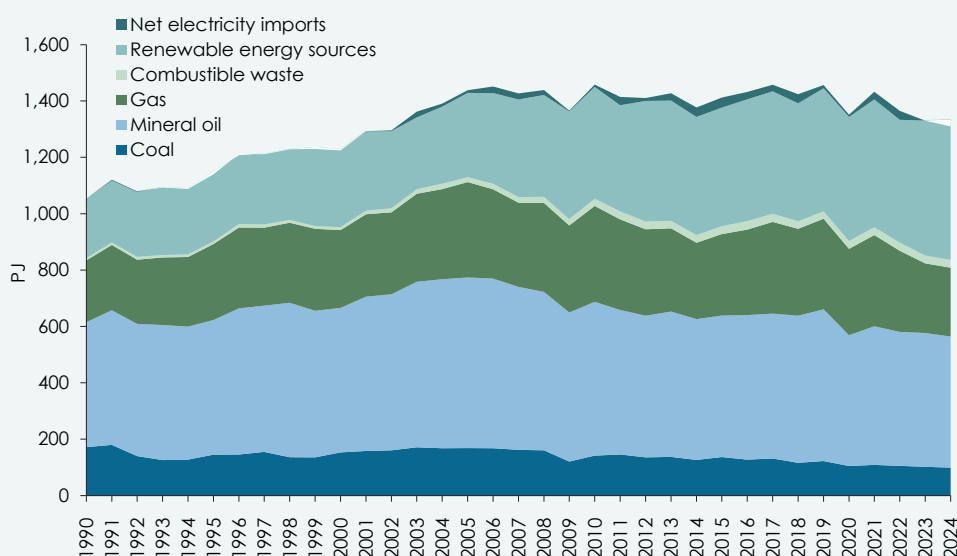
After an increase in gross domestic energy consumption of 6 percent in 2021, Austria's energy consumption fell in the two following years (2022 –4.7 percent, 2023 –2.5 percent). The forecast value of the preliminary energy balance for 2024 implies a continuation of the downward trend (–1.5 percent to 1,310 PJ). Essentially, the ongoing economic downturn, but also the replacement of gas heating systems and a lower number of heating degree days led to a decline in the consumption of coal, oil and gas. The significant reduction in the price of natural gas resulted in a slight decline in gas consumption in 2024 only (–1 percent, 2023 –14.5 percent). Due to the ongoing expansion of

renewable energy production capacities, Austria was once again a net exporter of electricity in 2024. The most significant positive balance since 1990 was 24 PJ (2023: 258 TJ).

In terms of volume, energy consumption from fossil sources is likely to have fallen by a total of 14 PJ in 2024, while that from renewable sources is expected to have increased by 19.8 PJ. This means that the share of fossil energy in total consumption fell by 0.2 percentage points to just under 62 percent. However, there is still a great need for action in order to achieve the Austrian goal of climate neutrality by 2040 and the European climate targets, also against the backdrop of a possible economic upturn in the following years.

The ongoing economic downturn led to a decline in gross domestic energy consumption in 2024.

Figure 9: Gross domestic consumption by energy source in Austria



Source: Statistics Austria, energy balance 1970-2023. 2024: preliminary energy balance 2024.

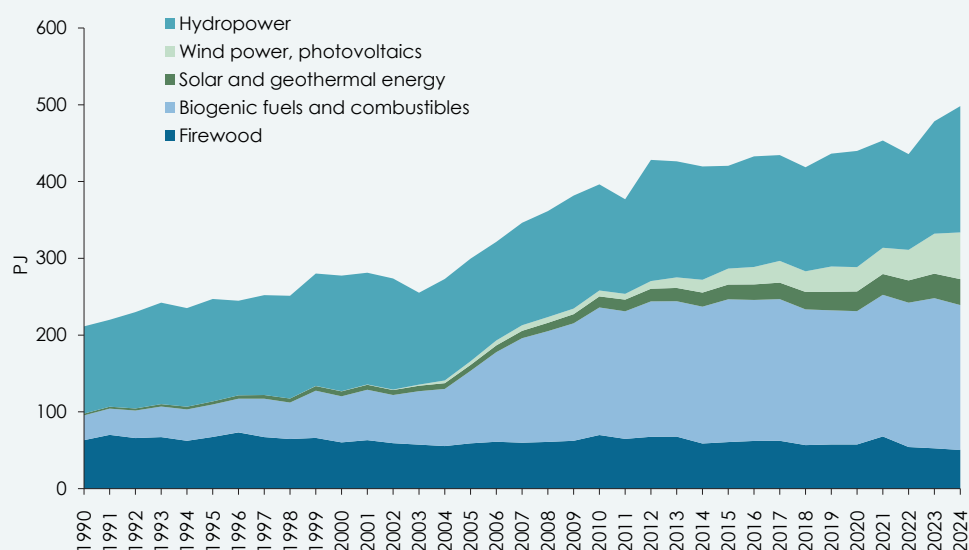
1.9 Gross domestic consumption from renewable sources continues to rise

