ISPRA
Istituto Superiore per la Protezione e la Ricerca Ambientale

Sistema Nazionale per la Protezione dell'Ambiente

Efficiency and decarbonization indicators in Italy and in the biggest European Countries. Edition 2023

RAPPORTI
386/2023

ISPRA
Istituto Superiore per la Protezione e la Ricerca Ambientale

Sistema Nazionale per la Protezione dell'Ambiente

Efficiency and decarbonization indicators in Italy and in the biggest European Countries. Edition 2023

RAPPORTI
386/2023

Informazioni legali
L'Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), insieme alle 21 Agenzie Regionali (ARPA) e Provinciali (APPA) per la protezione dell'ambiente, a partire dal 14 gennaio 2017 fa parte del Sistema Nazionale a rete per la Protezione dell'Ambiente (SNPA), istituito con la Legge 28 giugno 2016, n.132.

Le persone che agiscono per conto dell'Istituto non sono responsabili per l'uso che può essere fatto delle informazioni contenute in questa pubblicazione.

ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale
Via Vitaliano Brancati, 48 – 00144 Roma
www.isprambiente.gov.it

ISPRA, Rapporti 386/2023
ISBN 978-88-448-1161-7

Elaborazione grafica
Grafica di copertina: Alessia Marinelli - ISPRA – Area Comunicazione Ufficio Grafica
ISPRA – Area Comunicazione

Coordinamento pubblicazione online:
Daria Mazzella
ISPRA – Area Comunicazione

05 maggio 2023

Autori

Antonio Caputo

Contatti:

Antonio Caputo

Tel. 0650072540
e-mail antonio.caputo@isprambiente.it
Area VAL-ATM
Sezione scenari di emissione, modelli integrati e indicatori

“If one tells the truth, one is sure, sooner or later, to be found out.”
Oscar Wilde, Epigrams.

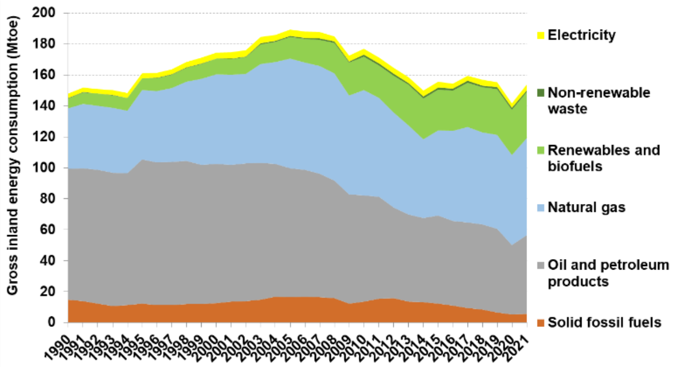
INDEX

EXECUTIVE SUMMARY

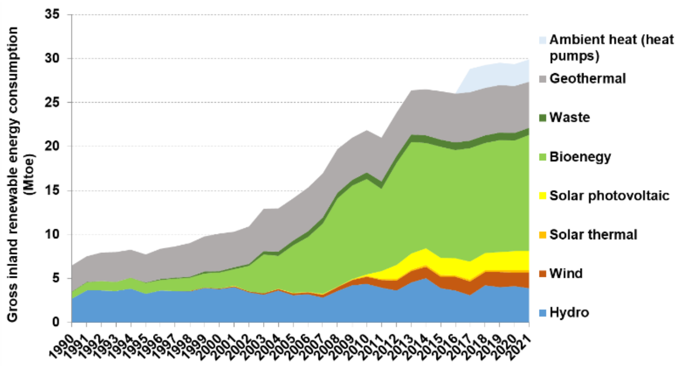
NATIONAL DATA

Italian energy consumption and GHG emissions

National gross inland energy consumption shows an increasing trend from 1990 until 2005 when it peaked at 189.4 Mtoe, then there was a reduction accelerated by the effects of the economic crisis with the minimum value of 149.8 Mtoe reached in 2014. After the fall occurred in 2020 due to SARS-CoV-2 pandemic in 2021 a rebound of consumption has been recorded (+8.5% higher than 2020), with 153.7 ktoe.



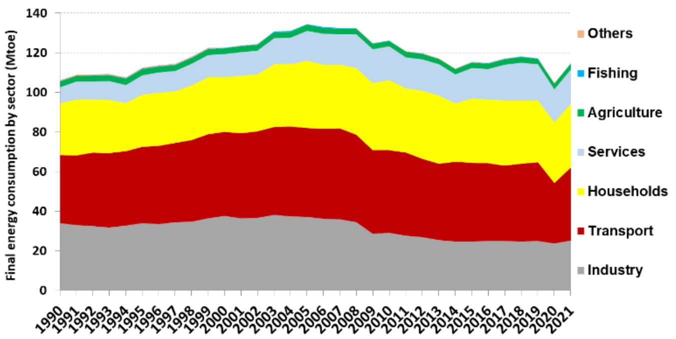
Fossil fuels are the main vectors in the national energy system. From 1990 to 2007, the average ratio of fossil fuels over the gross domestic consumption was more than 90%, although with a slight decline. Subsequently, the share of fossil energy is severely reduced. From 1990 to 2021 the share of fossil energy decreased from 95.5% to 80.1%, with the lowest value in 2020 (78.9%). The decline has become particularly steep since 2007. The national fuel mix has changed considerably since the 1990s. Oil products accounted for the predominant component with 57.3% of gross domestic consumption in 1990. The share of oil products has steadily decreased to 31.7% in 2020, with a rebound in 2021 (33.2%). In the period 1990-2021 there was a corresponding increase in the share of natural gas, from 26.3% to 40.6% (the share in 2020 was 41.2%). The share of solid fuels fluctuated around an average value of 8%. Since 2012, the share of such fuels has steadily decreased, accounting for 3.6% of gross inland consumption in 2021.



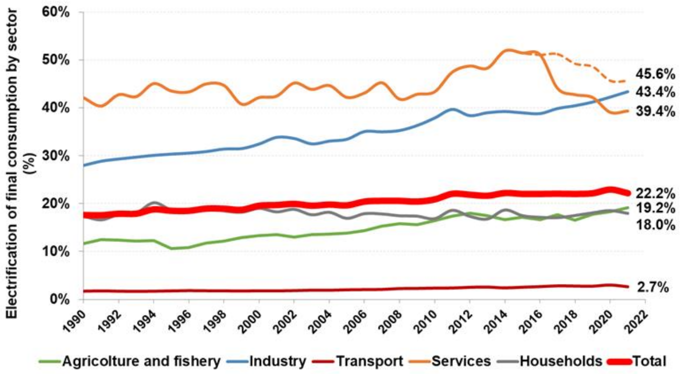
The share of energy from renewable sources is complementary to that observed for fossil fuels. From 1990 to 2007 there was a steady increase in the share of renewable sources from 4.4% to 9%. After 2007 the share accelerated to 20.7% of gross inland consumption in 2020 and a slight decrease in 2021 (19.4%). Renewable gross inland consumption has more than quadrupled from 6.5 Mtoe in 1990 to 29.9 Mtoe in 2021.

In the past the main sources of renewable energy have been geothermal and hydro, which accounted for more than 80% of gross inland consumption of renewable energy from 1990 to 2000. The remaining share was mainly met by biomass and wastes (bioenergy). Since 2000, the bioenergy has shown a considerable growth, and since 2007 it has exceeded 50% of share. In 2021, the share of bioenergy is 47%. In recent years, solar energy (thermal and photovoltaic) and wind energy have also assumed significant role and together represent 14.1% of total renewable energy consumption. Since 2017 the heat pumps energy has been recorded in the EUROSTAT budget. Such item in 2021 was 8.4% of renewable gross inland consumption.

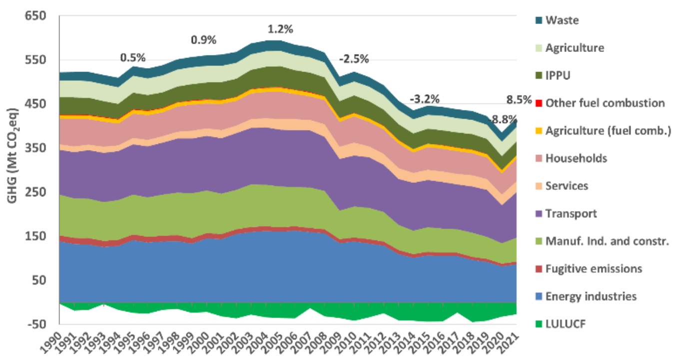
The final energy consumption per sector shows structural peculiarities for each sector and different sensitivities to the contingency, such as economic crisis since 2008 or 2020 lockdown which have mainly affected the productive sectors. Since 1990 until 2021 industry shows a decline of final energy consumption of 25.8%, while the services show a sharp increase of 113.6%. The trend of final consumption in the household sector is quite variable depending upon different climatic conditions that affect the consumption. The residential sector shows an increase in consumption of 22.9% in 2021 compared to 1990 level. The overall trend for transport, including international aviation, increases by 7.5%, after the fall in 2020 due to the lockdown measures.



Since the 1990s, the structure of sectors in terms of energy consumption has changed considerably. Services account for an increasingly share of final consumption from 7.8% in 1990 to 15.4% in 2021, while industry reduces its share of energy consumption from 32.6% to 22.3% over the same period. Consumption in the household sector shows a growing trend until 2010 followed by slight decrease with large fluctuations mainly related to the average temperature. The sector does not appear to have been affected by the contraction due to the economic crisis as the other sectors. The average share of consumption in other sectors (mainly agriculture and fisheries) is under 3%.



The electrification of final consumption is a key strategy to mitigate greenhouse gas emissions if pursued in parallel with the spread of renewable energy for electricity production. The share of electricity in final energy consumption increases constantly since 1990 and in 2021 is 22.2%, slightly below the 2020 level (23%). The sectoral electrification level of final consumptions is quite different. The electricity in industry is 43.4% of final consumption. Services show the highest share of electricity consumption, with a significant increase from 2008 reaching more than 50% of the sector's final consumption in 2014 and 2015. In the last years the share decreased (39.4% in 2021) mainly because of the considerable increase in final consumption of ambient heat from heat pumps that did not appear in energy balances until 2017. Without such item, the electrification of the sector in 2021 is 45.6%. The rate of electrification of final consumption in industry has been steadily increasing since 1990, with the rate clearly accelerating since 2005. In this sector, electricity consumption in 2021 is 43.4% of final consumption. The levels of electrification of consumption in the household and transport sectors show no significant increases and in 2021 were 18% and 2.7% respectively, both slightly below the 2020 level. Agriculture and fisheries show a steadily increase of electrification, similarly to industry, and in 2021 the level was 19.2%.



Total GHG emissions show an increasing trend until 2005, followed by decrease accelerated because of the effects of the economic crisis. In 2020 GHG emissions (385 Mt CO_{2eq}) was heavily affected by lockdown measure to contain SARS-CoV-2 pandemic. GHG emissions fell by 26.2% in 2020 compared to 1990 and by 35.2% compared to 2005. All sectors reduced the emissions, albeit at different rates. In parallel with the declining energy consumption the GHG emissions associated with industrial activities (energy, manufacturing, construction, and industrial processes) have decreased particularly steeply since 2005. In 2021 a rebound was recorded for all sectors, although total emissions remained below the 2019 level. The 2021 GHG emissions fell by 19.9% compared to 1990 and by 13.9% compared to 2005. ISPRA's preliminary estimates for 2022 show that GHG emissions are on the same level of the previous year (+0.1% compared to 2021).

Emissions from manufacturing and construction decreased of 41.6% from 2005 to 2021. Transports show steady growth with a reversal of the trend only after 2007 and the sharp decrease in 2020; 2021 emissions 19.5% lower than 2005. The civil sector (households and services) increases the emissions since 1990

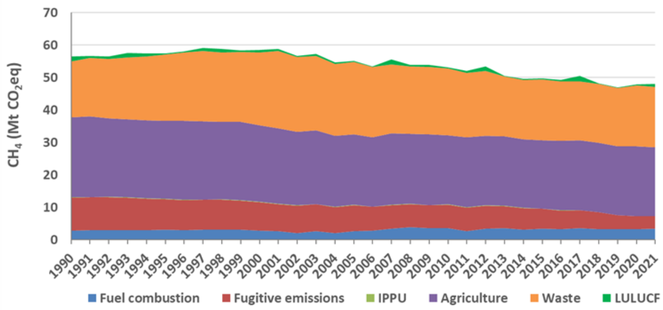
(+9%), with a significant difference between households and services, while the former sector reduces the emissions by 12% the latter increases of 108.6%.

GHG emissions per capita increased from 9.2 t CO_{2eq} in 1990 to 10.3 t CO_{2eq} in 2004, in the following years there was a rapid decline up to 6.5 t CO_{2eq} in 2020. In 2021 the GHG emissions per capita is 7 t CO_{2eq}. The GHG emissions per capita decrease from 2005 to 2021 with an average annual rate of -2.5%, while the average annual rate of decrease from 1990 is -0.9%.

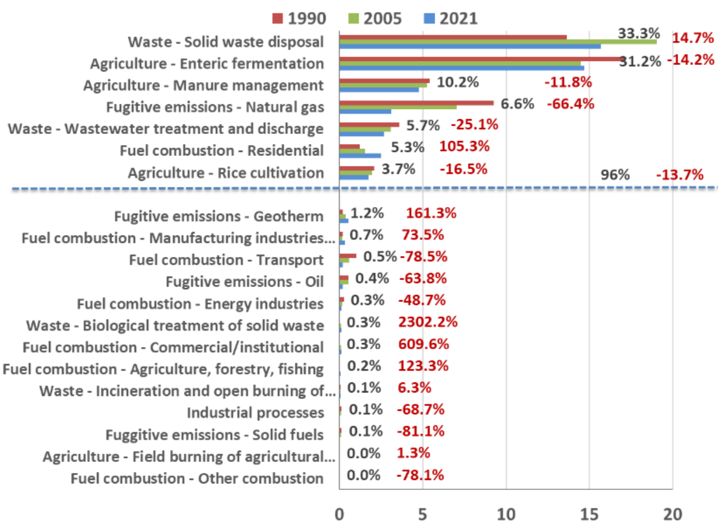
Methane emissions

Methane is a powerful greenhouse gas, second only to carbon dioxide in terms of its contribution to global warming (IPCC, 2021). Methane has a Global Warming Potential (GWP) 85 times that of CO2 over a period of 20 years, although CO2 has an atmospheric lifetime of thousands of years, while methane disappears in about 10-15 years. The rapid decay of methane and its high impact on atmospheric temperature make it a primary objective to curb in a timely and effective manner the climate change.

According to the recent report of the International Energy Agency (IEA, 2021) and IPCC (2022) reducing anthropogenic methane emissions is one of the most effective strategies, including in economic terms, to rapidly reduce the rate of warming and contribute significantly to efforts to limit the increasing global temperature.



National methane emissions, without the contribution of natural sources, represent on average 10.5%±0.8% of CO_2eq emissions from 1990 to 2021, with a rather variable trend. Methane emissions without LULUCF decreased from 55 to 47.1 Mt CO_2eq from 1990 to 2021 (-14.3%). The reduction of methane emissions is much lower than the reduction of total GHG (-19.9%). Moreover, GHGs other than methane reduced the emissions by 20.6% from 1990. These rates show the need to achieve methane emissions reduction from the main sources.



Among the main sources of methane emissions, waste recorded in 2021 a significant increase in emissions compared to 1990 levels (+7.1%). The agriculture recorded a reduction of 13.8% and fugitive emissions of 61.7%. Considering only methane emissions, agriculture contributes with 45.1% of emissions in 2021, while the waste sector accounts for 39.4%. Fugitive emissions make up 8.3%, and unburned methane in the energy sector accounts for 7.2%.

By far the most important source of the agricultural sector is represented by enteric fermentation, or the digestive processes of farm animals. This source represents 69.1% of methane emissions from the agriculture in 2021, followed by manure management with 22.5% and rice cultivation with 8.3%. Emissions due to the combustion of agricultural residues in the open field represent a marginal 0.1%.

In the waste sector, the dominant source of methane emissions is represented by the disposal of solid waste, responsible in 2021 for 84.5% of sector's methane emissions, the next source is represented by wastewater treatment, with 14.5% of methane emissions. The remaining two sources, biological treatment of solid waste and incineration and open field burning, account for a marginal share of emissions of just over 1%.

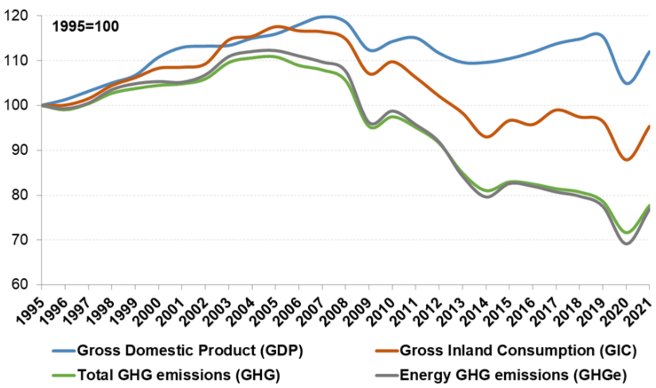
Most of the fugitive methane emissions are due to the natural gas supply chain (production, transport, and distribution) which in 2021 accounts for 80% of total fugitive methane emissions with a share that has decreased significantly since 1990, when it was 91.2%. Oil and natural gas supply chains have recorded reductions in methane emissions of more than 60% since 1990.

Unburned methane emissions in the energy sector are mainly due to the dominant source of the civil and agricultural sectors. Such sources represent a share of 80.1% in the methane emissions by energy sector in 2021, followed by manufacturing and construction industries with 9.6%, transport with 6.4% and energy industries with 3.9%.

Arranging in descending order the methane emissions recorded in 2021 from all sources it can be noted that 96% of methane emissions come from seven key sources that emit 45.2 Mt CO_2eq. Emissions from key sources decreased by 13.7% since 1990. Minor sources, which are cumulatively responsible for 4% of emissions, are 27.7% lower than in 1990. The disposal of municipal solid waste is the first key source with a third of total methane emissions, followed by enteric fermentation with 31.2%. The first two sources are responsible for almost two-thirds of methane emissions.

Energy intensity and decarbonization indicators

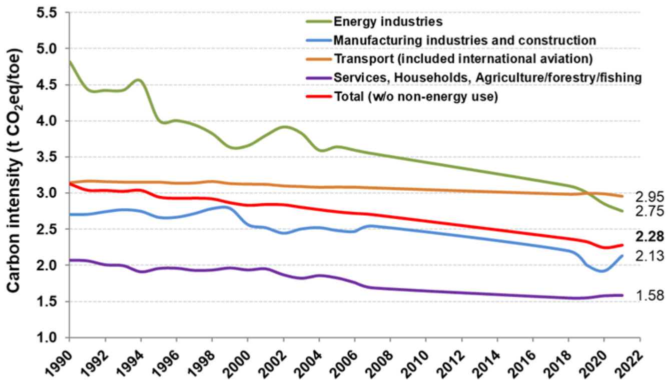
To assess the relationship between energy consumption, economy and GHG emissions the trends of gross inland energy consumption (GIC), gross domestic product (GDP) and GHG emissions are analysed. GDP and GIC have parallel trends up to 2005. Then the two parameters begin to diverge showing an increasingly decoupling. GHG emissions growth was slower than that of GDP until 2005, highlighting a relative decoupling. After 2005, the divergence between the two parameters becomes increasingly marked showing even absolute decoupling when the GDP increased and GHG decreased (2015-2019).



Decoupling is also evident from the decreasing trend in the ratio of GIC to GDP since 2005. The decreasing trend in energy GHG emissions per unit of primary energy consumption is mainly due to the replacement of higher carbon fuels with natural gas, mostly in power sector and industry, and to the increase of renewable share. The same decreasing trends are confirmed for final energy consumption (net of non-energy uses) per unit of GDP and for GHG emissions per unit of final energy consumed.

In the period 1995-2021 the GIC per unit of GDP decreased from 107.5 toe/M€ to 91.5 toe/M€ (-14.8%). Over the same period, GHG emissions per unit of GDP fell by 30.4%, from 357.3 t CO_{2eq} / M€ to 248.8 t CO_{2eq}/M€, while energy emissions per primary energy unit goes from 2.81 t CO_{2eq}/toe to 2.21 t CO_{2eq}/toe, with a reduction of 21.1%. Since 2005 there has been an acceleration in the decrease of energy intensity (on the economy side) and decarbonization of the national economy up to 2019/2020, once again highlighting the growing decoupling of economic activity, energy consumption and GHG emissions. The causes can be manifold and among the main ones is the contraction of industrial activities, which are more energetic intensive as compared to services characterized by lower energy intensity and higher value added. Regarding GHG emissions per unit of energy consumed (primary and final), there has been an accelerated rate of decrease since 2005 mainly due to the increase in the share of energy from renewable sources since 2007. Only in 2021 the indicators show a turning point with an upward trend.

Decarbonization at sectoral level can be assessed by energy emissions and energy consumption by sector. The carbon intensity by energy is the ratio between GHG emissions and energy consumption. The average carbon intensities by sector shows notable differences between sectors depending upon the different

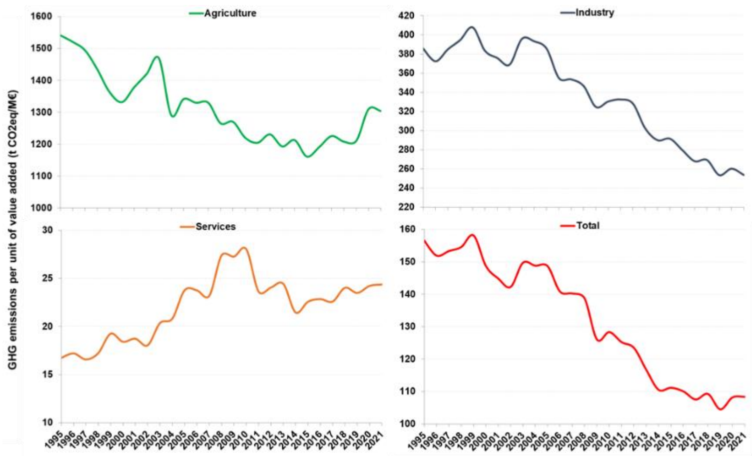


deployment of renewable sources and electrification of final energy consumption. The carbon intensity of energy industries decreases by 42.9% in 2021 compared to 1990 from 4.82 t CO_{2eq}/toe to 2.75 t CO_{2eq}. The carbon intensity of manufacturing industry in 2021 is 2.13 t CO_{2eq}/toe decreasing by 21.2% compared to 1990 level. The transport carbon intensity, including international aviation, is 2.95 t CO_{2eq}/toe (-6.1% compared to 1990) and shows the highest value in the last years with the slowest decreasing slope since 1990 among sectors. The carbon intensity in the civil sector, together with agriculture and fisheries, is 1.58 t CO_{2eq}/toe, 23.8% down compared to 1990 value. All declining trends of these indicators are statistically significant to Mann-Kendall test ($p<0.001$). Overall, the carbon intensity for the energy consumption considered, accounting by 95%±1.2% of gross energy inland consumption from 1990 to 2021, is 2.28 tCO_{2eq}/toe (-27% compared to 1990 level).

Energy and economy indicators at sectoral level

The carbon and energy intensity indicators by sector are calculated matching the GHG emissions by sector with respective energy consumption and value added. Sector emissions include only direct emissions and emissions from electricity self-production (for industry). Emissions due to electricity consumption from the grid are not considered. Regarding GHG emissions and final energy consumption, only energy emissions were considered, while process emissions for the industrial and agricultural sectors were also considered in comparison with value added.

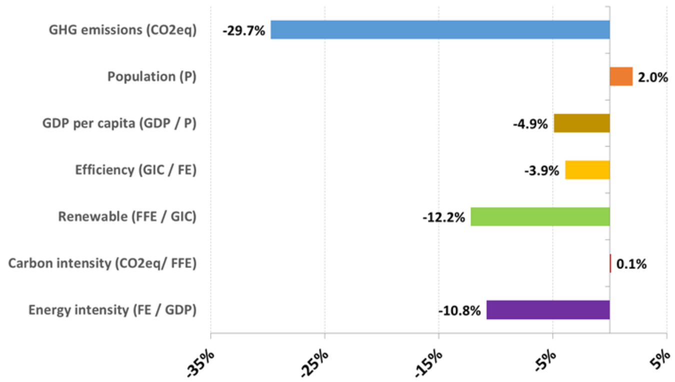
Overall, emissions from the economic activities considered fell by 20.1% in 2021 compared to 1995. Combustion emissions are reduced by 23.9%, while process emissions are reduced by 14.3%. GHG emissions from considered sectors represent on average 34.9±0.8% of total GHG emissions. The energy intensities (toe/M€) of industry and agriculture are lower than 1995 level, while services are higher although in the last years the sector intensity decreases significantly. Moreover, in the last years also agriculture intensities show increasing trends. Aggregate energy intensity decreased by 14.8% over the period 1995-2021 but increased by 5.2% in 2021 since 2014. The energy intensity increase observed after 2014 is driven by agriculture and services.



Carbon intensity, the ratio between GHG emissions and value added, decreases because of the increasing renewable energy share and the increasing share of fuels with lower carbon content, such as natural gas. The carbon intensities per unit of value added are very different among sectors. Agriculture has the highest values, while in the services are recorded the lowest ones. Both sectors show increasing emissions per unit of value added in the last years. As for services the indicators increased until 2010, then also in this sector there was a relative decarbonization up to 2014 followed by another increasing trend. The total trend is heavily determined by industry which records a steadily reduction of the carbon intensity.

Kaya identity and decomposition analysis

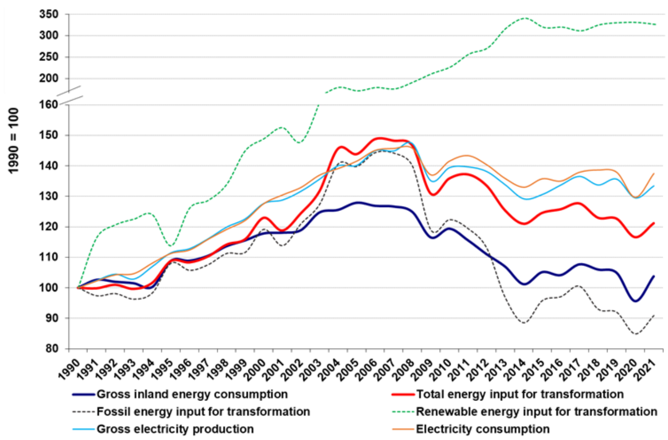
Decomposition analysis is a technique for studying the variation of an indicator in each time interval in relation to the variation of its determinants. In other words, the variation of a parameter is decomposed in the variation of the parameters that determine it. The starting point of the analysis is the construction of an identity equation, where the variable whose variation over time is to be studied is represented as the product of components considered as the causes of the observed variation. For the identity, the components must be reports, where the denominator of a component is the numerator of the next one. This identity, called Kaya by the economist Yoichi Kaya, is provided *a priori,* and must be realized according to a conceptual model consistent with the physical constraints of the studied variable, in addition to the considerations related to the availability of data and the objectives of the analysis.



The GHG emissions are decomposed in six driving factors: 1) population; 2) economic growth per capita; 3) efficiency; 4) renewable energy deployment; 5) carbon intensity from fossil fuels; 6) final energy intensity. The outcomes of decomposition analysis, carried out according *Logarithmic mean Divisia index* (Ang, 2005), shows that the effect of the factors that led to a reduction of emissions in the period 2005-2021 prevailed over the effect of the factors that led to an increase of emissions. The population and carbon intensity are the only driving factors that have contributed to the growth of emissions (+2% and 0.1% respectively). The remaining factors have led to a reduction of emissions. The share of renewable energy (fossil energy consumption / gross inland energy consumption) played a significant role (-12.2%) followed by the final energy intensity (final energy consumption / GDP; -11.6%) and GDP per capita (-10.8%). The efficiency factor (gross inland consumption / final energy consumption) contributed with -3.9%. The overall contribution of each factor leads to -29.7% of GHG emissions over the period 2005-2021.

Power sector

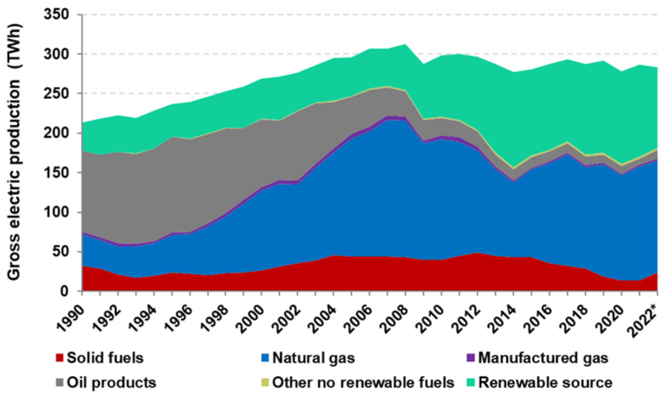
Thermoelectric and renewable electricity production



The growth of electricity consumption in the final energy consumptions makes this sector one of the main players in the national energy system. Since 2001 the energy consumption for electricity generation has increased at higher rates than gross inland energy consumption. The growth of consumption of renewable energy corresponds to the decrease of fossil energy.

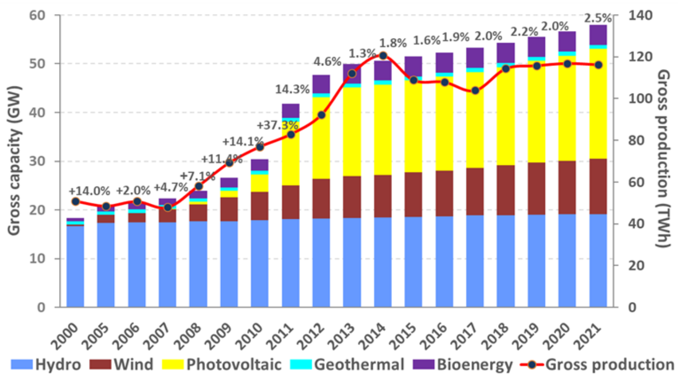
Gross electricity production rose from 216.6 TWh to 289.1 TWh from 1990 to 2021 (+33.5%). Electricity consumption increased from 218.8 TWh to 300.9 TWh over the same period (+37.5%). After a constant growth of gross electricity production and consumption, since 2007 there has been a downward trend because of the economic crisis. In 2020 there has been a further downfall of electricity production and consumption. In 2021 there was a relevant increase of electricity production and consumption, respectively +3% and +6% compared to 2020. The average share of net import of electricity is around 15% of electricity consumption with wide fluctuations and a sensible reduction in the last years up to 2020 (11.3%). In 2021 the share came back to 14.2%.

As regards the energy mix in power sector, natural gas increased steadily since 1990 at the expense of oil products (in 2021, 49.8% of electricity production from natural gas and about 2.7% from petroleum products, while in 1990 the two percentages were 18.3% and 47.4%, respectively). The share of solid fuels showed fluctuations around the average of 11.5% with a sharp reduction in the last years (4.9% in 2021). Preliminary estimates for 2021 show an upward trend with relevant increase of solid fuels share around 8%.



In 2005 the share of electricity from renewable sources compared to total production accounted for only 16% of national production. After 2007, renewable sources share increased significantly up to the top of 2014, when the share reached 43.1%. In 2021 the renewable share in electricity production is 40.2%, while preliminary estimate shows an abrupt contraction in 2022 (35.5%), mainly due to the sharp reduction of hydroelectric generation.

Total thermal power in 2021 is 61.9 GW with a sharp contraction since 2012, when the installed capacity reached the peak of 80.2 GW. Combined cycle plants, regardless of cogeneration or non-cogeneration production, show a significant increase in gross efficient power, from 7.9 GW in 2000 to a maximum of 43.4 GW in 2011-2012. Subsequently, these plants show a steady reduction in efficient power up to 40.1 GW in 2021.



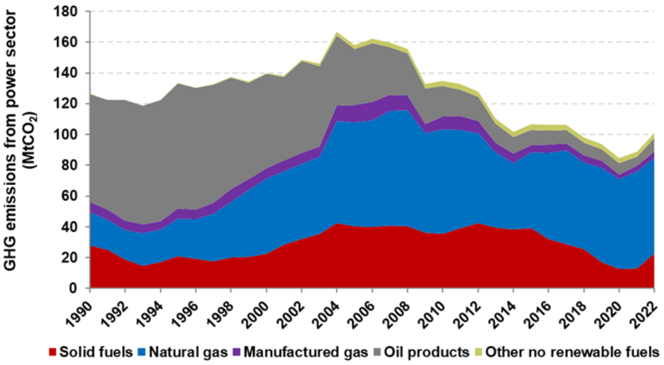
As for renewable power, there has been a significant increase in installed capacity by 2000. In 2021 the renewable gross efficient power was 58 GW. The highest annual growth rate was recorded in 2011 when the new power compared to the previous year was 11.3 GW, of which 9.5 GW of PV plants and 1.1 GW of wind plants. After 2014 the additional new power per year was around 1 GW.

About plants powered by bioenergy, it should be emphasized the rapid increase from 2008 to 2013 and the subsequent stabilization of gross efficient power with new installations of few MWs per year up to 2018 and a decrease in the last years. Biogas fuelled plants went from 0.37 GW in 2008 to 1.46 GW in 2021. The growth of plants fed with liquid biofuels in the period 2008-2013 is particularly rapid, from 0.12 GW to 1.04 GW, then it is reduced to 0.95 GW in 2021. Plants fuelled by solid biomass and waste increased from 1.07 GW in 2008 to 1.73 GW in 2018. Since 2018 the power of solid biomass plants shows a downward trend, while the power of waste plants increases. In 2021 the total power is 1.7 GW, of which 0.92 powered by wastes. Such trends can be explained by the reduction in incentives for bioenergy powered plants. The future development of such plants does not seem independent of some forms of incentives.

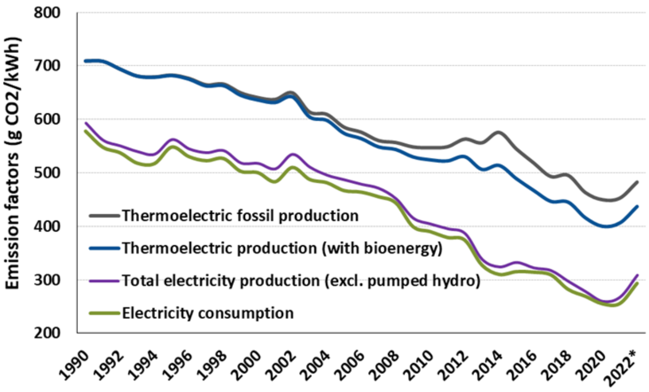
CO_2 emissions and emission factors

The amount of CO_2 emitted from power sector in 2021 was 89 Mt (of which 76.9 Mt for electricity generation and 12.1 Mt for heat production) equal to 22.1% of national GHG emissions.

Until the first half of the 1990s, CO_2 emissions from oil & oil products accounted for a significant share of total emissions from power sector. In 1995, the share of emissions from oil & oil products amounted to 61% of emissions. Subsequently, the share of CO_2 from these sources has steadily decreased to 6.6% in 2021. However, it should be noted that such sources include synthetic gases from gasification processes, with an increasing share since 2000. Taking fuel oil alone, the CO_2 emissions decreased from 61% to 1.8% from 1995 to 2021 with the first recorded increase in 2021 compared to the previous year. The share of natural gas emissions increased from 18.5% in 1995 to 70.9% in 2021. The share of emissions from solid fuels, mainly coal, was constantly increasing up to 2014 when the peak of 37.6% was reached but in the following years was recorded a sharp reduction up to 14.7% in 2020 and 2021. The preliminary estimate shows a relevant increase in 2022, around 22.3%.



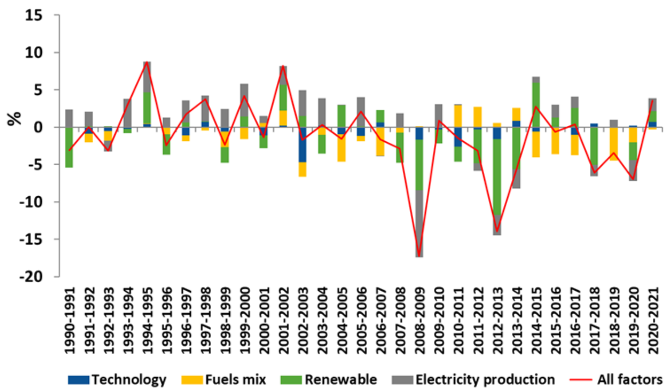
The emission factor for national gross thermoelectric production decreases from 1990 to 2021 from 709.1 g CO_2/kWh to 406.6 g CO_2/kWh with the first increase ever recorded in 2021 compared to the previous year. The decrease is mainly due to the increasing share of natural gas and the continuous reduction of the specific emission factor of this fuel, which in turn is due to the increase in the electrical conversion efficiency of plants. The use of bioenergy with zero carbon balance among other fuels that contribute 10.1% of thermoelectric production in 2021 also plays an important role. The difference between the emission factors of the thermoelectric plants with or without the contribution of bioenergy shows the role of such sources in reducing the emission factor. The difference becomes significant after 2000 because of the increase in the amount of solid biomass and municipal or similar solid waste used for electricity production and the even greater increase in bioliquids and biogas observed after 2008.



The electricity production from renewable sources reduces the emission factor for total electricity production since renewable sources have not CO_2 emissions. The emission factor for electricity consumption is further reduced due to the share of electricity imported from abroad whose emissions are released outside the national territory. Along with an increase of electricity production from 1990 to 2021 of 72.5 TWh, there was a decrease of CO_2 emissions of 49.5 Mt. The reduction of emission factors for electricity generation from 2007 to 2014 was mainly due to the increase or renewable electricity production, while the decrease recorded since 2015 is essentially due to the increasing share of natural gas.

Decomposition analysis

The variation in GHG emissions from thermoelectric production is due to several factors such as electricity generation technology, the fossil fuel used, the contribution of renewable sources and electricity demand. Decomposition analysis was applied to assess the relative contribution of these components. This technique is widely used in the analysis of environmental data.



The factors considered in the analysis (technology, type of fuel, renewable sources) contribute to CO_2 emissions reduction where the increase in electricity production has the opposite effect. The results of the analysis show that technological, renewable sources, and fuel mix factors contribute to the reduction of CO_2 emissions from 1990 to 2021 respectively for 19.6%, 27.3% and 16.4%, while the increase in electricity production leads to an increase in emissions of 24%. The cumulative effect of the four factors led to a reduction in atmospheric CO_2 emissions in 2021 of 39.2% compared to emissions observed in 1990 (-49.5 $MtCO_2$). In other words, the reduction due to the change in the technological factor (decrease in the specific emission factors of fossil fuels) over the period 1990-2021 would have been 24.8 Mt CO_2 if the other factors remained unchanged. The reduction due to the fuels mix change would have been 20.7 Mt CO_2, while the increasing renewable share would have led to a reduction in emissions of 34.5 Mt CO_2. These effects are offset by a net increase in electricity production which would have resulted in an increase in emissions of 30.4 Mt CO_2 without the contribution of the other factors.

Since 2007 the role of renewable sources becomes more relevant than the other factors. Moreover, it should be underlined that since 2007 the economic crisis has significantly reduced the consumption of fossil fuels while increasing the share of renewable sources as result of the priority of dispatching renewable electricity. In any case, each unit of renewable electricity contributes far more to the reduction of atmospheric emissions than any other factor, if an equivalent amount of fossil electricity is replaced.

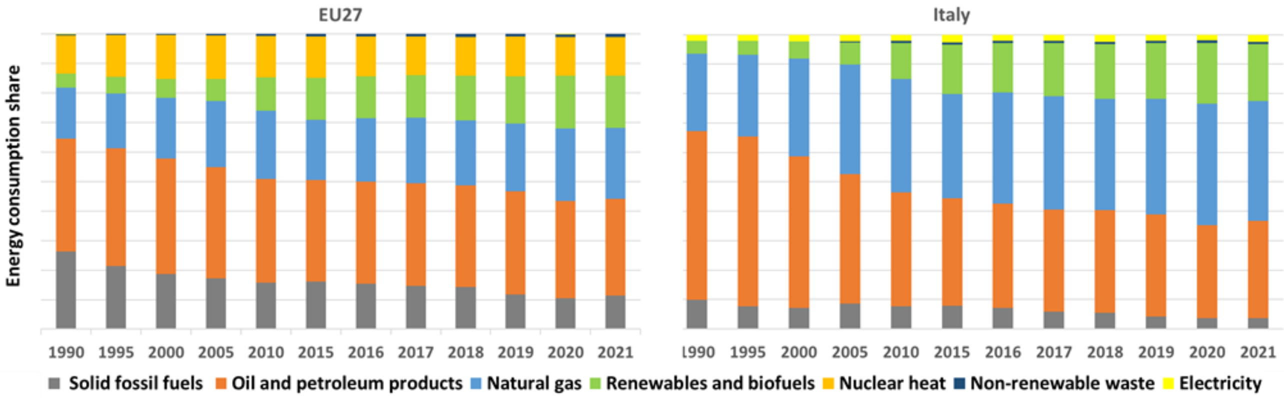
ITALY AND THE BIGGEST EUROPEAN COUNTRIES

Efficiency and decarbonization indicators

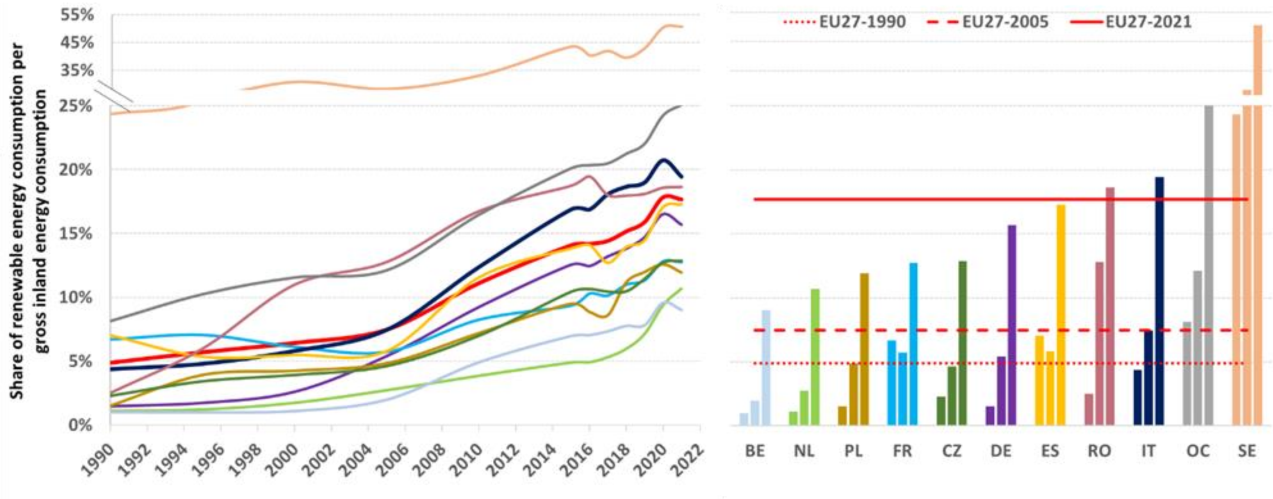
Comparison of decarbonization and efficiency indicators is carried out among Italy and the largest European Countries. The EU Member States with more than 3% of EU27 GHG emissions or more than 3% of EU27 GDP in 2020 are considered for comparison. The Member States examined (Germany, France, Italy, Spain, Poland, the Netherlands, Belgium, Romania, and Sweden) represented 81.5% of the population in EU27 in 2020, 81.6% of GHG emissions and 83.1% of GDP. The gross inland energy consumption accounted for 82.5% of the energy consumption of EU27.