According to the Nowcast, gross domestic energy consumption covered by wind power and photovoltaics is expected to grow by 17 percent in 2024 (2023 +31 percent), while that from solar and geothermal energy increased by 5.5 percent (2023 +10.3 percent). According to preliminary data, total gross domestic consumption from renewable sources rose by 4.1 percent in 2024 (2023 +9.8 percent), which represents a slowdown in expansion dynamics. Bio-genic fuels and combustibles remained the most important renewable energy sources in

2024, accounting for 37.9 percent of gross domestic energy consumption, although the amount used decreased by 3.5 percent compared to the previous year. This was followed by hydropower with 33 percent, wind power and photovoltaics with 12.2 percent and woodfuel with 10.1 percent of gross domestic consumption. The share of solar and geothermal energy remained fairly stable at 6.8 percent. The continuing increase in the importance of renewable energy sources underlines the sustainable trend towards decarbonisation, although average annual growth has slowed from 3.6 percent (2000-2010) to 2.2 percent (2011-2024) in the long term.

Gross domestic energy consumption from wind power and photovoltaics as well as solar and geothermal energy grew only moderately in 2024 compared to the previous year.

Figure 10: Gross domestic consumption of renewable energy sources



Source: Statistics Austria, energy balance 1970-2023. 2024: preliminary energy balance 2024.

Austria's income from electricity exports fell in 2024, although significantly more electricity was exported in terms of volume.

1.10 Further improvement in foreign trade balance for energy

At 13.4 billion €, the value of energy imports in 2024 was almost a quarter lower than in the previous year, reflecting the decline in energy prices. The amount of imported energy remained almost constant (2024: 1,050 PJ, 2023: 1,045 PJ). The most significant decreases were in expenditure on imported

heating oil (–49 percent), natural gas (–42 percent) and electricity (–38 percent), with the imported quantities of heating oil and electricity decreasing by 36.5 percent and 12.2 percent respectively and natural gas increasing by around 5 percent. The 23 percent reduction in expenditure on energy imports is therefore mainly due to price changes.

Table 1: Foreign trade in energy sources

	Exports				Imports				Balance							
	2015	2022	2023	2024	2015	2022	2023	2024	2015	2022	2023	2024				
	Million €															
Coal	1.8	2.1	25.0	4.8	475	1,347	1,060	617	–	473	–	1,345	–	1,035	–	612
Crude oil	0.0	0.0	0.0	0.0	3,097	3,647	4,437	4,458	–	3,097	–	3,647	–	4,437	–	4,458
Heating oil	121.0	0.0	0.0	0.0	33	87	41	21	+	88	–	87	–	41	–	21
Petrol	476.5	555.2	638.1	569.9	499	1,043	685	642	–	23	–	488	–	47	–	72
Diesel fuel	477.9	717.4	858.7	736.4	2,177	6,168	4,093	3,432	–	1,699	–	5,450	–	3,234	–	2,695
Natural gas	314.6	1,016.6	720.1	280.0	2,701	9,207	5,027	2,858	–	2,387	–	8,191	–	4,307	–	2,578
Electricity	856.9	4,506.6	4,159.0	2,850.2	1,103	4,574	2,181	1,349	–	246	–	67	+	1,978	+	1,501
Total	2,249	6,798	6,401	4,441	10,085	26,074	17,522	13,376	–	7,836	–	19,276	–	11,121	–	8,935
PJ																
Coal	0.3	0.0	0.0	2.6	119.4	105.3	104.0	101.3	–	119.1	–	105.3	–	104.0	–	98.7
Crude oil	0.0	0.0	0.0	0.0	344.6	218.3	321.6	324.7	–	344.6	–	218.3	–	321.6	–	324.7
Heating oil	21.6	11.2	16.3	17.2	0.5	1.6	0.1	0.1	+	21.1	+	9.6	+	16.3	+	17.1
Petrol	38.6	23.6	27.8	28.1	33.3	32.4	28.5	29.7	+	5.3	–	8.9	–	0.7	–	1.6
Diesel fuel	34.0	25.1	36.6	35.5	155.6	190.1	153.2	148.7	–	121.6	–	165.0	–	116.6	–	113.2
Natural gas ¹	49.4	69.8	72.1	43.9	454.4	524.6	359.6	377.3	–	405.0	–	454.9	–	287.4	–	333.4
Electricity	69.6	71.6	77.8	92.5	105.8	102.9	77.6	68.1	–	36.2	–	31.3	+	0.3	+	24.4
Total	213.4	201.2	230.7	219.8	1,213.6	1,175.3	1,044.6	1,049.9	–	1,000.2	–	974.1	–	813.8	–	830.0

Source: Statistics Austria, energy balance 1970-2023, preliminary energy balance 2024, foreign trade statistics; WDS – WIFO Data System. – ¹ Natural gas transit through Austria is no longer shown in the current energy balance. The values printed here for the import and export of natural gas are taken from the foreign trade statistics and also include transit.