Energy consumption and gross domestic product

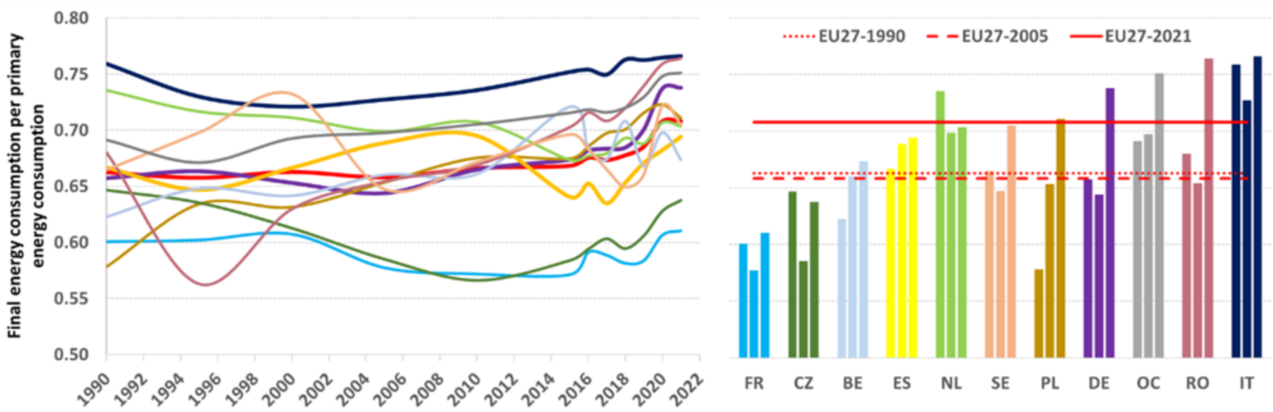
Since 1990, European environmental policies have led to a significant change of the energy mix in the Member States. The nuclear energy represents 13.1% of EU27 gross inland consumption in 2021, quite stable since 1990 (12.9%). On the other hand, solid fuels energy faces significant contraction since 1990. EU27 share decreased from 26.3% to 11.4% from 1990 to 2021, higher than 2020 (10.5%). There are still significant shares in some of the largest States such as Germany (18%), Poland (41.9%) and Czechia (30.2%). Oil and petroleum products, on the other hand, show a modest reduction at European level (from 38.3% in 1990 to 32.7% in 2021) with different trends among the States. Natural gas energy consumption shows a considerable increase in almost all States and at EU27 level ranges from 17.1% in 1990 to 23.9% in 2021. Renewable energy shows a significant increase in EU27 from 4.9% in 1990 to 17.7%.



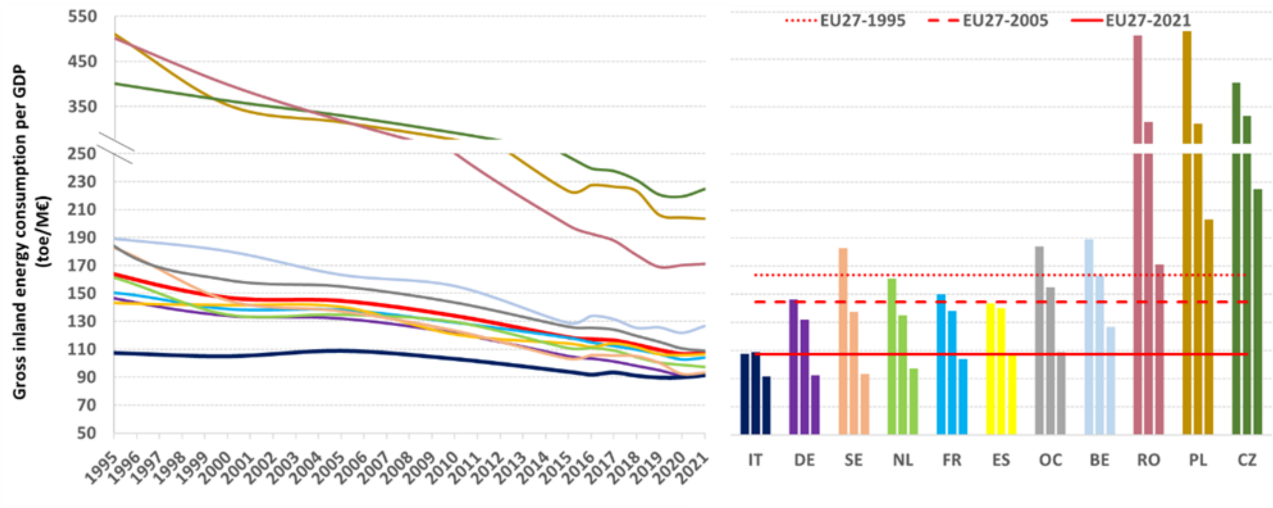
The Italian share of solid fuels, mainly coal, in gross inland consumption decreased from 9.9% in 1990 to 3.6% in 2021. On the other hand, the share of natural gas for Italy goes from 26.3% to 40.6%. The share of oil and petroleum products goes from 57.3% to 33.2% and renewable share grew from 4.4% to 19.4%, below the 2020 level of 20.7%. Italy’s renewable share is among the highest in the Countries examined, only Sweden’s share is higher than the Italian one. The share of fossil fuels is significantly reduced in almost all European Countries. The EU27 average decreased from 82% in 1990 to 69.1% in 2021. Among the examined Countries, the Netherlands and Poland shares are still higher than 85%, respectively 87.7% and 88%.



The ratio between the final energy consumption (including non-energy uses) and gross inland consumption is an indicator of energy efficiency. Since 1990 the ratio for Italy has been around the average of 0.76 vs 0.7 the average EU27. To evaluate energy transformation efficiency, it is useful to consider energy consumption without non-energy uses. In other words, the ratio between final energy consumption and primary energy. The Italian energy transformation efficiency is higher than any other Countries examined. Only Romania approaches the Italian value in 2021.



The gross inland energy consumption per unit of gross domestic product (GDP) is an indicator of the Country's economic and energy efficiency (energy intensity). Italy was one of the European Countries with lower energy intensity until 1995, when it was behind only to Denmark, then lost positions and in 2021 has the 5th lower values, upper than Ireland, Denmark, Malta and Luxembourg. Among the biggest EU27 Countries, Italy continues having the lowest energy intensity followed by Germany and Sweden.



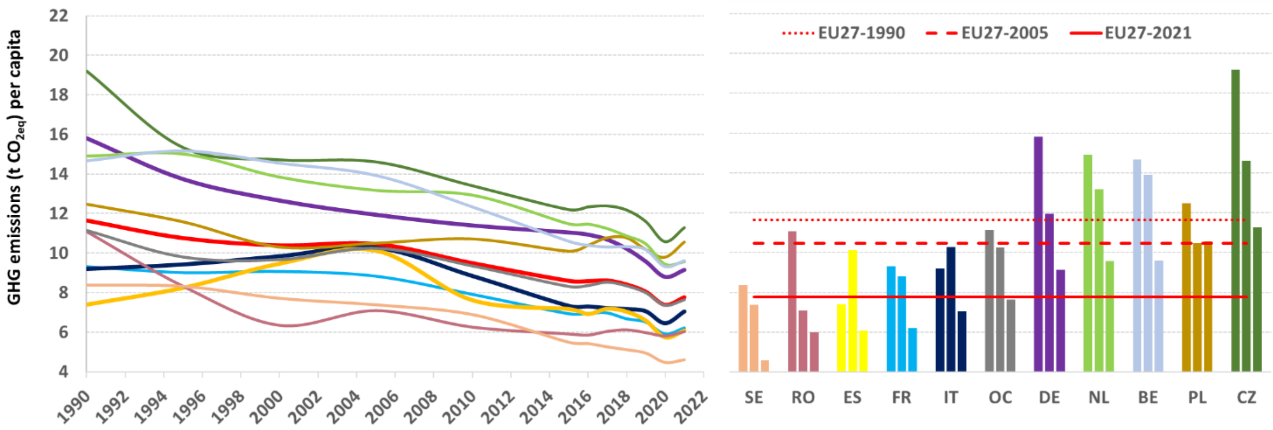
The final energy intensity (ratio between final energy consumption, including non-energy uses, and gross domestic product) follows similar trends of energy intensity with a sudden reduction in the European Countries which, starting from higher levels than Italy, reach Italian figures and in some cases exceed them. Since 1995 Italy shows considerable energy and economic efficiency, the final energy intensity reduced by 11.6% from 1995 to 2021; much higher reductions have occurred in the other European Countries (-29.9% in EU27). The reasons for the reduction in energy intensity observed are manifold such as the increase in building efficiency, industrial efficiency improvement, the electrification of final consumption and the shift of economy towards high value added and low energy consumption activities of services to the detriment of industrial sectors.

European Countries show a wide range of electrification of final energy consumption (energy uses only) in 2021 ranging from 14.6% in Latvia to 41.6% in Malta. Italy is just below the EU27 average with 22.2% *vs* 22.8%. Among the biggest Countries, Sweden, France, and Spain have higher levels of electrification than Italy, respectively 34.3%, 26.7%, and 24.9%. At the lowest end there are Romania and Poland with 15.7% and 16.7% respectively.

At sectoral level, the Member States' electrification of final energy consumption shows different figures although with a common growing trend. The electrification of industry final consumption in Italy is among the highest in Europe (43.4% in 2021). Services show the highest percentages of electrification among sectors. The Italian share in 2021 is 39.4%, well below the EU27 average (46.3%), as well as the electrification in households (18% in Italy, 24.6% in EU27). The transport sector shows the lowest percentages of electrification and in 2021 Italy is one of the three EU27 Countries with the highest share (2.7%), after Sweden (5%) and Austria (3.5%).

Greenhouse gas emissions and energy consumption

Italy's GHG emissions per capita from 1990 to 2021 is 8.8±1.2 t CO_2eq (ISPRA, 2023a). Emissions per capita increased until 2004 when the maximum value of 10.3 t CO_2eq was reached, then a reduction of up to 6.4 t CO_2eq was observed in 2020. In 2021 the emissions per capita are 7 t CO_2eq. Italian emissions per capita have always been below the European average. EU27 average emissions per capita in 2021 are 7.8 t CO_2eq.



As for carbon intensity, GHG emissions by energy consumption, all Countries have reduced the emissions per unit of gross inland energy consumption since 1990. Such indicator is sensible to the Country's energy mix. Carbon intensity of Italy is higher than the European average, also for the contribute of nuclear power in many Countries. By unbundling nuclear power from gross inland consumption, Italy's figures are below the EU27 average (2.7 t CO_2eq *vs* 2.8 t CO_2eq in 2021).

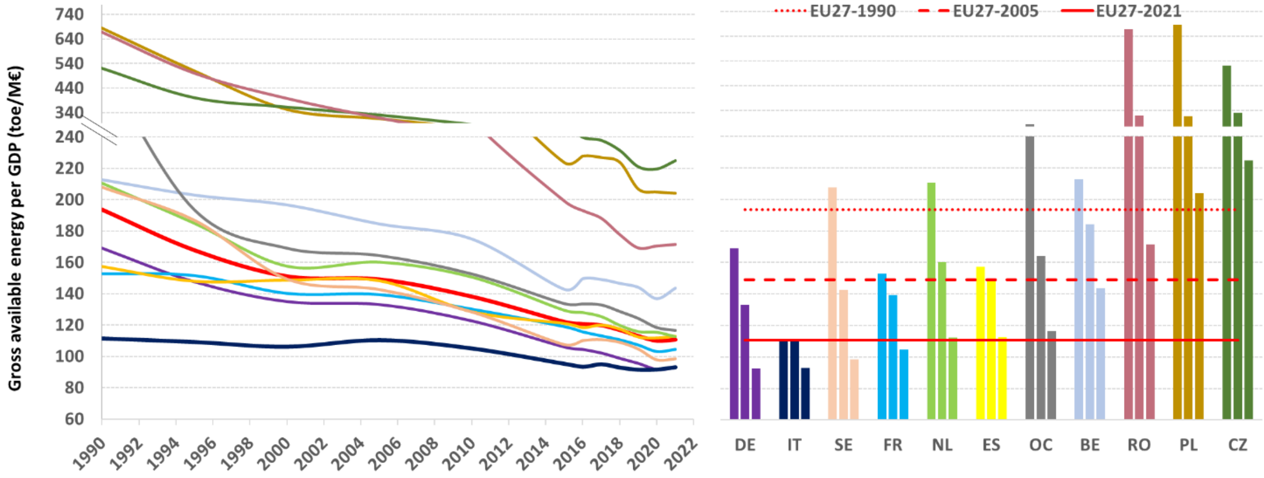
The ratio between GHG emissions and gross domestic product is the carbon intensity related to economy. Such indicator is sensible to the Country's energy mix, as the intensity related to energy, and even more sensible to economy structure: share of services and industry. Moreover, the Countries' GDP is also determined by activities related to international bunkers, whose emissions are memo items in the emissions inventories. The indicator shows a reduction for all European Countries and Italy's figures are just below the EU27 average in 2021 (0.26 t CO_2eq/k€ *vs* 0.25 t CO_2eq/k€). Sweden and France have the lowest values: 0.09 t CO_2eq/k€ and 0.18 t CO_2eq/k€, respectively. Poland is at the upper end with 0.74 t CO_2eq/k€, followed by Czechia and Romania with 0.62 t CO_2eq/k€ and 0.58 t CO_2eq/k€.

The indicators show that Italy, compared to the biggest EU27 Countries, has historically high energy and economy efficiency with a significant share of renewable energy and natural gas in the energy mix, and one of the lowest emissions per capita in Europe. The gross energy intensity per unit of GDP in Italy is higher only to those of Ireland, Denmark, Malta, and Luxembourg, while the carbon intensity per unit of GDP is just below the EU27 average and very close to carbon intensities recorded in Germany, Belgium, and Spain, among the biggest Countries. The carbon intensity per gross energy consumption is higher than the European average because of the significant share of nuclear heat in EU27. The carbon intensity per gross energy consumption without the nuclear heat shows that Italy's intensity is higher only than those of Sweden, the Netherlands, and Belgium, among the biggest Countries. Although some indicators show that many Countries have improved their GHG emissions performance, sometimes achieving better results than Italy, the following factors need to be considered:

- Countries with high shares of solid fuels or oil and petroleum products have greater potential for reducing emissions from fossil fuels than those available in Italy, where the fossil mix is mainly represented by natural gas and further GHG emissions reductions are possible only increasing the renewable share and improving efficiency.
- In several Countries there is a significant contribution of nuclear power with emissive advantages, a source of energy which is not without controversy and which some Countries intend to phase out gradually (Germany, Belgium), even though recent events, such as Russian-Ukrainian war from February 2022 determined revisions of the nuclear plants decommissioning planning. Moreover, the uncertainty about the timing of the nuclear power plant maintenance program remains considerable also in France which is currently suffering from the shutdown of 25 out of 56 reactors.

The emissive performance of a Country depends closely on its economic structure. Countries with a predominance of productive activities in the service sector or with significant shares of non-energy consumption, such as the Netherlands, show lower emissions per GDP and energy consumed.

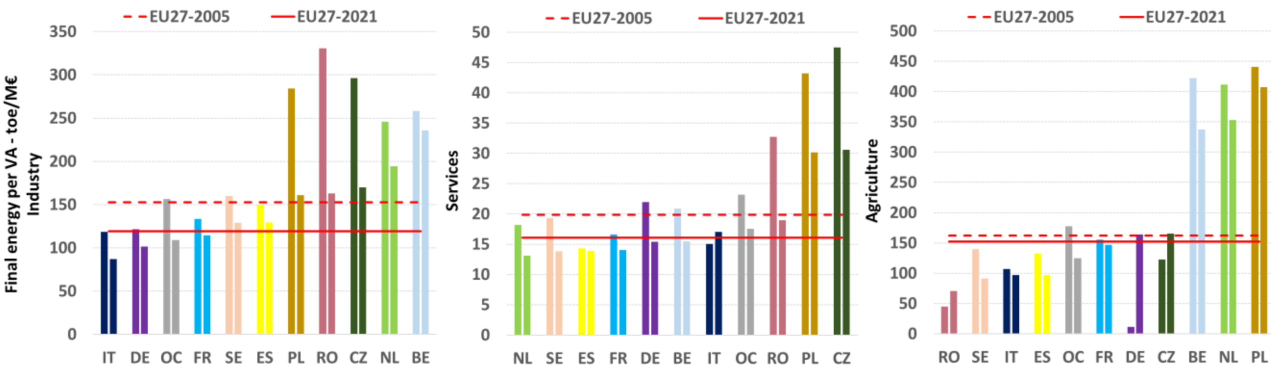
The inclusion of the contribution of international bunkers in the elaboration of energy intensity and carbon intensity per unit of GDP shows that Italy, together with Germany, are at the top positions among the largest Countries.



The comparison of efficiency and decarbonization indicators at sectoral level among Member States shows a rather heterogeneous situation. As for industry in Italy, the final energy intensity, ratio between final energy consumption and value added, has been comparable to that of Germany since 2005 and shows a decreasing trend from 2005 to 2021. Among the European Countries only Ireland, Denmark, Malta, and Estonia have lower industry energy intensities than Italy in 2021. Among the Countries examined the Netherlands and Belgium show the highest energy intensities for industry. The average annual rate of the sector energy intensity from 2005 to 2021 decreased of -1.9% for Italy against -1.5% for European average.

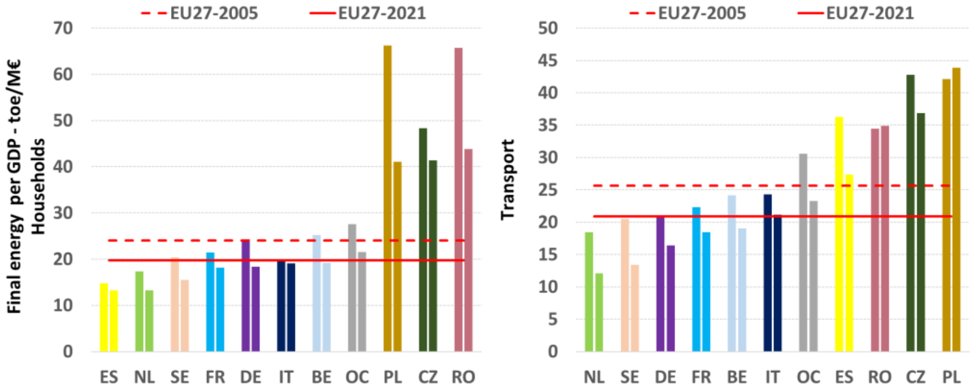
In commercial and public services Italy shows a countertrend of energy intensity compared to other European Countries in recent years. Italy is the only Country, among the biggest ones, whose energy intensity in the sector increased since 2005. The outcome is also due to the accounting of energy consumed by heat pumps whose data for Italy started from 2017 in EUROSTAT database, such item has significantly increased the sector energy intensity. The average annual rate of energy intensity from 2005 to 2021 shows an increase of 0.8% for Italy against a decrease of -1.3% for European average.

The agriculture sector shows a general decrease of energy intensity in EU27. In 2021, among the considered Countries, only Romania and Sweden have lower energy intensity than Italy. The average annual rate of sector energy intensity from 2005 to 2021 decreased of -0.6% for Italy against -0.4% for European average.



In the household sector, from 2005 to 2021 the biggest Countries show significative reductions of energy consumption per unit of GDP (from -0.7% per annum in Spain to -2.9% per annum in Poland), while Italy do not show any relevant change (-0.1%). The energy intensity trend for Italian transport is broadly comparable to EU27 average.

The ranking of the examined Countries for households and transport shows that in 2021 the Italian energy intensity is near the European average and that there is wide room to improve the sectors' performance.

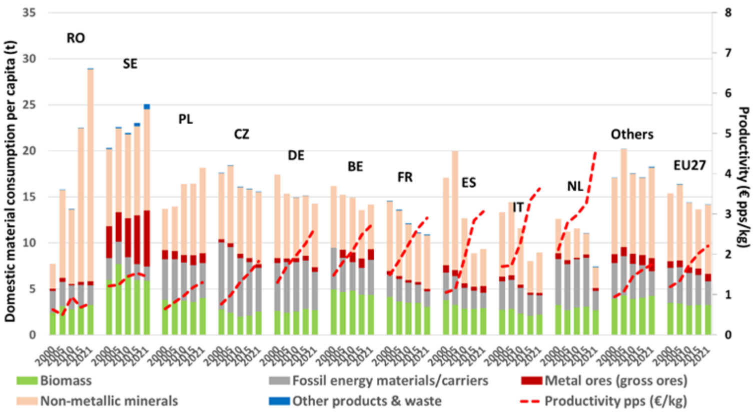


What is seen for energy intensity is reflected in the carbon intensity (t CO_2eq/M€), but this indicator is sensible to the role of renewable energies, nuclear power and electricity import in the Countries' energy balance because such sources do not generate GHG emissions. Among the biggest Countries, the Italian industry has carbon intensities higher only than those of Sweden and Germany. For agriculture, the Italian carbon intensity in 2021 is among the lowest in Europe, after Malta, Sweden, and Greece. The European average is 74.1% higher than the Italian intensity.

On the other hand, the civil sector (households and services) in Italy shows wide room for improvement with values higher than the EU27 average (+22.3% for households and +50.8% for services). The Italian civil sector therefore shows very wide emission reduction potentials, especially considering the sectoral electrification of final consumption in 2021 is much below the EU27 average (households: 18% *vs* 24.6%; services: 39.4% *vs* 46.3%).

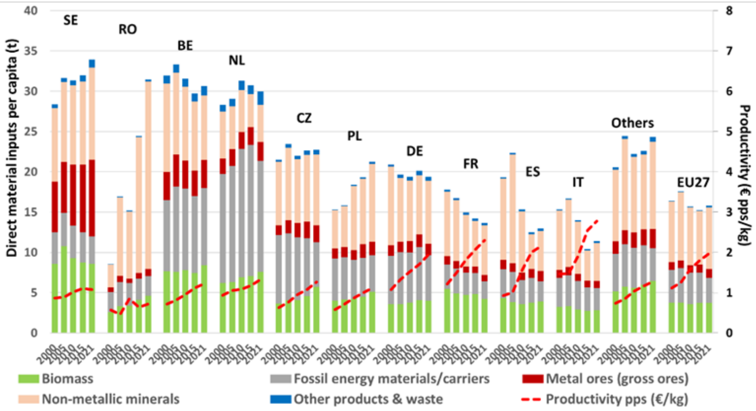
Material flow accounts

Indicators of *direct material inputs (DMI)* and *domestic material consumption (DMC)* describe, in aggregate terms, the direct use and provenance of natural resources and products. The first indicator includes all materials which have an economic value and are used for production and consumption activities and the indicator is calculated as the sum of internal extractions and imports. The second indicator represents domestic consumption of matter in the national economy net of exports and is calculated by subtracting from direct material inputs the share of physical exports.



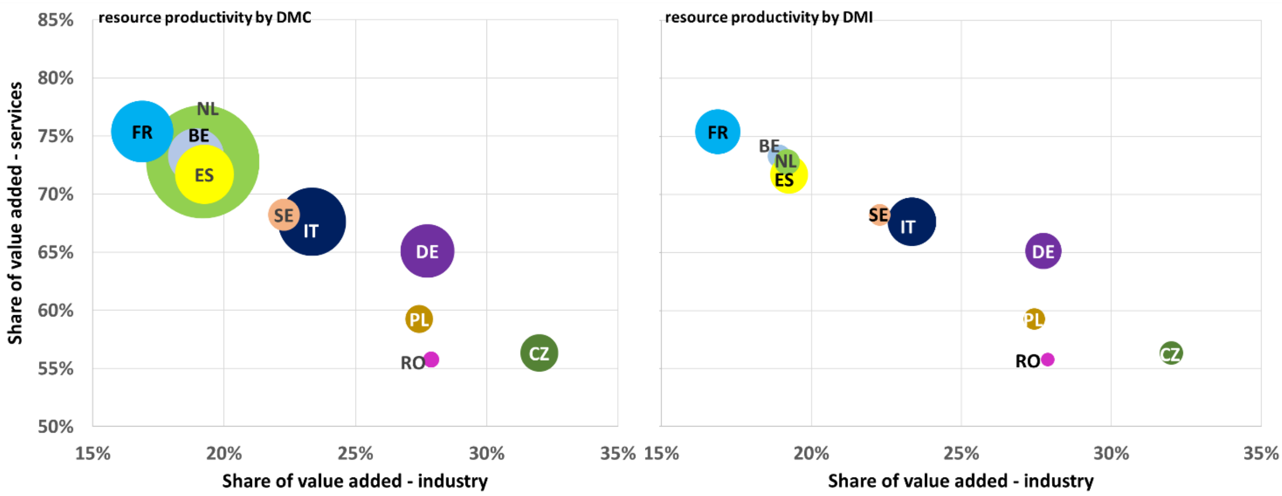
Since 2000, there has been a decrease of average DMC per capita in the European Countries. In 2021 the Netherlands has the lowest consumption per capita of matter among all EU27 Countries followed by Italy with the 2nd lowest value. As for resource productivity there is a general increase since 2000, although the absolute values of the Countries are very different. The average annual growth rates among the biggest Countries range from 0.8% for Sweden to 5.2% for Spain; Italy's annual rate is 3.7%. The Netherlands shows the highest value (5.7 €/kg in 2021), followed by Italy (3.4 €/kg). Germany and France productivities are 2.7 €/kg and 3.1 €/kg, respectively.

Direct material inputs (DMI) include all materials which are economically valued and are directly used in production and consumption activities. Such indicator is equal to the sum of internal extractions and imports. Since this indicator represents domestic consumption without exports, it is useful for assessing actual material consumption, including that not used in domestic production and consumption activities and addressed to exports. Sweden, Romania, Belgium, and the Netherlands have high share of fossil extraction, biomass, and metal ores destined for exports and shows the highest DMI per capita among the biggest European Countries, far above the European average. It is also clear the increasing DMI per capita recorded in Romania. Italy recorded in 2021 the lowest value among all European Countries (11.4 t per capita *vs* EU27 average of 15.8 t per capita).



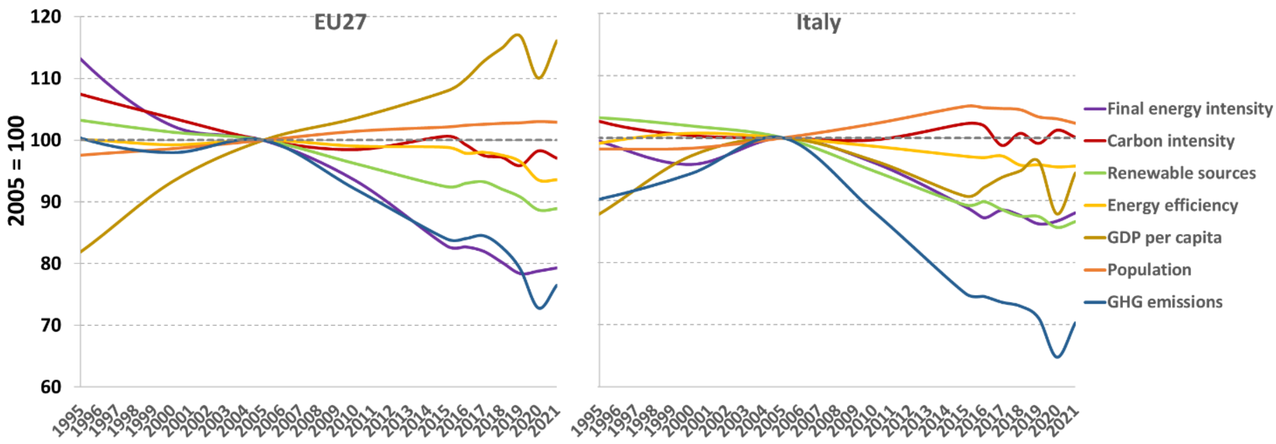
As for resource productivity Italy have the 2nd highest value among the European Countries (2.67 €/kg), the 1st one is recorded for Ireland (2.72 €/kg). The productivity of the Netherlands for this indicator (1.4 €/kg) do not show high performance as for DMC.

The resource productivity for each Country considering the relative positioning of the Countries' economy in the industry/service space shows that Italy, despite having a higher share of industrial value added than France and Spain, has higher productivity (DMC), a clear result of greater efficiency in the use of resources, mainly in the industrial sector. This result is in line with what was seen for energy intensity indicators. Considering the DMI the resource productivity is significantly lower than for DMC. Productivity in the Netherlands falls by 75.2% compared to DMC productivity. For the other Countries the decrease ranges from 7.9% for Romania to 54.4% for Belgium. The Italian figure is 22.2%.



Kaya identity and decomposition analysis

The trend of *kaya identity* parameters for EU27 and Italy in the period 1995-2021 shows a quite different pattern as for the driving factors in GHG reductions. Whereas in EU27 the most powerful factor seems to be the final energy intensity, in Italy both renewable sources and final energy intensity (final energy consumed per unit of GDP) are the driving factors. Moreover, in EU27 population and GDP increase their trend, while in Italy such factors have downward trend. The GHG emission change is the integrated result of the driving factors change. So, in EU27 is evident an absolute decoupling between economy and GHG emissions while in Italy only a relative decoupling is recorded.



The outcomes of decomposition analysis show that in Italy the final energy efficiency played a less important role than in other Countries because of the better performance of the indicator in Italy already in 2005. Moreover, unlike Italy most Countries recorded the sensible increase of GDP per capita since 2005.

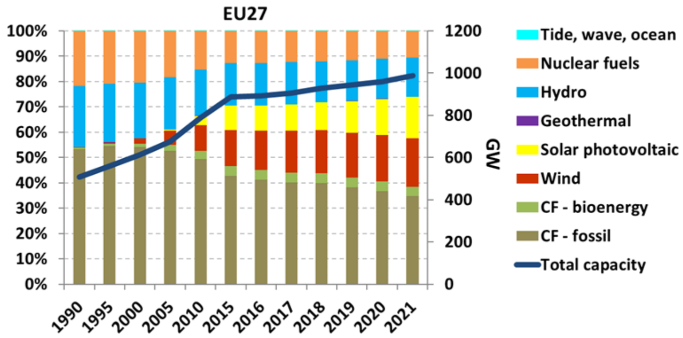
The higher decoupling observed in other Countries than in Italy does not necessarily correspond to emission reductions in line with the targets. According to EEA (2022), among the largest Countries, in Germany the effort sharing emissions exceeded the available national annual emission allocations; regarding renewable energy, France do not meet the 2020 renewable share target outlined in its national renewable energy action plans; as for efficiency target Germany, Belgium, and Sweden, among the biggest Countries, had not reduced their final energy consumption enough to meet their 2020 final energy targets. In relation to the indicative targets for primary energy consumption, Belgium and Poland had not met their 2020 targets. Moreover, it should be emphasized that the decomposition analysis focuses on the relative change of the parameters, without assigning any weight to the starting points. The absolute values of parameters and relative trends in the biggest European Countries have been investigated in the previous paragraphs. As already mentioned, the economic and energy efficiency of the Italian system is among the highest in Europe. The last edition of the *International Energy Efficiency Scorecard*, issued by ACEEE in 2022, reported for Italy the drop of four ranks since the previous edition in 2018, mainly due to buildings section, but Italy managed to rank within the top five, after France, UK, Germany, and the Netherlands. The ACEEE International Energy Efficiency Scorecard evaluates the efficiency policies and performance of 25 of the most energy-consuming Countries globally. ACEEE used 36 metrics, both policy and performance-oriented metrics, to score each Country's efforts to save energy and reduce greenhouse gas emissions across four categories: buildings, industry, transportation, and overall national energy efficiency progress. "*Policy metrics highlight best practices in government actions and can be either qualitative or quantitative. Examples include national targets for energy efficiency, building and appliance labelling, and fuel economy standards for vehicles. The performance-oriented metrics are quantitative and measure energy use per unit of activity or service extracted. Examples include the efficiency of thermal power plants, energy intensities of buildings and industry, and average on-road vehicle fuel economy.*" (Subramanian *et al.*, 2022).

The efficiency improvement cannot be separated from the assessment of the potentials and cost effectiveness of the energy system change, as well as a mindful assessment of the economy structure must be considered, especially concerning the role of services and industry.

Power sector

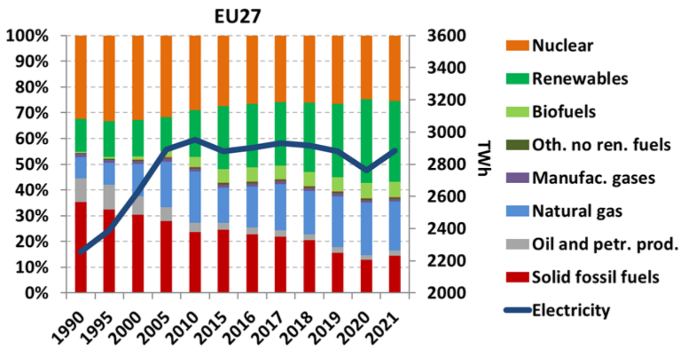
Power capacity and electricity production

The power sector is one of the main objectives of the measures aimed to decarbonize the economy, both for the amount of emissions and potential for deployment of renewable energy sources. The Countries examined for comparison with Italy account for 83.4% of EU27 gross electricity production in 2021.



The installed capacity in 1990 consisted mainly of thermoelectric plants (54% in EU27), nuclear (21.8%) and hydroelectric (24%). Wind and photovoltaic sources had marginal shares. In 2021 the thermoelectric capacity was 38.5%, 10.6% nuclear, 15.3% hydroelectric, 19.1% wind, and 16.4% photovoltaic. The total capacity has increased by 46.3% in 2021 compared to 2005, from 676 GW to 989 GW. The nuclear capacity is the only one with a relevant reduction, from 123 GW to 105 GW (-14.6%). It is also noteworthy the increase of bioenergy net capacity from 15.8 GW in 2005 to 36.3 GW in 2021, representing 9.5% of total thermoelectric capacity.

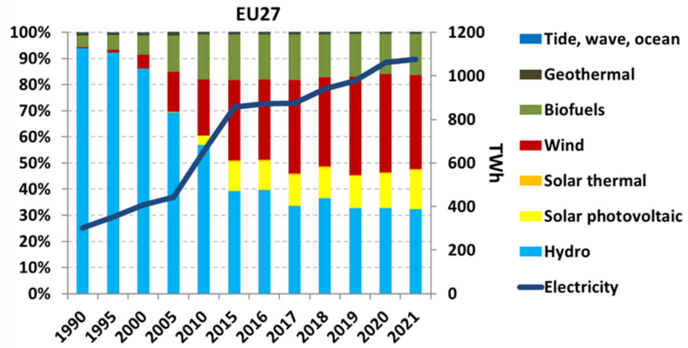
There is considerable heterogeneity of power capacity among Countries. In Poland, there is a clear prevalence of thermoelectric plants with a minor role for bioenergy. The nuclear plants, which are not present in Italy and Poland among the considered Countries, make up significant share of the capacity in France (43.3%), Sweden (15.4%), Belgium (22.3%), and Czechia (20.4%), although the shares of other Countries are not negligible (from 1.1% in the Netherlands to 7.5% in Romania). Since 1990, hydroelectric capacity has accounted for a considerable proportion of traditional renewable sources in Romania, Spain, France, Italy and Sweden. In all the Countries examined, the share of thermoelectric and nuclear capacity shows a considerable reduction. Wind power has increased in all Countries since 2005. Photovoltaic plants begun to have significant shares only after 2010.



Gross electricity production in Europe has shown a marked increase from 1990 to 2010, followed by stability up to 2019 and a sharp decrease in 2020 due to measures adopted to contain SARS-CoV-2 pandemic. In 2021 the electricity production comes back to the 2019 level; 14.5% of EU27 electricity production without pumping comes from solid fuels and 19.1% from natural gas. Oil and petroleum products account for 1.8%. Nuclear source accounts for 25.4% and 37.3% comes from renewable energy (renewables and biofuels). All considered Countries increased the electricity production since 1990, from 6.5% in Germany to 79.3% in Spain, except Romania whose electricity production decreased by 8%.

The energy mix in the examined Countries is quite heterogeneous, mainly as far as fossil fuels are concerned. In 2021, solid fuels make up 71.3% of electricity production in Poland, 41.1% in Czechia, and 28.2% in Germany. France has the highest electricity production from nuclear plants in Europe (68.9% in 2021), followed by Belgium (50.6%), Czechia (36.9%) and Sweden (30.8%), among the examined Countries. In the other Countries the nuclear electricity ranges from 11.9% in Germany to 19.1% in Romania, while the Netherlands have the lowest end share of electricity from nuclear source (3.1%). Poland and Italy do not have nuclear plants. At EU27 level, the nuclear source provides around a quarter of electricity production (25.4%). Italy and the Netherlands have the highest share of electricity by natural gas in 2021, 50.2% and 46.4% respectively.

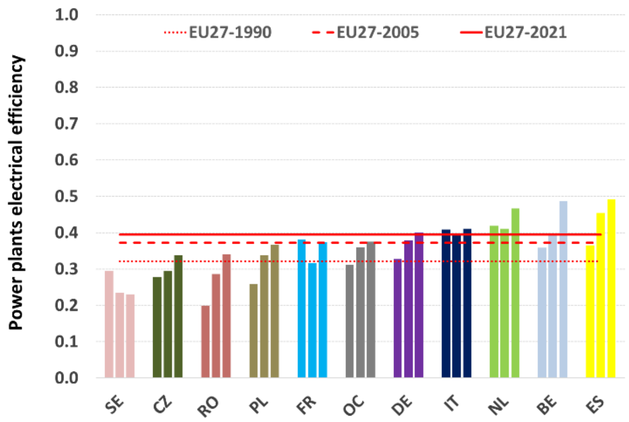
As regards electricity production from renewable sources, the share in EU27 has increased from 13.4% to 37.3% since 1990 to 2021. Since 2005 the renewable share has shown a steady increasing trend except in 2021 which recorded a decrease compared to 2020 (38.4%). In all the Countries examined there is a marked increase of renewable electricity production with a strong acceleration since 2005. After 2015 the growth slowed down and has resumed in recent years, although with different rates among the States. Sweden has one of the highest renewable shares in Europe.

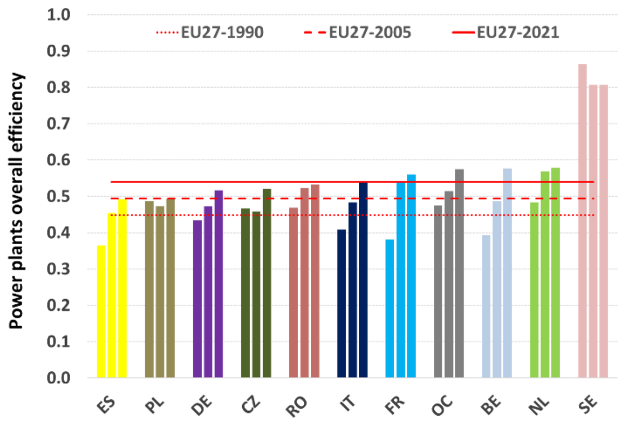


Efficiency of thermal power plants

The most important parameter for assessing the efficiency of an electricity generation system is the transformation efficiency of fuels into electricity and heat. The electrical efficiency of Italian non-cogeneration plants (0.456 in 2021) is among the highest in the biggest European Countries after Belgium (0.458) and the Netherlands (0.501). In 2021, the Italian average is over the EU27 average (0.425). As concerns the electrical efficiency of CHP plants, in 2021 Spain shows the highest value among the main European Countries (0.652), far higher than the EU27 average (0.37). Italy's electrical efficiency is 0.38. The total efficiency, for electricity and heat production, of the Italian cogeneration plants (0.595) is below the EU27 average (0.635) and increased of 20.1% since 1990.

The Italian electrical efficiency for all power plants (CHP and electricity only) in 2021 is 0.411, exceeded by Spain, Belgium, and the Netherlands, from 0.466 to 0.491. Sweden has the lowest electrical efficiency among the examined Countries (0.231), well below the EU27 average (0.395). The overall efficiency of Italian plants, for electricity and heat production, is 0.537, just below the EU27 average (0.539). Sweden shows the highest value (0.807) due to the highest ratio between heat and electricity recorded in this Country in CHP plants (more than 2.5), followed by Romania (1.79).

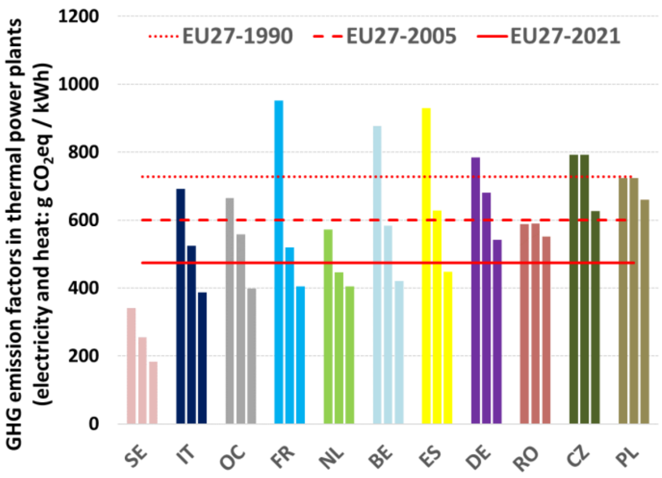




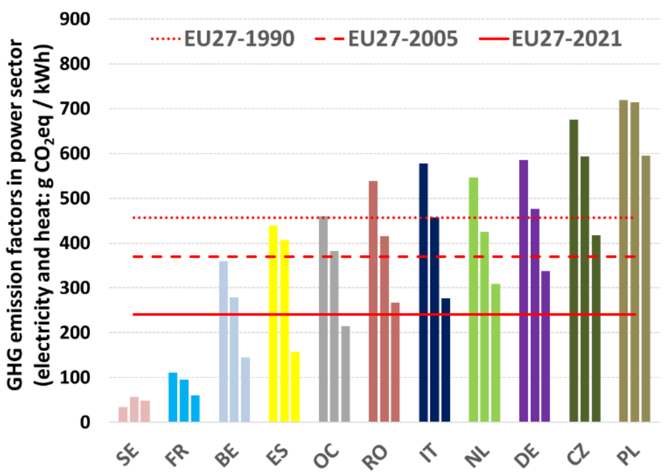
Greenhouse gas emissions from the electricity sector

Since 1990 there has been a decoupling between electricity production and GHG emissions by power sector in almost all European Countries, although emissions show a significant decrease only after 2005, with an increasing decoupling mainly due to the growing share of renewables.

GHG emission factors for electricity and heat production due to fuel combustion in thermal power plants reduced since 1990. In 2021 the emission factor in Italy (386.3 g CO_2eq/kWh) is higher only than that of Sweden (182.4 g CO_2eq/kWh), where the thermal power plants are mainly fuelled by bioenergy. Spain, Sweden, Belgium, and the group of smallest Countries have the largest reductions since 2005 (from -28% to -28.9%), followed by Italy (-26.3%). Germany reduced the emission factor by 20.5%. At the lowest end of reduction rate there are Romania (-6.4%), Poland (-8.9%), and the Netherlands (-9.3%).



The emission factors for total electricity and heat production by the whole power sector, including renewable and nuclear power production, in Italy are higher than the European average (276.6 *vs* 241 g CO_2eq/kWh). All Countries with lower emission factors than Italy have relevant amount of electricity by nuclear plants. The average EU27 emission factor shows a reduction of 34.9%, compared to the 2005 level, while Italy reduced its emission factor by 39.4% ranking the 3rd higher reduction rate among the biggest Countries. Spain and Belgium recorded the highest rates of reduction since 2005, -61.3% and -48% respectively, on the other side Poland and Sweden have the lowest ones, -16.7% and -14.7% respectively. The emission factor in Germany, which has the highest share of European GHG emissions by power sector, decreased by -29% since 2005.



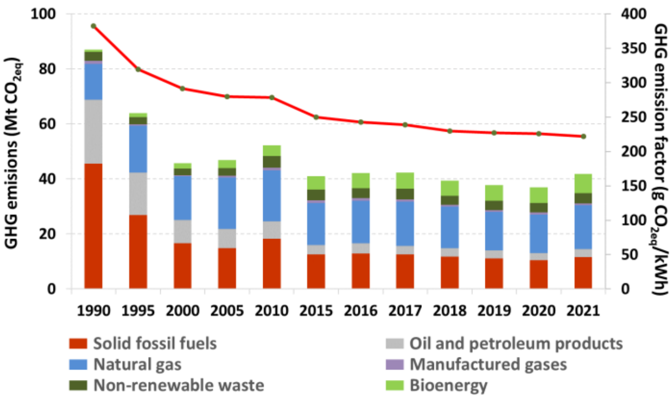
The outcomes allow to conclude that Italy have one of the lowest GHG emission factor for electricity production by fuel mix combustion among the biggest European Countries. Italian GHG emission factor by thermal plants occupies the 11th position, well below the European average. The Italian fuels mix, with greater share of natural gas than other Countries and the contribution of bioenergy, is a driving factor for the emission factor in thermal power plants.