Net energy imports increased by 2 percent in 2024. At the same time, financial outflows decreased by around 19 percent; however, the foreign trade balance for energy remained negative in 2024 in value terms (–8.9 billion €; Table 1).

The need for energy imports is therefore still associated with high financial outflows abroad. In addition to a diversification of supply sources and the rapid expansion of renewable energy sources, the utilisation of efficiency potential also plays an important role in becoming less dependent on foreign suppliers and strengthening energy security.

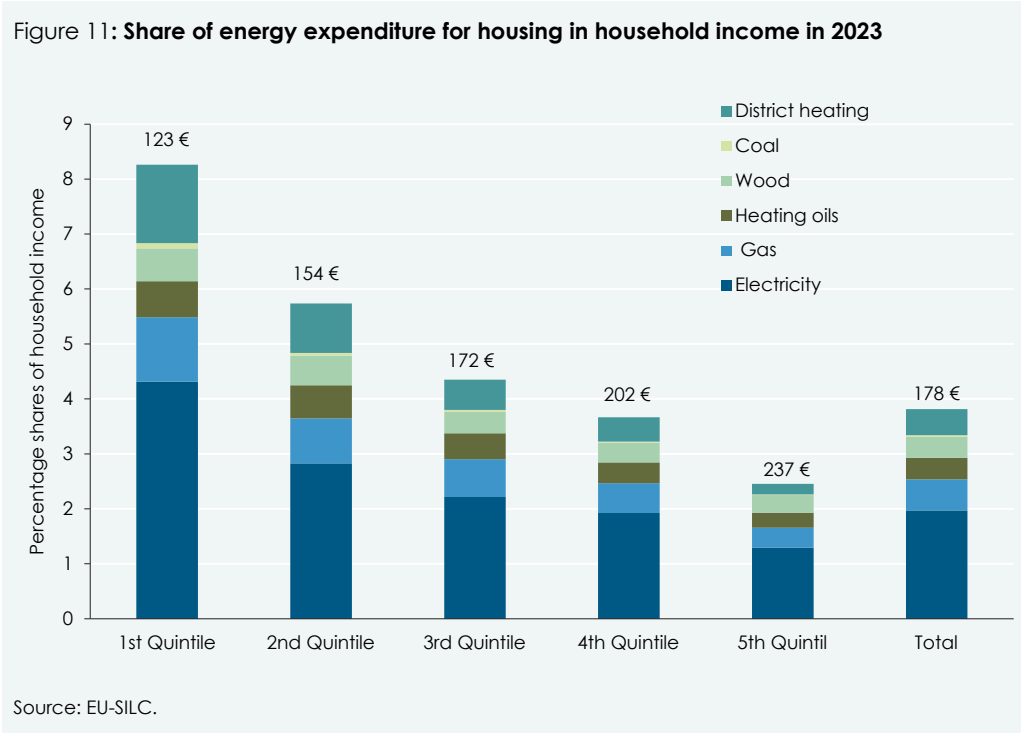
1.11 Energy remains a significant cost factor for private households

In 2023 – more recent data is not yet available – the average monthly energy expenditure of private households rose to 178 €, an

increase of around 24 percent compared to the previous year (143 €). The mild winter and continued economical energy consumption only partially offset the higher prices. The slight decline in the share of energy expenditure in household income to an average of 3.4 percent (–0.1 percentage points compared to 2022) is noteworthy. It can be attributed to volume increases in income.

The burden nevertheless remained high in the lowest income quintile: here, energy expenditure as a share of household income amounted to 8.3 percent and was thus once again well above the average. Private households with low incomes therefore continue to spend an above-average proportion of their budget on energy. Measures to improve energy efficiency are particularly important for these groups in order to reduce the cost burden in the long term.

Energy expenditure on housing rose again in 2023, despite a declining share of income.



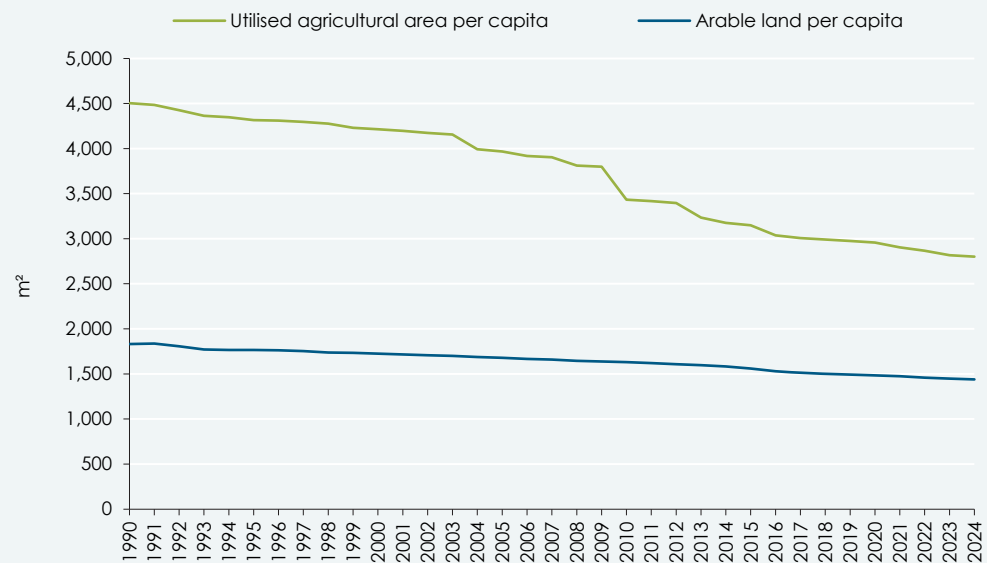
2. Agricultural production and nitrogen balance in Austria