As a result of many factors (fuel mix shift, efficiency, share of renewable) Italy reduced the emission factor for electricity production by 53.7% from 1990 to 2021 (-44.2% since 2005), against a reduction of 42.1% in Germany (30.6% since 2005) and 27.4% in Poland (19.6% since 2005). The reduction rate in Poland is the lowest among the biggest emitters in Europe. If Germany and Poland had reduced their GHG emission factors since 1990 at the same rate of Italy, it would have led (with the same electricity production) to avoid around 68 Mt CO_2eq in 2021 (about 103 Mt CO_2eq considering also heat production), about 11% of EU27 emissions from power sector. The power plants in Germany and Poland are still fuelled by significant shares of high-carbon content solid fuels, such as lignite, and the transition to natural gas has been much slower than in Italy.

Heat-only producers

Heat production accounts for a significant share of energy transformation processes. Plants dedicated to heat production for district heating and other uses (mainly for industry) consume an important share of the energy in the European balance. In 2021 the energy consumption of plants for heat production in EU27 was 18.7 Mtoe of which 0.67 Mtoe from geothermal and solar thermal, and 0.29 Mtoe from heat pumps. The energy consumption of fuels was 17.8 Mtoe, of which 6.2 Mtoe from bioenergy. Bioenergy consumption shows a rapidly growing share: the consumption in 2021 is more than double the 2005 level and is more than 8 times the consumption in 1990.

Total energy consumption in 2021 is less than that recorded in 1990 and a marked fuel shift has occurred with decrease of solid fuels and, to a greater extent, of oil and petroleum products being replaced by natural gas and bioenergy. The contribution of other renewable sources (more than 90% from geothermal energy and the rest from solar thermal) and heat pumps recorded an increasing trend and in 2021 represent 5.6% of total consumption.



As a result of fuel shift and decreasing energy consumed (-27.1%) and heat production (-17.2%), GHG emissions registered a sharp decrease by 52% since 1990. GHG emission factor decreased by 42%. At EU27 level the GHG emissions from these plants were 41.8 Mt CO_2eq in 2021. Since 2005 the emission factors decreased by 20.7% in EU27 (from 279.7 to 221.9 g CO_2eq/kWh). Italy's emission factor in 2021 is 17.4% lower than the EU27 average. The relevant solid fuels or non-renewable waste consumption in Poland and Germany results in higher emission factors, respectively 98.8% and 43.8% higher than the Italian one.

CONCLUSIONS

The results show that Italy has one of the most efficient energy and economic systems among the biggest Countries in Europe. Energy intensity per unit of GDP as well as resource productivity are among the lowest in Europe despite a relevant role of industry in the Italian economy. Low energy intensity often corresponds to more service-based economies with a minor role of industrial activities. EU27's carbon intensity per unit of energy consumption is on average lower than Italian one, since in several Countries is present a not negligible share of nuclear energy.

GHG emissions trends depend on many factors. The emission reductions in European Countries are mainly due to the decreasing energy intensity and increasing renewable energy consumption. In 2020 the measures adopted to contain the diffusion of SARS-CoV-2 pandemic heavily affected the European economy and GHG emissions. Independently from contingencies there is a clear decoupling between GDP and GHG emissions in the European Countries, although decoupling does not necessarily correspond to the emission reductions in line with the 2020 targets for some Country, as for Germany. The potential for reducing emissions must be assessed also considering the starting points of the driving factors and the costs to change the energy system, as well as the economy structure, especially concerning the services and industry assets.

Sectoral decarbonization indicators in Italy show sectors such as industry and agriculture with energy intensities among the lowest in Europe and sectors such as households and services occupying the last positions among European Countries with very wide emission reduction potentials, especially considering the level of electrification of final consumption that for such sectors is among the lowest in Europe. Such outcomes are consistent with the worrying distance of Italian projections from the target to be achieved in 2030 (ISPRA, 2023b). The emissions target is only on sectors not subject to the emission trading system, i.e. transport, civil, agriculture, waste and small industry, sectors ruled by Effort Sharing Regulation (ESR) with specific national targets. Emissions from large plants as thermal power plants, refineries, cement plants, steel plants, etc. are in the European cap and trade system of emission trading. The projections, carried out with the existing measures up to 31st December 2021, show that Italy would reduce the ESR emissions by 28.4% compared to 2005 level against the current target of -33%. The distance is even greater with the more challenging target of -43.7% proposed by the European Commission and approved by the European Parliament.

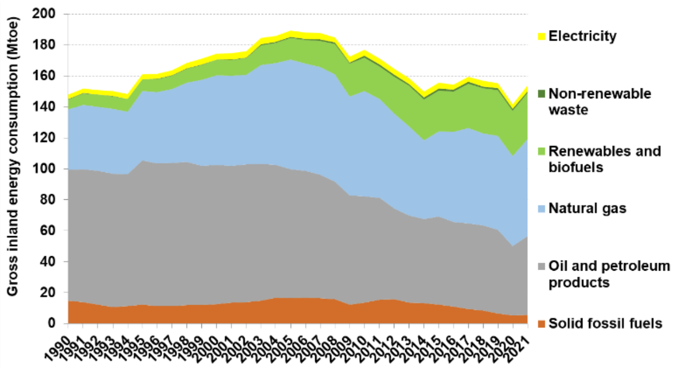
As for the power sector Italy reduced its emission factor for electricity production by 53.7% from 1990 to 2021, compared with a reduction of 42.1% in Germany and 27.4% in Poland (the lowest reduction rate among the biggest emitters in Europe). Poland and Germany have the highest share of lignite consumption and the highest emission factors among the biggest Countries. In such Countries the transition to natural gas has been slower than in Italy. The reduction of GHG emission factors since 1990 in Germany and Poland with the rate recorded for Italy, at parity of electricity production, would have avoided around 68 Mt CO_2eq in 2021 (about 103 Mt CO_2eq considering also heat production), about 11% of the EU27's GHG emissions from power sector.

SOMMARIO (Italiano)

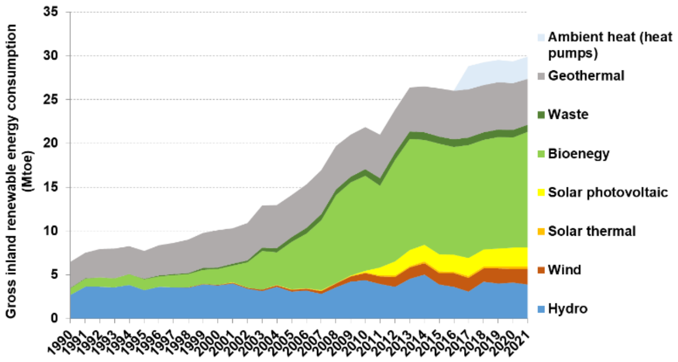
DATI NAZIONALI

Consumi di energia ed emissioni di gas serra

Il consumo interno lordo nazionale di energia mostra un andamento crescente dal 1990 fino al 2005, quando ha raggiunto il picco di 189,4 Mtep, successivamente si registra una riduzione accelerata dagli effetti della crisi economica con il valore minimo di 149,8 Mtep raggiunto nel 2014. Dopo il calo avvenuto nel 2020 a causa della pandemia di SARS-CoV-2 nel 2021 si osserva un rimbalzo dei consumi (+8,5% in più rispetto al 2020), con 153,7 ktep.



I combustibili fossili sono i principali vettori del sistema energetico nazionale. Dal 1990 al 2007, il rapporto medio tra combustibili fossili e consumo interno lordo è stato superiore al 90%, anche se con un leggero calo. Successivamente, la quota di energia fossile viene fortemente ridotta. Dal 1990 al 2021 la quota di energia fossile è scesa dal 95,5% all'80,1%, con il valore più basso nel 2020 (78,9%). Il declino è diventato particolarmente marcato dal 2007. Il mix nazionale di combustibili è cambiato considerevolmente dal 1990. I prodotti petroliferi hanno rappresentato la componente predominante con il 57,3% del consumo interno lordo nel 1990. La quota di prodotti petroliferi è costantemente diminuita al 31,7% nel 2020, con un rimbalzo nel 2021 (33,2%). Nel periodo 1990-2021 si è registrato un corrispondente aumento della quota di gas naturale, dal 26,3% al 40,6% (la quota nel 2020 era del 41,2%). La quota di combustibili solidi oscillava intorno a un valore medio dell'8%. Dal 2012, la quota di tali combustibili è costantemente diminuita, rappresentando il 3,6% del consumo interno lordo nel 2021.

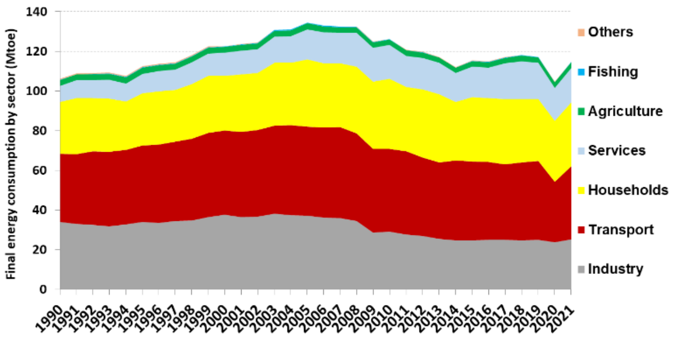


La quota di energia da fonti rinnovabili è complementare a quella osservata per i combustibili fossili. Dal 1990 al 2007 si è registrato un costante aumento della quota di fonti rinnovabili dal 4,4% al 9%. Dopo il 2007 la quota ha accelerato al 20,7% del consumo interno lordo nel 2020 e una leggera diminuzione nel 2021 (19,4%). Il consumo interno lordo rinnovabile è più che quadruplicato dal 1990, passando da 6,5 Mtep a 29,9 Mtep nel 2021.

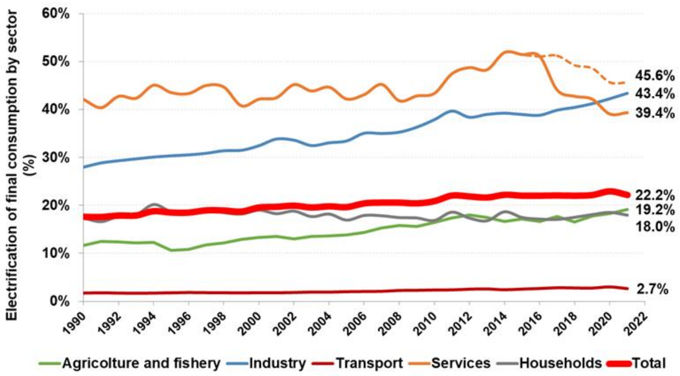
In passato le principali fonti di energia rinnovabile sono state la geotermia e l'idroelettrico, che hanno rappresentato oltre l'80% del consumo interno lordo di energia rinnovabile dal 1990 al 2000. La quota rimanente è stata coperta principalmente da biomassa e rifiuti (bioenergia). Dal 2000 le bioenergie hanno mostrato una crescita considerevole, e dal 2007 hanno superato il 50% della quota. Nel 2021, la quota di bioenergia è del 47%. Negli ultimi anni anche l'energia solare (termica e fotovoltaica) e l'energia eolica hanno assunto un ruolo significativo e insieme rappresentano il 14,1% del consumo totale di energia rinnovabile. Dal 2017 l'energia delle pompe di calore è stata registrata nel bilancio EUROSTAT. Tale voce nel 2021 è stata pari all'8,4% del consumo interno lordo rinnovabile.

Il consumo finale di energia per settore mostra peculiarità strutturali per ciascun settore e diverse sensibilità a fattori contingenti, come la crisi economica dal 2008 o il lockdown del 2020 che hanno colpito principalmente i settori produttivi. Dal 1990 al 2021 l'industria mostra un calo del consumo finale di energia del 25,8%, mentre i servizi mostrano un forte aumento del 113,6%. L'andamento dei consumi finali nel settore residenziale è abbastanza variabile a seconda delle diverse condizioni climatiche che influenzano i consumi. Il settore residenziale mostra un aumento dei consumi del 22,9% nel 2021 rispetto al 1990. La tendenza generale per i trasporti, compreso l'aviazione internazionale, aumenta del 7,5%, dopo il calo nel 2020 dovuto alle misure di lockdown.

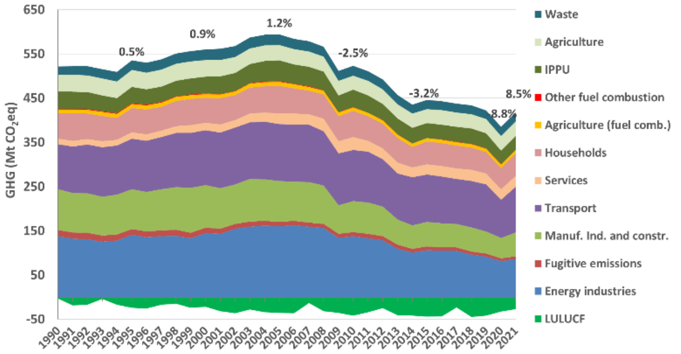
Dal 1990, la struttura dei settori in termini di consumo di energia è cambiata considerevolmente. I servizi rappresentano una quota crescente dei consumi finali dal 7,8% nel 1990 al 15,4% nel 2021, mentre l'industria riduce la sua quota di consumo energetico dal 32,6% al 22,3% nello stesso periodo. I consumi nel settore residenziale mostrano una tendenza in crescita fino al 2010, seguita da una leggera diminuzione con ampie fluttuazioni dovute principalmente alla variabilità delle condizioni climatiche. Il settore non sembra aver risentito della contrazione dovuta alla crisi economica come gli altri settori. La quota media dei consumi negli altri settori (principalmente agricoltura e pesca) è inferiore al 3%.



L'elettrificazione dei consumi finali è una strategia chiave per mitigare le emissioni di gas serra se perseguita parallelamente alla diffusione delle energie rinnovabili per la produzione di energia elettrica. La quota di energia elettrica nei consumi finali aumenta costantemente dal 1990 e nel 2021 è del 22,2%, leggermente al di sotto del livello del 2020 (23%). Il livello di elettrificazione settoriale dei consumi finali è molto diverso. L'elettricità nell'industria è il 43,4% dei consumi finali. I servizi mostrano la quota più elevata di consumo di energia elettrica, con un aumento significativo rispetto al 2008 che ha raggiunto oltre il 50% dei consumi finali del settore nel 2014 e nel 2015. Negli ultimi anni la quota è diminuita (39,4% nel 2021), principalmente a causa del notevole aumento del consumo finale di calore ambiente da pompe di calore che non è registrato nei bilanci energetici Eurostat fino al 2017. Senza tale voce, l'elettrificazione del settore nel 2021 è del 45,6%. Il tasso di elettrificazione dei consumi finali nell'industria è in costante aumento dal 1990, con un netto aumento dal 2005. In questo settore, il consumo di energia elettrica nel 2021 è pari al 43,4% del consumo finale. L'elettrificazione dei consumi nei settori residenziale e trasporti non aumenta significativamente e nel 2021 i rispettivi livelli sono stati del 18% e del 2,7%, entrambi leggermente al di sotto del livello del 2020. L'agricoltura e la pesca mostrano un costante aumento dell'elettrificazione, analogamente all'industria, e nel 2021 il livello era del 19,2%.



Le emissioni totali di gas serra mostrano una tendenza all'aumento fino al 2005, seguita da una diminuzione accelerata a causa degli effetti della crisi economica. Nel 2020 le emissioni (385 Mt CO_2eq) sono state pesantemente colpite dalle misure di lockdown per contenere la pandemia di SARS-CoV-2. Le emissioni serra sono diminuite del 26,2% nel 2020 rispetto al 1990 e del 35,2% rispetto al 2005. Tutti i settori hanno ridotto le emissioni, anche se con tassi diversi. Parallelamente al calo del consumo di energia, le emissioni di gas serra associate alle industrie manifatturiere sono diminuite in modo particolarmente marcato dal 2005. Nel 2021 è stato registrato un rimbalzo per tutti i settori, sebbene le emissioni totali siano rimaste al di sotto del 2019. Le emissioni di gas serra nel 2021 sono diminuite del



19,9% rispetto al 1990 e del 13,9% rispetto al 2005. Le stime preliminari ISPRA al 2022 mostrano che le emissioni di GHG sono sullo stesso livello dell'anno precedente (+0,1% rispetto al 2021).

Le emissioni dell'industria manifatturiera e costruzioni sono diminuite del 41,6% dal 2005 al 2021. I trasporti mostrano una crescita costante con un'inversione di tendenza solo dopo il 2007 e la forte diminuzione nel 2020; le emissioni del 2021 sono inferiori del 19,5% rispetto al 2005. Il settore civile (residenziale e servizi) aumenta le emissioni dal 1990 (+9%), con una differenza significativa tra residenziale e servizi, mentre il primo settore riduce le emissioni del 12% e il secondo aumenta del 108,6%.

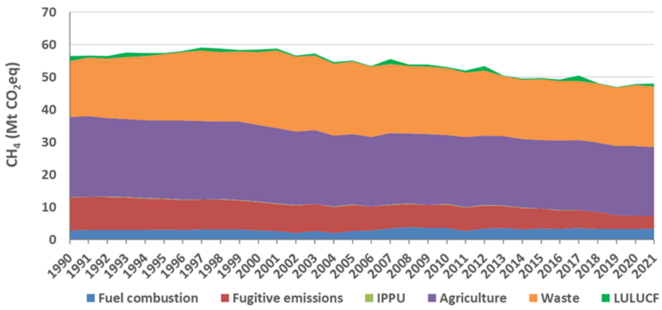
Le emissioni di gas serra *pro capite* sono aumentate da 9,2 t CO_2eq nel 1990 a 10,3 t CO 2eq nel 2004, negli anni successivi è stato registrato un rapido calo fino a 6,5 t CO_2eq nel 2020. Nel 2021 il valore è di 7 t CO_{2eq}. Le emissioni di gas serra *pro capite* diminuiscono dal 2005 al 2021 con un tasso medio annuo del -2,5%, mentre il tasso medio annuo di diminuzione dal 1990 è del -0,9%.

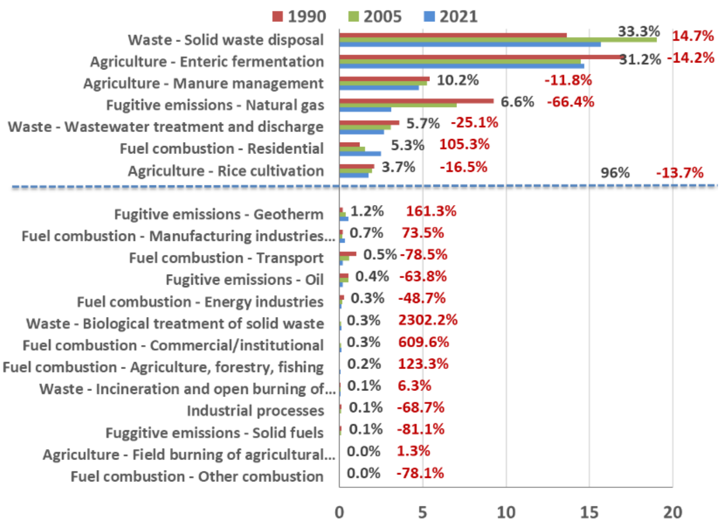
Emissioni di metano

Il metano è un potente gas serra, secondo solo all'anidride carbonica in termini di contributo al riscaldamento globale (IPCC, 2021). Il metano ha un potenziale di riscaldamento globale (GWP) 85 volte superiore a quello della CO_2 in un periodo di 20 anni, sebbene la CO2 abbia una vita atmosferica di migliaia di anni, mentre il metano scompare in circa 10-15 anni. Il rapido decadimento del metano e il suo elevato impatto sulla temperatura atmosferica ne fanno un obiettivo primario per frenare in modo tempestivo ed efficace il cambiamento climatico.

Secondo il recente rapporto dell'Agenzia Internazionale dell'Energia (IEA, 2021) e dell'IPCC (2022) ridurre le emissioni antropogeniche di metano è una delle strategie più efficaci, anche in termini economici, per ridurre rapidamente il tasso di riscaldamento e contribuire in modo significativo agli sforzi per limitare l'aumento della temperatura globale.

Le emissioni nazionali di metano, senza l'apporto di fonti naturali, rappresentano mediamente il 10,5%±0,8% delle emissioni di CO_2eq dal 1990 al 2021, con un andamento piuttosto variabile. Le emissioni di metano senza LULUCF sono diminuite da 55 a 47,1 Mt CO_2eq dal 1990 al 2021 (-14,3%). La riduzione delle emissioni di metano è molto inferiore alla riduzione del GHG totale (-19,9%). Inoltre, i gas serra diversi dal metano hanno ridotto le emissioni del 20,8% rispetto al 1990. Questi tassi mostrano la necessità di ottenere una riduzione delle emissioni di metano dalle principali fonti.





Tra le principali fonti di metano, i rifiuti hanno registrato nel 2021 un significativo aumento delle emissioni rispetto ai livelli del 1990 (+7,1%). L'agricoltura ha registrato una riduzione del 13,8% e le emissioni fuggitive del 61,7%. L'agricoltura contribuisce con il 45,1% delle emissioni di metano nel 2021, mentre il settore dei rifiuti rappresenta il 39,4%. Le emissioni fuggitive rappresentano l'8,3% e il metano incombusto nel settore energetico rappresenta il 7,2%.

Di gran lunga la fonte più importante del settore agricolo è rappresentata dalla fermentazione enterica, ovvero dai processi digestivi degli animali da allevamento.

Questa fonte rappresenta il 69,1% delle emissioni di metano dall'agricoltura nel 2021, seguita dalla gestione dei liquami con il 22,5% e dalla coltivazione del riso con l'8,3%. Le emissioni dovute alla combustione di residui agricoli in campo rappresentano un marginale 0,1%.

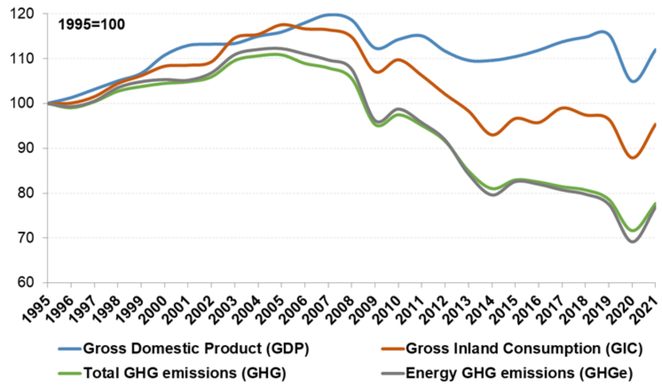
Nel settore dei rifiuti, la fonte dominante è rappresentata dallo smaltimento dei rifiuti solidi, responsabili nel 2021 dell'84,5% delle emissioni di metano del settore, la fonte successiva è rappresentata dal trattamento delle acque reflue, con il 14,5% delle emissioni di metano del settore. Le restanti due fonti, trattamento biologico dei rifiuti solidi e incenerimento e combustione in campo, rappresentano una quota marginale delle emissioni di poco superiore all'1%.

La maggior parte delle emissioni fuggitive di metano sono dovute alla filiera del gas naturale (produzione, trasporto e distribuzione) che nel 2021 rappresenta l'80% delle emissioni fuggitive totali di metano con una quota che è diminuita significativamente dal 1990, quando era del 91,2%. Le filiere di petrolio e gas naturale hanno registrato riduzioni di oltre il 60% dal 1990.

Le emissioni di metano incombusto nel settore energetico sono dovute principalmente alla fonte dominante dei settori civile e agricolo. Tali fonti rappresentano una quota dell'80,1% nelle emissioni di metano del settore energetico nel 2021, seguite dalle industrie manifatturiere e delle costruzioni con il 9,6%, dai trasporti con il 6,4% e dalle industrie energetiche con il 3,9%.

Disponendo in ordine decrescente le sorgenti di metano si può notare che il 96% delle emissioni di metano proviene da sette sorgenti chiave che emettono 45,2 Mt CO_2eq. Le emissioni dalle sorgenti chiave sono diminuite del 13,7% dal 1990. Le emissioni dalle sorgenti minori, che sono cumulativamente responsabili del 4% delle emissioni, sono inferiori del 27,7% rispetto al 1990. Lo smaltimento dei rifiuti solidi urbani è la prima sorgente chiave con un terzo delle emissioni totali di metano, seguita dalla fermentazione enterica con il 31,2%. Le prime due sorgenti sono responsabili di quasi due terzi delle emissioni di metano.

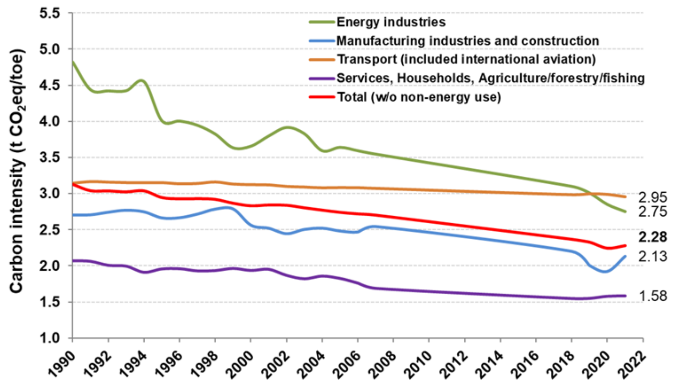
Intensità energetica e indicatori di decarbonizzazione



Per valutare le relazioni tra consumo energetico, economia ed emissioni di gas serra, vengono analizzate le tendenze del consumo interno lordo di energia (GIC), del prodotto interno lordo (PIL) e delle emissioni. Il PIL e il GIC hanno tendenze parallele fino al 2005. Successivamente i due parametri iniziano a divergere mostrando un disaccoppiamento sempre maggiore. La crescita delle emissioni di gas serra è stata più lenta di quella del PIL fino al 2005, evidenziando un relativo disaccoppiamento. Dopo il 2005, la divergenza tra i due parametri diventa sempre più marcata mostrando anche un disaccoppiamento assoluto quando il PIL è aumentato e i gas serra sono diminuiti (2015-2019).

Il disaccoppiamento è evidente anche dalla tendenza al ribasso del rapporto tra GIC e PIL dal 2005. La tendenza alla diminuzione delle emissioni di gas serra per unità di consumo di energia primaria è dovuta principalmente alla sostituzione di combustibili a più alto tenore di carbonio con gas naturale, principalmente nel settore energetico e nell'industria, e all'aumento della quota di energie rinnovabili. Le stesse tendenze decrescenti sono confermate per il consumo finale di energia (al netto degli usi non energetici) per unità di PIL e per le emissioni di gas serra per unità di energia finale consumata.

Nel periodo 1995-2021 il GIC per unità di PIL è sceso da 107,5 tep/M€ a 91,5 tep/M€ (-14,8%). Nello stesso periodo, le emissioni di gas serra per unità di PIL sono diminuite del 30,4%, passando da 357,3 t CO_2eq/M€ a 248,8 t CO_2eq/M€, mentre le emissioni di energia per unità di energia primaria passano da 2,81 t CO_2eq/tep a 2,21 tCO_2eq/tep, con una riduzione del 21,1%. Dal 2005 si è registrata un'accelerazione della diminuzione di intensità energetica per unità di PIL e della decarbonizzazione dell'economia nazionale fino al 2019/2020, evidenziando ancora una volta il crescente disaccoppiamento tra attività economica, consumo di energia ed emissioni di gas serra. Le cause possono essere molteplici e tra le principali c'è la contrazione delle attività industriali, che sono più energivore rispetto ai servizi caratterizzati da minore intensità energetica e maggiore valore aggiunto. Per quanto riguarda le emissioni di gas serra per unità di energia consumata (primaria e finale), dal 2005 si è registrata una accelerazione del tasso di diminuzione, dovuto principalmente all'aumento della quota di energia da fonti rinnovabili dal 2007. Solo nel 2021 gli indicatori mostrano una inversione con una tendenza al rialzo.



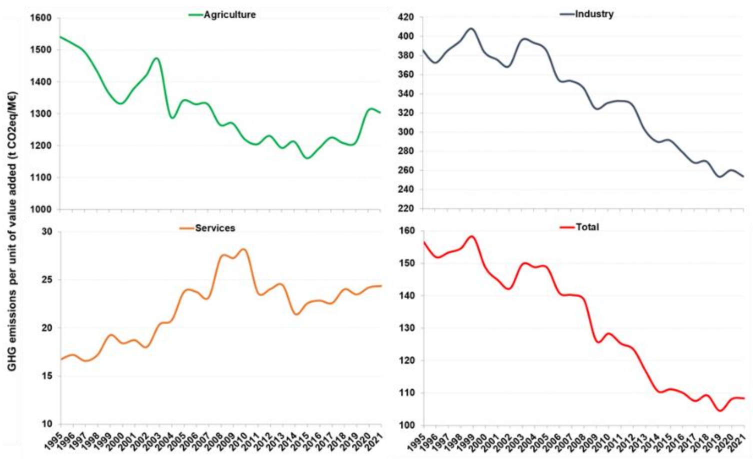
La decarbonizzazione a livello settoriale può essere valutata in base alle emissioni energetiche e al consumo energetico per settore. L'intensità di carbonio per energia è il rapporto tra emissioni di gas serra e consumo di energia. Le intensità medie di carbonio per settore mostrano notevoli differenze a seconda della diversa diffusione delle fonti rinnovabili e dell'elettrificazione dei consumi finali. L'intensità di carbonio delle industrie energetiche diminuisce del 42,9% nel 2021 rispetto al 1990 da 4,82 t CO_2eq/tep a 2,75 t CO_2eq. L'intensità di carbonio dell'industria manifatturiera nel 2021 è di 2,13 t CO_{2eq} / tep in diminuzione del 21,2% rispetto al livello del 1990. L'intensità di carbonio per i trasporti, compreso il trasporto aereo, è di 2,95 t CO_2eq/tep (-6,1% rispetto al 1990) e mostra il valore più alto degli ultimi anni tra i settori con la pendenza decrescente più bassa dal 1990. L'intensità di carbonio nel settore civile, insieme all'agricoltura e alla pesca, è di 1,58 t CO_2eq/tep, il 23,8% in meno rispetto al 1990. Tutte le tendenze al ribasso di questi indicatori sono statisticamente significative per il test di Mann-Kendall ($p<0.001$). Complessivamente, l'intensità di carbonio per il consumo energetico considerato, pari al 95%±1,2% del consumo interno lordo di energia dal 1990 al 2021, è di 2,28 tCO_2eq/tep (-27% rispetto al livello del 1990).

Indicatori dell'energia e dell'economia a livello settoriale

Gli indicatori di decarbonizzazione e di intensità energetica per settore sono calcolati confrontando le emissioni settoriali di gas serra con il rispettivo consumo energetico e valore aggiunto. Le emissioni settoriali comprendono solo le emissioni dirette e le emissioni derivanti dall'autoproduzione di energia elettrica (per l'industria). Le emissioni dovute al consumo di energia elettrica prelevata dalla rete non sono considerate. Per quanto riguarda le emissioni di gas serra e il consumo finale di energia, sono state considerate solo le emissioni energetiche, mentre le emissioni di processo per i settori industriale e agricolo sono state considerate anche rispetto al valore aggiunto.

Complessivamente, le emissioni derivanti dalle attività economiche considerate sono diminuite del 20,1% nel 2021 rispetto al 1995. Le emissioni da combustione sono ridotte del 23,9%, mentre le emissioni da processi sono ridotte del 14,3%. Le emissioni di gas serra dei settori considerati rappresentano in media il 34,9±0,8% delle emissioni totali di gas serra. Le intensità energetiche (tep/M€) dell'industria e dell'agricoltura sono inferiori a quelle del 1995, mentre per i servizi sono più elevate, anche se negli ultimi anni l'intensità del settore è diminuita notevolmente. Inoltre, negli ultimi anni anche le intensità agricole mostrano tendenze in aumento. L'intensità energetica aggregata è diminuita del 14,8% nel periodo 1995-2021, ma è aumentata del 5,2% nel 2021 dal 2014. L'aumento dell'intensità energetica osservato dopo il 2014 è trainato dall'agricoltura e dai servizi.

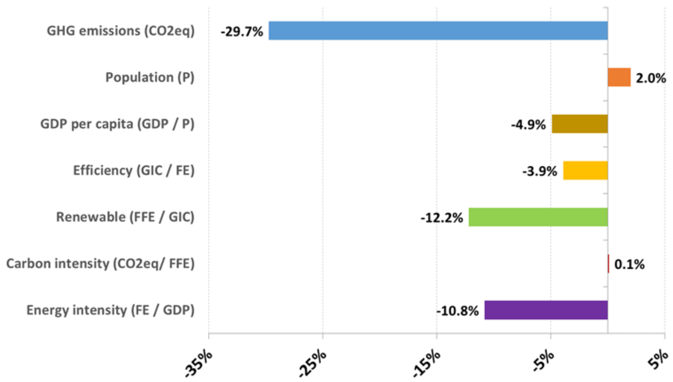
L'intensità di carbonio, rapporto tra emissioni di gas serra e valore aggiunto, diminuisce a causa della crescente quota di energia rinnovabile e di combustibili con contenuto di carbonio inferiore, come il gas naturale. Le intensità di carbonio per unità di valore aggiunto sono molto diverse da un settore all'altro. L'agricoltura ha i valori più alti, mentre nei servizi si registrano quelli più bassi. Entrambi i settori mostrano un aumento delle emissioni per unità di valore aggiunto negli ultimi anni. Per quanto riguarda i servizi gli indicatori sono aumentati fino al 2010, successivamente anche in questo settore si registra una relativa decarbonizzazione fino al 2014 seguita da un altro incremento. La tendenza totale è fortemente determinata dall'industria che registra una costante riduzione dell'intensità di carbonio.



Identità di Kaya e analisi della decomposizione

L'analisi di decomposizione è una tecnica per studiare la variazione di un indicatore in ogni intervallo di tempo in relazione alla variazione dei suoi fattori determinanti. In altre parole, la variazione di un parametro viene scomposta nella variazione dei parametri che lo determinano. Il punto di partenza dell'analisi è la costruzione di un'equazione di identità, dove la variabile studiata è rappresentata come il prodotto di componenti considerate come le cause della variazione osservata. Per l'identità, i componenti devono essere rapporti, dove il denominatore di un componente è il numeratore del successivo. Questa identità, chiamata Kaya dall'economista Yoichi Kaya, è fornita *a priori*, e deve essere realizzata secondo un modello concettuale coerente con i vincoli fisici della variabile studiata, oltre alle considerazioni relative alla disponibilità dei dati e agli obiettivi dell'analisi.

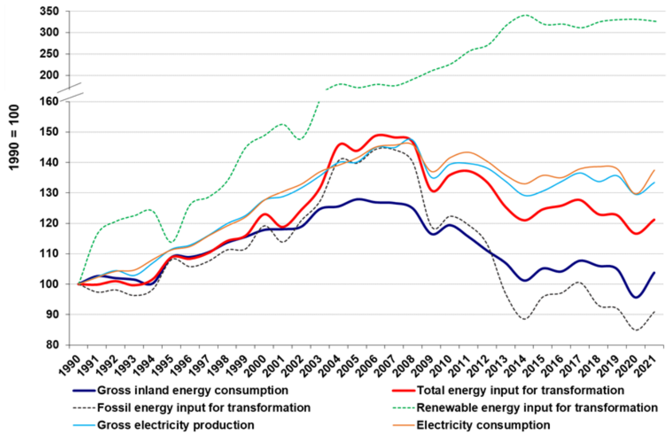
Le emissioni di gas serra sono decomposte in sei fattori: 1) popolazione; 2) crescita economica *pro capite*; 3) efficienza; 4) diffusione delle energie rinnovabili; 5) intensità di carbonio da combustibili fossili; 6) intensità energetica finale. I risultati dell'analisi di decomposizione, effettuata secondo il *Logarithmic mean Divisia index* (Ang, 2005), mostrano che l'effetto dei fattori che hanno portato a una riduzione delle emissioni nel periodo 2005-2021 ha prevalso sull'effetto dei fattori che hanno portato ad un aumento delle emissioni. La popolazione e l'intensità di carbonio sono gli unici fattori determinanti che hanno contribuito alla crescita delle emissioni (+2% e 0,1% rispettivamente). I restanti fattori hanno determinato una riduzione delle emissioni. La quota di energie rinnovabili (consumo di energia fossile / consumo interno lordo) ha giocato un ruolo significativo (-12,2%) seguita dall'intensità energetica finale (consumo finale di energia / PIL; -11,6%) e dal PIL pro capite (-10,8%). Il fattore efficienza (consumo interno lordo / consumo finale di energia) ha contribuito con -3,9%. Il contributo complessivo di ciascun fattore porta al -29,7% delle emissioni di gas serra nel periodo 2005-2021.



Settore elettrico

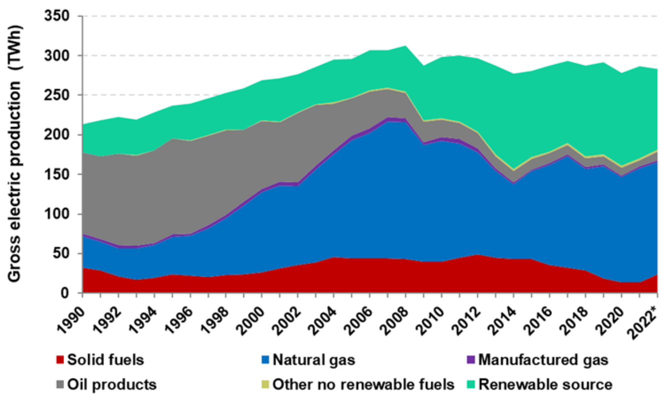
Produzione di energia termoelettrica e rinnovabile

La crescita dei consumi di energia elettrica nei consumi finali di energia rende questo settore uno dei principali attori del sistema energetico nazionale. Dal 2001 il consumo di energia per la produzione di elettricità è aumentato a tassi superiori al consumo interno lordo di energia. La crescita del consumo di energia rinnovabile corrisponde alla diminuzione dell'energia fossile.



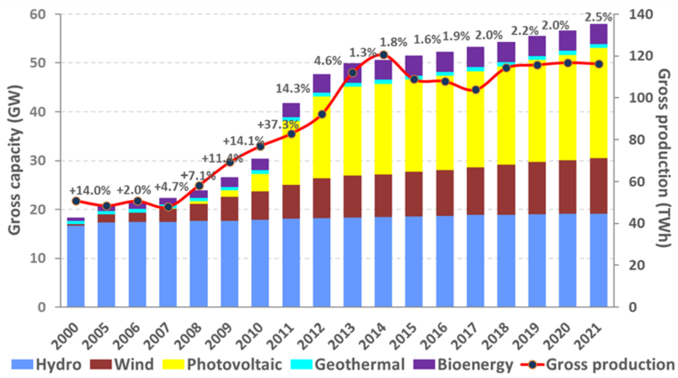
La produzione lorda di energia elettrica è passata da 216,6 TWh a 289,1 TWh dal 1990 al 2021 (+33,5%). I consumi di energia elettrica sono aumentati da 218,8 TWh a 300,9 TWh nello stesso periodo (+37,5%). Dopo una costante crescita della produzione e del consumo di energia elettrica, dal 2007 si è registrata una tendenza al ribasso a causa della crisi economica. Nel 2020 c'è stata un'ulteriore caduta della produzione e del consumo. Nel 2021 si è registrato un rilevante incremento della produzione e dei consumi di energia elettrica, rispettivamente +3% e +6% rispetto al 2020. La quota media delle importazioni nette di energia elettrica è pari a circa il 15% del consumo con ampie fluttuazioni e una sensibile riduzione negli ultimi anni fino al 2020 (11,3%). Nel 2021 la quota è tornata al 14,2%.

Per quanto riguarda il mix energetico nel settore energetico, il gas naturale è aumentato costantemente dal 1990 a scapito dei prodotti petroliferi (nel 2021 il 49,8% della produzione di energia elettrica da gas naturale e circa il 2,7% da prodotti petroliferi, mentre nel 1990 le due percentuali erano rispettivamente del 18,3% e del 47,4%). La quota di combustibili solidi ha mostrato oscillazioni intorno alla media dell'11,5% con una forte riduzione negli ultimi anni (4,9% nel 2021). Le stime preliminari per il 2021 mostrano una tendenza al rialzo con un rilevante aumento della quota di combustibili solidi intorno all'8%.



Nel 2005 la quota di energia elettrica da fonti rinnovabili rispetto alla produzione totale rappresentava solo il 16% della produzione nazionale. Dopo il 2007, la quota è aumentata significativamente fino alla fine del 2014, quando ha raggiunto il 43,1%. Nel 2021 la quota rinnovabile nella produzione di energia elettrica è pari al 40,2%, mentre le stime preliminari mostrano una brusca contrazione nel 2022 (35,5%), principalmente a causa della forte riduzione della produzione idroelettrica.

La potenza termica totale nel 2021 è di 61,9 GW con una forte contrazione dal 2012, quando la capacità installata ha raggiunto il picco di 80,2 GW. Gli impianti a ciclo combinato, indipendentemente dalla produzione di cogenerazione o non cogenerazione, mostrano un significativo incremento della potenza efficiente lorda, passando da 7,9 GW nel 2000 ad un massimo di 43,4 GW nel 2011-2012. Successivamente, questi impianti mostrano una costante riduzione fino a 40,1 GW nel 2021.

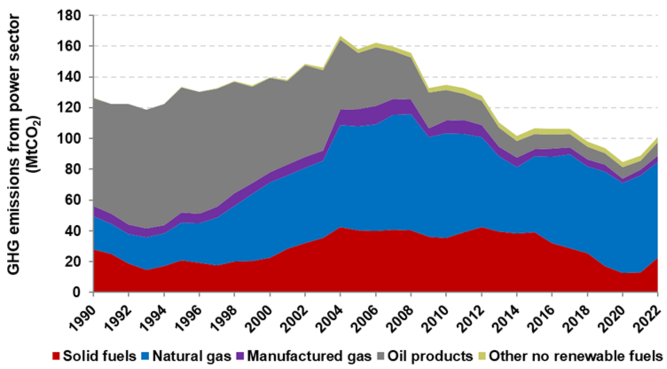


Per quanto riguarda l'energia rinnovabile, nel 2000 si è registrato un aumento significativo della capacità installata. Nel 2021 la potenza efficiente lorda rinnovabile era di 58 GW. Il più alto tasso di crescita annuo è stato registrato nel 2011 quando la nuova potenza rispetto all'anno precedente è stata di 11,3 GW, di cui 9,5 GW di impianti fotovoltaici e 1,1 GW di impianti eolici. Dopo il 2014 la nuova potenza aggiuntiva è stata di circa 1 GW all'anno.

Per gli impianti alimentati a bioenergia, va sottolineato il rapido incremento dal 2008 al 2013 e la successiva stabilizzazione della potenza efficiente lorda con nuove installazioni di pochi MW all'anno fino al 2018 e una diminuzione negli ultimi anni. Gli impianti alimentati a biogas sono passati da 0,37 GW nel 2008 a 1,46 GW nel 2021. La crescita degli impianti alimentati con biocarburanti liquidi nel periodo 2008-2013 è particolarmente rapida, da 0,12 GW a 1,04 GW, per poi ridursi a 0,95 GW nel 2021. Gli impianti alimentati da biomasse solide e rifiuti sono aumentati da 1,07 GW nel 2008 a 1,73 GW nel 2018. Dal 2018 la potenza degli impianti a biomassa solida mostra una tendenza al ribasso, mentre aumenta la potenza degli impianti di rifiuti. Nel 2021 la potenza totale è di 1,7 GW, di cui 0,92 alimentati da rifiuti. Tali tendenze possono essere spiegate dalla riduzione degli incentivi per gli impianti alimentati a bioenergia. Lo sviluppo futuro di tali impianti non sembra indipendente da alcune forme di incentivi.

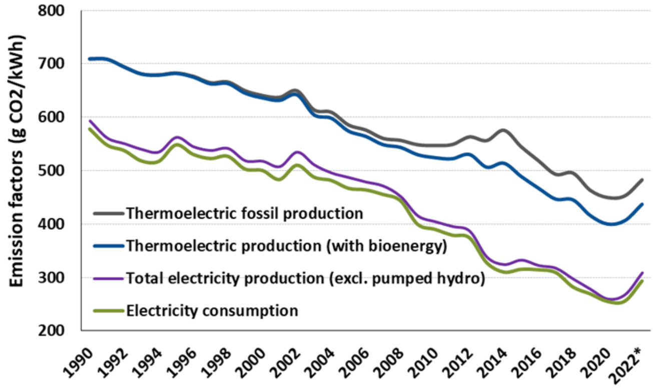
Emissioni di CO_2 e fattori di emissione

La quantità di CO_2 emessa dal settore elettrico nel 2021 è stata di 89 Mt (di cui 76,9 Mt per la produzione di energia elettrica e 12,1 Mt per la produzione di calore) pari al 22,1% delle emissioni nazionali di GHG.