Agriculture and forestry are more dependent on the environment and the use of natural resources than almost any other sector. In addition to its central role in food security through the production of food and animal feed, agriculture provides numerous ecosystem services. For example, it contributes to climate stability (Meyer et al., 2023) and the preservation of biodiversity by building up carbon in living biomass and soils.

In 2024, around 31 percent (2,571,000 ha) of Austria's land area was used for agriculture.

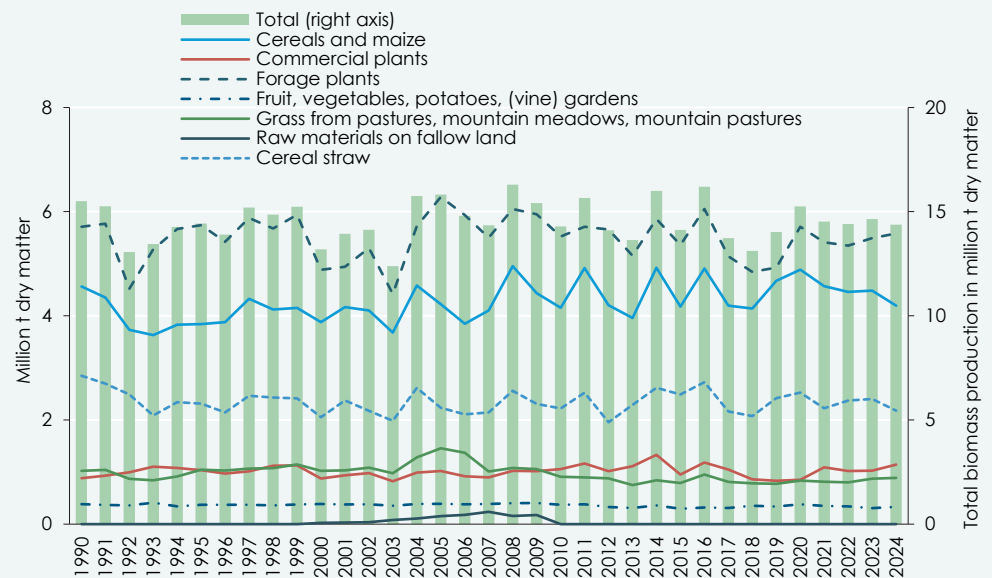
Of this, 1,320,800 ha (51.4 percent) was arable land and 1,182,000 ha (46.0 percent) was permanent grassland. The remainder was made up of permanent crops, and home and kitchen gardens. Since 1990, the cultivated arable land in Austria has decreased by around 85,600 ha (6 percent). This left 2,801 m² per person available for food production, meaning that the cultivated area was more than a third smaller than in 1990 (Figure 12).

Figure 12: Development of agricultural area per capita



Source: Statistics Austria (various years), cultivation on arable land, field crop harvest.

Figure 13: Production of economically usable biomass by agriculture in Austria



Source: Statistics Austria (various years), cultivation on arable land, field crop harvest; WIFO calculations based on Buchgraber et al. (2003); DLG forage value table; Resch (2007). Straw is a by-product of cereal production (excluding maize); a standardised grain/straw ratio of 1 : 0.9 is assumed. Loss factors for fodder production according to Buchgraber et al. (2003).

In view of stagnating yields per hectare and population growth, the constant reduction in agricultural land is jeopardising food security.

Although the production of biomass on arable land is not following the declining trend in arable land due to slightly increasing yields per hectare and the expansion of maize production, it has largely stagnated for decades (Figure 13) with weather-related fluctuations. This is particularly problematic in view of the increase in demand as a result of population growth (Statistics Austria, 2024a). If dietary behaviour remains

unchanged, domestic agriculture will make an increasingly smaller contribution to food security, which will heighten dependence on imports.

Sufficient availability of nutrients such as nitrogen, phosphorus and potassium is of central importance for soil fertility and the production of biomass as food and animal feed, and as a raw material for industrial

applications. Nutrients are removed from the soil when the crop is harvested. For high crop yields, it is therefore necessary to replace these nutrients with fertilisers. Easily soluble mineral or organic fertilisers (e.g. farm manure, compost) are used as fertilisers. However, excessive fertilisation has a negative impact on the environment. Nutrients that are not absorbed by plants can enter ground and surface waters or – particularly in the case of nitrogen fertilisers – escape into the atmosphere in gaseous form.