Fino alla prima metà degli anni 1990, le emissioni di CO_2 da petrolio e prodotti petroliferi rappresentavano una quota significativa delle emissioni totali del settore energetico. Nel 1995, la quota di emissioni da tali fonti ammontava al 61% delle emissioni. Successivamente, la quota è costantemente diminuita fino al 6,6% nel 2021. Tuttavia, va notato che tali fonti includono gas sintetici provenienti da processi di gassificazione, con una quota crescente dal 2000. Considerando solo l'olio combustibile, la quota delle emissioni di CO_2 è diminuita dal 61% all'1,8% dal 1995 al 2021, con il primo aumento registrato nel 2021 rispetto all'anno precedente. La quota di emissioni di gas naturale è aumentata dal 18,5% nel 1995 al 70,9% nel 2021. La quota di emissioni da combustibili solidi, principalmente carbone, è stata in costante aumento fino al 2014, quando è stato raggiunto il picco del 37,6%, ma negli anni successivi è stata registrata una forte riduzione fino al 14,7% nel 2020 e nel 2021. La stima preliminare mostra un aumento rilevante nel 2022, intorno al 22,3%.

Il fattore di emissione per la produzione termoelettrica lorda nazionale diminuisce dal 1990 al 2021 da 709,1 g CO 2/kWh a 406,6 g CO_2/kWh con il primo aumento mai registrato rispetto all'anno precedente nel 2021. La diminuzione è dovuta principalmente alla crescente quota di gas naturale e alla continua riduzione del fattore di emissione specifico di questo combustibile, che a sua volta è dovuta all'aumento dell'efficienza di conversione elettrica degli impianti. Svolge un ruolo importante anche l'uso di bioenergia con bilancio a zero emissioni di carbonio che contribuisce al 10,1% della produzione termoelettrica nel 2021. La differenza tra i fattori di emissione degli impianti termoelettrici con o senza il contributo della

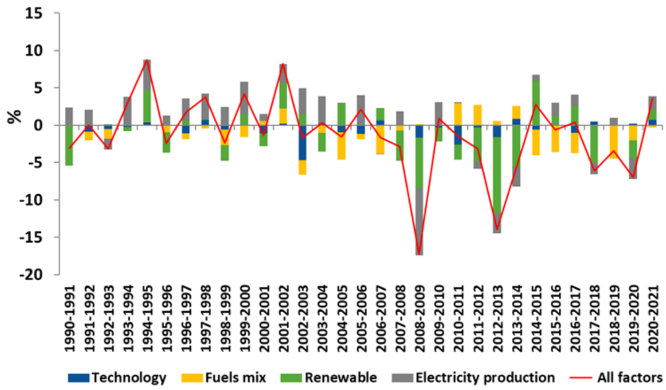


bioenergia mostra il ruolo di tali fonti nella riduzione del fattore di emissione. La differenza diventa significativa dopo il 2000 a causa dell'aumento della quantità di biomassa solida e rifiuti solidi urbani utilizzati per la produzione di energia elettrica e l'aumento ancora maggiore di bioliquidi e biogas osservato dopo il 2008.

La produzione di energia elettrica da fonti rinnovabili riduce il fattore di emissione per la produzione totale di energia elettrica poiché le fonti rinnovabili non hanno emissioni di CO_2. Il fattore di emissione per il consumo di energia elettrica è ulteriormente ridotto grazie alla quota di energia elettrica importata dall'estero le cui emissioni sono contabilizzate fuori dal territorio nazionale. Insieme ad un aumento della produzione di energia elettrica dal 1990 al 2021 di 72,5 TWh, si è registrata una diminuzione delle emissioni di CO_2 di 49,5 Mt. La riduzione dei fattori di emissione dal 2007 al 2014 è dovuta principalmente all'aumento della produzione elettrica da fonti rinnovabili, mentre la diminuzione registrata dal 2015 è dovuta essenzialmente alla crescente quota di gas naturale.

Analisi di decomposizione

La variazione delle emissioni di gas serra derivanti dalla produzione termoelettrica è dovuta a diversi fattori come la tecnologia di generazione elettrica, il combustibile fossile utilizzato, il contributo delle fonti rinnovabili e la domanda di elettricità. L'analisi di decomposizione è stata applicata per valutare il contributo relativo di questi fattori. La tecnica è ampiamente utilizzata nell'analisi dei dati ambientali.



I fattori considerati nell'analisi (tecnologia, tipo di combustibile, fonti rinnovabili) contribuiscono alla riduzione delle emissioni di CO_2 laddove l'aumento della produzione di energia elettrica ha l'effetto opposto. I risultati dell'analisi mostrano che la tecnologia, le rinnovabili e il mix di combustibili contribuiscono alla riduzione delle emissioni di CO_2 dal 1990 al 2021 rispettivamente del 19,6%, 27,3% e 16,4%, mentre l'aumento della produzione di energia elettrica porta ad un aumento delle emissioni del 24%. L'effetto cumulato dei quattro fattori ha portato a una riduzione delle emissioni di CO_2 nel 2021 del 39,2% rispetto alle emissioni osservate nel 1990 (-49,5 $MtCO_2$). In altre parole, la riduzione dovuta alla modifica del fattore tecnologico (diminuzione dei fattori di emissione specifici dei combustibili fossili) nel periodo 1990-2021 sarebbe stata di 24,8 Mt CO_2 se gli altri fattori fossero rimasti invariati. La riduzione dovuta al cambiamento del mix di combustibili sarebbe stata di 20,7 Mt CO_2, mentre la crescente quota di rinnovabili avrebbe portato ad una riduzione di 34,5 Mt CO_2. Tali effetti sono compensati da un aumento netto della produzione di energia elettrica che avrebbe comportato un aumento di 30,4 Mt CO_2 senza il contributo degli altri fattori.

Dal 2007 il ruolo delle fonti rinnovabili diventa più rilevante degli altri fattori. Inoltre, va sottolineato che dal 2007 la diminuzione della domanda elettrica dovuta alla crisi economica ha ridotto significativamente il consumo di combustibili fossili, aumentando al contempo la quota di fonti rinnovabili a seguito della priorità del dispacciamento di energia elettrica rinnovabile. In ogni caso, ogni unità di energia elettrica rinnovabile contribuisce alla riduzione delle emissioni in atmosfera molto più di qualsiasi altro fattore, se viene sostituita una quantità equivalente di elettricità fossile.

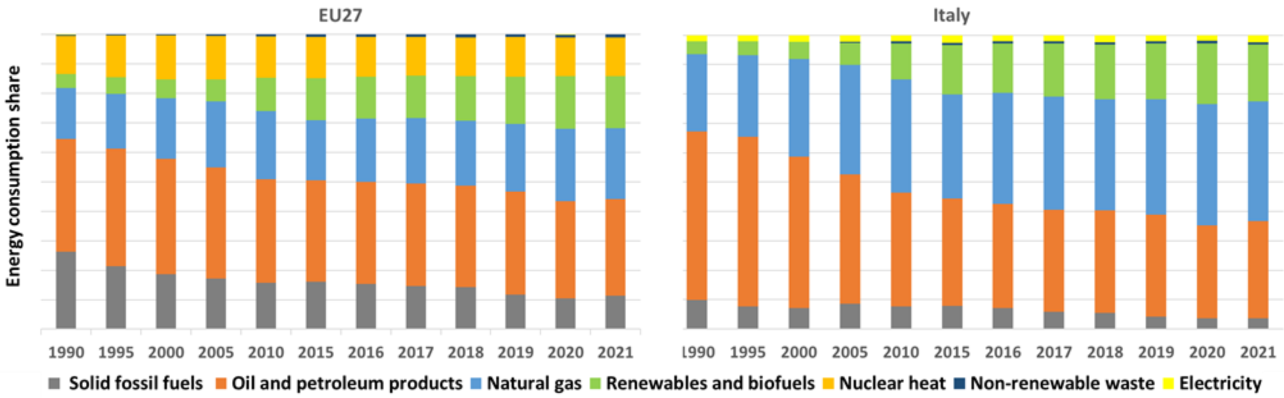
L'ITALIA E I MAGGIORI PAESI EUROPEI

Indicatori di efficienza e decarbonizzazione

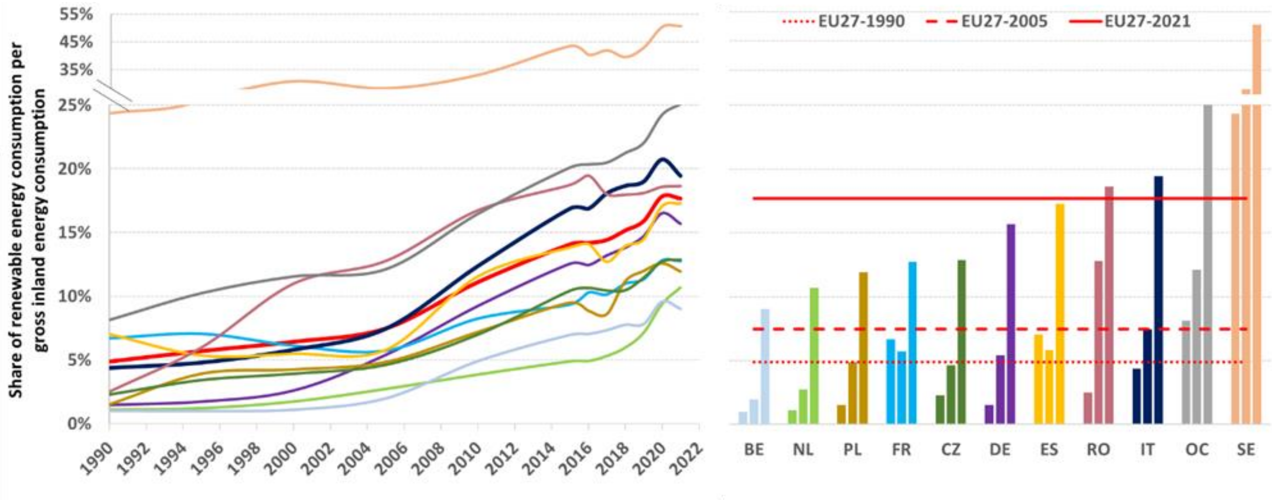
Gli indicatori di decarbonizzazione ed efficienza sono stati esaminati per l'Italia e i maggiori Paesi Europei. Gli Stati membri dell'UE con più del 3% delle emissioni di gas a effetto serra dell'UE27 o più del 3% del PIL dell'UE27 nel 2020 sono considerati a fini di confronto. Gli Stati membri esaminati (Germania, Francia, Italia, Spagna, Polonia, Paesi Bassi, Belgio, Romania e Svezia) rappresentavano nel 2020 l'81,5% della popolazione dell'UE27, l'81,6% delle emissioni di gas a effetto serra e l'83,1% del PIL. Il consumo interno lordo di energia ha rappresentato l'82,5% del consumo energetico dell'UE27.

Consumo di energia e prodotto interno lordo

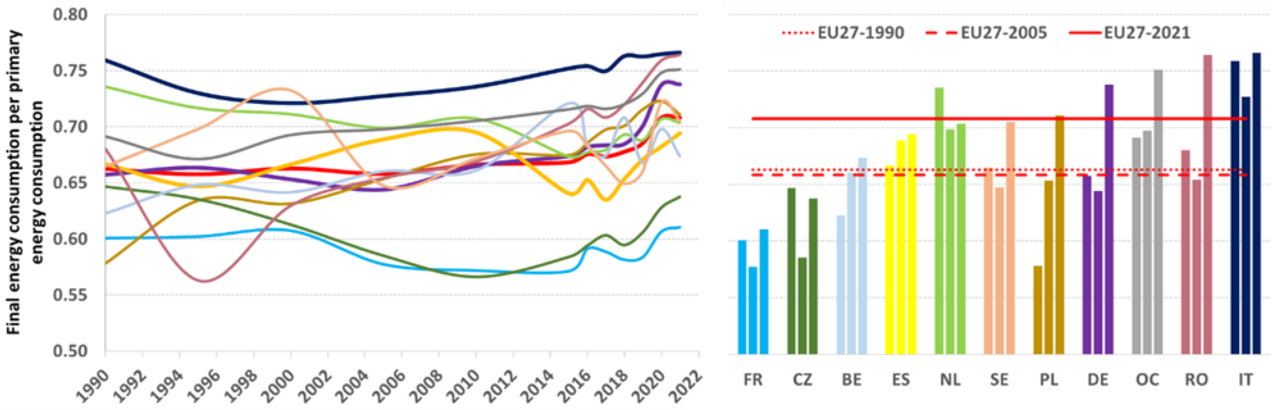
Dal 1990, le politiche ambientali europee hanno portato a un cambiamento significativo del mix energetico negli Stati membri. L'energia nucleare rappresenta il 13,1% del consumo interno lordo dell'UE27 nel 2021, abbastanza stabile dal 1990 (12,9%). D'altra parte, l'energia da combustibili solidi subisce una contrazione significativa dal 1990. La quota dell'UE-27 è scesa dal 26,3% all'11,4% dal 1990 al 2021, superiore a quella del 2020 (10,5%). Ci sono ancora quote significative in alcuni degli Stati più grandi come Germania (18%), Polonia (41,9%) e Cechia (30,2%). Il petrolio e i prodotti petroliferi, invece, mostrano una modesta riduzione a livello europeo (dal 38,3% del 1990 al 32,7% del 2021) con andamenti diversi tra gli Stati. Il consumo di energia del gas naturale mostra un aumento considerevole in quasi tutti gli Stati e a livello dell'UE27 varia dal 17,1% nel 1990 al 23,9% nel 2021. L'energia rinnovabile mostra un aumento significativo nell'UE27 dal 4,9% nel 1990 al 17,7%.



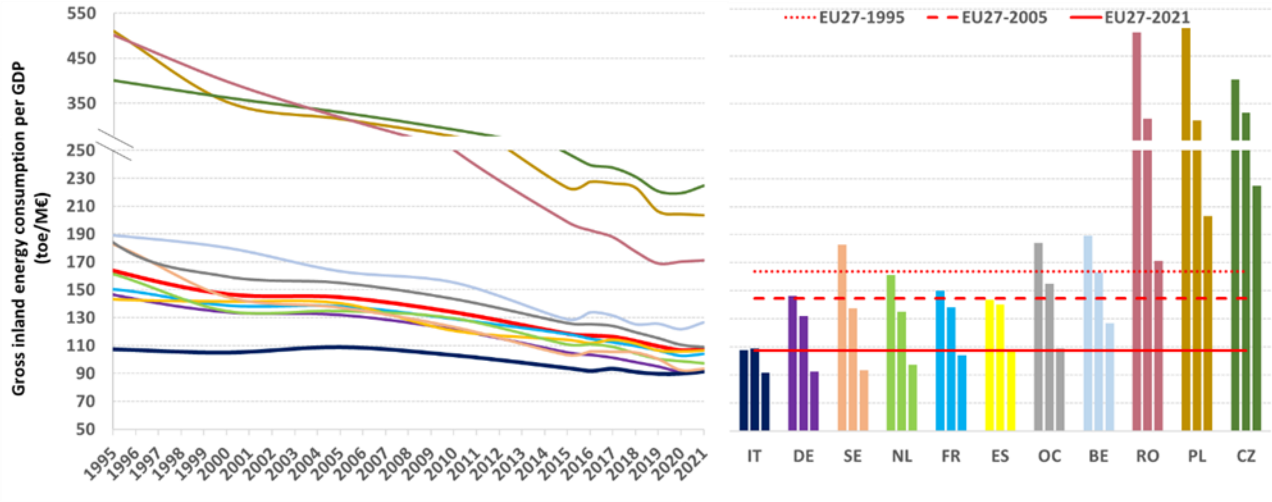
La quota italiana di combustibili solidi, principalmente carbone, nel consumo interno lordo è diminuita dal 9,9% del 1990 al 3,6% del 2021. La quota di gas naturale per l'Italia passa invece dal 26,3% al 40,6%. La quota di petrolio e prodotti petroliferi passa dal 57,3% al 33,2% e la quota delle rinnovabili è cresciuta dal 4,4% al 19,4%, al di sotto del livello del 20,7% del 2020. La quota di rinnovabili dell'Italia è tra le più alte nei Paesi esaminati, solo la quota della Svezia è superiore a quella italiana. La quota di combustibili fossili è significativamente ridotta in quasi tutti i Paesi Europei. La media dell'UE27 è scesa dall'82% nel 1990 al 69,1% nel 2021. Tra i Paesi esaminati, le quote dei Paesi Bassi e della Polonia sono ancora superiori all'85%, rispettivamente all'87,7% e all'88%.



Il rapporto tra il consumo finale di energia (compresi gli usi non energetici) e il consumo interno lordo è un indicatore dell'efficienza energetica. Dal 1990 il rapporto per l'Italia si aggira intorno alla media di 0,76 contro lo 0,7 della media UE27. Per valutare l'efficienza della trasformazione energetica, è utile considerare il consumo di energia senza usi non energetici. In altre parole, il rapporto tra consumo finale di energia ed energia primaria. L'efficienza di trasformazione energetica italiana è superiore a qualsiasi altro Paese esaminato (0,77 in Italia *vs* 0,71 nell'UE27). Solo la Romania si avvicina al valore italiano nel 2021.



Il consumo interno lordo di energia per unità di prodotto interno lordo (PIL) è un indicatore dell'efficienza economica ed energetica (intensità energetica). L'Italia è stata uno dei Paesi Europei con minore intensità energetica fino al 1995, quando era dietro solo alla Danimarca, poi ha perso posizioni e nel 2021 ha il quinto valore, superiore a Irlanda, Danimarca, Malta e Lussemburgo. Tra i maggiori Paesi dell'UE27, l'Italia continua ad avere la più bassa intensità energetica seguita da Germania e Svezia.



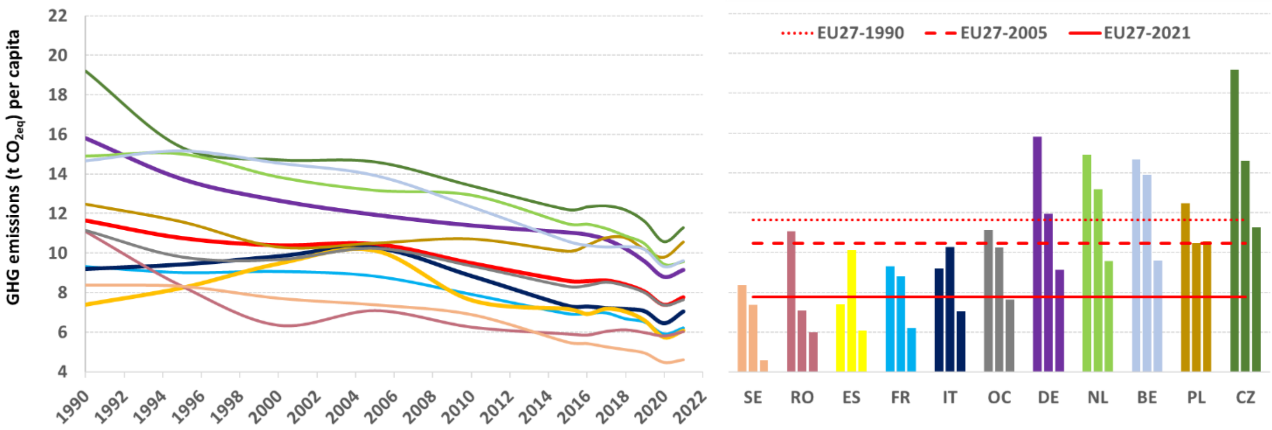
L'intensità energetica finale (rapporto tra i consumi finali di energia, compresi gli usi non energetici, e il prodotto interno lordo) segue andamenti simili con una repentina riduzione nei Paesi europei che, partendo da livelli superiori a quelli italiani, raggiungono i valori italiani e in alcuni casi li superano. Dal 1995 l'Italia mostra una notevole efficienza energetica ed economica, l'intensità energetica finale ridotta di 1 1. 6% dal 1995 al 2021; riduzioni molto più elevate si sono verificate negli altri Paesi europei (-29. 9% nell'UE27). Le ragioni della riduzione dell'intensità energetica osservata sono molteplici come l'aumento dell'efficienza edilizia, il miglioramento dell'efficienza industriale, l'elettrificazione dei consumi finali e lo spostamento dell'economia verso attività ad alto valore aggiunto e basso consumo energetico dei servizi a scapito dei settori industriali.

I Paesi europei mostrano una vasta gamma di elettrificazione dei consumi finali di energia (solo usi energetici) nel 2021 che va dal 14,6% in Lettonia al 41,6% a Malta. L'Italia è appena al di sotto della media UE27 con il 22,2% contro il 22,8%. Tra i Paesi più grandi, Svezia, Francia e Spagna hanno maggiori livelli di elettrificazione rispetto all'Italia, rispettivamente del 34,3%, 26,7% e 24,9%. All'estremità più bassa ci sono Romania e Polonia con il 15,7% e il 16,7% rispettivamente.

A livello settoriale, l'elettrificazione del consumo finale di energia da parte degli Stati membri mostra cifre diverse, sebbene con una tendenza comune alla crescita. L'elettrificazione dei consumi finali dell'industria in Italia è tra le più alte d'Europa (43,4% nel 2021). I servizi mostrano le più alte percentuali di elettrificazione tra i settori; tuttavia, la quota italiana nel 2021 è del 39,4%, ben al di sotto della media UE27 (46,3%), così come l'elettrificazione nel residenziale (18% in Italia contro il 24,6% nell'UE27). Il settore dei trasporti mostra le percentuali più basse di elettrificazione tra i settori e nel 2021 l'Italia è uno dei tre Paesi dell'UE27 con la quota più alta (2,7%), dopo Svezia (5%) e Austria (3,5%).

Emissioni di gas serra e consumo energetico

Le emissioni di gas serra *pro capite* dell'Italia dal 1990 al 2021 sono 8,8±1,2 t CO_2eq (ISPRA, 2023a). Le emissioni *pro capite* sono aumentate fino al 2004 quando è stato raggiunto il valore massimo di 10,3 t CO_2eq, quindi nel 2020 è stata osservata una riduzione fino a 6,4 t CO_2eq. Nel 2021 le emissioni *pro capite* sono pari a 7 t CO_2eq. Le emissioni *pro capite* italiane sono sempre state al di sotto della media europea. Le emissioni medie *pro capite* dell'UE27 nel 2021 sono 7. 8 t CO_2eq.



Per quanto riguarda l'intensità di carbonio, le emissioni di gas serra derivanti dal consumo di energia, tutti i Paesi hanno ridotto le emissioni per unità di consumo interno lordo di energia dal 1990. Tale indicatore è sensibile al mix energetico. L'intensità di carbonio dell'Italia è superiore alla media europea, anche per il contributo del nucleare in molti Paesi. Disaggregando l'energia nucleare dal consumo interno lordo, il valore dell'Italia è inferiore alla media dell'UE27 (2,7 t CO_2eq *vs* 2,8 t CO_2eq nel 2021).

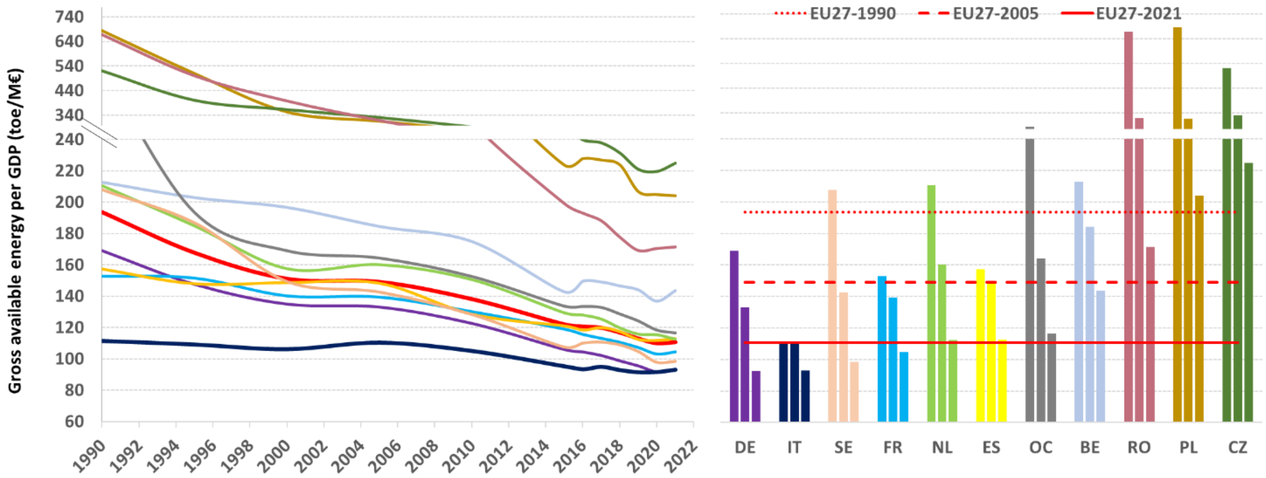
Il rapporto tra emissioni di gas serra e prodotto interno lordo è l'intensità di carbonio legata all'economia. Tale indicatore è sensibile al mix energetico e ancora più sensibile alla struttura economica: quota di servizi e industria. Inoltre, il PIL dei Paesi è determinato anche dalle attività legate ai bunker internazionali, le cui emissioni sono voci memo negli inventari delle emissioni. L'indicatore mostra una riduzione per tutti i Paesi europei e i dati dell'Italia sono appena al di sotto della media UE27 nel 2021 (0,26 t CO_2eq/k€ *vs* 0,25 t CO_2eq/k€). Svezia e Francia hanno i valori più bassi: 0,09 t CO_2eq/k€ e 0,18 t CO_2eq/k€, rispettivamente. La Polonia è all'estremità superiore con 0,74 t CO_2eq / k€, seguita da Cechia e Romania con 0,62 t CO_2eq / k€ e 0.58 t CO_2eq/k€.

Gli indicatori mostrano che l'Italia, rispetto ai maggiori Paesi dell'UE27, ha un'efficienza energetica ed economica storicamente elevata con una quota significativa di energie rinnovabili e gas naturale nel mix energetico e una delle emissioni *pro capite* più basse in Europa. L'intensità di energia lorda per unità di PIL in Italia è superiore solo a quelle di Irlanda, Danimarca, Malta e Lussemburgo, mentre l'intensità di carbonio per unità di PIL è appena inferiore alla media UE27 e molto vicina alle intensità di carbonio registrate in Germania, Belgio e Spagna, tra i Paesi più grandi. L'intensità di carbonio per consumo lordo di energia è superiore alla media europea a causa della quota significativa di energia nucleare nell'UE27. L'intensità di carbonio per consumo lordo di energia senza il nucleare mostra che l'intensità dell'Italia è superiore solo a quelle di Svezia, Paesi Bassi e Belgio, tra i Paesi più grandi. Sebbene alcuni indicatori mostrino che molti Paesi hanno migliorato le loro prestazioni in termini di emissioni di gas serra, ottenendo talvolta risultati migliori rispetto all'Italia, è necessario considerare i seguenti fattori:

- i Paesi con elevate quote di combustibili solidi o petrolio e prodotti petroliferi hanno maggiori potenzialità di riduzione delle emissioni da combustibili fossili rispetto a quelli disponibili in Italia, dove il mix fossile è rappresentato principalmente dal gas naturale e ulteriori riduzioni delle emissioni di gas serra sono possibili solo aumentando la quota di rinnovabili e migliorando l'efficienza.
- In diversi Paesi c'è un contributo significativo dell'energia nucleare con vantaggi emissivi, una fonte di energia non priva di problemi e che alcuni Paesi intendono eliminare gradualmente (Germania, Belgio), anche se recenti eventi, come l'invasione dell'Ucraina da parte della Russia del febbraio 2022 hanno determinato revisioni della pianificazione di disattivazione delle centrali nucleari. Inoltre, l'incertezza sui tempi del programma di manutenzione delle centrali nucleari rimane considerevole anche in Francia, che attualmente soffre della chiusura di 25 reattori su 56.

L'intensità emissiva di un Paese dipende strettamente dalla sua struttura economica. I Paesi con una predominanza di servizi o con quote significative di consumo non energetico, come i Paesi Bassi, mostrano minori emissioni per unità di PIL ed energia consumata.

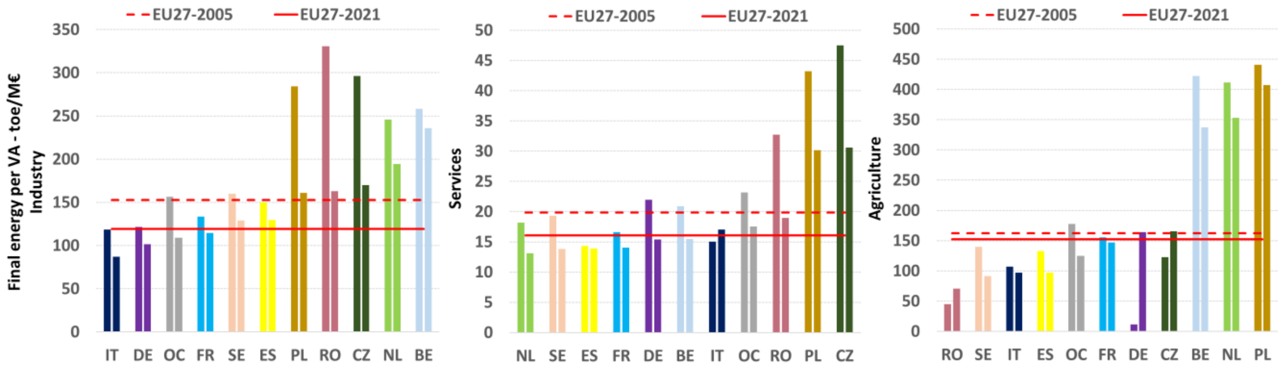
L'inclusione del contributo dei bunker internazionali nell'elaborazione dell'intensità energetica e dell'intensità di carbonio per unità di PIL mostra che l'Italia, insieme alla Germania, è ai primi posti tra i maggiori Paesi.



Il confronto degli indicatori di efficienza e di decarbonizzazione a livello settoriale tra gli Stati membri mostra una situazione piuttosto eterogenea. Per quanto riguarda l'industria in Italia, l'intensità energetica finale, il rapporto tra consumo finale di energia e valore aggiunto, è stata paragonabile a quella della Germania dal 2005 e mostra una tendenza decrescente dal 2005 al 2021. Tra i Paesi europei solo Irlanda, Danimarca, Malta ed Estonia hanno intensità energetiche industriali inferiori a quelle dell'Italia nel 2021. Tra i Paesi esaminati, i Paesi Bassi e il Belgio presentano le più elevate intensità energetiche per l'industria. L'intensità energetica del settore dal 2005 al 2021 è diminuita con un tasso medio annuo del -1,9% per l'Italia contro il -1,5% della media europea.

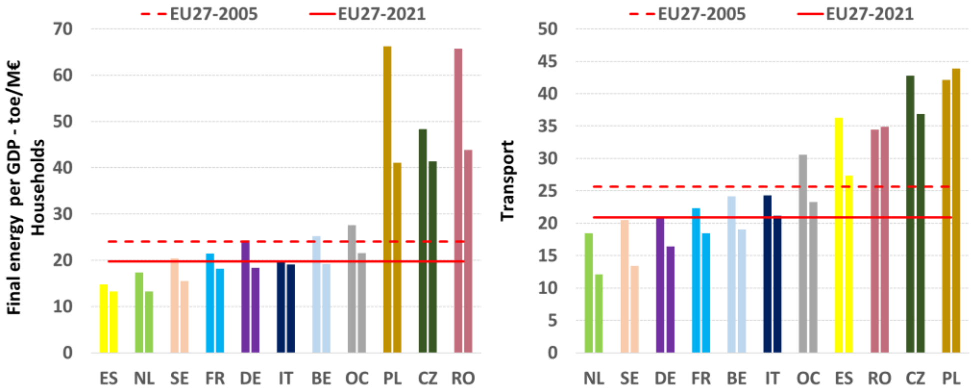
Nei servizi l'Italia mostra negli ultimi anni una controtendenza dell'intensità energetica rispetto ad altri Paesi europei. L'Italia è l'unico Paese, tra i più grandi, la cui intensità energetica nel settore è aumentata dal 2005. Il risultato è dovuto anche alla contabilizzazione dell'energia consumata dalle pompe di calore i cui dati per l'Italia sono partiti dal 2017 nel database EUROSTAT. L'inclusione di tale voce ha determinato un aumento dell'intensità energetica del settore. Il tasso medio annuo di intensità energetica dal 2005 al 2021 mostra un aumento dello 0,8% per l'Italia contro una diminuzione del -1,3% per la media europea.

Il settore agricolo mostra una diminuzione generale dell'intensità energetica nell'UE27. Nel 2021, tra i Paesi considerati, solo Romania e Svezia hanno intensità energetica inferiore all'Italia. L'intensità energetica del settore dal 2005 al 2021 è diminuita con un tasso medio annuo del -0,6% per l'Italia contro il -0,4% della media europea.



Nel settore residenziale, dal 2005 al 2021 i Paesi più grandi mostrano riduzioni significative dei consumi energetici per unità di PIL (da -0.7% annuo in Spagna al -2,9% annuo in Polonia), mentre l'Italia non mostra alcuna variazione rilevante (-0,1% annuo). L'andamento dell'intensità energetica per i trasporti italiani è sostanzialmente comparabile alla media dell'UE27.

La classifica dei Paesi esaminati per residenziale e trasporti evidenzia che nel 2021 l'intensità energetica italiana è vicina alla media europea e che c'è ampio margine di miglioramento dei settori.

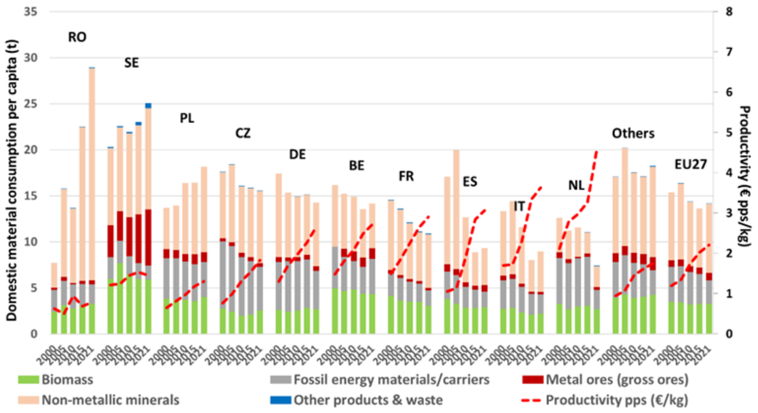


Quanto osservato per l'intensità energetica si riflette nell'intensità di carbonio (t CO_2eq/M€), ma questo indicatore è sensibile al ruolo delle energie rinnovabili, dell'energia nucleare e dell'importazione di elettricità nel bilancio energetico dei Paesi perché tali fonti non generano emissioni di gas serra. Tra i Paesi più grandi, l'industria italiana ha intensità di carbonio superiori solo a quelle di Svezia e Germania. Per l'agricoltura, l'intensità di carbonio italiana nel 2021 è tra le più basse d'Europa, dopo Malta, Svezia e Grecia. La media Europea è superiore del 74,1% rispetto all'intensità italiana.

Il settore civile (residenziale e servizi) in Italia mostra invece ampi margini di miglioramento con valori superiori alla media UE27 (+22,3% per il residenziale e +50,8% per i servizi). Il settore civile italiano mostra quindi potenzialità di riduzione delle emissioni molto ampie, soprattutto considerando che l'elettrificazione settoriale dei consumi finali nel 2021 è molto al di sotto della media UE27 (residenziale: 18% *vs* 24. 6%; servizi: 39. 4% *vs* 46. 3%).

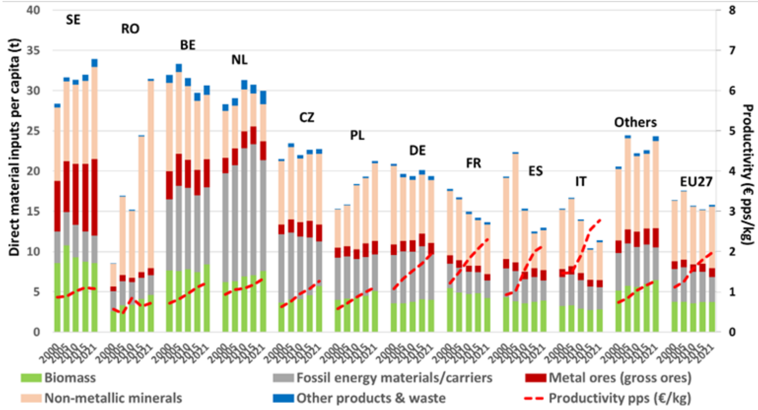
Flussi di materiali

Gli indicatori degli *input diretto di materiali* (DMI) e del *consumo interno di materiali (DMC)* descrivono, in termini aggregati, l'uso diretto e la provenienza delle risorse e dei prodotti naturali. Il primo indicatore comprende tutti i materiali che hanno un valore economico e sono utilizzati per attività di produzione e consumo ed è calcolato come la somma delle estrazioni interne e delle importazioni. Il secondo indicatore rappresenta il consumo interno di materia nell'economia nazionale al netto delle esportazioni ed è calcolato sottraendo dagli input materiali diretti la quota delle esportazioni fisiche.



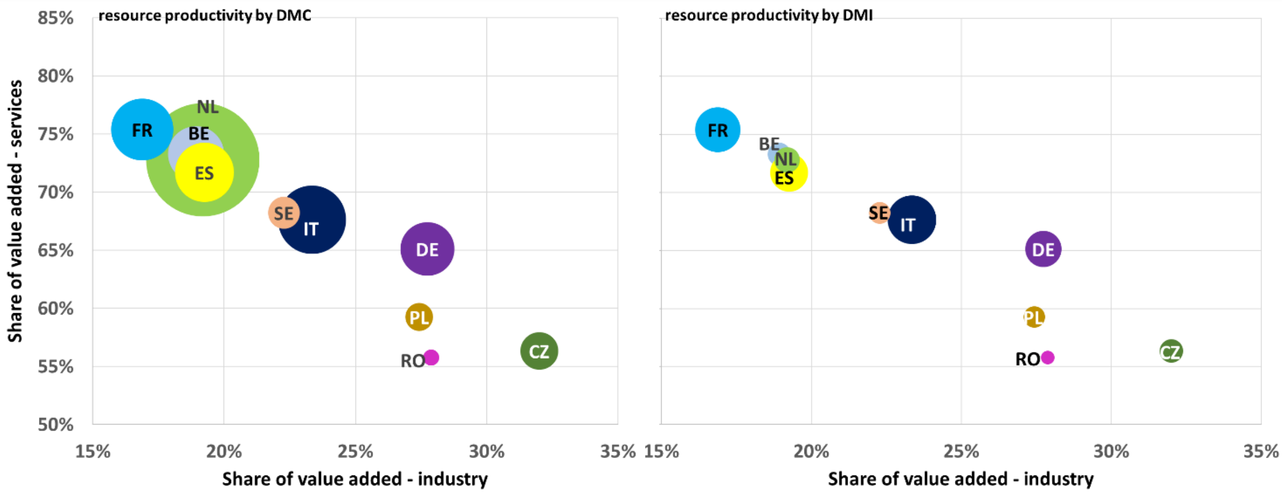
Dal 2000 si è registrata una diminuzione del DMC medio pro capite nei Paesi europei. Nel 2021 i Paesi Bassi hanno il più basso consumo pro capite di materia tra tutti i Paesi UE27 seguiti dall'Italia con il 2° valore più basso. Per quanto riguarda la produttività delle risorse, dal 2000 si registra un aumento generale, anche se i valori assoluti dei Paesi sono molto diversi. I tassi di crescita media annua tra i maggiori Paesi oscillano tra lo 0,8% per la Svezia al 5,2% per la Spagna; il tasso annuo dell'Italia è 3.7%. I Paesi Bassi presentano il valore più elevato di produttività (5.7 €/kg nel 2021), seguita dall'Italia (3.4 €/kg). Le produttività di Germania e Francia sono rispettivamente di 2,7 €/kg e 3,1 €/kg.

L'indicatore DMI comprende tutti i materiali di valore economico direttamente utilizzati nelle attività di produzione e di consumo. Tale indicatore è pari alla somma delle estrazioni interne e delle importazioni. Poiché rappresenta il consumo interno senza esportazioni, è utile per valutare il consumo effettivo di materiale, compreso quello non utilizzato nelle attività interne di produzione e consumo e destinato alle esportazioni. Svezia, Romania, Belgio e Paesi Bassi hanno alte quote di estrazione fossile, biomassa e minerali metallici destinati all'esportazione e mostrano il più alto DMI *pro capite* tra i più grandi Paesi europei, molto al di sopra della media europea. È anche chiaro l'aumento del DMI *pro capite* registrato in Romania. L'Italia ha registrato nel 2021 il valore più basso tra tutti i Paesi europei (11,4 t *pro capite vs* media UE27 di 15,8 t *pro capite*).



Per quanto riguarda la produttività delle risorse l'Italia ha il secondo valore più alto tra i Paesi europei (2,67 €/kg), il primo si registra per l'Irlanda (2,72 €/kg). La produttività dei Paesi Bassi per questo indicatore (1.4 €/kg) non mostra prestazioni elevate come per DMC.

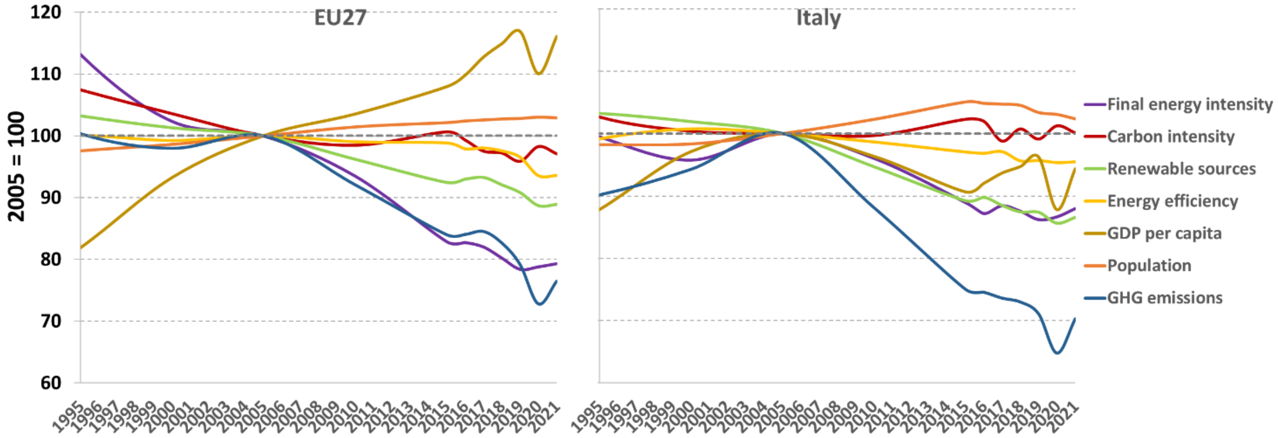
La produttività delle risorse per ciascun Paese, considerando il posizionamento relativo dell'economia dei Paesi nel rapporto industria/servizi, mostra che l'Italia, pur avendo una quota di valore aggiunto industriale superiore a quella della Francia e della Spagna, ha una maggiore produttività (DMC), risultato evidente di una maggiore efficienza nell'uso delle risorse, principalmente nel settore industriale. Questo risultato è in linea con quanto osservato per gli indicatori di intensità energetica. Considerando il DMI la produttività delle risorse è significativamente inferiore rispetto al DMC. La produttività nei Paesi Bassi è inferiore del 75,2% rispetto alla produttività DMC. Per gli altri Paesi la diminuzione varia dal 7,9% per la Romania al 54,4% per il Belgio. Il dato italiano è del 22,2%.



Identità di Kaya e analisi della decomposizione

La tendenza dei parametri di *identità kaya* per l'UE27 e l'Italia nel periodo 1995-2021 mostra un quadro eterogeneo per quanto riguarda i fattori determinanti della riduzione dei gas a effetto serra. Mentre nell'UE27 il fattore principale sembra essere l'intensità energetica finale, in Italia sia le fonti rinnovabili che l'intensità energetica finale (energia finale consumata per unità di PIL) sono i fattori determinanti. Inoltre, nell'UE27 la popolazione e il PIL aumentano, mentre in Italia tali fattori hanno una tendenza al ribasso.