The nitrogen balance according to the method developed by the OECD and modified by Eurostat (Figure 14; OECD & Eurostat, 2013) takes into account not only fertilisers but also the synthesis of atmospheric nitrogen via the root system of plants and atmospheric deposition. The resulting nutrient inputs are compared with the removal by the harvested crop. If the balance is positive, more nitrogen is added to the agricultural

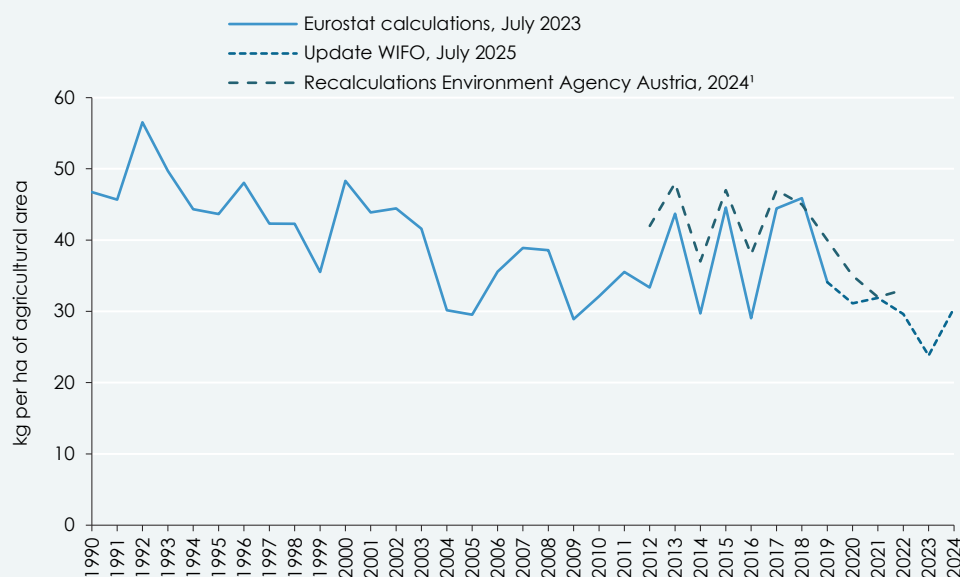
cycle than is removed. As the balance surplus increases, so does the risk of undesirable side effects. A reduction in mineral fertilisation is positive for the environment and often also associated with economic benefits.

The amount of nitrogen fertiliser applied in Austria has been falling slightly since 1990. On the one hand, the annual fluctuations are due to the unpredictable nutrient requirements of crops at the time of fertilisation. On the other, the statistics record the quantities sold on the market and not the quantities actually applied.

In the current balance sheet, it is noticeable that the nitrogen surplus per hectare of agricultural land again increased significantly in 2024, as more mineral fertiliser was applied. In previous years, the use of mineral fertilisers had decreased significantly in some cases due to inflation.

Nitrogen (fertilisation) is necessary to ensure high yields in the long term, but is also a significant source of emissions.

Figure 14: **Nitrogen balance**



Source: Eurostat, gross nutrient balance 1990-2019 (data retrieved on 22 August 2025, data as of 19 August 2025); Environment Agency Austria (2024). Austrian nitrogen and phosphorus balance in agriculture according to Eurostat specifications; WIFO calculations. – ¹ Recalculation for the years 2000 to 2022 on behalf of the Federal Ministry of Agriculture, Forestry, Regions and Water Management using new nutrient coefficients relevant for Austria.

3. Special topic: the role of grid-scale battery storage in the energy transition

3.1 Introduction

The Austrian electricity industry is undergoing a far-reaching transformation in order to be able to cover 100 percent of domestic electricity demand from renewable sources by 2030 (in accordance with the Renewable Energy Expansion Act – EAG). This energy transition will be realised through the market entry and expansion of new technologies,

which will gradually replace older emission-intensive technologies such as thermal power plants. In particular, wind power and photovoltaic systems (PV systems) must be significantly expanded in order to achieve the climate targets. The resulting technology mix determines the generation costs and therefore the price level and CO₂ emissions. However, politically prescribed expansion targets do not necessarily lead to a cost-

Battery storage and photovoltaic systems can increase each other's value and make the energy transition more cost-efficient.

efficient technology mix (while complying with CO₂ targets and ensuring security of supply). It is therefore important to create a

legislative and regulatory framework in which new technologies can enter the market without redistributive subsidies².

The role of large-scale battery storage systems in the energy transition

Large-scale battery storage systems are of central importance for the success of the energy transition. They help to solve one of the biggest challenges: the fluctuating availability of electricity from wind power and photovoltaics. By temporarily storing surplus energy when the sun is shining or the wind is strong and releasing it back into the grid when demand is high or there is a lull, they increase the stability of the electricity grid and make the electricity supply more secure. This balancing mechanism can make the further expansion of renewable energies more cost-efficient and limit the need for expensive grid expansion.

Important terms

Large-scale battery storage systems are large, stationary battery systems that store electrical energy chemically. They can react quickly to fluctuations in the electricity grid.

Pumped storage power plants are a traditional form of energy storage in Austria. They pump water into an elevated reservoir when electricity is cheap and release it through turbines to generate electricity when needed. Although they fulfil a similar function to batteries (storing electricity and releasing it when needed), they are treated as a separate technology in this article.

Two-hour and four-hour storage systems describe the storage capacity of a battery in relation to its maximum output. A four-hour storage system can deliver its maximum output over a period of four hours before it is empty. For example, a storage system with 10 megawatts (MW) of power and a capacity of 40 megawatt hours (MWh) can feed 10 MW of electricity into the grid for four hours. Two-hour storage systems can supply their maximum output for two hours accordingly.

Major technological advances have been made in battery storage systems in recent years. From an economic point of view, there are good arguments in favour of battery storage and PV systems being complementary technologies, i.e. mutually increasing their value. On the one hand, PV systems increase the value of storage systems because their fluctuating production generates price cycles that create arbitrage opportunities for batteries. On the other hand, batteries increase the value of PV systems by storing cheap photovoltaic electricity at midday, which can be sold at higher prices in the evening. As a result, prices rise at midday and fall in the evening, which can lead to lower average prices. In certain evening hours, thermal power plants remain switched off, which avoids CO₂ emissions, variable costs, and ramp-up costs. Storage systems also allow PV system operators³ to extend the time frame in which they can offer their electricity on the market, reducing the need for midday feed-in restrictions. Another complementary technology is the transmission grid. In high-capacity lines, cheap photovoltaic electricity can flow across Europe to areas where prices are higher (e.g., due to different weather conditions). At the same time, battery storage can supplement or replace grid expansion by their strategic placement at critical grid points.

Investments in such complementary technologies make it more likely that the politically desired expansion of photovoltaics and wind power will take place to a sufficient extent even without subsidies. This is because there is a cannibalisation effect with PV systems: more photovoltaics reduces prices when the sun is shining, until the price even become negative and PV systems have to be curtailed in order to ensure grid stability. In this context, battery storage systems also increase the value of individual PV systems because they raise the price of electricity due to the additional demand at midday. This means that additional photovoltaic capacities can be economically viable even without government subsidies. Conversely, batteries can partially substitute photovoltaics: if storage systems discharge in the late afternoon while PV systems are still feeding into the grid, this lowers the electricity price and thus the profitability of the PV systems. As soon as the battery fleet is large enough to measurably influence prices, it can thus partially reduce the value of PV systems again.

3.2 Potential of battery storage systems

Developments on the electricity market and the expansion of photovoltaics in recent years have created an environment that

² This refers to government subsidies that provide financial support for certain technologies (such as photovoltaics or battery storage) in order to accelerate their market entry and expansion. These subsidies are often financed from general tax revenues or via levies on the electricity price and thus lead to redistribution.

³ In the article, the term includes both profit-oriented commercial players (e.g., operators of large solar parks) who trade electricity on the market and private system operators. The latter reduce the amount of electricity purchased from the grid through their own consumption, which has an impact on the general demand profile on the electricity market.

favours arbitrage via electricity storage systems.

Figure 15 (first graph) shows the median hourly electricity demand (load) in Austria. Demand is high in the morning and evening and lower at midday. At night, it was slightly lower in 2024 than in 2019, possibly due to energy-saving measures and the recession. During the day, however, the demand profile has changed. While it was relatively flat in 2019, there were two pronounced peaks at around 8 a.m. and 6 p.m. in 2024. The curve can be explained by the electricity production of PV systems (Figure 15, second graph). This peaks at midday. The PV systems producing for self-consumption reduce demand, especially at midday. This results in greater fluctuations over the course of the day. The second graph also shows the significant increase in photovoltaic capacity compared to 2019, with more photovoltaic electricity being generated in winter 2024 than in summer 2019, even in 50 percent of the midday hours.

Figure 15 (third graph) shows the residual load, i.e. the electricity demand after deducting the production of run-of-river power plants, wind turbines, biomass and PV systems. The residual load also fluctuated more significantly in 2024 than in 2019. As a result, it can now often be optimal for gas-fired power plants to stop producing during the day, but this means that the costs of ramping up in the evening are added to the marginal generation costs. The residual load is mainly covered by storage hydropower plants, gas-fired power plants and electricity imports. These technologies have relatively high marginal costs, which leads to high electricity prices, as can be seen from the electricity exchange price (Figure 15, fourth graph). Despite lower demand, the electricity price in 2024 was significantly higher than in 2019 due to the higher natural gas price, increased CO₂ prices, but also higher costs for restarting thermal power plants (and possibly greater market power) in the evening (Jha & Leslie, 2025). The price peaks in the morning (at around 7:00 a.m.) and in the evening (at around 7:00 p.m.) are pronounced. In the five-year interval in 2024, the variability of electricity prices was higher both over the course of the year (due to a higher difference between the 3rd and 1st quartile) and over the course of the day.