La variazione delle emissioni di gas serra è il risultato integrato della variazione dei fattori determnanti. Quindi, nell'UE27 è evidente un disaccoppiamento assoluto tra economia ed emissioni di GHG mentre in Italia si registra solo un disaccoppiamento relativo.



I risultati dell'analisi di decomposizione mostrano che in Italia l'efficienza energetica finale ha giocato un ruolo meno importante rispetto ad altri Paesi a causa della migliore performance dell'indicatore in Italia già nel 2005. Inoltre, a differenza dell'Italia, la maggior parte dei Paesi ha registrato un sensibile aumento del PIL *pro capite* dal 2005.

Il maggiore disaccoppiamento osservato in altri Paesi rispetto all'Italia non corrisponde necessariamente a riduzioni delle emissioni in linea con gli obiettivi. Secondo l'AEA (2022), tra i Paesi più grandi, in Germania le emissioni dai settori ESD nel 2020 ha superato le assegnazioni nazionali annuali di emissioni disponibili; per quanto riguarda le energie rinnovabili, la Francia non raggiunge l'obiettivo di quota rinnovabile 2020 delineato nei suoi piani d'azione nazionali per le energie rinnovabili; per quanto riguarda l'obiettivo di efficienza Germania, Belgio e Svezia, tra i maggiori Paesi, non hanno ridotto il loro consumo finale di energia in misura sufficiente a raggiungere i loro obiettivi energetici finali per il 2020. Per quanto riguarda gli obiettivi indicativi per il consumo di energia primaria, il Belgio e la Polonia non hanno raggiunto i loro obiettivi per il 2020. Inoltre, va sottolineato che l'analisi di decomposizione si concentra sulla variazione relativa dei parametri, senza assegnare alcun peso ai punti di partenza. I valori assoluti dei parametri e dei relativi andamenti nei maggiori Paesi europei sono stati indagati nei paragrafi precedenti. Come già accennato, l'efficienza economica ed energetica del sistema italiano è tra le più alte d'Europa. L'ultima edizione *dell'International Energy Efficiency Scorecard*, rilasciata da ACEEE nel 2022, ha riportato per l'Italia il calo di quattro posizioni rispetto all'edizione precedente nel 2018, principalmente a causa della sezione edifici, ma l'Italia è riuscita a posizionarsi tra i primi cinque, dopo Francia, Regno Unito, Germania e Paesi Bassi. L'ACEEE International Energy Efficiency Scorecard valuta le politiche di efficienza e le prestazioni di 25 dei Paesi con maggiori consumi di energia a livello globale. ACEEE ha utilizzato 36 metriche, sia politiche che orientate alle prestazioni, per valutare gli sforzi di ciascun Paese per risparmiare energia e ridurre le emissioni di gas serra in quattro categorie: edifici, industria, trasporti e progressi complessivi dell'efficienza energetica nazionale. "*Le metriche politiche evidenziano le migliori pratiche nelle azioni governative e possono essere qualitative o quantitative. Gli esempi includono obiettivi nazionali per l'efficienza energetica, l'etichettatura degli edifici e degli elettrodomestici e gli standard di risparmio di carburante per i veicoli. Le metriche orientate alle prestazioni sono quantitative e misurano il consumo di energia per unità di attività o servizio fornito. Gli esempi includono l'efficienza delle centrali termiche, le intensità energetiche degli edifici e dell'industria e il risparmio medio di carburante dei veicoli su strada.* " (Subramanian *et al.*, 2022).

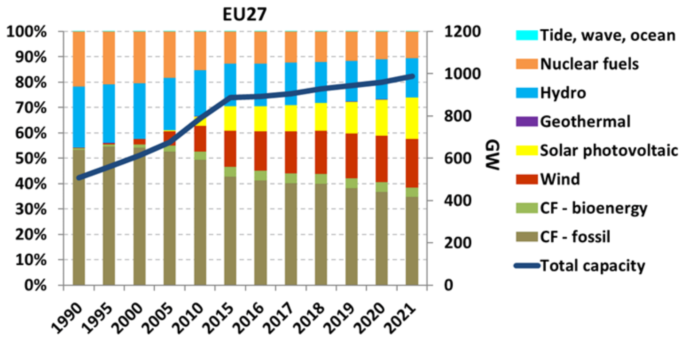
Il miglioramento dell'efficienza non può prescindere dalla valutazione delle potenzialità e della fattibilità economica per modificare il sistema energetico, così come deve essere valutata la struttura economica, soprattutto per quanto riguarda il ruolo dei servizi e dell'industria.

Settore elettrico

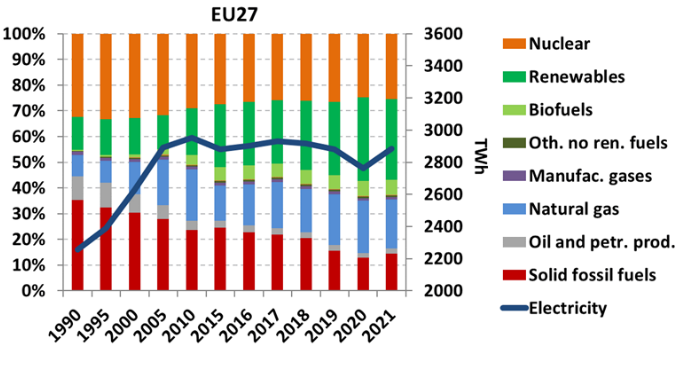
Capacità e produzione di energia elettrica

Il settore elettrico è uno dei principali obiettivi delle misure indirizzate a decarbonizzare l'economia, sia per la quantità di emissioni che per il potenziale di diffusione delle fonti energetiche rinnovabili. I Paesi esaminati per il confronto con l'Italia rappresentano l'83,4% della produzione lorda di energia elettrica dell'UE27 nel 2021.

La capacità installata nel 1990 in EU27 era costituita principalmente da centrali termoelettriche (54% nell'UE27), nucleari (21,8%) e idroelettriche (24%). Le fonti eoliche e fotovoltaiche avevano quote marginali. Nel 2021 la capacità termoelettrica è stata del 38,5%, del 10,6% nucleare, del 15,3% idroelettrica, del 19,1% eolica e del 16,4% fotovoltaica. La capacità totale è aumentata del 46,3% nel 2021 rispetto al 2005, passando da 676 GW a 989 GW. La capacità nucleare è l'unica con una riduzione rilevante, da 123 GW a 105 GW (-14,6%). Da segnalare anche l'aumento della capacità netta di impianti alimentati da bioenergia, da 15,8 GW nel 2005 a 36,3 GW nel 2021, pari al 9,5% della capacità termoelettrica totale.



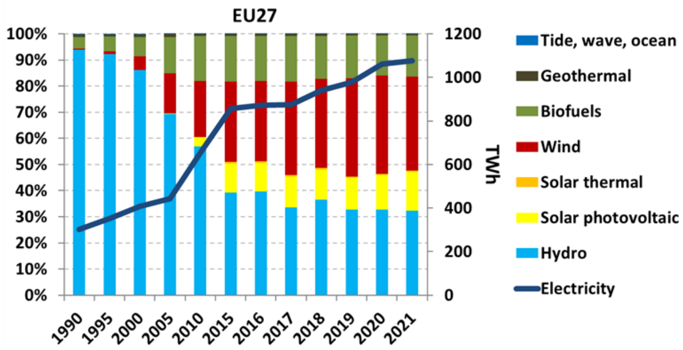
Vi è una notevole eterogeneità di capacità tra i Paesi. In Polonia, c'è una netta prevalenza di impianti termoelettrici con un ruolo minore per la bioenergia. Le centrali nucleari, che non sono presenti in Italia e Polonia tra i Paesi considerati, costituiscono una quota significativa della capacità in Francia (43,3%), Svezia (15,4%), Belgio (22,3%) e Cechia (20,4%), sebbene le quote degli altri Paesi non siano trascurabili (dall'1,1% dei Paesi Bassi al 7,5% della Romania). Dal 1990, la capacità idroelettrica ha rappresentato una quota considerevole delle fonti rinnovabili tradizionali in Romania, Spagna, Francia, Italia e Svezia. In tutti i Paesi esaminati, la quota di capacità termoelettrica e nucleare mostra una notevole riduzione. L'energia eolica è aumentata in tutti i Paesi dal 2005. Gli impianti fotovoltaici hanno iniziato ad avere quote significative solo dopo il 2010.



La produzione lorda di energia elettrica in Europa ha mostrato un marcato aumento dal 1990 al 2010, seguito da stabilità fino al 2019 e una forte diminuzione nel 2020 a causa delle misure adottate per contenere la pandemia di SARS-CoV-2. Nel 2021 la produzione di energia elettrica torna ai livelli del 2019; Il 14,5% della produzione di elettricità dell'UE27 senza pompaggio proviene da combustibili solidi e il 19,1% dal gas naturale. Il petrolio e i prodotti petroliferi rappresentano l'1,8%. La fonte nucleare rappresenta il 25,4% e il 37,3% proviene da energie rinnovabili (rinnovabili e biocarburanti). Tutti i Paesi considerati hanno aumentato la produzione di elettricità dal 1990, dal 6,5% in Germania al 79,3% in Spagna, ad eccezione della Romania la cui produzione di elettricità è diminuita dell'8%.

Il mix energetico nei Paesi esaminati è molto eterogeneo, soprattutto per quanto riguarda i combustibili fossili. Nel 2021, i combustibili solidi rappresentano il 71,3% della produzione di elettricità in Polonia, il 41,1% in Cechia e il 28,2% in Germania. La Francia ha la più alta produzione di energia elettrica da centrali nucleari in Europa (68,9% nel 2021), seguita da Belgio (50,6%), Cechia (36,9%) e Svezia (30,8%), tra i Paesi esaminati. Negli altri Paesi l'elettricità nucleare varia dall'11,9% della Germania al 19,1% della Romania, mentre i Paesi Bassi hanno la quota finale più bassa di energia elettrica da fonte nucleare (3,1%). La Polonia e l'Italia non hanno centrali nucleari. In UE27 la fonte nucleare fornisce circa un quarto della produzione di elettricità (25,4%). L'Italia e i Paesi Bassi hanno la quota più alta di elettricità da gas naturale nel 2021, rispettivamente il 50,2% e il 46,4%.

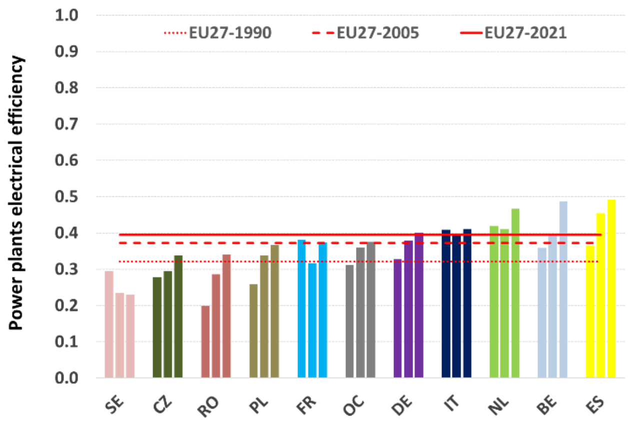
Per quanto riguarda la produzione di energia elettrica da fonti rinnovabili, la quota nell'UE27 è aumentata dal 13,4% al 37,3% dal 1990 al 2021. Dal 2005 la quota rinnovabile ha mostrato un andamento in costante aumento tranne nel 2021 che ha registrato una diminuzione rispetto al 2020 (38,4%). In tutti i Paesi esaminati si registra un marcato aumento della produzione di energia elettrica rinnovabile con una forte accelerazione dal 2005. Dopo il 2015 la crescita ha rallentato ed è ripresa negli ultimi anni, anche se con tassi diversi tra gli Stati. La Svezia ha una delle più alte quote rinnovabili in Europa.

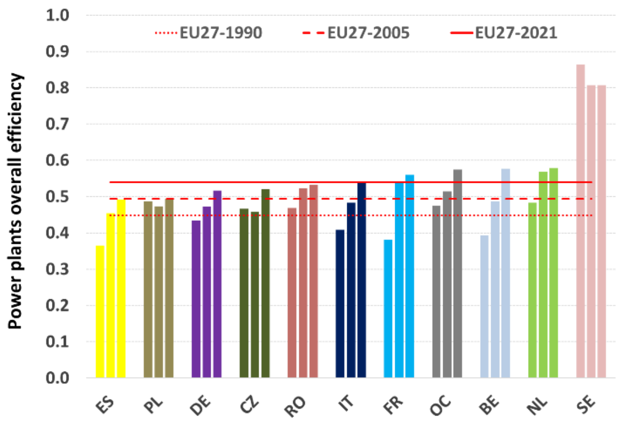


Efficienza delle centrali termiche

Il parametro più importante per valutare l'efficienza di un sistema di generazione di energia elettrica è l'efficienza di trasformazione dei combustibili in elettricità e calore. L'efficienza elettrica degli impianti italiani non di cogenerazione (0,456 nel 2021) è tra le più elevate nei maggiori Paesi europei, dopo Belgio (0,458) e Paesi Bassi (0,501). Nel 2021 la media italiana è superiore alla media UE27 (0,425). Per quanto riguarda l'efficienza elettrica degli impianti di cogenerazione, nel 2021 la Spagna mostra il valore più alto tra i principali Paesi europei (0,652), di gran lunga superiore alla media UE27 (0,37). L'efficienza elettrica dell'Italia è 0,38. Il rendimento complessivo, per la produzione di energia elettrica e calore, degli impianti di cogenerazione italiani (0,595) è inferiore alla media UE27 (0,635) ed è aumentato del 20,1% dal 1990.

L'efficienza elettrica italiana per tutte le centrali (CHP e no CHP) nel 2021 è di 0,411, superata da Spagna, Belgio e Paesi Bassi, da 0,466 a 0,491. La Svezia presenta l'efficienza elettrica più bassa tra i Paesi esaminati (0,231), ben al di sotto della media UE27 (0,395). Il rendimento complessivo degli impianti italiani, per la produzione di energia elettrica e calore, è pari a 0,537, appena al di sotto della media UE27 (0,539). La Svezia mostra il valore più alto (0,807) a causa del più alto rapporto tra calore ed elettricità registrato in questo Paese negli impianti di cogenerazione (oltre 2,5), seguita dalla Romania (1,79).

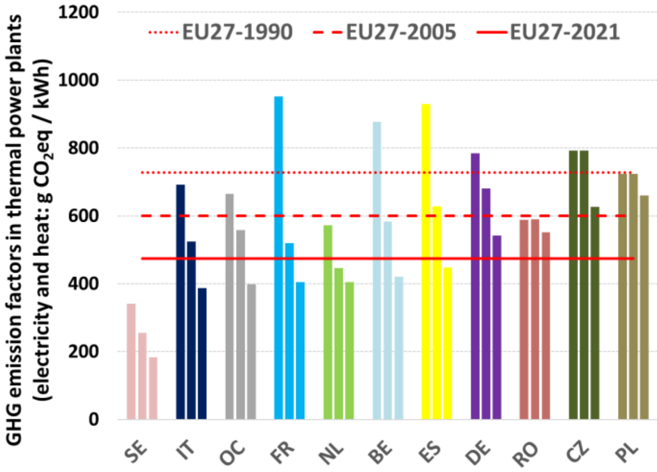


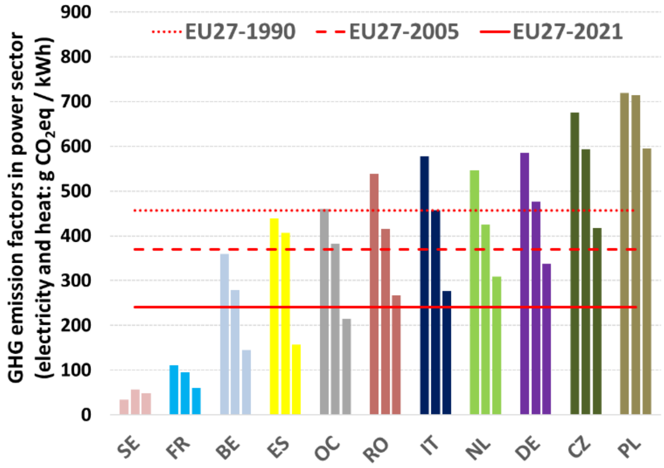


Emissioni di gas a effetto serra prodotte dal settore elettrico

Dal 1990 c'è stato un disaccoppiamento tra produzione di energia elettrica ed emissioni di gas serra per settore elettrico in quasi tutti i Paesi europei, anche se le emissioni mostrano una significativa diminuzione solo dopo il 2005, con un disaccoppiamento crescente dovuto principalmente alla crescente quota di rinnovabili.

I fattori di emissione di gas serra per la produzione di elettricità e calore dovuti alla combustione nelle centrali termiche si sono ridotti dal 1990. Nel 2021 il fattore di emissione in Italia (386,3 g CO_2eq/kWh) è superiore solo a quello della Svezia (182,4 g CO_2eq/kWh), dove le centrali termoelettriche sono alimentate principalmente da bioenergia. Spagna, Svezia, Belgio e il gruppo dei Paesi minori registrano le maggiori riduzioni dal 2005 (da -28% a -28,9%), seguiti dall'Italia (-26,3%). La Germania ha ridotto il fattore di emissione del 20,5%. All'estremità più bassa del tasso di riduzione ci sono Romania (-6,4%), Polonia (-8,9%) e Paesi Bassi (-9,3%).





I fattori di emissione per la produzione totale di energia elettrica e calore da parte dell'intero settore elettrico, compresa produzione rinnovabile e nucleare, in Italia sono superiori alla media europea (276,6 *vs* 241 g CO_2eq/kWh). Tutti i Paesi con fattori di emissione inferiori all'Italia hanno una quantità rilevante di energia elettrica da centrali nucleari. Il fattore di emissione medio dell'UE27 mostra una riduzione del 34,9%, rispetto al livello del 2005, mentre l'Italia ha ridotto il fattore di emissione del 39,4%, terzo tasso di riduzione più alto tra i maggiori Paesi. Spagna e Belgio hanno registrato i tassi di riduzione più elevati dal 2005, rispettivamente -61,3% e -48%, dall'altra parte Polonia e Svezia hanno i tassi più bassi, rispettivamente -16,7% e -14,7%. Il fattore di emissione in Germania, che ha la più alta quota di emissioni di gas serra dal settore elettrico i Europa, è diminuito del -29% dal 2005.

I risultati consentono di concludere che l'Italia ha uno dei più bassi fattori di emissione di gas serra per la produzione di energia termoelettrica tra i maggiori Paesi europei. Il fattore di emissione GHG italiano degli impianti termici occupa l'undicesima posizione, ben al di sotto della media europea. Il mix di combustibili italiano, con una quota maggiore di gas naturale rispetto ad altri Paesi e il contributo della bioenergia, è un fattore determinante per il fattore di emissione delle centrali termoelettriche.

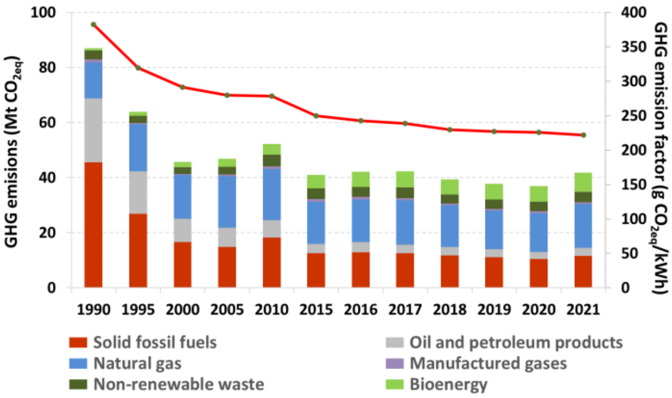
A seguito di molti fattori (spostamento del mix di combustibili, efficienza, quota di rinnovabili) l'Italia ha ridotto il fattore di emissione per la produzione di energia elettrica del 53,7% dal 1990 al 2021 (-44,2% dal 2005), contro una riduzione del 42,1% in Germania (30,6% dal 2005) e del 27,4% in Polonia (19,6% dal 2005). Il tasso di riduzione in Polonia è il più basso tra i maggiori emettitori in Europa. Se Germania e Polonia avessero ridotto i loro fattori di emissione GHG dal 1990 con lo stesso tasso dell'Italia, ciò avrebbe evitato, a parità di produzione di energia elettrica, l'emissione di circa 68 Mt CO_2eq nel 2021 (circa 103 Mt CO_2eq considerando anche la produzione di calore), circa l'11% delle emissioni EU27 dal settore elettrico. Le centrali termoelettriche in Germania e Polonia sono ancora alimentate da quote significative di combustibili solidi ad alto contenuto di carbonio, come la lignite, e la transizione al gas naturale è stata molto più lenta rispetto all'Italia.

Produttori di solo calore

La produzione di calore rappresenta una quota significativa dei processi di trasformazione dell'energia. Gli impianti dedicati alla produzione di calore per il teleriscaldamento e altri usi (principalmente per l'industria) consumano una quota importante dell'energia nel bilancio europeo. Nel 2021 il consumo energetico degli impianti per la produzione di calore nell'UE27 è stato di 18,7 Mtep, di cui 0,67 Mtep da geotermia e solare termica e 0,29 Mtep da pompe di calore. Il consumo energetico dei carburanti è stato di 17,8 Mtep, di cui 6,2 Mtep da bioenergia. Il consumo di bioenergia mostra una quota in rapida crescita: il consumo nel 2021 è più del doppio del livello del 2005 ed è più di 8 volte il consumo nel 1990.

Il consumo totale di energia nel 2021 è inferiore a quello registrato nel 1990 e si è verificato un marcato spostamento del combustibile con una diminuzione dei combustibili solidi e, in misura maggiore, della sostituzione del petrolio e dei prodotti petroliferi con gas naturale e bioenergia. Il contributo delle altre fonti rinnovabili (oltre il 90% da geotermia e il resto da solare termico) e delle pompe di calore ha registrato un andamento in crescita e nel 2021 rappresentano il 5,6% dei consumi totali.

Come risultato della variazione del mix combustibile, della diminuzione di energia consumata (-27,1%) e della produzione di calore (-17,2%), le emissioni di gas serra hanno registrato una forte diminuzione dal 1990 (-52%). Il fattore di emissione è diminuito del 42%. A livello UE27 le emissioni di gas serra di questi impianti sono state di 41,8 Mt CO_2eq nel 2021. Dal 2005 i fattori di emissione sono diminuiti del 20,7% nell'UE27 (da 279,7 a 221,9 g CO_2eq/kWh). Il fattore di emissione dell'Italia nel 2021 è inferiore del 17,4% rispetto alla media UE27. Il relativo consumo di combustibili solidi o rifiuti non rinnovabili in Polonia e Germania si traduce in fattori di emissione più elevati, rispettivamente superiori del 98,8% e del 43,8% rispetto a quello italiano.



CONCLUSIONI

I risultati mostrano che l'Italia ha uno dei sistemi energetici ed economici più efficienti tra i principali Paesi europei. L'intensità energetica per unità di PIL e la produttività delle risorse sono tra le più basse d'Europa, nonostante un ruolo rilevante dell'industria nell'economia italiana. La bassa intensità energetica corrisponde spesso a economie basate sui servizi con un ruolo minore delle attività industriali. L'intensità di carbonio per unità di consumo energetico dell'UE27 è mediamente inferiore a quella italiana, poiché in diversi Paesi è presente una quota non trascurabile di energia nucleare.

L’andamento delle emissioni di gas serra dipende da molti fattori. Le riduzioni delle emissioni nei Paesi europei sono dovute principalmente alla diminuzione dell'intensità energetica e all'aumento del consumo di energia rinnovabile. Nel 2020 le misure adottate per contenere la diffusione della pandemia di SARS-CoV-2 hanno inciso pesantemente sull'economia europea e sulle emissioni di gas serra. Indipendentemente dalle contingenze c'è un netto disaccoppiamento tra PIL ed emissioni di GHG nei Paesi europei, anche se il disaccoppiamento non corrisponde necessariamente alle riduzioni delle emissioni in linea con gli obiettivi al 2020 per alcuni Paesi, come per la Germania. Il potenziale di riduzione delle emissioni deve essere valutato anche considerando i punti di partenza dei fattori determinanti e i costi per cambiare il sistema energetico, nonché la struttura economica, in particolare per quanto riguarda i servizi e gli asset industriali.

Gli indicatori di decarbonizzazione settoriale in Italia mostrano settori come l'industria e l'agricoltura con intensità energetiche tra le più basse d'Europa e settori come residenziale e servizi che occupano le ultime posizioni tra i Paesi europei, con potenzialità di riduzione delle emissioni molto ampie, soprattutto considerando il livello di elettrificazione dei consumi finali che per tali settori è tra i più bassi in Europa. Tali esiti sono coerenti con la preoccupante distanza delle proiezioni italiane dall'obiettivo da raggiungere nel 2030 (ISPRA, 2023b). L'obiettivo di emissione riguarda solo i settori non soggetti al sistema di scambio delle quote di emissione, vale a dire trasporti, civile, agricoltura, rifiuti e piccola industria, settori disciplinati dal regolamento sulla condivisione degli sforzi (ESR) con obiettivi nazionali specifici. Le emissioni provenienti da grandi impianti come centrali termiche, raffinerie, cementifici, acciaierie, ecc. rientrano nel sistema europeo *cap and trade* dello scambio di emissioni. Le proiezioni delle emissioni, effettuate con le misure esistenti fino al 31 dicembre 2021, mostrano che l'Italia ridurrebbe le emissioni ESR del 28,4% rispetto al livello del 2005 contro l'attuale obiettivo del -33%. La distanza diventa ancora maggiore con l'obiettivo più sfidante del -43,7% proposto dalla Commissione europea e approvato dal Parlamento europeo.

Per quanto riguarda il settore elettrico, l'Italia ha ridotto il fattore di emissione per la produzione di elettricità di 53.7% dal 1990 al 2021, a fronte di una riduzione del 42,1% in Germania e 27,4% in Polonia (il tasso di riduzione più basso tra i maggiori emettitori in Europa). Polonia e Germania hanno la più alta quota di consumo di lignite e i più alti fattori di emissione tra i maggiori Paesi. In tali Paesi la transizione al gas naturale è stata più lenta che in Italia. La riduzione dei fattori di emissione di gas serra dal 1990 in Germania e Polonia con il tasso registrato per l'Italia, a parità di produzione di energia elettrica, avrebbe evitato circa 68 Mt CO_2eq nel 2021 (circa 103 Mt CO_2eq considerando anche la produzione di calore), circa l'11% delle emissioni di gas serra dell'UE27 dal settore elettrico.

INTRODUCTION

Country's greenhouse gas (GHG) emissions depend on many factors related to the economic activities and lifestyle. In European Union (EU27), energy emissions accounted for about 77% of total emissions in 2021, from 69.8% in France to 84.5% in Germany, among the biggest Countries. Italian GHG emissions from the energy sector are 79.7%. The energy system underlying economic activities is therefore the main area of investigation to understand the driving factors for GHG emissions. The fuel mix, as well as energy efficiency, in terms of transformation of primary energy and economic output, are key factors. The economic activities themselves, which are also driven by the users' demands, are driving factors of GHG emissions, and the reduction of such activities inevitably leads to emissions reduction. While energy efficiency can be considered as intrinsic driving factors of the energy system, the demand for goods and services can be regarded as an extrinsic economic factor, although both energy and economy systems are intertwined and difficult to be treated as separate systems. The economic crisis that has affected the world's major economies, including Italy, since 2007-2008, has made the task of discerning the driving factors or GHG emissions even more difficult. After more than a decade Italy and Greece, among the EU Countries, have suffered the most significant impacts of the economic crisis. Even though Italy recovered since 2015, up to 2019 was the only Country which had not yet filled the gap of GDP per capita loss in EU. Moreover in 2020 the SARS-CoV-2 pandemic caused a further decline of the economy in all the European Countries. In 2021 the European economy experienced a marked recovery but the Russian-Ukrainian war that broke out in the first half of 2022 adversely affected the growth projections. Such events heavily impacted on GHG emissions and European climate policy.

Climate and energy policies are undergoing an in-depth review following what was agreed at COP21 in Paris in 2015, when the Parties decided to keep the rise of global average temperature well below 2°C and to do everything possible to limit the increase to 1.5°C above pre-industrial levels. The historic significance of the Paris Agreement lies in the key point that virtually all the States of the world have committed to reduce their GHG emissions by 2030, through mitigation plans. In the context of emissions mitigation policies, the EU has already played an important role since the ratification of the Kyoto Protocol, when it committed to reducing the GHG emissions, in the period 2008-2012, by 8% compared to 1990. This commitment was shared among the Member States and Italy was allocated a reduction of emissions of 6.5%. In 2012, an agreement was reached between the Parties on the continuation of the Kyoto Protocol through the Doha Amendment, which sets reduction commitments for the period 2013-2020. Italy ratified the Doha Amendment with Law of 3 May 2016. The Doha Amendment entered into force on 31 December 2020, with 148 Countries.

In 2007, before what was agreed at the international level, the European Council had already expressed the need for the EU to initiate a transition to a low-carbon economy through an integrated approach that included energy policies to curb climate change. In particular, the Council had set binding targets to be achieved by 2020, such as 20% reduction of GHG emissions compared to 1990, the share for renewable energy consumption set to 20% of the EU energy consumption, the use of biofuels for 10% of the amount of fuel used in the transport sector and the indicative target of reducing energy consumption by 20% compared to the 2007 Reference Scenario projections for 2020. Following the Council's conclusions, the "Climate and Energy Package" was approved, i.e. a set of legislative measures aimed at implementing the commitments was put in place.

For 2030 the European reduction targets reflected the commitments made by the EU under the Paris Agreement: reduction of GHG emissions by at least 40% compared to 1990, achievement of at least 32% of energy consumption from renewables and the achievement of at least 32.5% increase in energy efficiency compared to projections of the expected energy used in 2030. Another target directly related to the electricity system is the achievement of 15% for electrical interconnections in 2030. In this context, Italy has issued its National Energy and Climate Plan (AA.VV., 2019), which establishes national 2030 targets on energy efficiency, renewable sources and the reduction of GHG emissions. The National Energy and Climate Plan is now under revision to consider all change occurred in the EU climate and energy policies after 2019.

With the European Green Deal, the European Commission proposed in September 2020 to raise the 2030 GHG emission reduction target, including carbon removals from forestry activities, to at least 55% compared to 1990, with a view to achieving emissive neutrality by 2050 as established in the European Commission's Long Term Strategy (2018a, 2018b). In this context, as required for each EU Member State by article 15 of the Regulation (UE) 2018/1999 (Governance Regulation), Italy adopted its National Long-Term Strategy on the reduction of GHG emissions (LTS) in January 2021 (AA.VV., 2021) identifying the possible pathways that could allow to achieve a condition of emission neutrality by 2050, i.e. the balance between GHG emissions and CO_2 removals, with the possible use of geological capture and storage systems or CO_2 reuse.

On 14 July 2021 the European Commission presented a proposal for amending the Renewable Energy Directive increasing the current target to at least 40% renewable energy sources in the EU's overall energy mix by 2030. Relevant actions are required across all sectors to achieve the new targets, including increased energy efficiency and renewable energy. Such actions are considered in the Italy's Recovery and Resilience Plan submitted in 2021 to European Commission in compliance with EU's extraordinary recovery effort, Next Generation EU: the plan agreed by EU leaders in July 2020 to overcome the economic and social impact of the pandemic facing the environmental, technological, and social challenges of our time.

The Commission started the process of making detailed legislative proposals by July 2021 (Fit-for-55 package) to implement and achieve the increased ambition that will enable EU to move towards a climate-neutral economy by 2050 – an economy with net-zero GHG emissions. Among other measures the Commission put forward a proposal for a recast directive on energy efficiency. The proposal raises the level of ambition of the EU energy efficiency target and makes it binding by requiring EU Countries to collectively ensure a reduction in primary energy consumption of 39% compared to the trend established in the PRIMES 2007 scenario. Moreover, the Fit-for-55 package has put forward several legislative proposals that translate the European hydrogen strategy into concrete European hydrogen policy framework.

In reaction to the Russian invasion of Ukraine since 24th February, there is growing support across the European Parliament to increase the EU's 2030 renewable energy target ending the EU's dependence on Russian fossil fuels. Currently, just over 22% of Europe's energy final consumption comes from renewables. From the 40% renewable energy target by 2030 proposed by European Commissions in July 2021, the European Parliament is now set to push for the target to be increased to 45%. On 18 May 2022 European Commission has presented the REPowerEU Plan to phase out EU dependency on Russian fossil fuels faster through energy savings, diversification of energy supplies, and accelerated deployment of renewable energy to replace fossil fuels in homes, industry, and power generation. Moreover, as for the hydrogen the ambition is to produce 10 Mt and import 10 Mt of renewable hydrogen in the EU by 2030 (EC, 2022a).

At present, the European target of reducing emissions by at least 55% by 2030, compared to 1990 levels, as reported in the second NDC transmitted by the EU in compliance with the Paris Agreement. The greenhouse gas reduction targets for Italy are those relating to the sectors included in the Effort Sharing Regulation (ESR) and the objectives for the LULUCF sector; the remaining part of the European target is divided among the sectors subject to the Emissions Trading System (ETS). The raise of the European target from -40% to -55% of emissions compared to 1990 led to a target for the ESR sectors for Italy at -43.7% compared to 2005, with the total EU target of ESR sectors now equal to -40%. This value was proposed by the European Commission and approved by the European Parliament on March 14, 2023. On 30 March 2023, the European Parliament and the Council reached a provisional agreement to raise the binding renewable energy target to at least 42.5% by 2030.

Regardless any target the negotiating processes among EU Countries cannot ignore the peculiarities of Member States energy systems as well as the technical and economic potentials to change their systems. The development of a Country's productive structure involves not only technological aspects but also the economic and social ones affecting the daily lives of millions of people. The definition of climate targets must therefore consider several factors. If GDP is an essential factor, as an expression of a Country's investment capacity, it is equally essential to consider other aspects of energy and economy systems, such as industry share, fuel mix used by each Country and the cost effectiveness for changes. In other words, the inertia of any complex systems and the decreasing returns of investments aimed at changing a particular equilibrium state cannot be ignored. This does not mean that a given situation cannot be changed, but we should be aware of both the resources needed and the consequences. As far as energy sources are concerned, there are different reduction potentials between Countries with a significant share of high-carbon fuels and Countries with a very small share of high carbon content fuels. It can be misleading to only consider GDP as the investment capacity without looking at the different reduction potentials and the related costs.

This report does not aim at the analysis of energy and production systems but at the analysis of Italian performance indicators and the comparison with the largest European Countries concerning energy consumption and climate-changing emissions. The analysis will not go into details on factors determining the energy needs of the Countries such as the geographical-climatic factor or demographic and social factors. No indicator is immune to criticism and weaknesses: the energy intensity (energy consumption per GDP) in the buildings sector is affected by climatic factors, not only by efficiency; the industry sector includes a wide range of activities with very different energy requirements, so the relative shares of activities is a crucial factor for sector's intensity. While aware of the role played by these factors on energy requirements and efficiency, the objective of the analysis is to examine at macroscopic level the main indicators of decarbonization and energy efficiency in the European Countries *rebus sic stantibus*. If the former indicators provide information on climate-changing gases emissions per unit of energy used or per unit of wealth produced, the latter provide information on how efficiently energy is used to produce wealth. The two families of indicators are strongly interlinked because if the production of goods and services cannot be separated from energy consumption, the consumption of energy from fossil fuels in turn determines climate-changing gas emissions. The economy decarbonization can be pursued by acting both on the energy sources used to produce goods and services and on the efficiency of energy use, acting on both fronts are the most virtuous path that can be taken. Concerning the energy sources, useful strategies point to shift towards a fuel mix with lower carbon content, therefore mainly made up of natural gas, or increasing the renewable share of energy that are not without other environmental worries, e.g. the combustion of biomass and the consequent emission of atmospheric contaminants harmful to air quality or the consumption of soil by wind and photovoltaics power plants. On the energy efficiency side, the goal is obviously optimization, which consists in achieving more with less. In other words, to reduce as much as possible the losses and inefficiencies for the production of commodities (e.g. from the buildings heating system, to moving by vehicles, production of steel, cement, paper, textiles and so on).

In a highly interconnected system, the identification of the causes of a given phenomenon, such as GHG emissions, is a thorny issue, however it is possible to assess the role of the different driving factors according to a conceptual model that establishes coherent relationships between the factors considered. To assess the role of the factors behind the change in GHG emissions, Kaya analysis and decomposition analysis was applied to study the variation of a parameter in a time interval in relation to the variation of its driving factors.

The power sector is a key stone of any energy system. The electricity generation accounts for a significant share of the energy sector, around one third of European energy GHG emissions. The EU long-term strategy by 2050 (EC, 2018a, b) examines different development scenarios and highlights how electricity will become the main energy carrier, from 22% of final energy consumption in 2015, to 41%-53% in 2050. The growing role of the electricity sector requires an examination of electricity generation systems in the Member States. The analysis in the largest European Countries was therefore carried out concerning the fuel mix, the transformation efficiency, and the GHG emission factors. The same analysis, although less detailed, was carried out for plants producing heat only that represent a significant share of energy consumption, especially in the Countries of Northern Europe.

1 NATIONAL DATA

Energy data of Italy have been downloaded from the EUROSTAT database in the complete energy balances section (https://ec.europa.eu/eurostat/data/database, last update 24 March 2023). The GHG emissions have been submitted by ISPRA to UNFCCC and available at the url: https://unfccc.int/.

The preliminary estimates for 2022 are elaborated by ISPRA based on data by SNAM for the distribution of natural gas, MASE (Ministry of Environment and Energy Security) for coal and petroleum products consumptions updated to 31 December 2022. The preliminary estimates are characterized by considerable uncertainty and will be revised with final data.

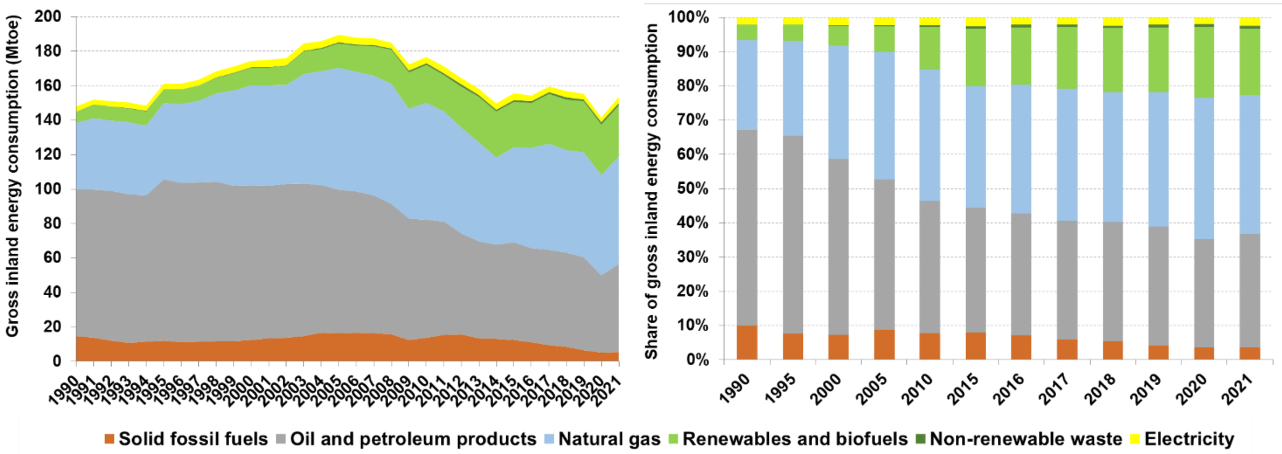
1.1 Energy consumption and GHG emissions

National gross inland energy consumption shows an increasing trend from 1990 until 2005 when it peaked at 189.4 Mtoe, then there was a reduction accelerated by the effects of the economic crisis with the minimum value of 149.8 Mtoe reached in 2014. As shown in Table 1.1 and Figure 1.1 gross energy consumption in 2020 furtherly decreased as consequence of lockdown to contain SARS-CoV-2 pandemic (-8.9% lower than 2019 level and -4.4% lower than 1990 level). In 2021 followed a rebound of consumption (+8.5% higher than 2020), with 153.7 ktoe. Moreover, preliminary estimates for 2022 national energy consumptions by sources are provided. Such esteems have high uncertainty and could be deeply revised with consumptive data.

Table 1.1 – Gross inland energy consumption by energy source (Mtoe).

Energy source	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	*2022**
Solid fossil fuels	14.6	12.3	12.6	16.5	13.7	12.3	11.0	9.3	8.5	6.5	5.1	5.5	*7.7*
Oil and petroleum products	84.9	93.2	89.9	83.3	68.4	56.7	54.8	55.4	54.7	54.0	44.9	51.0	*52.0*
Natural gas	39.0	44.7	57.9	70.7	68.1	55.3	58.1	61.5	59.5	60.9	58.3	62.4	*56.2*
Renewables and biofuels	6.5	7.7	10.1	14.1	21.9	26.3	26.0	28.8	29.3	29.5	29.3	29.9	*28.2*
Non-renewable waste	0.2	0.2	0.3	0.7	1.0	1.1	1.2	1.1	1.1	1.2	1.2	1.1	*1.2*
Electricity	3.0	3.2	3.8	4.2	3.8	4.0	3.2	3.2	3.8	3.3	2.8	3.7	*3.9*
Heat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*0.0*
Total	**148.1**	**161.2**	**174.5**	**189.4**	**176.8**	**155.7**	**154.3**	**159.5**	**157.0**	**155.4**	**141.6**	**153.7**	***149.1***

Figure 1.1– Gross inland energy consumption and share by energy source.



Fossil fuels are the main vectors in the national energy system. From 1990 to 2007, the average ratio of fossil fuels over the gross domestic consumption was more than 90%, although with a slight decline.

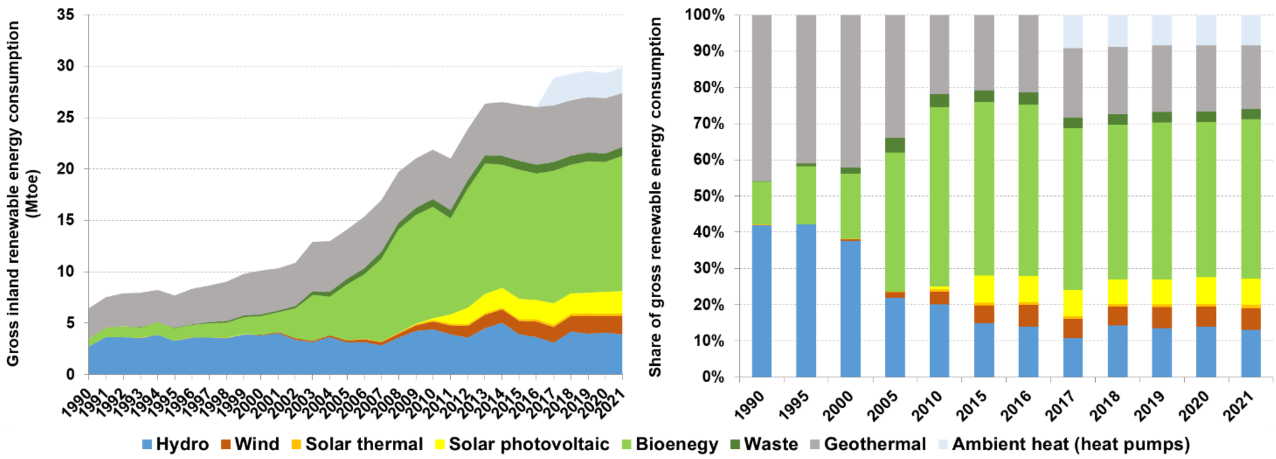
Subsequently, the share of fossil energy is severely reduced. From 1990 to 2021 the share of fossil energy decreased from 95.5% to 80.1%, with the lowest value in 2020 (78.9%). The decline has become particularly steep since 2007. The national fuel mix has changed considerably since the 1990s. Oil products accounted for the predominant component with 57.3% of gross domestic consumption in 1990. The share of oil products has steadily decreased to 31.7% in 2020, with a rebound in 2021 (33.2%). In the period 1990-2021 there was a corresponding increase in the share of natural gas, from 26.3% to 40.6% (the share in 2020 was 41.2%). The share of solid fuels fluctuated around an average value of 8%. Since 2012, the share of such fuels has steadily decreased, accounting for 3.6% of gross inland consumption in 2021.