Figure 15 illustrates the complementarity of photovoltaics and battery storage: the expansion of photovoltaics reinforces the price cycles and makes arbitrage lucrative. On the other hand, batteries allow PV systems to participate in the high electricity prices in the evening and raise prices at midday. In

contrast, there is no complementarity with inflexible base load technologies such as run-of-river and nuclear power: their low marginal costs and constant production smooth out prices and thus reduce arbitrage opportunities. If, on the other hand, evening demand peaks are covered by gas-fired power plants that can be ramped up quickly, large-scale battery storage systems are more of a substitute. This raises the scientifically and economically relevant question of the "optimal" size of the battery fleet.

3.3 Current research results

In July 2025, the Austrian transmission system operator Austrian Power Grid (APG), Photovoltaic Austria, Graz University of Technology and d-fine published a joint study that forecasts the demand for battery storage and calculates the optimal amount of battery storage to minimise costs (Wiedner et al., 2025). In the model, battery storage systems with a total of 8.7 GW (including 2.7 GW of large and 6 GW of small storage systems) minimise the total costs. In addition, there are pumped storage power plants, which play a similar role to battery storage.

The APG model is based on the assumption that the capacities of battery storage systems are fully used and that the operators behave in a "system- and grid-friendly" manner. However, even with perfect competition, the price-taking storage operators, who are geared towards maximising profits, will not always make their entire capacity available. It is also not clear which capacities will enter the market without subsidies. An equilibrium model is required to understand how profit-maximising storage operators act on a market.

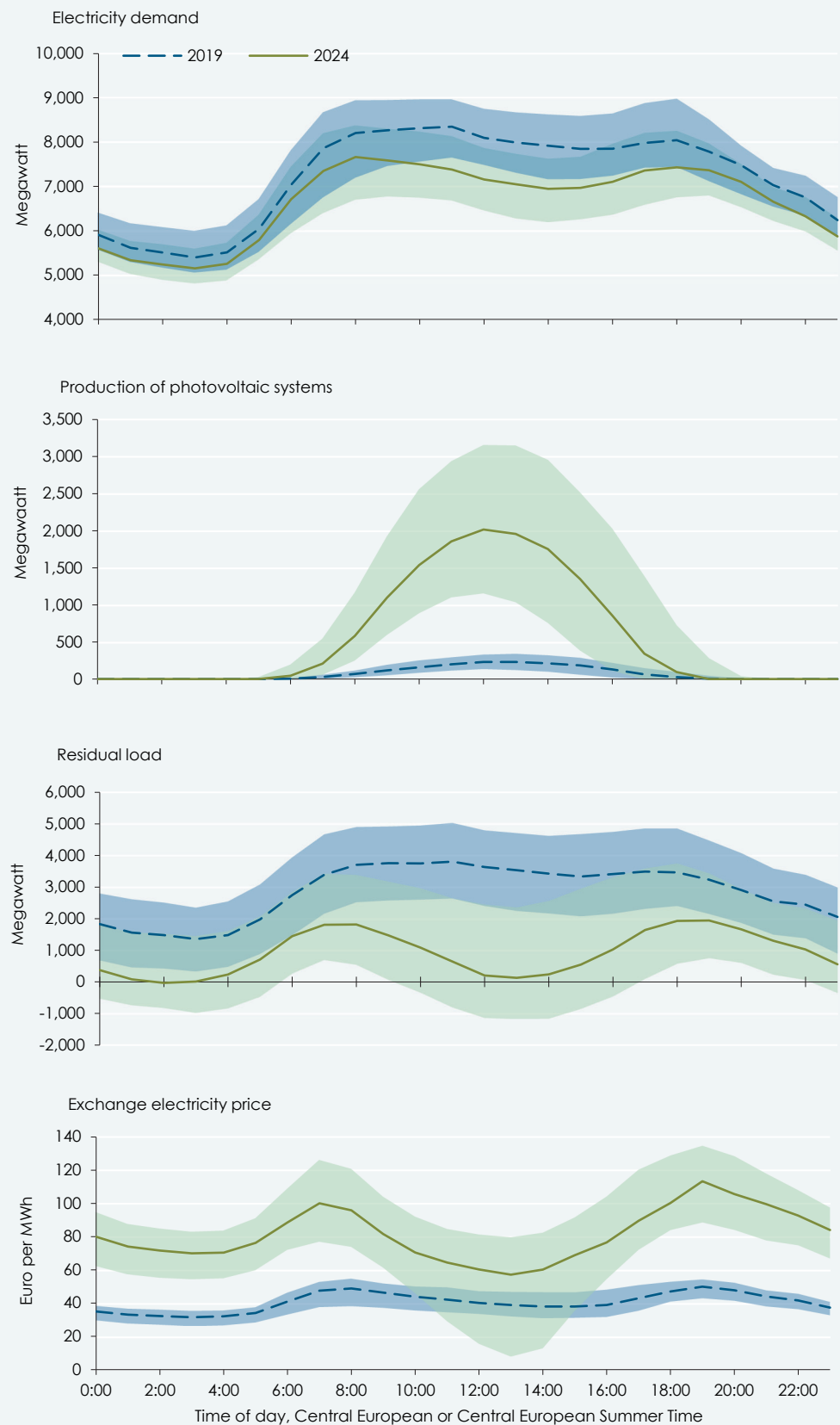
Butters et al. (2025) develop and analyse a dynamic equilibrium model based on data from California. In the model, price-taking storage operators optimise their purchases and sales over the course of the day. In equilibrium, the influence of the installed storage capacity on the electricity price decreases sharply. The first 5,000 MWh of battery storage reduce the average electricity price by 5.6 percent. An expansion from 25,000 MWh to 50,000 MWh, on the other hand, only reduces the price by 2.6 percent. Thermal power plants tend to shift the start of their production from 19:00 to 20:00. Battery storage reduces the profits of thermal power plants, but also those of PV systems, as battery storage feeds into the grid in the late afternoon and thus reduces the electricity price while PV systems are still producing.

The massive expansion of photovoltaics in recent years has significantly increased the daily fluctuations in electricity prices – and thus created a lucrative environment for battery storage systems.

The more storage capacity is installed, the smaller the additional price-dampening effect will be.

Figure 15: **Daily profiles of the Austrian electricity market**

Median, hourly



Source: ENTSO-E Transparency Platform; WIFO calculations. Annual average values. The coloured shading indicates the range between the first and third quartile.

In a second step, Butters et al. (2025) analyse optimal entry decisions in which investors compare the expected profits with the capital costs and the expected cost reduction of photovoltaics alone does not ensure that a significant number of batteries enter the market. A subsidy of 30 percent, as provided for in the "Inflation Reduction Act", was expected to increase the installed storage capacity in California to 5,000 MWh by 2030. In reality, the state already had 15,763 MW of battery storage capacity in May 2025, including around 2,500 MW behind the meter. This meant that there was approximately 13.3 GW of large-scale storage, which corresponded to an energy capacity of around 53 GWh for typical four-hour batteries (around 26.5 GWh for two-hour batteries). This strong expansion was achieved through regulatory measures and subsidies.

The results for California cannot be directly transferred to Austria, as the climatic conditions are different, Austria is integrated into the European electricity market and already has significant storage hydropower plants. According to a scaling based on population size, the 5,000 MWh from Butters et al. (2025) would correspond to around 1,125 MWh in the case of Austria – however, this is a rough estimate and not a forecast. One gigawatt hour of storage capacity would therefore reduce the average electricity price by 5 percent. By way of comparison, the maximum capacity of Austrian pumped storage power plants is currently 3,512 MW (ENTSO-E Transparency Platform). A decreasing price effect with increasing storage capacity is also to be expected for Austria.

In the model by Andrés-Cerezo and Fabra (2023), the welfare-maximising battery storage capacity was selected in such a way that the total costs are minimised by the additional reduction in marginal electricity generation costs corresponding to the investment costs. In this case, the marginal costs and thus the electricity prices are not completely flat throughout the day, as the costs for additional storage units would have to be zero. Therefore, the costs for storage determine the price fluctuations. Andrés-Cerezo and Fabra (2023) also analysed the

influence of the market power of electricity producers. In times of high demand, this is exercised more strongly, causing prices to rise disproportionately in the early morning and evening, for example. Relative to the case without market power, this results in higher investments in storage facilities. With market power, the price peaks are smoothed out less by batteries, as the operators anticipate the effect of their own actions on prices.

3.4 Regulatory considerations

As battery storage systems can smooth and reduce electricity prices and accelerate the expansion of PV systems, it makes sense to accelerate the expansion of storage capacities. However, in order to realise the full potential of battery storage systems, it is important to consider aspects of competition economics. For example, Andrés-Cerezo and Fabra (2023) discuss the case where the PV systems and the batteries have the same owner. In this case, the storage operator also considers how the operation of the storage system affects the profits of the power plant. This can lead to low welfare.

At grid level, grid connection procedures must be transparent and swift. If batteries are positioned in the right places, this can limit or reduce the cost of the necessary grid expansion. The framework conditions for grid connection procedures in Austria are organised by E-Control. Within this framework, the grid operator (e.g. APG) checks the technical feasibility. The location of a storage facility is approved by local and regional authorities, whereby the grid operator must agree to the connection.

It also makes sense to allow operators of photovoltaic and wind power plants to retrofit batteries at their grid point. In general, new PV systems should be supplemented with batteries wherever possible in order to optimise their operation on the one hand and to make the best possible use of the grid connection on the other. In California, energy companies have been given a mandatory procurement target for storage (Butters et al., 2025). This would also be an option for Austria.

A cleverly designed regulatory framework emphasises the potential of battery storage and makes it possible to limit or postpone grid expansion in a targeted manner.

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