The share of energy from renewable sources is complementary to that observed for fossil fuels. From 1990 to 2007 there was a steady increase in the share of renewable sources from 4.4% to 9%. After 2007 the share accelerated to 20.7% of gross inland consumption in 2020 and a slight decrease in 2021 (19.4%). Renewable gross inland consumption has more than quadrupled from 6.5 Mtoe in 1990 to 29.9 Mtoe in 2021.

Table 1.2 – Gross inland renewable energy consumption by energy source (Mtoe).

Energy source	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	*2022**
Hydro	2.7	3.2	3.8	3.1	4.4	3.9	3.6	3.1	4.2	4.0	4.1	3.9	*2.4*
Wind	0.0	0.0	0.0	0.2	0.8	1.3	1.5	1.5	1.5	1.7	1.6	1.8	*1.8*
Solar thermal	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	*0.3*
Solar photovoltaic	0.0	0.0	0.0	0.0	0.2	2.0	1.9	2.1	1.9	2.0	2.1	2.2	*2.4*
Biomass	0.8	1.2	1.8	5.4	10.8	12.6	12.3	12.9	12.5	12.8	12.6	13.2	*12.9*
Waste	0.0	0.1	0.2	0.6	0.8	0.8	0.9	0.9	0.8	0.9	0.8	0.8	*0.8*
Geothermal	3.0	3.2	4.3	4.8	4.8	5.5	5.6	5.5	5.4	5.4	5.3	5.3	*5.2*
Heat pump	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	2.6	2.5	2.5	2.5	*2.4*
Total	**6.5**	**7.7**	**10.1**	**14.1**	**21.9**	**26.3**	**26.0**	**28.8**	**29.3**	**29.5**	**29.3**	**29.9**	***28.2***

Figure 1.2 – Gross inland renewable energy consumption trend and share by energy source.



In the past the main sources of renewable energy have been geothermal and hydro, which accounted for more than 80% of gross inland consumption of renewable energy from 1990 to 2000. The remaining share was mainly met by biomass and wastes (bioenergy). Since 2000, the bioenergy has shown a considerable growth, and since 2007 it has exceeded 50% of share. In 2021, the share of bioenergy is 47%. In recent years, solar energy (thermal and photovoltaic) and wind energy have also assumed significant role and together represent 14.1% of total renewable energy consumption. Since 2017 the heat pumps energy has been recorded in the EUROSTAT budget. Such item in 2021 was 8.4% of renewable gross inland consumption.

Primary energy is the gross inland energy consumption without non-energy consumption. Non-energy consumption from 1990 to 2021 represented an average of 5.2% of gross domestic consumption with a decreasing trend from 7% in 1990 to 3.8% in 2021. The sharp reduction in consumption in 2020 is heavily affected by the lockdown of economic activities due to the SARS-CoV-2 pandemic (Figure 1.3).

Final energy consumption, including non-energy uses, is on average 79.8% of primary energy. Primary and final energy consumption peaked in 2005 and declined thereafter up to 2014. Following the economic crisis, a sharp reduction in energy consumption has been observed since 2008. The decline from 2005 to the lowest value in 2014 (142.7 Mtoe of primary energy and 116 Mtoe of final consumption) was 21.1% for primary energy and 17.2% for final consumption. After 2014 there is an increase in final consumption with wide fluctuations and a drastic reduction in 2020. In 2021 a rebound has been recorded and values for primary and final consumption are respectively 7.3% and 3.6% higher than in 1990. Final energy consumption without the no energy uses in 2021 is 8.3% higher than in 1990.

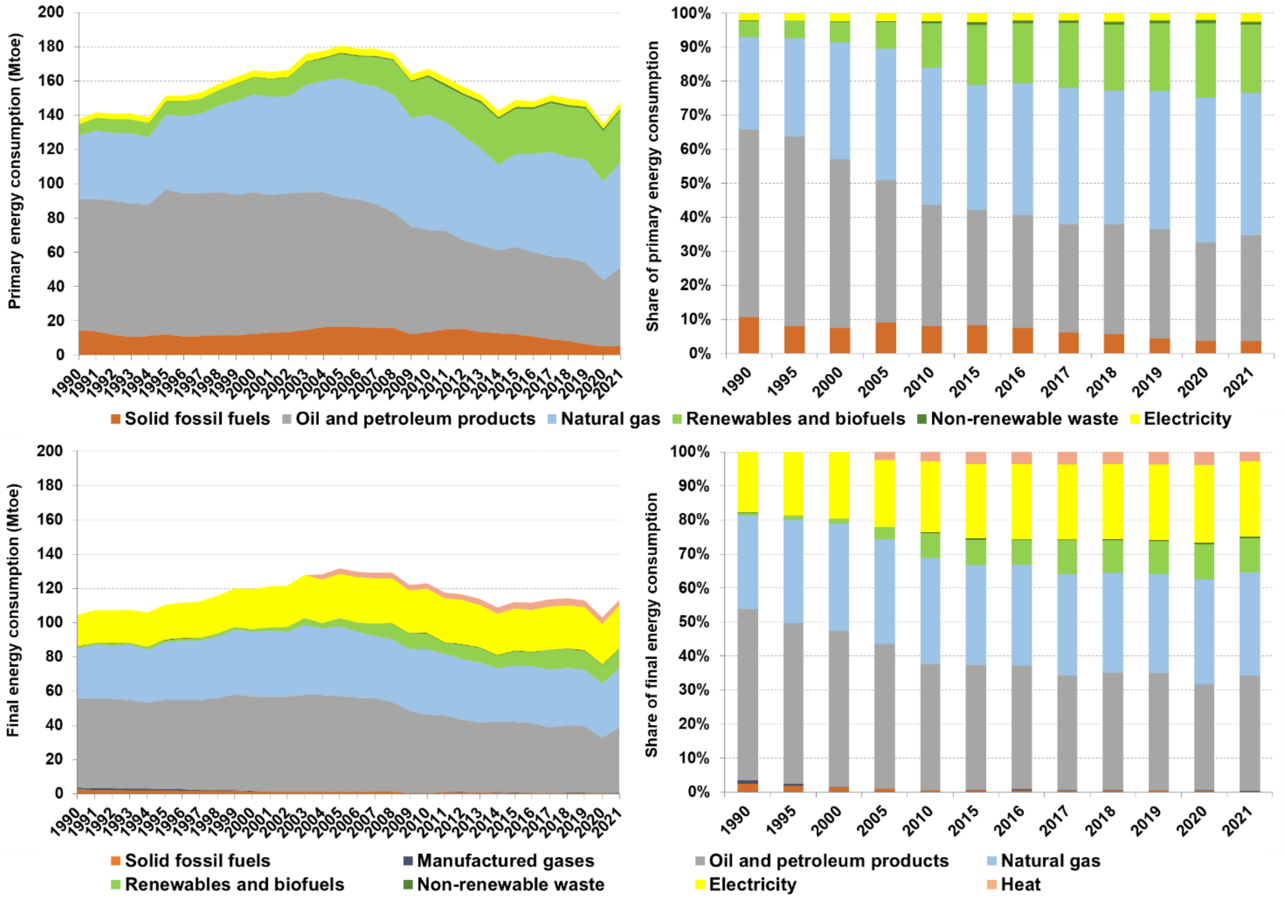
Table 1.3 – Primary energy consumption by energy source (Mtoe).

Energy source	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Solid fossil fuels	14.6	12.1	12.4	16.3	13.5	12.2	10.9	9.3	8.5	6.4	5.1	5.5
Oil and petroleum products	76.1	84.5	82.6	75.9	59.5	50.8	49.2	48.2	48.3	47.7	38.8	45.8
Natural gas	37.3	43.7	57.0	69.7	67.5	54.7	57.4	60.9	58.9	60.3	57.6	61.8
Renewables and biofuels	6.5	7.7	10.1	14.1	21.9	26.3	26.0	28.8	29.3	29.5	29.3	29.9
Non-renewable waste	0.2	0.2	0.3	0.7	1.0	1.1	1.2	1.1	1.1	1.2	1.2	1.1
Electricity	3.0	3.2	3.8	4.2	3.8	4.0	3.2	3.2	3.8	3.3	2.8	3.7
Primary energy	**137.7**	**151.4**	**166.1**	**180.8**	**167.3**	**149.1**	**148.0**	**151.6**	**149.8**	**148.4**	**134.8**	**147.8**

Table 1.4 – Final energy consumption by energy source (Mtoe).

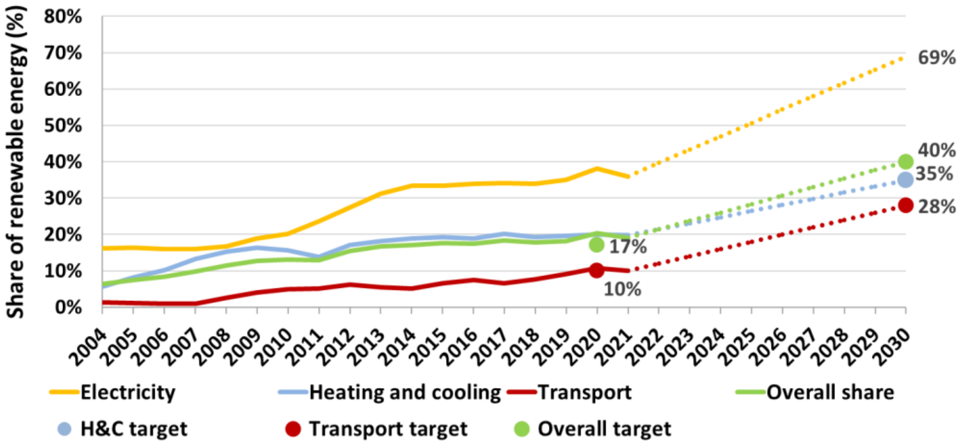
Energy source	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Solid fossil fuels	2.7	2.0	1.5	1.3	0.6	0.5	0.7	0.5	0.6	0.6	0.4	0.3
Oil and petroleum products	52.7	52.1	55.0	56.0	45.6	41.2	40.5	38.3	39.4	38.9	32.2	38.4
Manufactured gas	0.9	0.8	0.3	0.0	0.0	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Natural gas	28.7	33.7	37.6	40.6	38.5	33.0	33.2	33.9	33.6	33.0	31.8	34.4
Renewables and biofuels	0.9	1.4	1.7	4.5	9.1	8.4	8.0	11.3	11.0	10.9	10.7	11.4
Non-renewable waste	0.1	0.1	0.1	0.1	0.2	0.3	0.3	0.2	0.3	0.3	0.3	0.3
Electricity	18.5	20.5	23.5	25.9	25.7	24.7	24.6	25.1	25.2	25.1	23.7	25.1
Heat	0.0	0.0	0.0	3.1	3.3	3.9	4.0	4.1	4.1	4.2	3.9	3.1
Final energy	**104.5**	**110.5**	**119.7**	**131.5**	**123.1**	**112.1**	**111.6**	**113.6**	**114.3**	**113.1**	**103.1**	**113.2**
No energy final consumption	**10.4**	**9.8**	**8.4**	**8.6**	**9.6**	**6.6**	**6.3**	**7.9**	**7.2**	**7.0**	**6.8**	**5.9**

Figure 1.3 – Primary and final energy consumption trends by sources.



Directive 2009/28/EC establishes the shares of energy from renewable sources on gross final consumption by 2020 for each Country of the European Union; these shares include renewable energy consumption for electricity generation, heat and cooling, and transport. The Italian share of energy from renewable sources in 2020, according to the criteria established by the afore mentioned Directive, is 20.4% compared to gross final consumption, a value higher than the target of 17% to be achieved by 2020. The share of renewable energy in 2020 is more than three times the value recorded in 2004 when it accounted for only 6.3% of gross final consumption. In the period 2004-2020 the share of renewable energy grew by an average of 0.9 percentage points per year with a slowdown since 2014. The renewable share increase in the electricity sector is particularly notable, from 2008 to 2020 it rose from 16.6% to 38.1%. In transport, the share increases up to 10.7% in 2020, higher than 10% target to be achieved by 2020. The heating and cooling sector share is 19.9% in 2020. In 2021 a further slowdown was recorded in the overall share (19%) and the three sectors (transport 10%; H&C 19.7%; Electricity 36%). Figure 1.4 shows the trajectories from 2021 that Italy must perform to achieve the EU 2030 targets according to the European Commission proposal to revise the Renewable Energy Directive. For the renewables in electricity the European Commission estimate needed to support the REPowerEU plan is reported, while for H&C 1.5 percentage point annual increase from 2020 is reported (EC, 2022b). European targets must be translated in national targets after the formal adoption of Renewable Energy Directive. Up to 2020 transport and overall renewable were mandatory targets, while electricity and H&C targets were indicative targets. In 2030 the target for heating and cooling will be mandatory.

Figure 1.4 – Share of renewable energy by sector. National targets in 2020 European targets in 2030 are reported. Actual trends up to 2021 are shown and trajectories to achieve EU 2030 targets as defined in the EC proposal to revise the Renewable Energy Directive. European targets must be translated in national targets. For the renewables in electricity the EC estimate needed to support the REPowerEU plan is reported, while for H&C 1.5 percentage point annual increase from 2020 is reported (EC, 2022b).



In Table 1.5 the gross inland energy consumption is explicated in terms of final uses and transformation and losses energy.

Table 1.5 – Energy consumption by sector.

Settori	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Transformation & losses	31.5	38.4	42.9	46.9	41.9	34.9	34.2	34.9	33.3	32.8	30.8	33.5
Industry	34.1	33.9	37.6	37.2	29.0	24.9	25.1	24.9	24.7	24.9	23.9	25.3
Transport*	34.2	38.6	42.5	44.8	41.7	39.5	39.1	37.9	39.4	39.8	30.5	36.8
Households	26.1	26.3	27.6	33.9	35.4	32.5	32.2	32.9	31.9	31.1	30.7	32.0
Services	8.2	9.8	11.5	15.1	17.0	15.4	15.4	18.2	19.0	18.2	16.6	17.4
Agriculture	2.9	3.0	2.9	3.0	2.7	2.7	2.7	2.7	2.8	2.7	2.8	2.9
Fishing	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Others	0.4	0.6	0.2	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.0	0.1
No energy final use	10.4	9.8	8.4	8.6	9.6	6.6	6.3	7.9	7.2	7.0	6.8	5.9
Statistical differences	0.1	0.5	0.6	-0.5	-0.9	-1.1	-1.1	-0.4	-1.6	-1.5	-0.6	-0.4
Total	**148.1**	**161.2**	**174.5**	**189.4**	**176.8**	**155.7**	**154.3**	**159.5**	**157.0**	**155.4**	**141.6**	**153.7**

* including international aviation

Figure 1.5 shows trends and shares of energy consumption by sector. Sectors with more than 20% share of consumption in 2021 are transformation and losses (21.8%), households (20.8%), and transport, including international aviation (23.9%). Industry and services sectors take 16.5% and 11.4%, respectively.

Figure 1.5 – Energy consumption trend and share by sector. Transport includes international aviation.

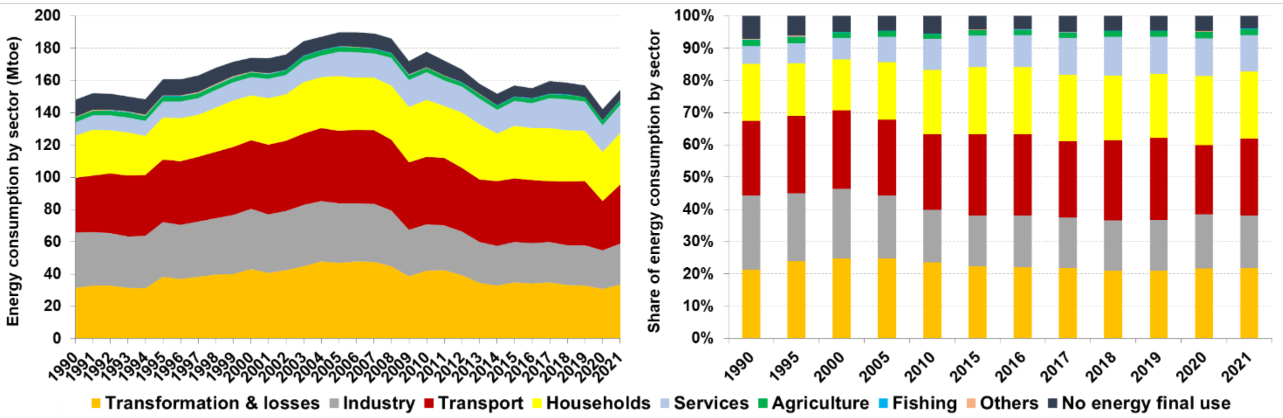
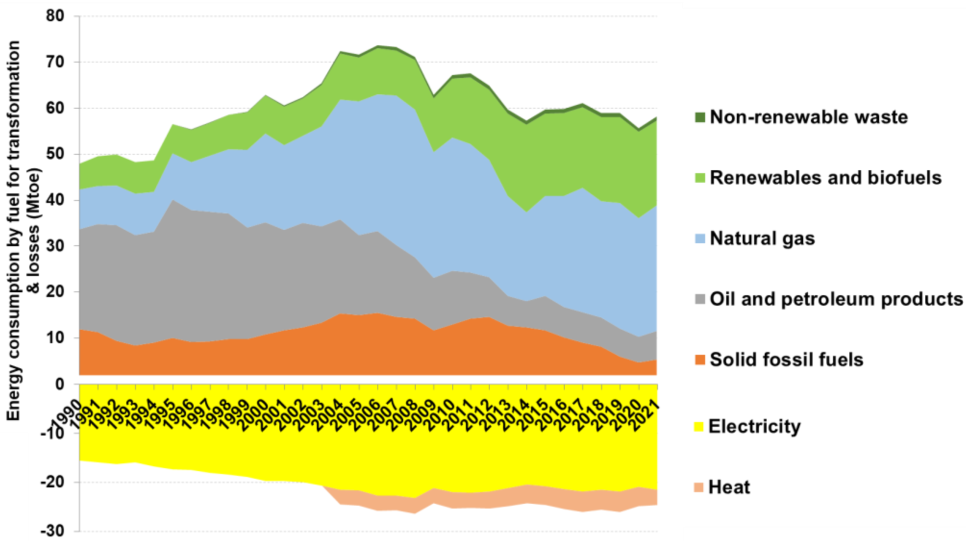


Figure 1.6 makes clear the continuous shrinking of solid fossil fuels and, most of all, oil & petroleum products. On the other hand, natural gas and renewable sources increased their shares.

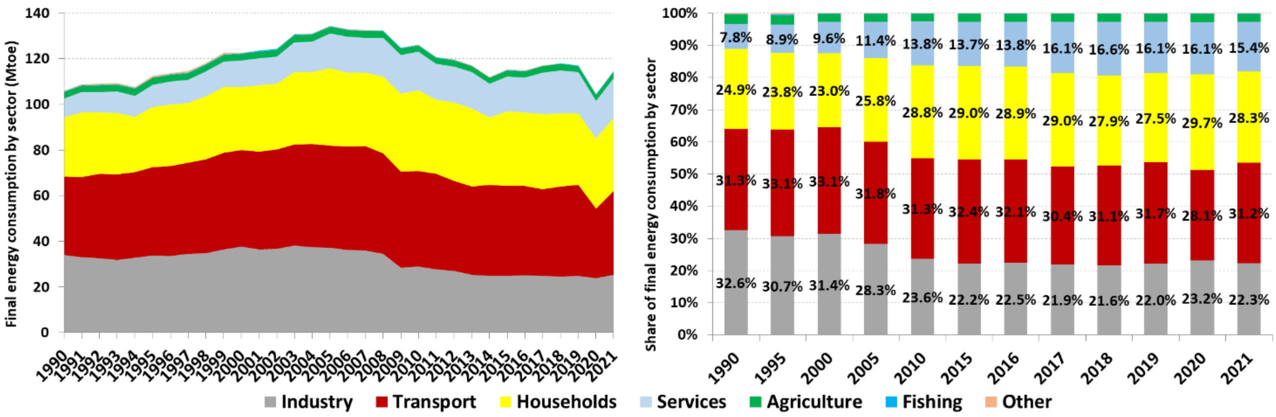
Figure 1.6 – Energy consumption trend by fuel for transformation and losses.



The final energy consumption per sector shows structural peculiarities for each sector and different sensitivities to the contingency, such as economic crisis since 2008 or 2020 lockdown which have mainly affected the productive sectors. Since 1990 until 2021 industry shows a decline of final energy consumption of 25.8%, while the services show a sharp increase of 113.6%. The trend of final consumption in the household sector is quite variable depending upon different climatic conditions that affect the consumption. The residential sector shows an increase in consumption of 22.9% in 2021 compared to 1990 level. The overall trend for transport, including international aviation, increases by 7.5%, after the fall in 2020 due to the lockdown measures.

Since the 1990s, the structure of sectors in terms of energy consumption has changed considerably. Services account for an increasingly share of final consumption from 7.8% in 1990 to 15.4% in 2021, while industry reduces its share of energy consumption from 32.6% to 22.3% over the same period. Consumption in the household sector shows a growing trend until 2010 followed by slight decrease with large fluctuations mainly related to the average temperature. The sector does not appear to have been affected by the contraction due to the economic crisis as the other sectors. The average share of consumption in other sectors (mainly agriculture and fisheries) is under 3%.

Figure 1.7 – Final energy consumption trend and share by sector. Transport includes international aviation.



The details of energy consumption by sources and sector show the peculiar consumption structure for each sector. The transport sector has a dominant energy source, oil & petroleum products (89.3% in 2021), and very small amount of electricity consumption (2.7%). On the other hand, industry has more diversified energy sources, high level of electricity consumption (43.4%) but small renewable share (2%). As for the civil sector in the household's sector there is a growing share of renewable energy since 2000 (21.3% in 2021), while in the services sector the renewable energy use starts only since 2017 (15.1% in 2021), mainly due to the beginning of the recording of energy consumption by heat pumps in the Eurostat database. As for electricity consumption the civil sectors in 2021 recorded 18% for households and 39.6% for services.

Figure 1.8 – Final energy consumption trend and share by energy source.

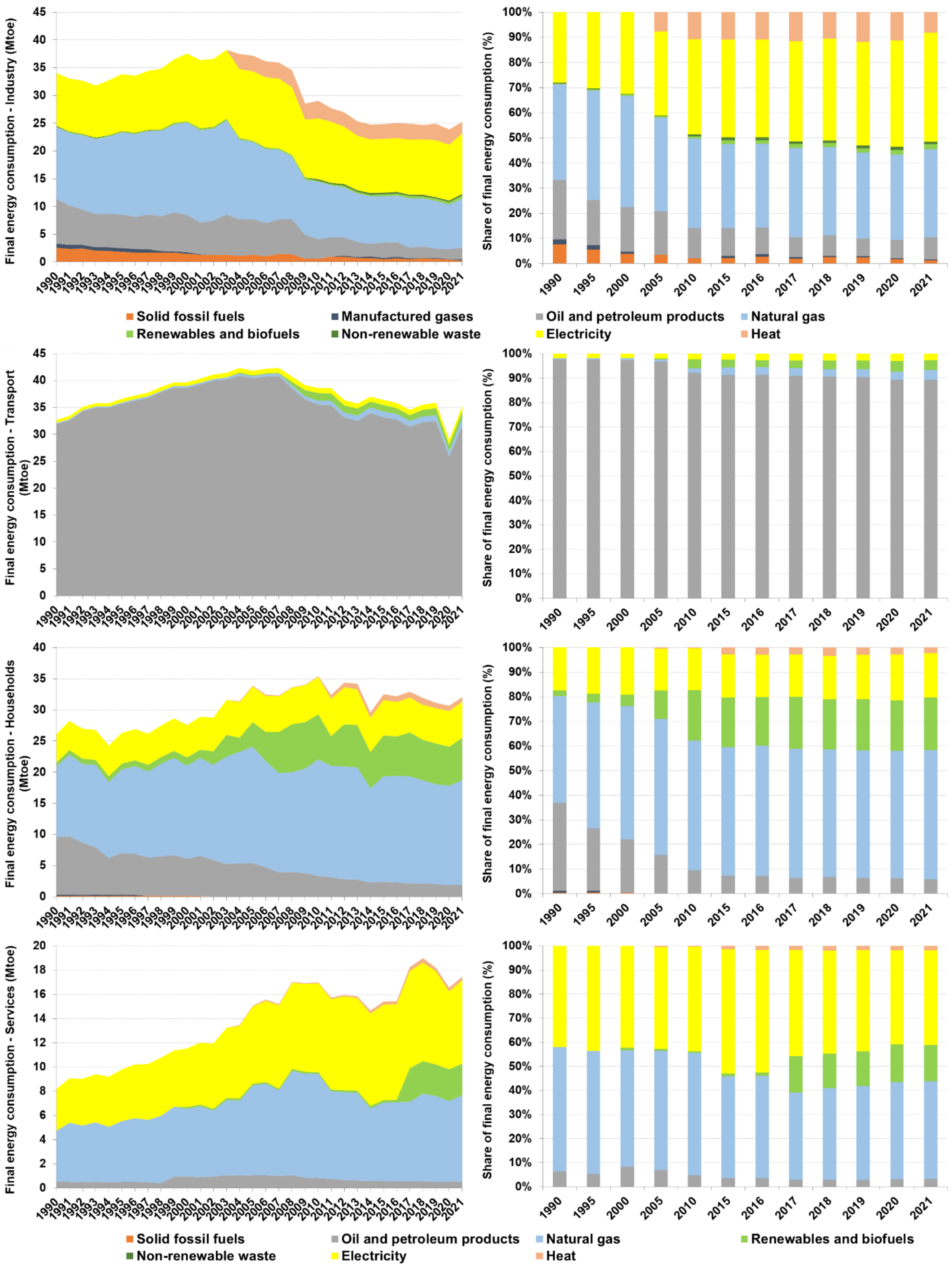
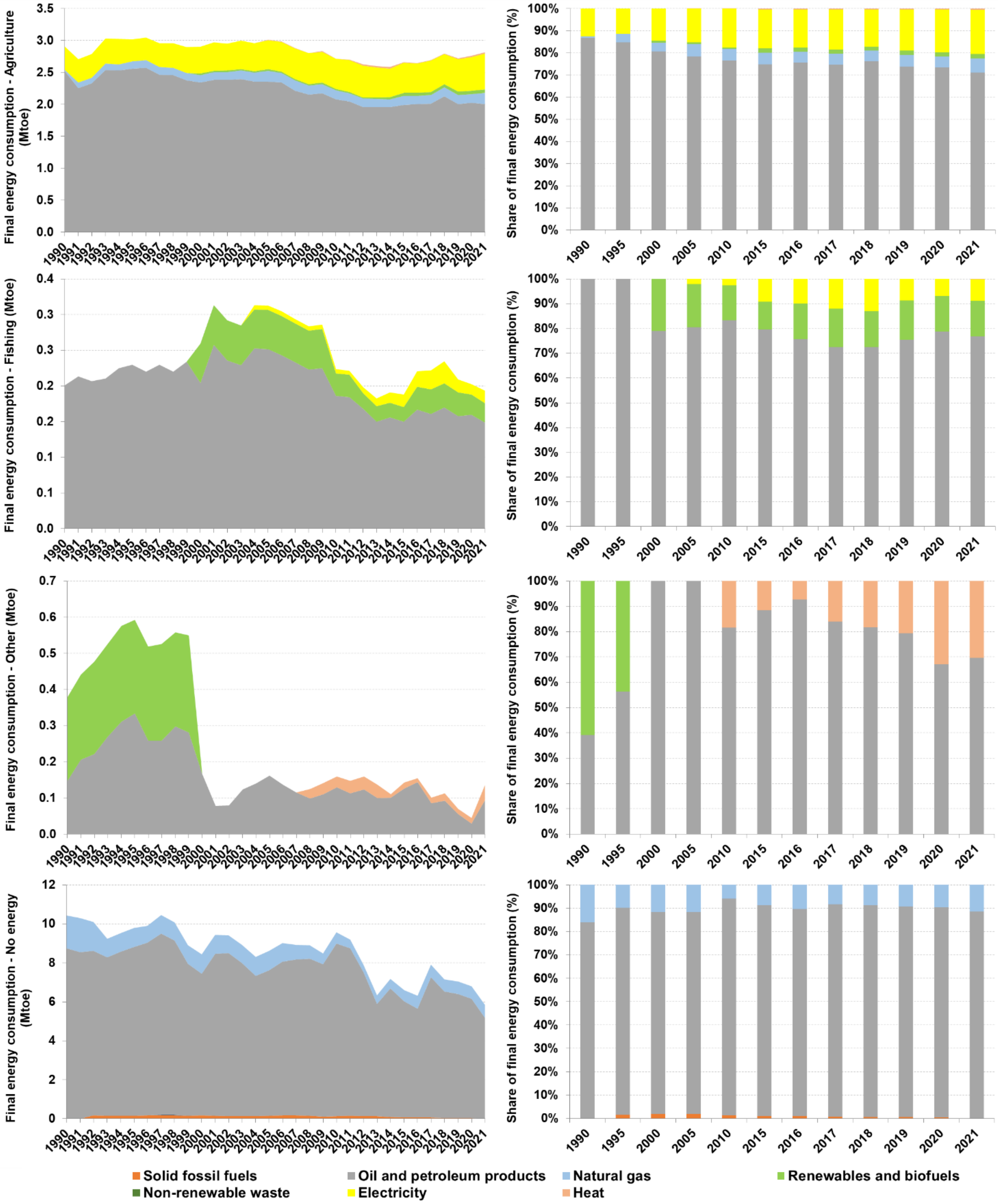


Figure 1.9 shows the energy consumption for minor sectors and no energy uses. All sectors have significant share of oil & petroleum products consumptions even though sectors as agriculture and

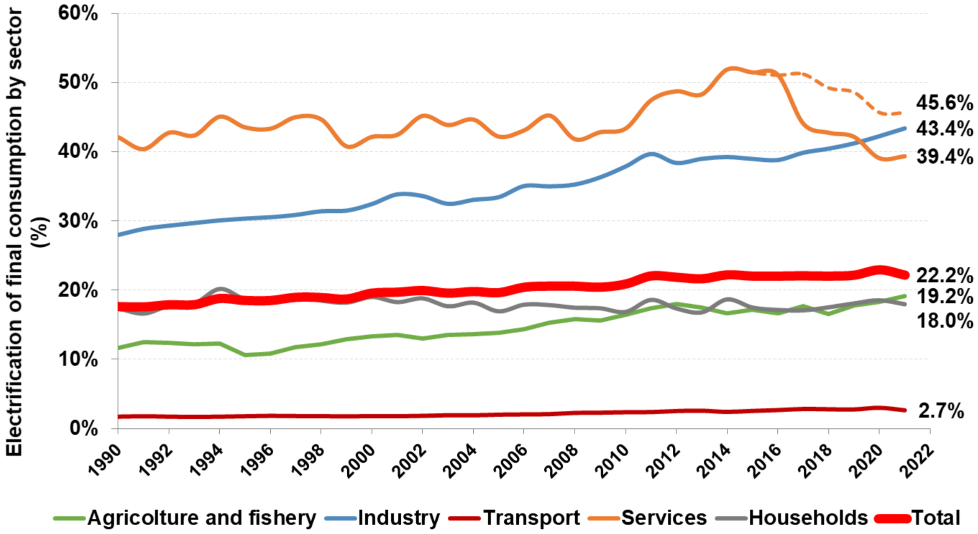
fishing show a growing share of electricity. In the fishing sector also a relevant share of renewable energy is recorded since 2000.

Figure 1.9 – Final energy consumption trend and share by energy source.



The electrification of final consumption is a key strategy to mitigate greenhouse gas emissions if pursued in parallel with the spread of renewable energy for electricity production. The share of electricity in final energy consumption increases constantly since 1990 and in 2021 is 22.2%, slightly below the 2020 level (23%). As already seen the sectoral electrification level of final consumptions is quite different. Services show the highest share of electricity consumption, with a significant increase from 2008 reaching more than 50% of the sector's final consumption in 2014 and 2015. In the last years the share decreased (39.4% in 2021) mainly because of the considerable increase in final consumption of ambient heat from heat pumps that did not appear in energy balances until 2017. Without such item, the electrification of the sector in 2021 is 45.6%. The rate of electrification of final consumption in industry has been steadily increasing since 1990, with the rate clearly accelerating since 2005. In this sector, electricity consumption in 2021 is 43.4% of final consumption. The levels of electrification of consumption in the household and transport sectors show no significant increases and in 2021 were 18% and 2.7% respectively, both slightly below the 2020 level. Agriculture and fisheries show a steadily increase of electrification, similarly to industry, and in 2021 the level was 19.2%.

Figure 1.10 – Electrification of final energy consumption by sector.



Data of national greenhouse gas emissions are reported in more detail in the National Inventory of greenhouse gas emissions that ISPRA updates and submits annually to the competent authorities at national and international level (ISPRA, 2023a). Greenhouse gas emissions are expressed in CO_{2eq}. Starting from the 2023 submission under the UNFCCC (*United Nations Framework Convention on Climate Change*), the GWP in use for the various greenhouse gases is that established by the IPCC V *Assessment Report* (2013). For methane it is 28, while for nitrous oxide it is 265.

The emission estimation methodology and emission factors for each sector and its sources are detailed in the National Greenhouse Gas Emission Inventory. The emissions examined in this report follow the same sectoral nomenclature used internationally for the reporting of emission estimates. Tables are organized according to a common format: Common Reporting Format (CRF). Energy emissions and process emissions are included in this format.

Energy emissions of greenhouse gases are due to the combustion of fuels of different nature. In addition, fugitive emissions, i.e., emissions that occur along the chain from production to final use of fossil fuels, and emissions from geothermal sources are included in this category. Process emissions of greenhouse gases occur because of oxidation reactions other than combustion or other redox reactions, such as fermentation. Most methane emissions are due to the latter type of reactions.

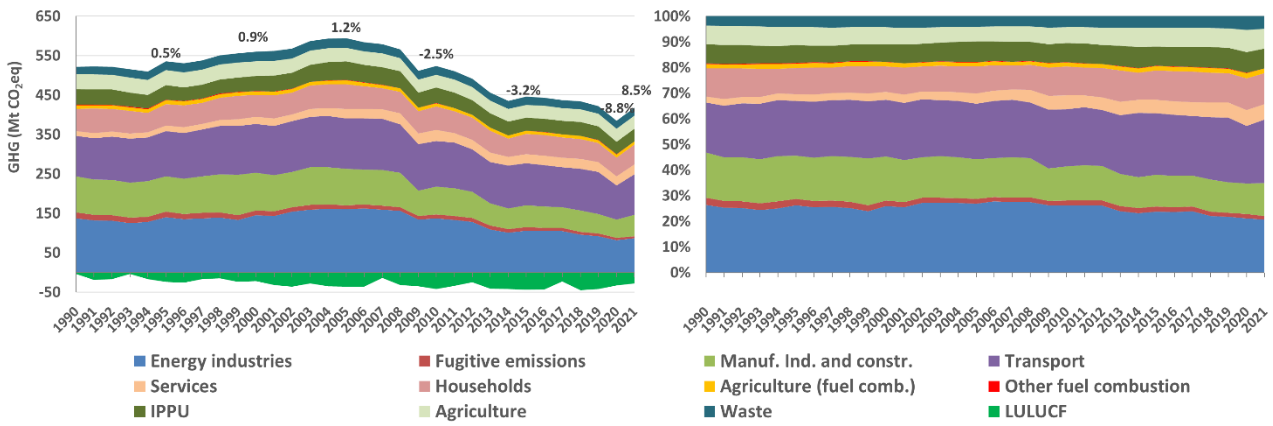
Table 1.6 – GHG emissions by CRF source (MtCO₂eq.).

Source	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022*
Energy industries	137.6	140.6	144.9	159.9	137.5	106.1	104.7	104.8	95.8	91.7	81.6	86.4	*94.7*
Fugitive emissions	14.2	13.4	12.1	10.6	9.7	8.7	7.9	7.9	7.4	7.0	6.2	5.7	*5.1*
Manuf. Ind. and constr.	92.1	90.2	96.2	92.3	70.1	55.6	54.4	53.1	54.2	50.0	45.8	53.9	*50.7*
Transport	102.2	114.2	123.9	128.4	115.9	106.7	105.6	101.5	105.1	106.3	86.6	103.3	*109.0*
Services	57.2	54.6	56.0	62.9	59.4	51.7	51.9	51.7	50.0	48.3	47.5	50.4	*44.9*
Households	12.0	14.2	17.4	23.8	28.7	23.2	23.7	23.7	25.3	24.9	23.9	25.0	*22.3*
Agriculture (fuel comb.)	9.1	9.5	8.8	9.2	8.0	7.6	7.7	7.7	8.2	7.7	7.8	7.8	*7.8*
Other fuel combustion	1.1	1.6	0.9	1.3	0.7	0.5	0.5	0.3	0.4	0.5	0.6	0.3	*0.3*
IPPU	39.3	37.3	38.4	47.2	39.0	33.3	33.6	33.9	34.9	34.0	31.0	31.9	*30.3*
Agriculture	37.7	38.1	37.2	34.6	32.2	32.1	33.0	32.6	32.3	32.2	33.4	32.7	*32.7*
Waste	19.0	22.0	24.1	24.1	22.4	20.3	20.0	19.9	19.9	19.7	20.5	20.2	*20.2*
LULUCF	-3.5	-23.9	-21.6	-35.6	-41.7	-44.0	-43.2	-23.3	-45.2	-41.8	-32.5	-27.5	*-27.5*
Total w/o LULUCF	**521.5**	**535.7**	**560.0**	**594.2**	**523.5**	**445.7**	**443.0**	**437.3**	**433.6**	**422.3**	**385.0**	**417.6**	***417.9***

Total GHG emissions show an increasing trend until 2005, followed by decrease accelerated because of the effects of the economic crisis. In 2020 GHG emissions (385 Mt CO_{2eq}) was heavily affected by lockdown measure to contain SARS-CoV-2 pandemic. GHG emissions fell by 26.2% in 2020 compared to 1990 and by 35.2% compared to 2005. All sectors reduced the emissions, albeit at different rates. In parallel with the declining energy consumption the GHG emissions associated with industrial activities (energy, manufacturing, construction, and industrial processes) have decreased particularly steeply since 2005. In 2021 a rebound was recorded for all sectors, although total emissions remained below the 2019 level. The 2021 GHG emissions fell by 19.9% compared to 1990 and by 13.9% compared to 2005. ISPRA's preliminary estimates for 2022 show that GHG emissions are on the same level of the previous year (+0.1% compared to 2021).

Emissions from manufacturing and construction decreased of 41.6% from 2005 to 2021. Transport sector shows steady growth with a reversal of the trend only after 2007 and the sharp decrease in 2020; 2021 emissions 19.5% lower than 2005. The civil sector (households and services) increases the emissions since 1990 (+9%), with a significant difference between households and services, while the former sector reduces the emissions by 12% the latter increases of 108.6%.

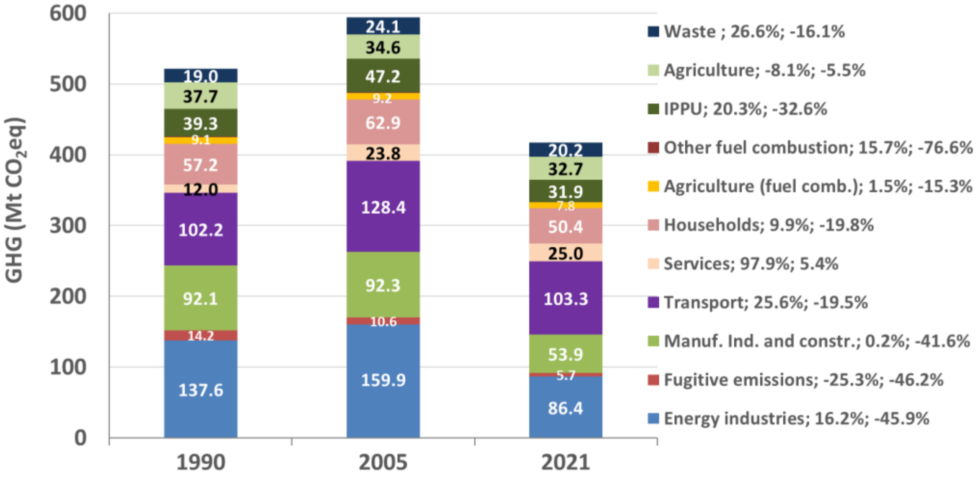
Figure 1.11 – GHG emissions trend and share by source.



In 2021 energy industries, together with fugitive emissions, have 22.1% of the emission share, followed by the transport sector (24.7%) and the civil sector (18.1%). The sectors mentioned, together with all other energy sector, such as manufacturing and construction industries, combustion from agriculture and fisheries, account for 79.7% of total GHG emissions. The energy emissions share increased from 1990 to 2008 followed by a steady contraction mainly due to the emissions reduction from the energy industries.

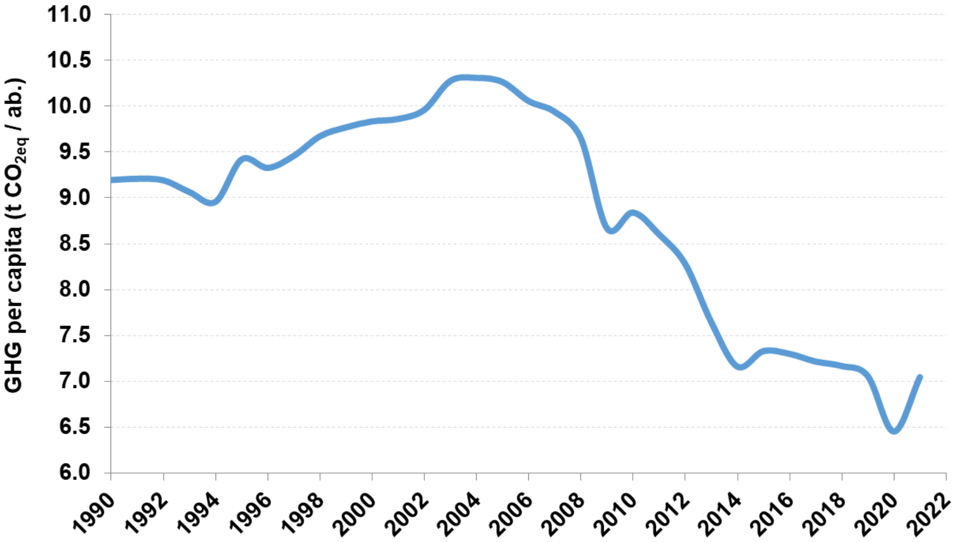
Figure 1.12 shows how each sector changed the emissions since 2005. Almost all sectors reduced the emissions, but it is worth noting that some sectors, such as agriculture (processes emissions) or transport (energy emissions) appear harder to abate than other sectors, as energy industries or manufacture industries.

Figure 1.12 – GHG emissions by source in 1990, 2005, and 2021. For each source category in the legend the first percentage is the 1990-2005 change, the second one is the 2005-2021 change.



GHG emissions per capita increased from 9.2 t CO_{2eq} in 1990 to 10.3 t CO_{2eq} in 2004, in the following years there was a rapid decline up to 6.5 t CO_{2eq} in 2020. In 2021 the GHG emissions per capita is 7 t CO_{2eq}. The GHG emissions per capita decrease from 2005 to 2021 with an average annual rate of -2.5%, while the average annual rate of decrease from 1990 is -0.9%.

Figure 1.13 – Trend of per capita GHG emissions.



1.1.1 Methane emissions

Methane is a powerful greenhouse gas, second only to carbon dioxide in terms of its contribution to global warming (IPCC, 2021). Methane has a Global Warming Potential (GWP) 85 times that of CO2 over a period of 20 years, although CO_2 has an atmospheric lifetime of thousands of years, while methane disappears in about 10-15 years. The rapid decay of methane and its high impact on atmospheric temperature make it a primary objective to curb in a timely and effective manner the climate change.

According to the recent report of the International Energy Agency (IEA, 2021) and IPCC (2022) reducing anthropogenic methane emissions is one of the most effective strategies, including in economic terms, to rapidly reduce the rate of warming and contribute significantly to efforts to limit the increasing global temperature.

National methane emissions

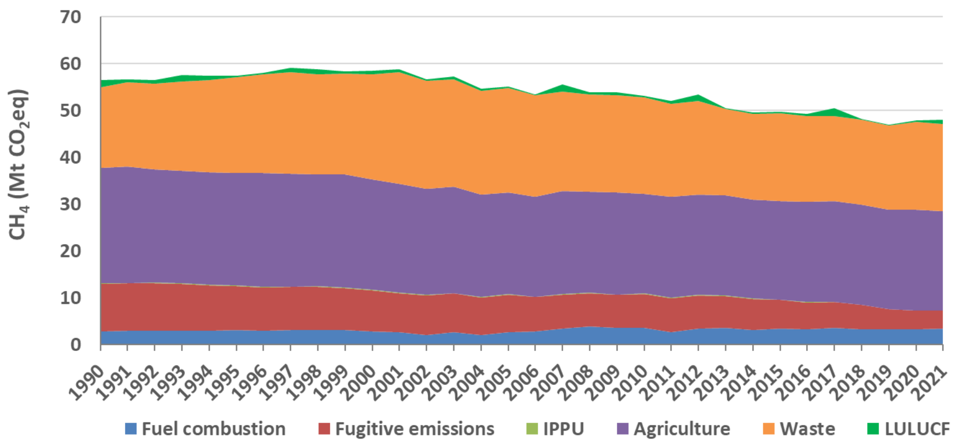
National methane emissions, without the contribution of natural sources, represent on average 10.5%±0.8% of CO_2eq emissions from 1990 to 2021, with a rather variable trend. Methane emissions without LULUCF decreased from 55 to 47.1 Mt CO_2eq from 1990 to 2021 (-14.3%). The reduction of methane emissions is much lower than the reduction of total GHG (-19.9%). Moreover, GHGs other than methane reduced the emissions by 20.6% from 1990. These rates show the need to achieve methane emissions reduction from the main sources.

Table 1.7 – Methane emissions by source (Mt CO2eq).

Source	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Combustion	2.7	3.0	2.8	2.6	3.5	3.4	3.3	3.5	3.3	3.3	3.1	3.4
Fugitive	10.1	9.4	8.8	8.0	7.3	6.1	5.7	5.5	5.1	4.2	4.1	3.9
IPPU	0.1	0.2	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Agriculture	24.6	24.1	23.5	21.7	21.2	21.2	21.5	21.5	21.3	21.2	21.5	21.2
Waste	17.3	20.4	22.5	22.3	20.6	18.6	18.3	18.2	18.2	18.0	18.8	18.5
Total	**55.0**	**57.0**	**57.7**	**54.7**	**52.7**	**49.3**	**48.8**	**48.8**	**48.0**	**46.8**	**47.5**	**47.1**

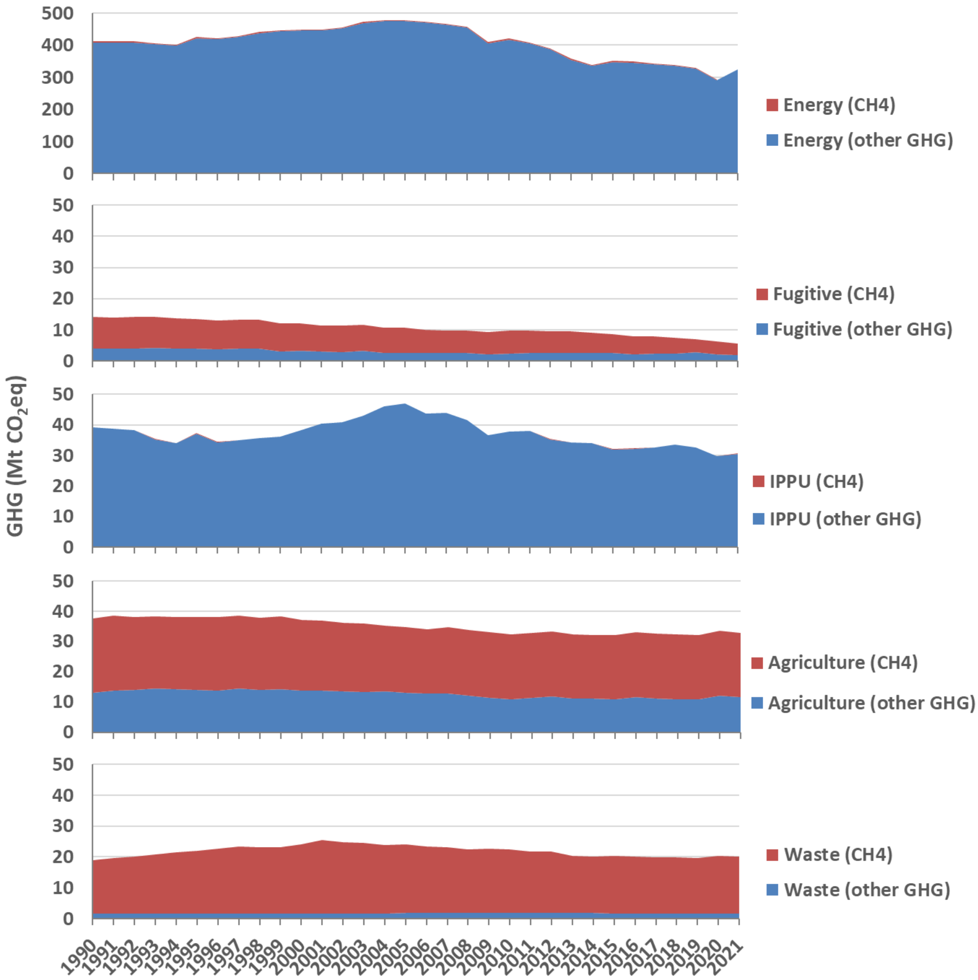
Figure 1.14 shows the decreasing trends of methane emissions by source and make clear the dominant role of agriculture and waste sources.

Figure 1.14 – Trends of methane emissions by source (Mt CO2eq).



The sources contribute differently to methane emissions. Some sector, as IPPU, emits a marginal share of methane, while the emissions by waste are almost entirely of methane.

Figure 1.15 – Trends of methane and other GHGs emissions by source (Mt CO2eq).



Among the main sources, waste recorded in 2021 a significant increase in emissions compared to 1990 levels (+7.1%). The agriculture recorded a reduction of 13.8% and fugitive emissions of 61.7%. Considering only methane emissions, agriculture contributes with 45.1% of emissions in 2021, while the waste sector accounts for 39.4%. Fugitive emissions make up 8.3%, and unburned methane in the energy sector accounts for 7.2%.

By far the most important source of the agricultural sector is represented by enteric fermentation, or the digestive processes of farm animals. This source represents 69.1% of methane emissions from the agriculture in 2021, followed by manure management with 22.5% and rice cultivation with 8.3%. Emissions due to the combustion of agricultural residues in the open field represent a marginal 0.1%.

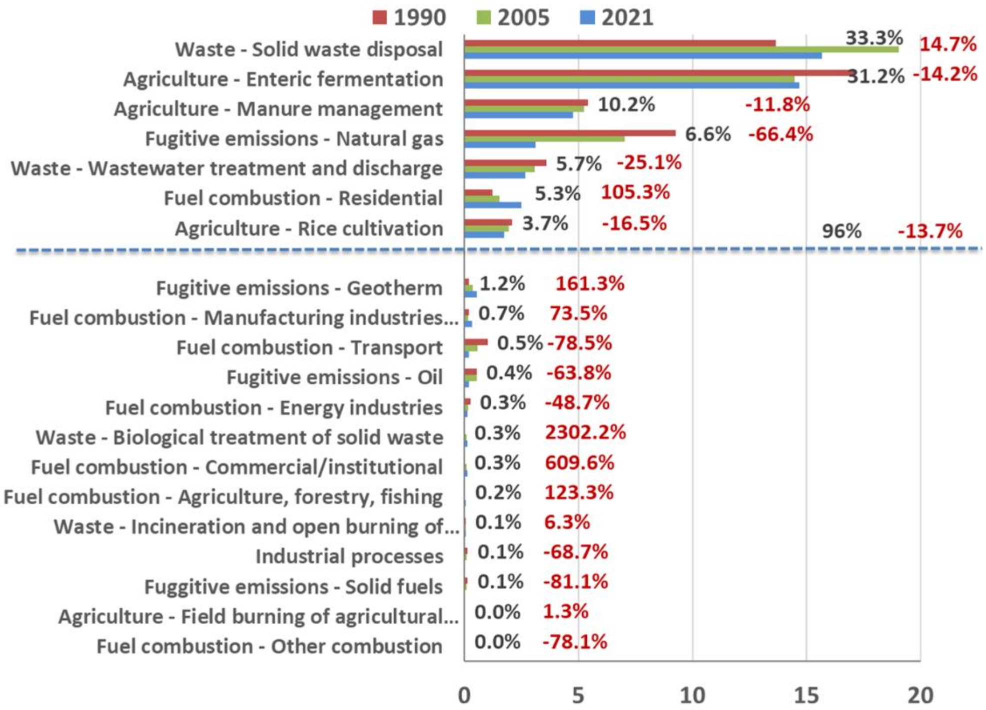
In the waste sector, the dominant source of methane emissions is represented by the disposal of solid waste, responsible in 2021 for 84.5% of sector's methane emissions, the next source is represented by wastewater treatment, with 14.5% of methane emissions. The remaining two sources, biological treatment of solid waste and incineration and open field burning, account for a marginal share of emissions of just over 1%.

Most of the fugitive methane emissions are due to the natural gas supply chain (production, transport, and distribution) which in 2021 accounts for 80% of total fugitive methane emissions with a share that has decreased significantly since 1990, when it was 91.2%. Oil and natural gas supply chains have recorded reductions in methane emissions of more than 60% since 1990.

Unburned methane emissions in the energy sector are mainly due to the dominant source of the civil and agricultural sectors. Such sources represent a share of 80.1% in the methane emissions by energy sector in 2021, followed by manufacturing and construction industries with 9.6%, transport with 6.4% and energy industries with 3.9%.

Arranging in descending order the methane emissions recorded in 2021 from all sources it can be noted that 96% of methane emissions come from seven key sources that emit 45.2 Mt CO_2eq (Figure 1.16). Emissions from key sources decreased by 13.7% since 1990. Minor sources, which are cumulatively responsible for 4% of emissions, are 27.7% lower than in 1990. The disposal of municipal solid waste is the first key source with a third of total methane emissions, followed by enteric fermentation with 31.2%. The first two sources are responsible for almost two-thirds of methane emissions.

Figure 1.16 – Methane emissions by source in 1990, 2005 and 2021 (Mt CO_2eq). Data in descending order of 2021 values. The black labels next to the bars are the source's share in 2021, the red labels are the percentage change from 1990 to 2021. The cumulative values for the seven key sources are reported on the dotted line.



The waste sector has two key sources (MSW and disposal and wastewater treatment) with 39% of total methane emissions, while the agriculture has three sources (enteric fermentation, manure management and rice cultivation) with 45% of total methane emissions. The energy sector has a source for fugitive emissions (natural gas supply chain) and one for combustion (residential sector) which contribute 6.6% and 5.3% of total methane emissions respectively.

Agriculture

The sector accounts for 45.1% of national methane and the three main sources of agriculture represent 99.9% of methane emissions from the sector in 2021.

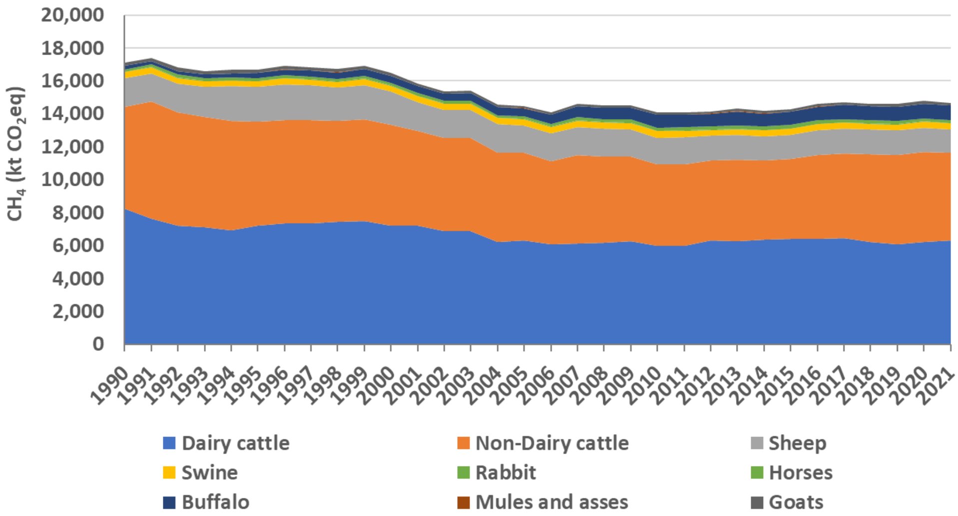
Table 1.8 – Methane emissions from the agriculture sources (Mt CO2eq).

Source	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Enteric fermentation	17.1	16.7	16.5	14.5	14.1	14.3	14.6	14.7	14.6	14.6	14.8	14.7
Manure management	5.4	5.2	5.1	5.2	5.1	5.0	5.0	5.0	4.9	4.9	4.9	4.8
Rice cultivation	2.1	2.2	1.9	2.0	2.0	1.9	1.9	1.8	1.8	1.8	1.8	1.8
Field burning of agric. residuals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**24.6**	**24.1**	**23.5**	**21.7**	**21.2**	**21.2**	**21.5**	**21.5**	**21.3**	**21.2**	**21.5**	**21.2**

The top source of methane is the ***enteric fermentation*** of livestock, which in 2021 accounts for 69.1% of methane emissions from the agricultural sector.

The number and mass of livestock are the main activity data for estimating emissions. To these parameters are added for the main animal categories parameters such as the production of milk, the percentage of fat in the milk, the percentage of grazing animals, the daily weight gain, the share of females that give birth, the quantity and quality of the diet and the coefficient of conversion into methane of the diet.

Figure 1.17 – Methane emissions trend from enteric fermentation by livestock.

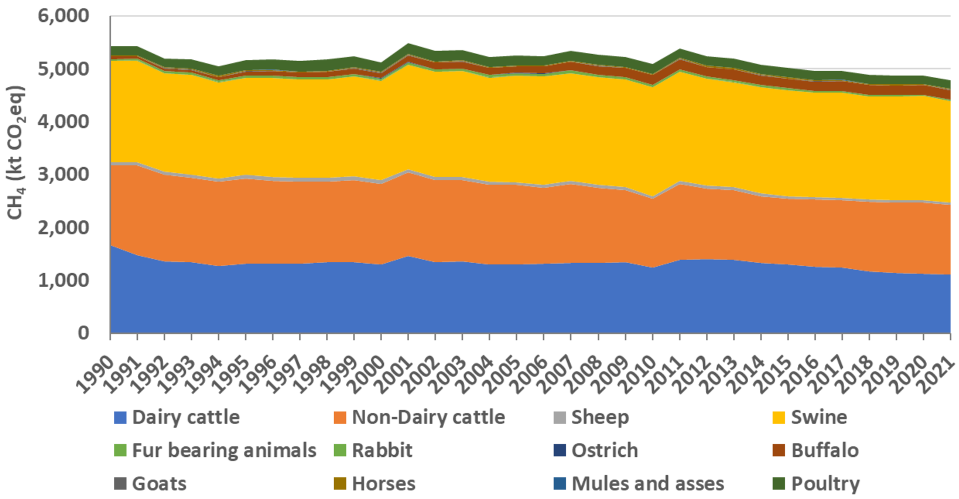


Dairy and non-dairy cattle represent the main source of methane emissions from enteric fermentation (79.3% of methane emissions in 2021), followed by sheep (9.7%). Buffaloes record a constant increase in emissions in parallel with the increase in livestock bred and in 2021 they determine 6% of methane emissions from the source.

Methane emissions from cattle and sheep decreased from 1990 to 2021, by just more than 19%, while for buffaloes there is an increase of a factor of about 4.5.

Manure management is the second largest source of methane emissions in the agriculture, with 22.5% of the sector's emissions. These emissions are generated by the decomposition of organic matter under anaerobic conditions, during treatment and storage, and on pasture. The most relevant factors of the emissions are the amount of manure produced, which depends on the number of animals and the rate of production per animal, and the share of anaerobic treatment, which depends on the adopted manure management. The storage of non-palatable manure (liquid waste), which takes place in environments essentially devoid of oxygen, generates a significant amount of methane compared to the management of solid manure. The temperature and duration of storage also affect methane production.

Figure 1.18 – Methane emissions trend from manure management by livestock.



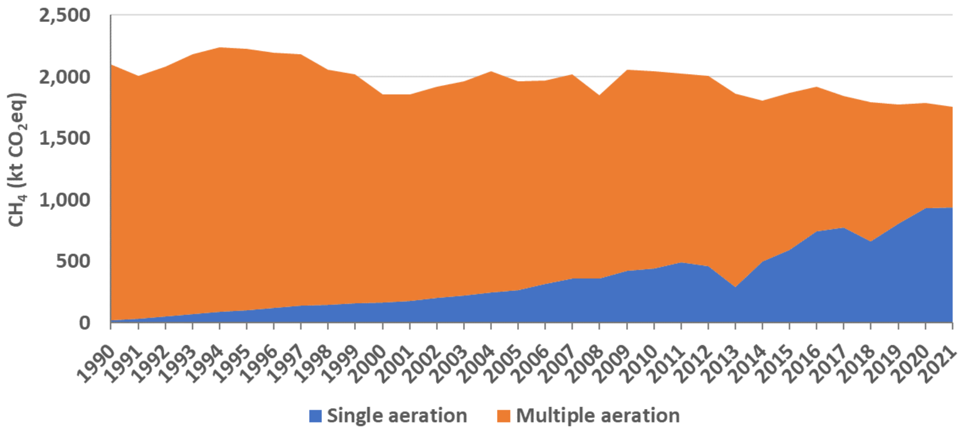
Dairy and non-dairy cattle represent the main source of methane emissions from manure management, accounting for 50.7% of the source's emissions in 2021, followed by swine, which contribute more than 40%. In 1990, the share of cattle was about 59% and that of swine 35%.

In the estimation of methane emissions from manure management, fugitive methane losses of plants are also considered, which are equal to 1% of total biogas production. This percentage is calculated on all the biogas produced which derives not only from livestock waste, but also from all the other organic components that feed the digester. The amount fugitive methane losses in 2020 and 2021 are respectively 386.4 and 404.3 kt CO_2eq.

Rice cultivation is the third source of methane emissions in the agriculture with 8.3% of sector's emissions. Emissions are generated by the decomposition of organic material in submerged rice fields of water by methanogenic microorganisms. Emissions depend on the extent of the crops, the length of the growing period, the irrigation regimes and usage of organic and inorganic soil improvers. Soil type, temperature and cultivated variety also affect methane emissions.

In 2021 the source emitted 62.7 kt CH_4, with a reduction of 16.5% compared to 1990. Although the total harvested area has increased by 5.4%, there is a gradual spread of the cultivation technique in which the surface is submerged for less time than the traditional technique and therefore with less methane emission. The average weighted methane factor from 1990 to 2021 decreased by 20.7%. This reduction is mainly due to the increasing share of area cultivated with single aeration (in which the dry-seeded sowing technique is applied).

Figure 1.19 – Methane emissions trend from rice cultivation by cultivation technique.



Waste

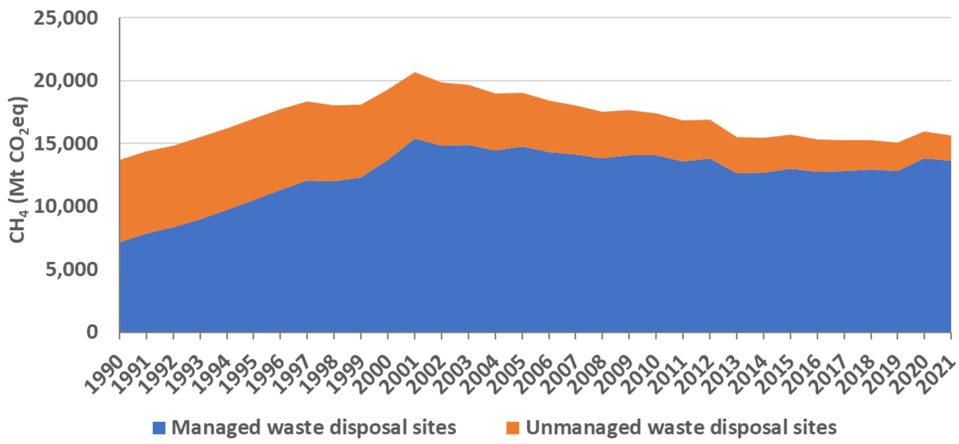
Waste sources emit 39.4% of national methane emissions. The disposal of solid waste is the dominant source, responsible in 2021 for 84.5% of the sector's methane emissions, the next source is represented by wastewater treatment and management with 14.5%.

Table 1.9 – Methane emissions from the waste sources (Mt CO2eq).

Source	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Solid waste disposal	13.7	16.9	19.3	19.0	17.4	15.7	15.3	15.3	15.3	15.1	16.0	15.7
Biological treatment of solid waste	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Incineration and open burning of waste	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Wastewater treatment and discharge	3.6	3.4	3.2	3.1	2.9	2.7	2.8	2.7	2.7	2.7	2.7	2.7
Total	**17.3**	**20.4**	**22.5**	**22.3**	**20.6**	**18.6**	**18.3**	**18.2**	**18.2**	**18.0**	**18.8**	**18.5**

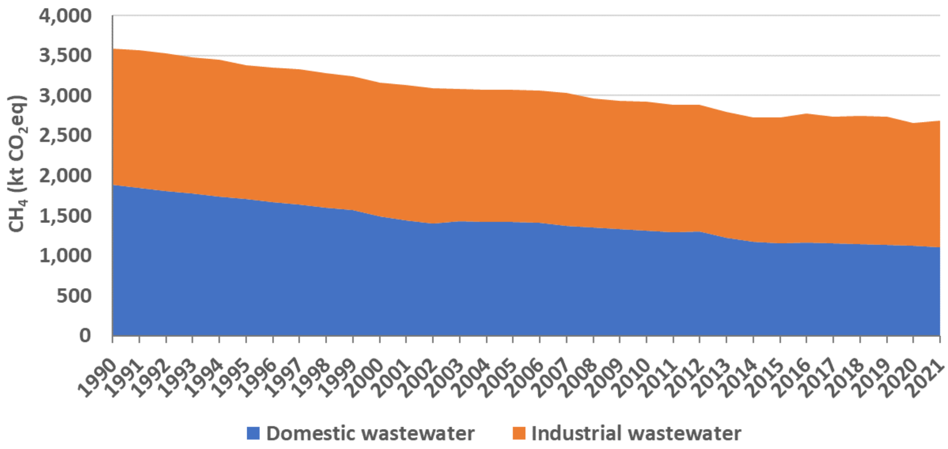
Landfilling of solid waste is a key category for methane, both for quantity and trend. The main parameters that influence the estimation of landfill emissions are, in addition to the quantity of waste disposed in landfills, the waste composition, the methane ratio in the biogas and the quantity collected and recovered. These parameters are strictly dependent on the waste management policies that start from the production and transport of waste, separate collection, treatment for volume reduction, stabilization, recycling, and energy recovery up to the deposition of the final residues in landfills. The disposal of solid waste in landfills contributes to a third of methane national emissions in 2021 (33.3%). Between 1990 and 2021, methane emissions from this source increased by 7.1%, from a value of 17.3 $MtCO_2eq$ to 18.5 $MtCO_2eq$. The emissions trend shows an increase from 1990 to 2001 (+51.1%) followed by a decreasing trend up to 2021 (-21%).

Figure 1.20 – Methane emissions trend from waste disposal for managed and unmanaged sites.



Anaerobic conditions can also arise within ***wastewater management*** systems. In addition, the sewage sludge and the organic substance contained in the sewage, if dispersed in the environment, can undergo anaerobic degradation. Methane emissions can therefore occur which are strictly connected to the characteristics of the wastewater and therefore to the quantity of organic substance present in the sewage, to the way in which they are managed as well as to the temperature. Methane emissions are estimated for both civil and industrial wastewater. Civil wastewater means mixed civil-industrial sewage deriving from strictly domestic activities and from commercial /industrial users, operating in an urban context. Methane emissions from civil wastewater show a significant reduction from 1990 to 2021 (41.1%) compared to an increase in the total organic load in treated wastewater of about 30% in the same period. As for industrial wastewater the methane emissions decrease by 7.3% in line with a decrease of the organic product of treated wastewater.

Figure 1.21 – Methane emissions trend from wastewater management for domestic and industrial wastewater.



Energy: fugitive emissions

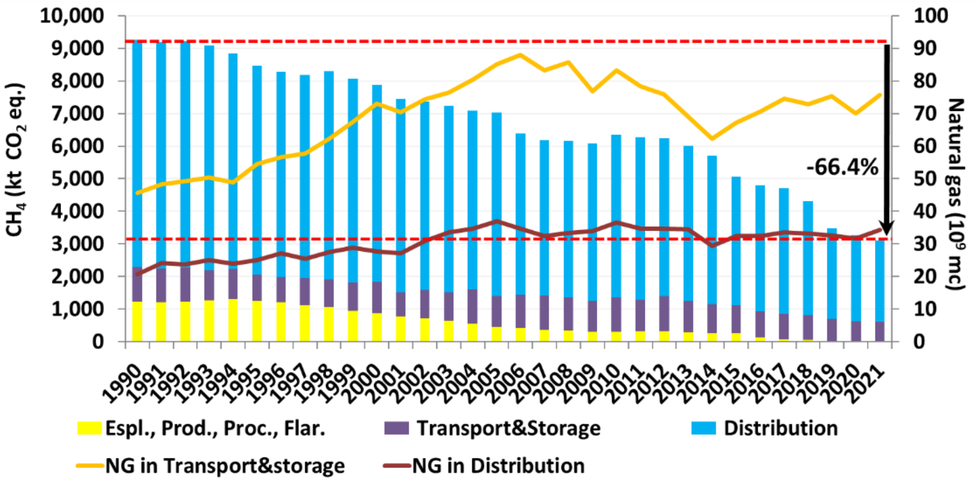
Fugitive emissions are 8.3% of national methane emissions. The ***natural gas supply chain*** accounts for 6.6% of national methane emissions and 80% of fugitive emissions in 2021. There has been a significant reduction in emissions since 1990 when represented 16.8% of national methane emissions and 91.2% of fugitive emissions.

Table 1.10 – Methane emissions from the fugitive sources (Mt CO_2eq).

Source	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Solid fuels	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Oil	0.5	0.6	0.5	0.5	0.4	0.4	0.2	0.2	0.2	0.1	0.2	0.2
Natural gas	9.3	8.5	7.9	7.0	6.3	5.1	4.8	4.7	4.3	3.5	3.3	3.1
Geothermal	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.6
Total	**10.1**	**9.4**	**8.8**	**8.0**	**7.3**	**6.1**	**5.7**	**5.5**	**5.1**	**4.2**	**4.1**	**3.9**

Transport, storage, and distribution of natural gas are the main sources of fugitive emissions with distribution in the dominant role. Fugitive emissions from the supply chain have been significantly reduced since 1990 because of many measures to improve the transport and distribution network performances. Since the 90s there has been the replacement in the distribution network from material characterized by high emission factors (gray cast iron with hemp and lead joints) to materials characterized by fewer joints and lower emission factors. In addition, the steel pipelines with cathodic protection for the corrosion prevention is increasingly extensive. Such improvements led to the methane emissions reduction of 66.4% from 1990 to 2021 compared to an increase in gas transported and distributed by almost 66% in the same period. Distributed natural gas meets the demand of users in the civil sector and small industry, while large industrial users are directly served by the transport network.

Figure 1.22 – Trend of methane emissions by source from the natural gas supply chain (left axis) and amount of natural gas transported and distributed (right axis). The dotted lines are the emission levels of 1990 and 2021.



The main sources transport-storage and distribution recorded emission reductions from 1990 to 2021 of 43.4% and 64.2%, respectively. In the transport-storage source, losses due to the transport, storage and regasification of liquefied natural gas are considered. The emission factors show a continuous decrease, an expression of the improvement in the performance of the transport and distribution network. The emission factor per unit of gas in the transport-storage source recorded a reduction of 65.9% from 1990 to 2021, while for distribution there was a decrease of 78.4% in the same period. The emission factor in the transport-storage source is about an order of magnitude lower than the emission factor in the distribution and shows that the grid set-up for the satisfaction of natural gas demand is a crucial factor for the reduction of fugitive emissions in the natural gas supply chain. In addition, the relevance of emissions from distribution, 80.3% of methane emissions from natural gas supply chain, makes this source the main objective for future actions to reduce fugitive emissions.

Energy: Combustion

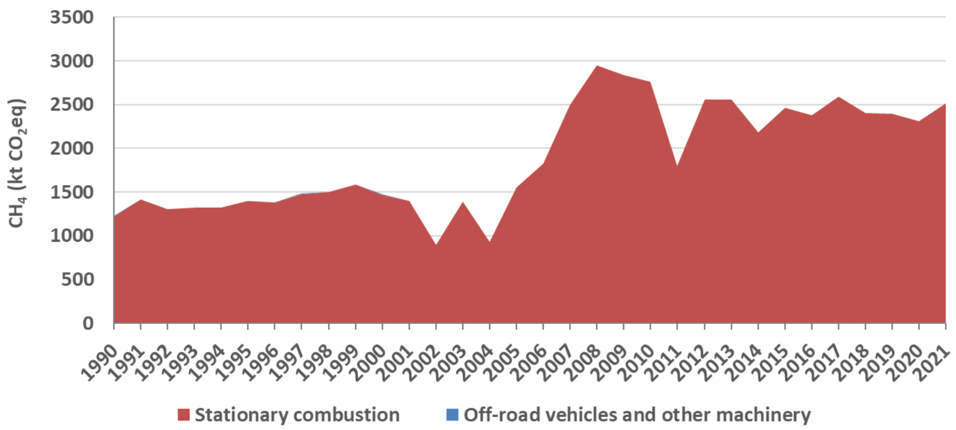
Energy sector emits 7.2% of national methane emissions. The residential sector is the main source with a growing share from 1990, when it contributed to 44.8% of sector's methane emissions, to 2021 with 74.2%.

Table 1.11 – Methane emissions from the energy sources (Mt CO_2eq).

Source	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Energy industries	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Manuf. industries and construction	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Transport	1.0	1.1	0.9	0.6	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
Other: Commercial /institutional	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other: Residential	1.2	1.4	1.5	1.6	2.8	2.5	2.4	2.6	2.4	2.4	2.3	2.5
Other: Agriculture /forestry/fishing	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other combustion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**2.7**	**3.0**	**2.8**	**2.6**	**3.5**	**3.4**	**3.3**	**3.5**	**3.3**	**3.3**	**3.1**	**3.4**

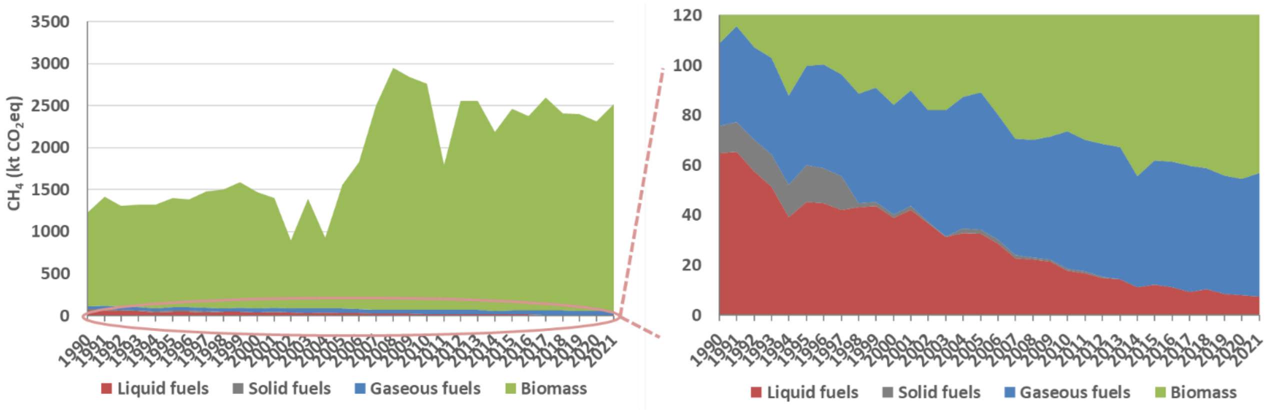
Greenhouse gas emissions in the sector originate from the energy used directly in buildings, mainly for heating. Emissions from stationary sources account for almost all methane emissions, while emissions from vehicles and other machinery represent a marginal share that from 1990 to 2021 decreased from 0.2% to 0.01%.

Figure 1.23 – Methane emissions trend from residential sector.



Methane emissions increased from 1990 to 2021 by 105.3% in the residential source compared to a 11.8% reduction in total greenhouse gas emissions in the sector. The decoupling is due to the increasing share of energy from biomass compared to other fuels and relative methane emissions. The sector's energy consumption oscillates around an average value without a particular trend, while the share of energy consumption from biomass has increased, going from an average of 14.2% in the 90s to an average of 25.5% in the last five years. Biomass essentially refers to the consumption of wood for heating.

Figure 1.24 – Methane emissions trend from residential sector by fuel.

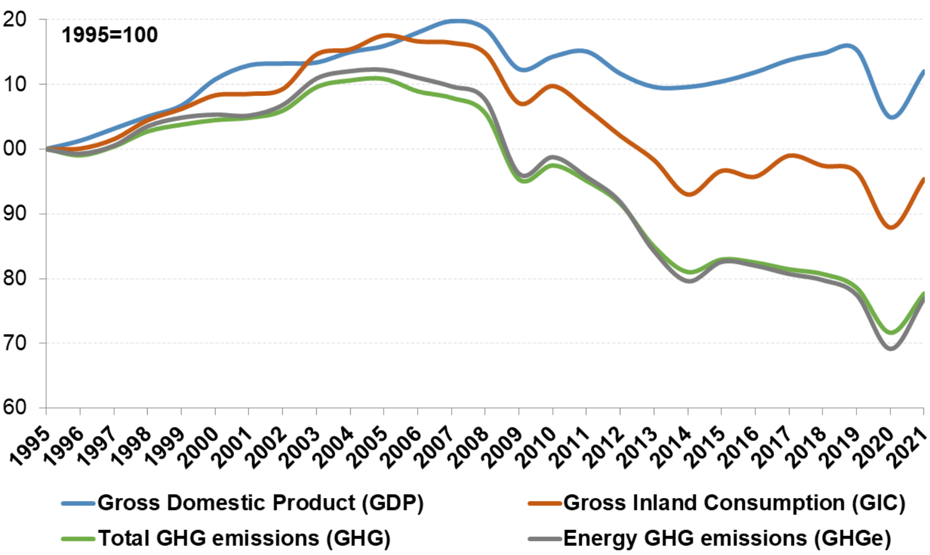


The share of methane emissions from biomass has always been prevalent but increased from 91% in 1990 to 97.7% in 2021. Other fuels contribute with fewer and fewer shares. The emission factors of methane and nitrous oxide from biomass for the entire time series examined are respectively 320 and 14 kg/TJ, much higher than those recorded for fossil fuels. However, unlike the sectors previously examined, in the residential sector the contribution of carbon dioxide is decisive in the overall greenhouse gas emissions and constitutes on average about 95% of greenhouse gas emissions. The emission factors of biomass, expressed in CO_2eq, thus also considering the zero emissions of CO_2, are lower than those of fossil fuels.

1.2 Energy intensity and decarbonization indicators

To assess the relationship between energy consumption, economy and GHG emissions the trends of gross inland energy consumption (GIC), gross domestic product and GHG emissions are analysed. GDP and GIC have parallel trends up to 2005. Then the two parameters begin to diverge showing an increasingly decoupling. GHG emissions growth was slower than that of GDP until 2005, highlighting a relative decoupling. After 2005, the divergence between the two parameters becomes increasingly marked showing even absolute decoupling when the GDP increased and GHG decreased (2015-2019).

Figure 1.25 – GHG emissions by sector.



Decoupling is also evident from the decreasing trend in the ratio of GIC to GDP since 2005. The decreasing trend in energy GHG emissions per unit of primary energy consumption is mainly due to the replacement of higher carbon fuels with natural gas, mostly in power sector and industry, and to the increase of renewable share. The same decreasing trends are confirmed for final energy consumption (net of non-energy uses) per unit of GDP and for GHG emissions per unit of final energy consumed.

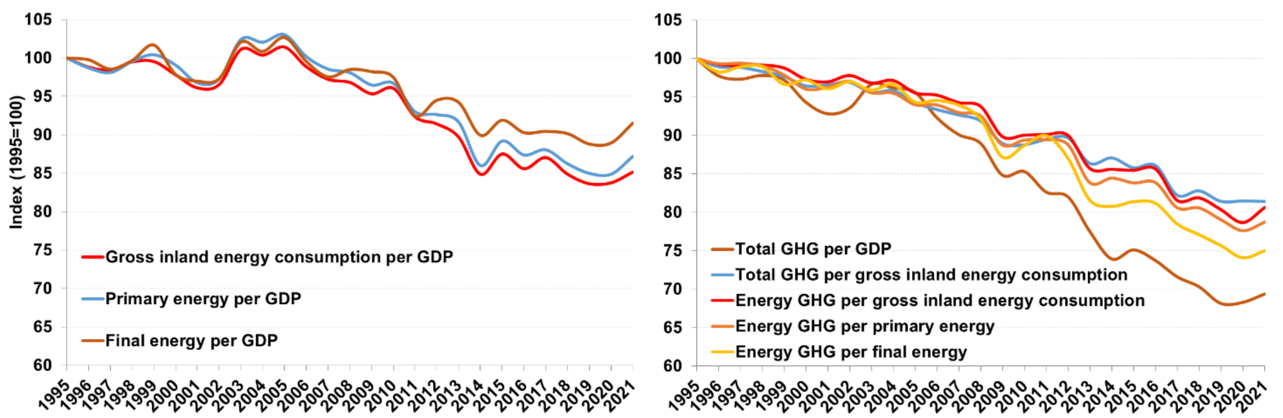
In the period 1995-2021 the GIC per unit of GDP decreased from 107.5 toe/M€ to 91.5 toe/M€ (-14.8%). Over the same period, GHG emissions per unit of GDP fell by 30.4%, from 357.3 t CO_{2eq} / M€ to 248.8 t CO_{2eq}/M€, while energy emissions per primary energy unit goes from 2.81 t CO_{2eq}/toe to 2.21 t CO_{2eq}/toe, with a reduction of 21.1%. All declining trends of the shown indicators are statistically significant to Mann-Kendall test ($p<0.001$). The preliminary estimates for 2022 show a further decrease of energy intensity and decarbonization indicators by GDP compared to the previous year. On the side of decarbonization indicators by energy consumption a relevant increase has been recorded.

Table 1.12 – Energy intensity by economy and decarbonization indicators.

	Indicators	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	*2022**
Energy intensity	GIC per GDP (toe/M€)	107.5	105.1	109.0	103.3	94.1	92.0	93.6	91.2	89.9	90.0	91.5	*85.5*
	Primary energy per GDP (toe/M€)	101.0	100.0	104.1	97.7	90.1	88.2	88.9	87.1	85.8	85.7	88.1	*82.2*
	Final energy per GDP (toe/M€)	73.7	72.1	75.7	71.8	67.7	66.5	66.6	66.4	65.4	65.5	67.4	*62.2*
Decarbonization	Total GHG per GDP (t CO_{2eq}/M€)	357.3	337.3	342.0	305.6	269.3	264.2	256.5	252.0	244.3	244.8	248.8	*239.6*
	Energy GHG per GDP (t CO_{2eq}/M€)	283.4	270.0	274.9	245.4	212.2	207.8	201.3	197.1	190.5	186.9	194.9	*187.7*
	Total GHG per GIC (t CO_{2eq}/toe)	3.32	3.21	3.14	2.96	2.86	2.87	2.74	2.76	2.72	2.72	2.72	*2.80*
	Primary energy emissions (t CO_{2eq}/toe)	2.81	2.70	2.64	2.51	2.36	2.36	2.26	2.26	2.22	2.18	2.21	*2.28*
	Final energy emissions (t CO_{2eq}/toe)	3.85	3.74	3.63	3.42	3.13	3.12	3.02	2.97	2.91	2.85	2.89	*3.02*

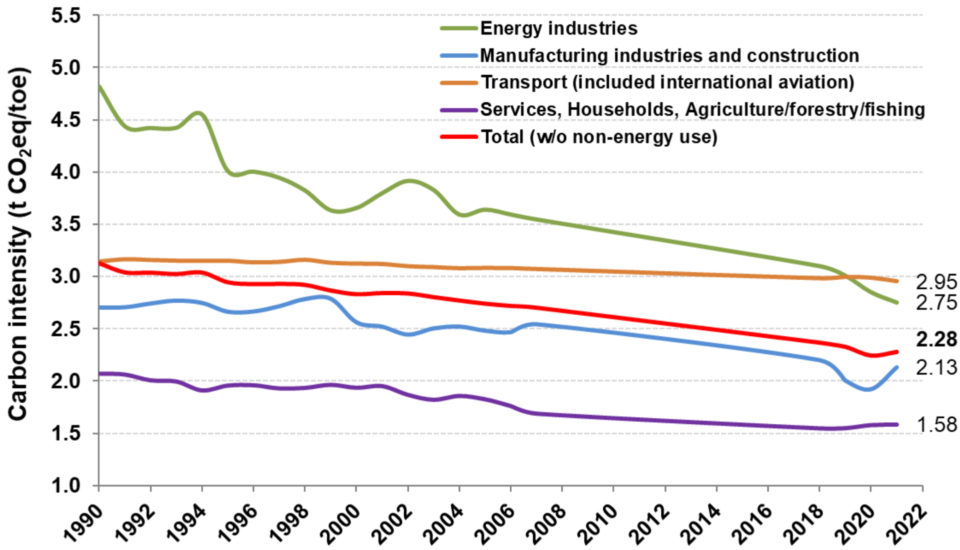
Since 2005 there has been an acceleration in the decrease of energy intensity (on the economy side) and decarbonization of the national economy up to 2019/2020, once again highlighting the growing decoupling of economic activity, energy consumption and GHG emissions. The decoupling between energy consumption and GDP leads to a decreasing energy intensity of the national economic system. The causes can be manifold and among the main ones is the contraction of industrial activities, which are more energetic intensive as compared to services characterized by lower energy intensity and higher value added. Regarding GHG emissions per unit of energy consumed (primary and final), there has been an accelerated rate of decrease since 2005 mainly due to the increase in the share of energy from renewable sources since 2007. Only in 2021 the indicators show a turning point with an upward trend.

Figure 1.26 – Energy intensity and decarbonization indexes.



Decarbonization at sectoral level can be assessed by energy emissions and energy consumption by sector. The carbon intensity by energy is the ratio between GHG emissions and energy consumption. The average carbon intensities by sector shows notable differences between sectors depending upon the different deployment of renewable sources and electrification of final energy consumption. The carbon intensity of energy industries decreases by 42.9% in 2021 compared to 1990 from 4.82 t CO_{2eq}/toe to 2.75 t CO_{2eq}. The carbon intensity of manufacturing industry in 2021 is 2.13 t CO_{2eq}/toe decreasing by 21.2% compared to 1990 level. The transport carbon intensity, including international aviation, is 2.95 t CO_{2eq}/toe (-6.1% compared to 1990) and shows the highest value in the last years with the slowest decreasing slope since 1990 among sectors. The carbon intensity in the civil sector, together with agriculture and fisheries, is 1.58 t CO_{2eq}/toe, 23.8% down compared to 1990 value. All declining trends of these indicators are statistically significant to Mann-Kendall test ($p<0.001$). Overall, the carbon intensity for the energy consumption considered, accounting by 95%±1.2% of gross energy inland consumption from 1990 to 2021, is 2.28 tCO_{2eq}/toe (-27% compared to 1990 level).

Figure 1.27 – Carbon intensity by sector.



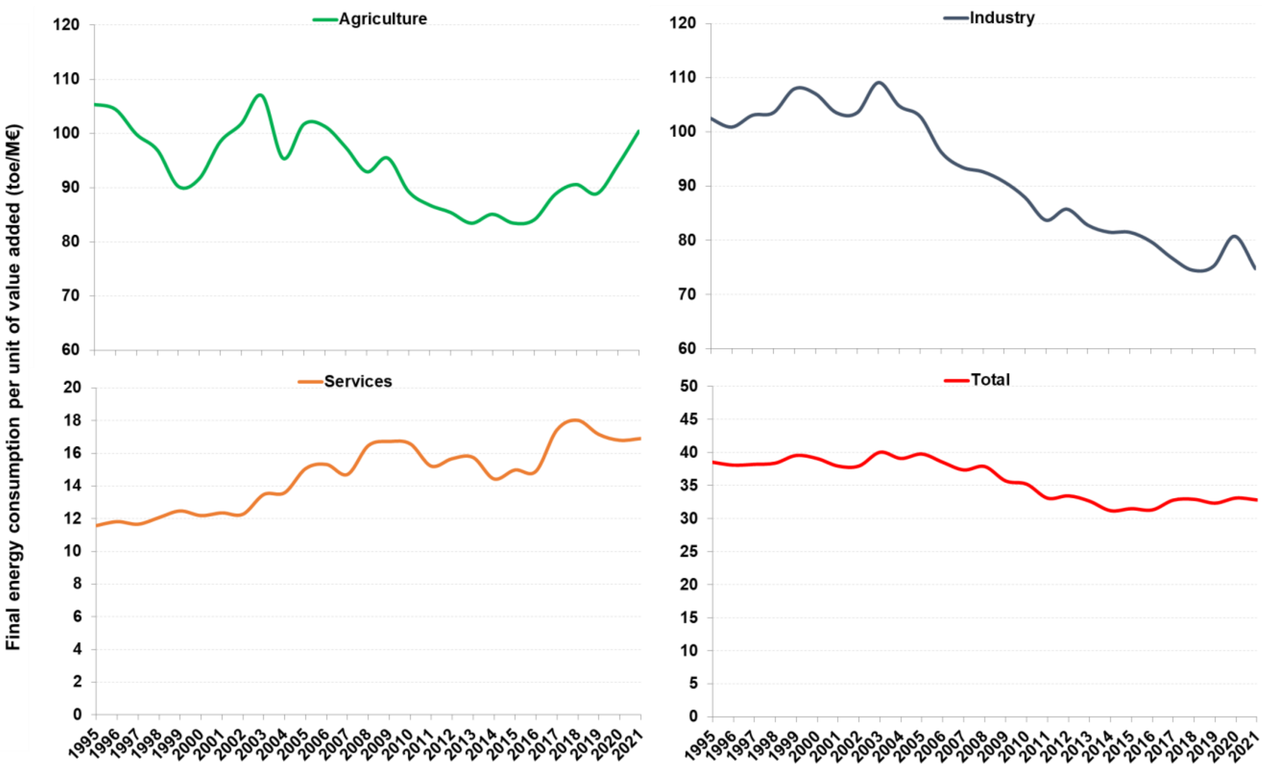
1.2.1 Energy and economic indicators at sectoral level

The carbon and energy intensity indicators by sector are calculated matching the GHG emissions by sector with respective energy consumption and value added. Sector emissions include only direct emissions and emissions from electricity self-production (for industry). Emissions due to electricity consumption from the grid are not considered. Regarding GHG emissions and final energy consumption, only energy emissions were considered, while process emissions for the industrial and agricultural sectors were also considered in comparison with value added.

For the agriculture sector, which includes fisheries and forestry, it is possible to establish a direct correspondence between final energy consumption, value added produced by the sector and atmospheric greenhouse gas emissions. For the services sector, value added was considered without the transport item, to compare value added, energy consumption and greenhouse gas emissions. As far as industry is concerned, value added relates to the activities of manufacturing and construction, net of the contribution of the manufacture of coke and oil-petroleum products and the contribution of the electricity sector. The whole considered is comparable with the final energy consumption and emissions of the industrial sector, attributable only to the activities of the manufacturing and construction industries.

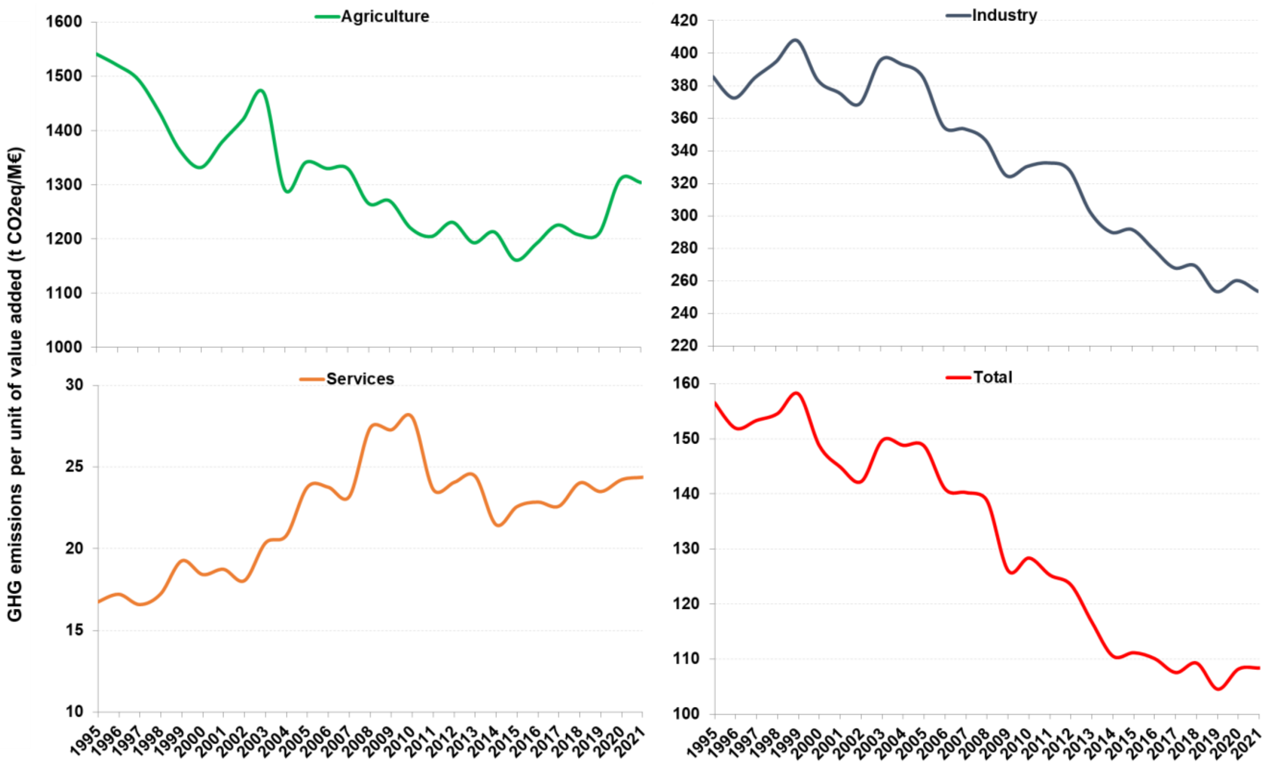
Overall, emissions from the economic activities considered fell by 20.1% in 2021 compared to 1995. Combustion emissions are reduced by 23.9%, while process emissions are reduced by 14.3%. GHG emissions from considered sectors represent on average 34.9±0.8% of total GHG emissions. The energy intensities (toe/M€) of industry and agriculture are lower than 1995 level, while services are higher although in the last years the sector intensity decreases significantly. Moreover, in the last years also agriculture intensities show increasing trends. Aggregate energy intensity decreased by 14.8% over the period 1995-2021 but increased by 5.2% in 2021 since 2014. The energy intensity increase observed after 2014 is driven by agriculture and services.

Figure 1.28 – Final energy intensity by value added.



Carbon intensity, the ratio between GHG emissions and value added, decreases because of the increasing renewable energy share and the increasing share of fuels with lower carbon content, such as natural gas. The carbon intensities per unit of value added are very different among sectors. Agriculture has the highest values, while in the services are recorded the lowest ones. Both sectors show increasing emissions per unit of value added in the last years. As for services the indicators increased until 2010, then also in this sector there was a relative decarbonization up to 2014 followed by another increasing trend. The total trend is heavily determined by industry which records a steadily reduction of the carbon intensity.

Figure 1.29 – Carbon intensity by value added.



1.2.2 Kaya identity and decomposition analysis

Decomposition analysis is a technique for studying the variation of an indicator in each time interval in relation to the variation of its determinants. In other words, the variation of a parameter is decomposed in the variation of the parameters that determine it. The starting point of the analysis is the construction of an identity equation, where the variable whose variation over time is to be studied is represented as the product of components considered as the causes of the observed variation. For the identity, the components must be reports, where the denominator of a component is the numerator of the next one. This identity, called Kaya by the economist Yoichi Kaya, is provided *a priori,* and must be realized according to a conceptual model consistent with the physical constraints of the studied variable, in addition to the considerations related to the availability of data and the objectives of the analysis.

The GHG emissions are decomposed in six driving factors: 1) population; 2) economic growth per capita; 3) efficiency; 4) renewable energy deployment; 5) carbon intensity from fossil fuels; 6) final energy intensity.

The analysis of decomposition makes it possible to evaluate the contribution of each determining factor. Identity is expressed in logarithmic form:

$$ln\left(CO_{2eq}\right) = ln(POP)\ x\ ln\left(\frac{GDP}{POP}\right)\ x\ ln\left(\frac{GIC}{FEC}\right)\ x\ ln\left(\frac{FFC}{CIL}\right)\ x\ ln\left(\frac{CO_{2eq}}{FFC}\right)\ x\ ln\left(\frac{FEC}{GDP}\right)$$

where:

CO_2eq: GHG emissions;

POP: population;

GDP/POP: Gross domestic product per capita – economy;

GIC/FEC: ratio between gross inland energy consumption and final energy consumption (included non-energy uses) - efficiency;

FFC/GIC: ratio between fossil energy consumption and gross inland energy consumption – renewable;

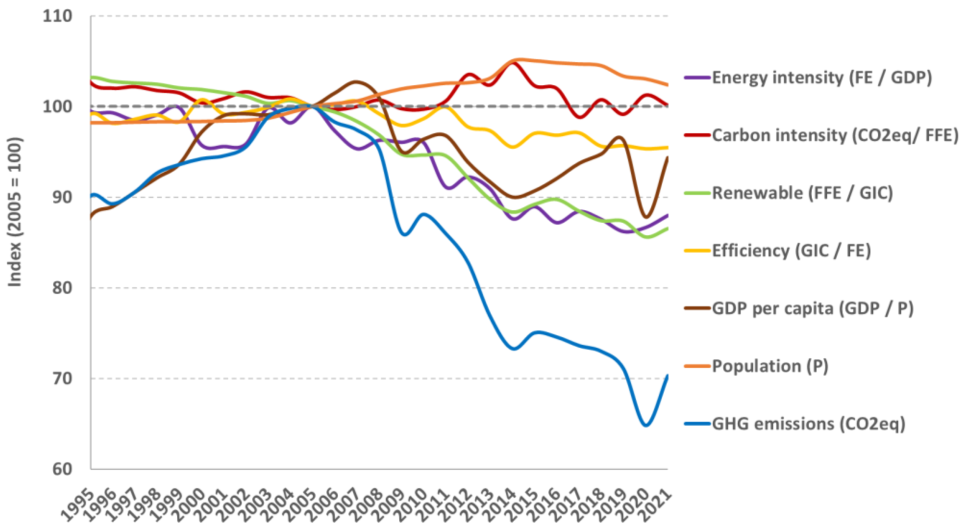
CO_2eq/FFC: ratio between CO_2eq emissions and fossil energy consumption – fossil fuel carbon intensity;

FEC/GDP: ratio between final energy consumption and gross inland consumption – final energy intensity.

The equation therefore allows to assess the effect of population, economic growth, efficiency, renewables, fossil fuel carbon intensity and energy intensity.

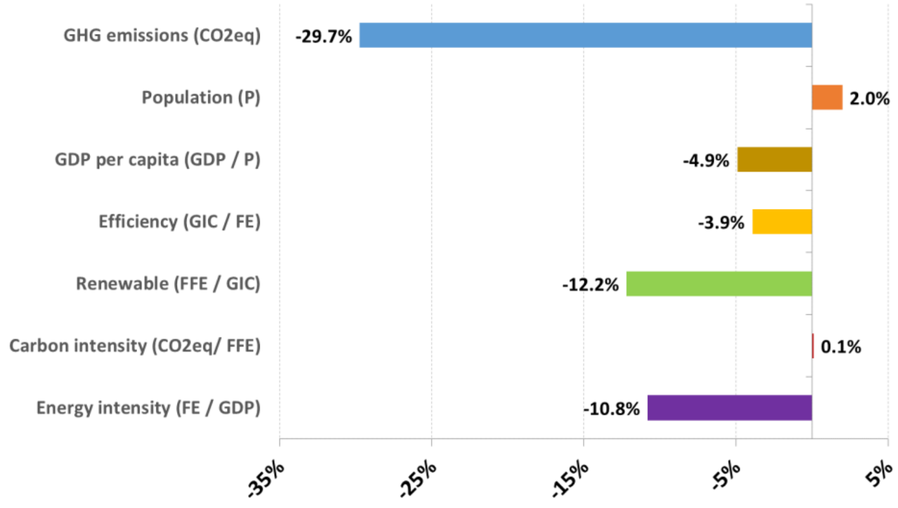
The trend of the Kaya Identity parameters in the period 1995-2021 is shown in Figure 1.30, with normalized values to 2005. The parameters considered constitute drivers that explain the variation in emissions. The reduction of emissions since 2005 is determined by factors such as energy intensity, renewable sources, GDP per capita, efficiency. Carbon intensity plays a less important role and population is the only factor driving an increase in emissions. GHG emissions reduction in 2020 has been mainly driven by economy contraction.

Figure 1.30– Performance of the national parameters of the Kaya Identity. Normalised values for 2005.



The outcomes of decomposition analysis, carried out according *Logarithmic mean Divisia index* (Ang, 2005), shows that the effect of the factors that led to a reduction of emissions in the period 2005-2021 prevailed over the effect of the factors that led to an increase of emissions. The population and carbon intensity are the only driving factors that have contributed to the growth of emissions (+2% and 0.1% respectively). The remaining factors have led to a reduction of emissions. The share of renewable energy (fossil energy consumption / gross inland energy consumption) played a significant role (-12.2%) followed by the final energy intensity (final energy consumption / GDP; -11.6%) and GDP per capita (-10.8%). The efficiency factor (gross inland consumption / final energy consumption) contributed with -3.9%. The overall contribution of each factor leads to -29.7% of GHG emissions over the period 2005-2021.

Figure 1.31 – Decomposition of the change in CO_2eq emissions from 2005 to 2021.



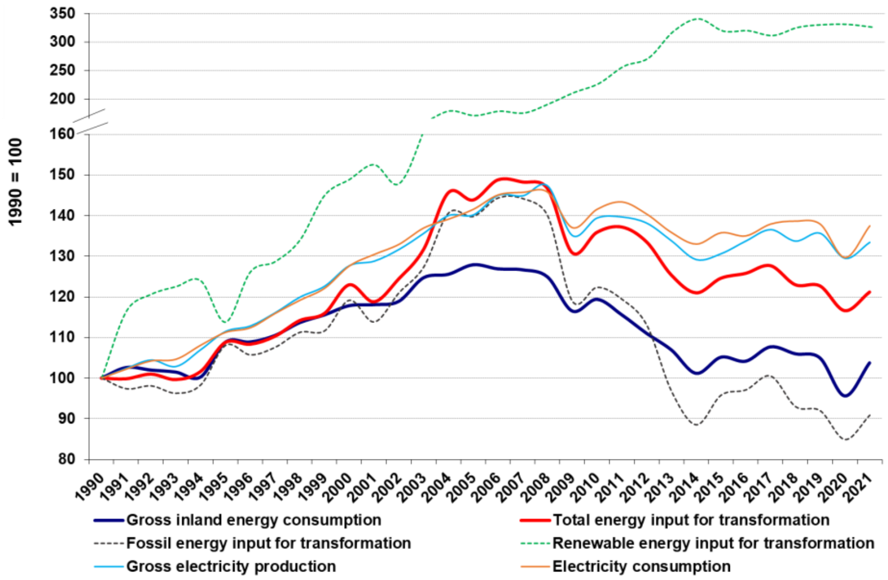
1.3 Power sector

All figures discussed in this chapter are reported at: https://emissioni.sina.isprambiente.it/inventario-nazionale/ in the section of emission factors in the power sector. The preliminary estimates for 2022 are elaborated by ISPRA based on data by TERNA (Monthly Report on the electricity system, December 2022), SNAM for the distribution of natural gas to thermoelectric power plants, MASE (Ministry of Environment and Energy Security) for coal and petroleum products consumptions updated to 31 December 2022. The preliminary estimates are characterized by considerable uncertainty and will be revised with final data.

1.3.1 Thermoelectric and renewable electricity production

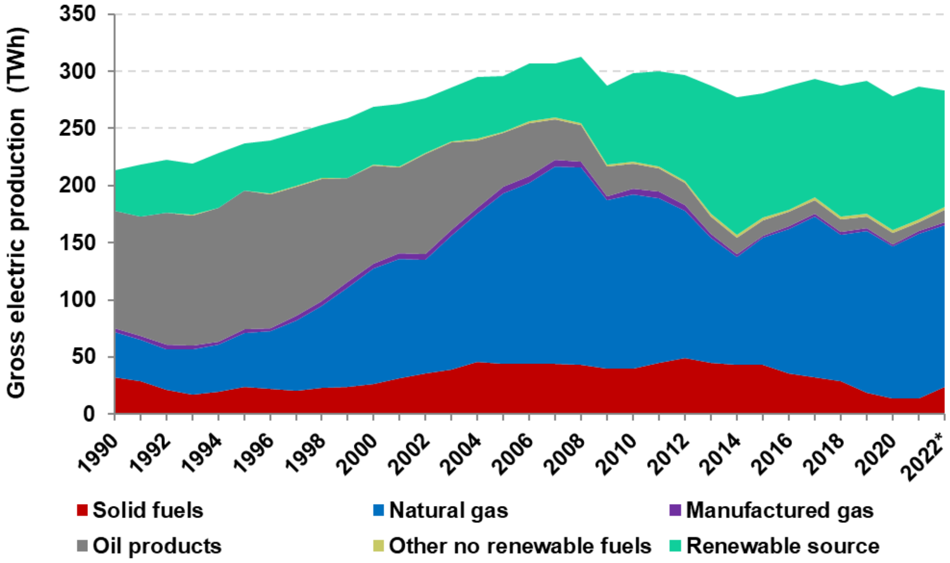
The growth of electricity consumption in the final energy consumptions makes this sector one of the main players in the national energy system. Since 2001 the energy consumption for electricity generation has increased at higher rates than gross inland energy consumption. The growth of consumption of renewable energy corresponds to the decrease of fossil energy.

Figure 1.32 – Indexed trends for gross inland energy consumption, energy consumption in the power sector to produce electricity and heat, electricity production and electricity.



Gross electricity production rose from 216.6 TWh to 289.1 TWh from 1990 to 2021 (+33.5%). Electricity consumption increased from 218.8 TWh to 300.9 TWh over the same period (+37.5%). After a constant growth of gross electricity production and consumption, since 2007 there has been a downward trend because of the economic crisis. In 2020 there has been a further downfall of electricity production and consumption. In 2021 there was a relevant increase of electricity production and consumption, respectively +3% and +6% compared to 2020. The average share of net import of electricity is around 15% of electricity consumption with wide fluctuations and a sensible reduction in the last years up to 2020 (11.3%). In 2021 the share came back to 14.2%.

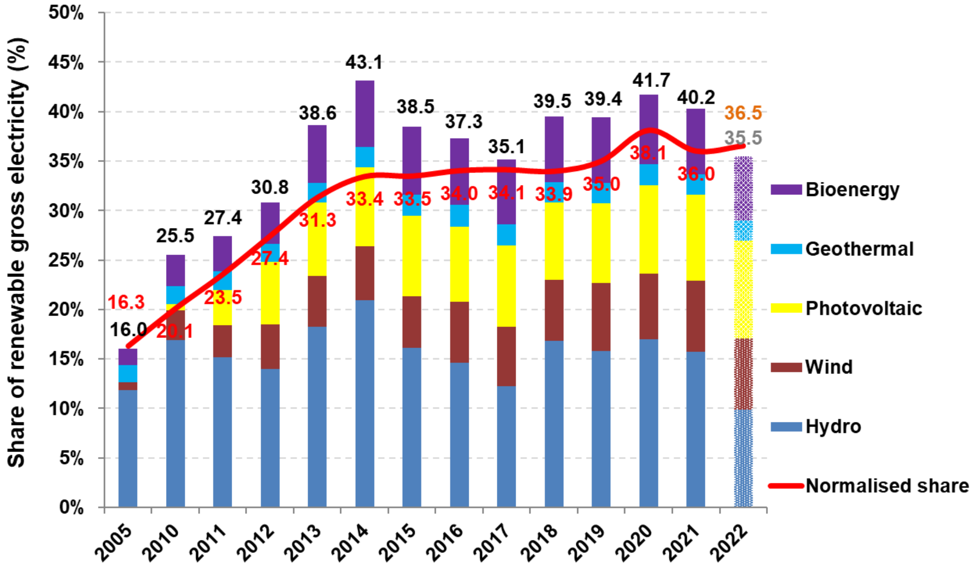
Figure 1.33 – Gross electricity production by energy source. * Preliminary estimate.



As regards the energy mix in power sector, natural gas increased steadily since 1990 at the expense of oil products (in 2021, 49.8% of electricity production from natural gas and about 2.7% from petroleum products, while in 1990 the two percentages were 18.3% and 47.4%, respectively). The share of solid fuels showed fluctuations around the average of 11.5% with a sharp reduction in the last years (4.9% in 2021). Preliminary estimates for 2021 show an upward trend with relevant increase of solid fuels share around 8%.

In 2005 the share of electricity from renewable sources compared to total production accounted for only 16% of national production. After 2007, renewable sources share increased significantly up to the top of 2014, when the share reached 43.1%. In 2021 the renewable share in electricity production is 40.2%, while preliminary estimate shows an abrupt contraction in 2022 (35.5%), mainly due to the sharp reduction of hydroelectric generation.

Figure 1.34 – Share of renewable gross electricity production by energy source (black labels) and normalised share (red line and labels) according to Directive 2009/28/EC until 2020 and Directive (EU) 2018/2001 from 2021.

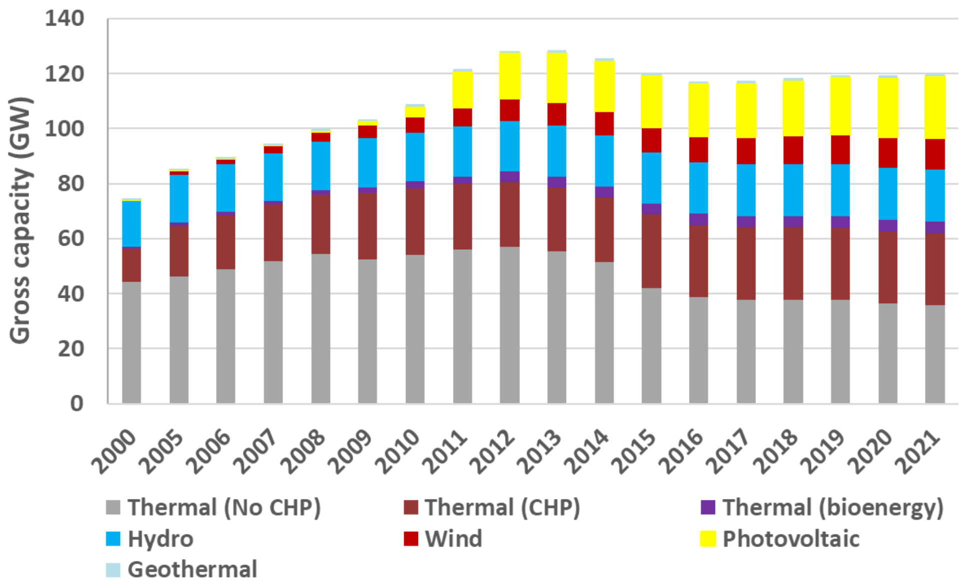


According to Directive 2009/28/EC methodology for the monitoring of European targets to 2020, the share of electricity from renewable sources compared to final gross consumption of electricity represents 38.1%. In 2021 the share, calculated according to Directive (EU) 2018/2001, decreased to 36%. Preliminary data for 2022 set the share to 36.5%.

1.3.1.1 Power capacity

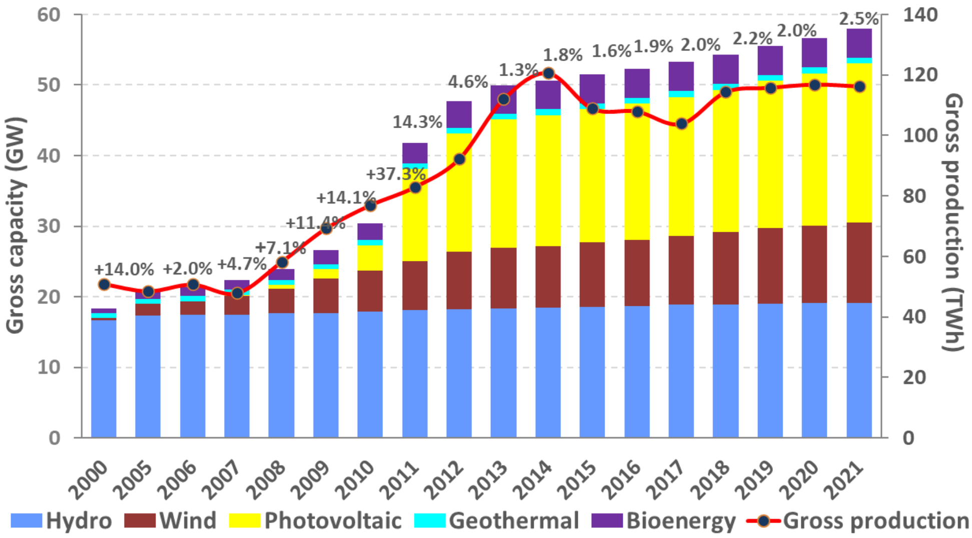
Total thermal power in 2021 is 61.9 GW with a sharp contraction since 2012, when the installed capacity reached the peak of 80.2 GW. Combined cycle plants, regardless of cogeneration or non-cogeneration production, show a significant increase in gross efficient power, from 7.9 GW in 2000 to a maximum of 43.4 GW in 2011-2012. Subsequently, these plants show a steady reduction in efficient power up to 40.1 GW in 2021.

Figure 1.35 – Gross efficient capacity of power plants.



As for renewable power, there has been a significant increase in installed capacity by 2000. In 2021 the renewable gross efficient power was 58 GW. The highest annual growth rate was recorded in 2011 when the new power compared to the previous year was 11.3 GW, of which 9.5 GW of PV plants and 1.1 GW of wind plants. After 2014 the additional new power per year was around 1 GW.

Figure 1.36 – Gross efficient capacity of plants from renewable sources (left axis) and gross electricity production (red line, right axis). The percentage increase in power compared to the previous year is also reported.



About plants powered by bioenergy, it should be emphasized the rapid increase from 2008 to 2013 and the subsequent stabilization of gross efficient power with new installations of few MWs per year up to 2018 and a decrease in the last years. Biogas fuelled plants went from 0.37 GW in 2008 to 1.46 GW in 2021. The growth of plants fed with liquid biofuels in the period 2008-2013 is particularly rapid, from 0.12 GW to 1.04 GW, then it is reduced to 0.95 GW in 2021. Plants fuelled by solid biomass and waste increased from 1.07 GW in 2008 to 1.73 GW in 2018. Since 2018 the power of solid biomass plants shows a downward trend, while the power of waste plants increases. In 2021 the total power is 1.7 GW, of which 0.92 powered by wastes. Such trends can be explained by the reduction in incentives for bioenergy powered plants. The future development of such plants does not seem independent of some forms of incentives.

The efficiency of power plants has been calculated from data issued by TERNA on fuel consumption and energy (electricity and heat) production. The amount of fuel used for electricity generation in CHP plants can be calculated by separating the share allocated to heat generation. The unbundling of fuels is processed by TERNA considering the consumption of an equivalent boiler that generates heat separately with an average efficiency that varies from year to year. For thermoelectric power plants and cogeneration plants, the total efficiency, electrical efficiency, and equivalent electrical efficiency are therefore calculated according to the following equations.

Total efficiency (εt) and electrical efficiency (εel) for all power plants and for CHP plants have been calculated with the following equations:

$$\varepsilon t = (H + E) / F$$

$$\varepsilon el = E / F$$

where H is the heat, E the electricity, and F the energy in the fuels.

The equivalent electrical efficiency, $\varepsilon' el$, is calculated with the equation:

$$\varepsilon'el = E / Fe$$

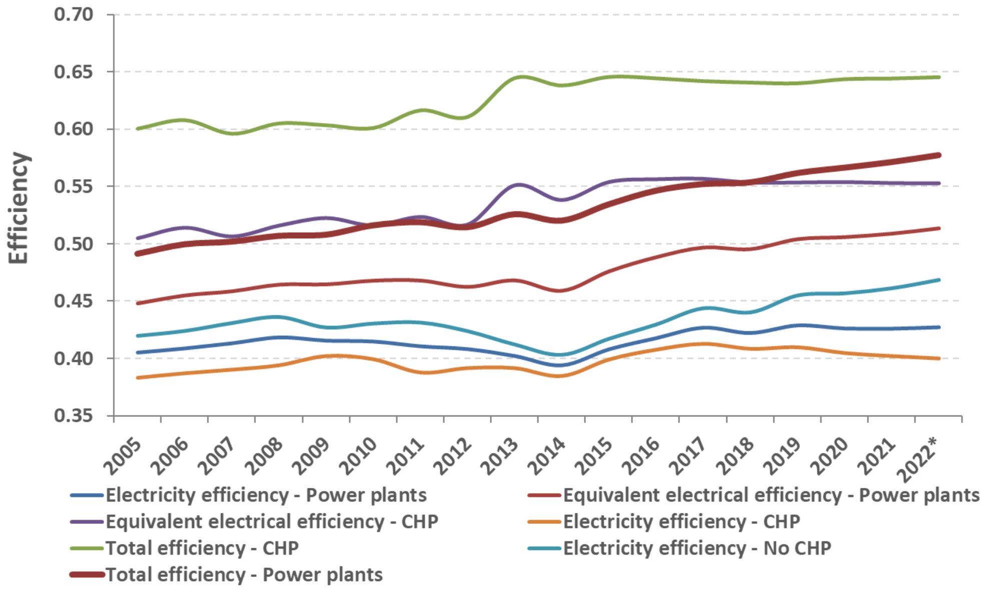
where Fe is the energy in the fuels used for the electricity production, calculated with the equation:

$$Fe = F - (Q / \eta t)$$

where Q is the heat produced and ηt is the reference thermal efficiency for a standard boiler. The average reference thermal efficiency calculated in 2021 is 0.893.

The efficiency of the thermoelectric plants has increased since 2005 mainly due to the contribution of cogeneration plants with greater efficiency than non-cogeneration plants. In 2021 the electricity efficiency of non-cogeneration plants was 46.1% while for cogeneration plants there was a total efficiency of 64.4% and an equivalent electrical efficiency of 55.3%. The total efficiency of the power plants is 57.1% with an increasing trend since 2005.

Figure 1.37 – Efficiency of power plants.

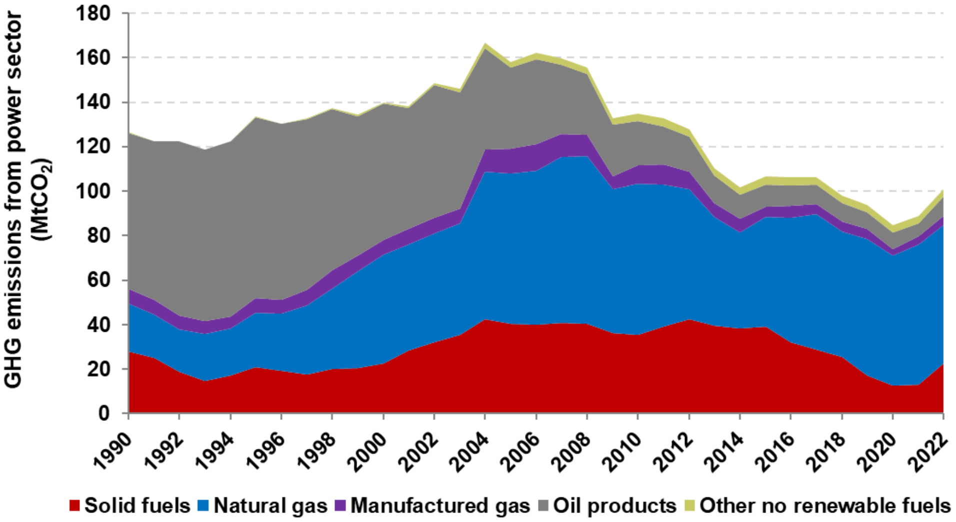


1.3.2 CO_2 emissions and emission factors

The amount of CO_2 emitted from power sector in 2021 was 89 Mt (of which 76.9 Mt for electricity generation and 12.1 Mt for heat production) equal to 22.1% of national GHG emissions.

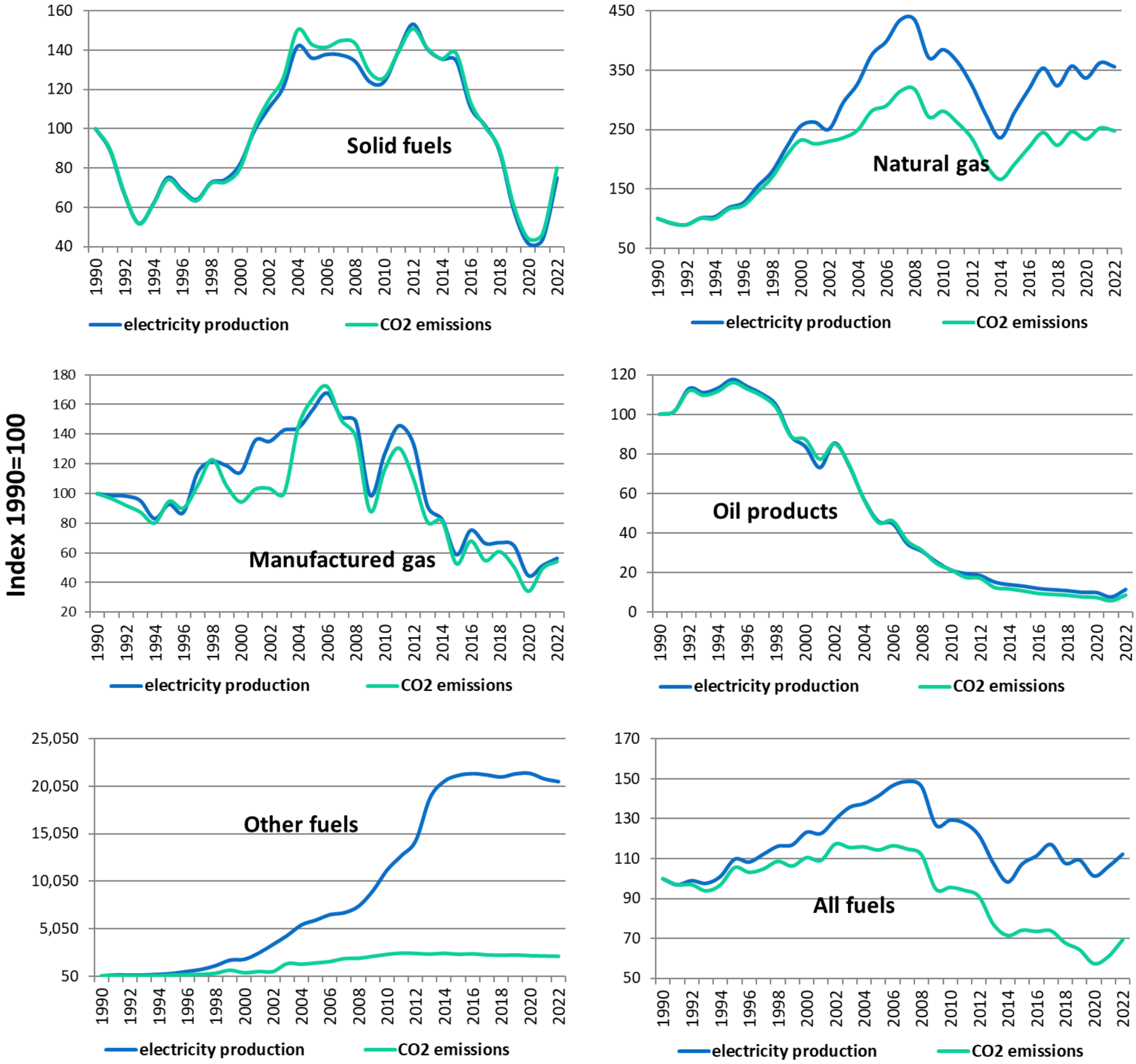
Until the first half of the 1990s, CO_2 emissions from oil & oil products accounted for a significant share of total emissions from power sector. In 1995, the share of emissions from oil & oil products amounted to 61% of emissions. Subsequently, the share of CO_2 from these sources has steadily decreased to 6.6% in 2021. However, it should be noted that such sources include synthetic gases from gasification processes, with an increasing share since 2000. Taking fuel oil alone, the CO_2 emissions decreased from 61% to 1.8% from 1995 to 2021 with the first recorded increase in 2021 compared to the previous year. The share of natural gas emissions increased from 18.5% in 1995 to 70.9% in 2021. The share of emissions from solid fuels, mainly coal, was constantly increasing up to 2014 when the peak of 37.6% was reached but in the following years was recorded a sharp reduction up to 14.7% in 2020 and 2021. The preliminary estimate shows a relevant increase in 2022, around 22.3%.

Figure 1.38 – Share of GHG emissions from power sector for by energy source.



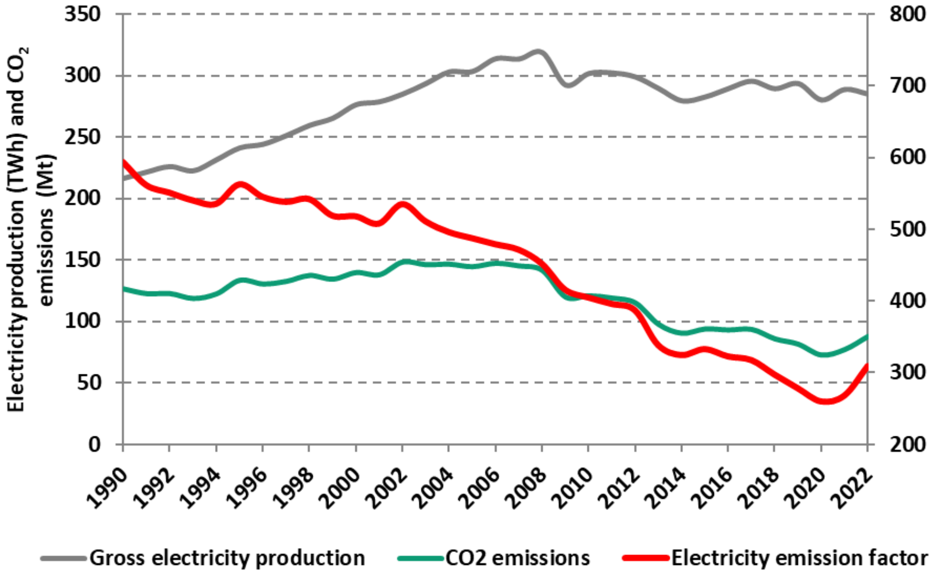
A relevant decoupling is recorded between electricity production and CO_2 emissions for natural gas, while for solid fuels, petroleum products and derived gases, there is substantial covariation of the two parameters. Such decoupling is due to the increasing efficiency of power plants fuelled with natural gas and the increasing share of bioenergy.

Figure 1.39 – Indexed change in thermoelectric production and CO_2 emissions per fuel (1990=100). Preliminary estimate in 2022.



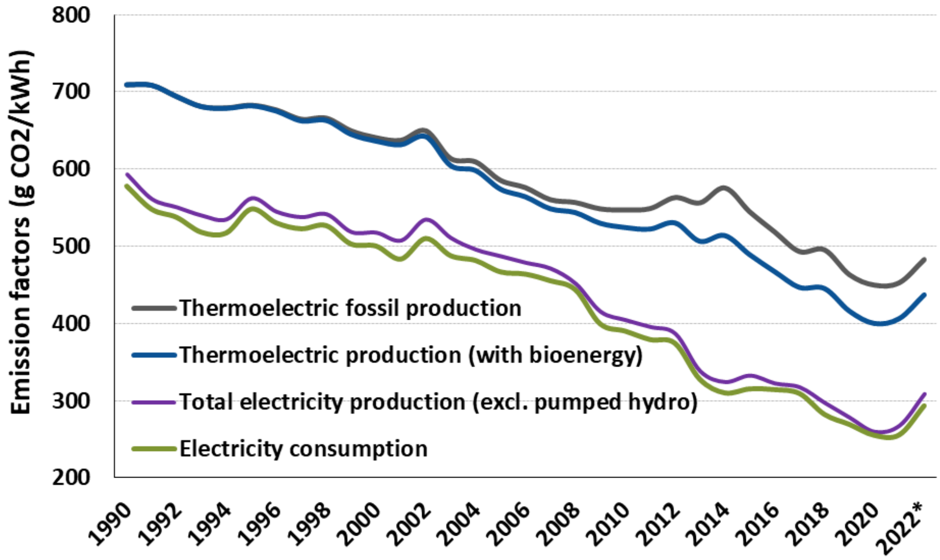
CO_2 emissions for electricity generation reached their highest point in 2002, with an increase of 17.4% over 1990, while thermoelectric production showed an increase of 30.1% over the same period. Emissions fell slightly from 2002 to 2008. After 2008 there has been a significant reduction of electricity production and CO_2 emissions because of the contraction of the economy triggered by the economic and financial crisis. After 2014 is observed a recovery in electricity production with a sharp fall in 2020 because of the SARS-CoV-2 pandemic and a rebound in 2021. Since 1990 emissions for electricity generation decreased by 39.2% in 2021, compared with an increase in electricity production of 33.5%.

Figure 1.40 – Trends of gross electricity production, CO_2 emissions (left axis), and emission factor (right axis).



The emission factor for national gross thermoelectric production decreases from 1990 to 2021 from 709.1 g CO_2/kWh to 406.6 g CO_2/kWh with the first increase ever recorded in 2021 compared to the previous year. The decrease is mainly due to the increasing share of natural gas and the continuous reduction of the specific emission factor of this fuel, which in turn is due to the increase in the electrical conversion efficiency of plants. The use of bioenergy with zero carbon balance among other fuels that contribute 10.1% of thermoelectric production in 2021 also plays an important role. The difference between the emission factors of the thermoelectric plants with or without the contribution of bioenergy shows the role of such sources in reducing the emission factor. The difference becomes significant after 2000 because of the increase in the amount of solid biomass and municipal or similar solid waste used for electricity production and the even greater increase in bioliquids and biogas observed after 2008.

Figure 1.41 – Trends emission factors in the power sector. * Preliminary estimate



The electricity production from renewable sources reduces the emission factor for total electricity production since renewable sources have not CO_2 emissions. The emission factor for electricity consumption is further reduced due to the share of electricity imported from abroad whose emissions are released outside the national territory. Along with an increase of electricity production from 1990 to 2021 of 72.5 TWh, there was a decrease of CO_2 emissions of 49.5 Mt. The reduction of emission factors for electricity generation from 2007 to 2014 was mainly due to the increase or renewable electricity production, while the decrease recorded since 2015 is essentially due to the increasing share of natural gas.

Table 1.13 – Emissions factors in the power sector (g CO_2/kWh).

Year	Gross thermo-electricity production (only fossils)	Gross thermo-electricity production[1]	Gross electricity production[2]	Electricity consumption	Gross thermo-electricity and heat production[1,3]	Gross electricity and heat production[2,3]	Heat production[3]
1990	709.3	709.1	593.1	577.9	709.1	593.1	
1995	682.9	681.8	562.3	548.2	681.8	562.3	
2000	640.6	636.2	517.7	500.4	636.2	517.7	
2005	585.2	574.0	487.2	466.7	516.5	450.4	246.7
2006	575.8	564.1	478.8	463.9	508.2	443.5	256.7
2007	560.1	548.6	471.2	455.3	497.0	437.8	256.3
2008	556.5	543.7	451.6	443.8	492.8	421.8	252.0
2009	548.2	529.9	415.4	399.3	480.9	392.4	260.5
2010	546.8	524.4	404.5	390.0	470.0	379.6	247.3
2011	548.5	522.4	395.6	379.1	461.0	367.7	227.8
2012	562.8	530.4	386.8	374.3	467.8	361.3	227.1
2013	555.9	506.5	338.2	327.5	438.7	317.8	218.2
2014	575.4	514.0	324.4	309.9	439.5	304.6	206.9
2015	544.3	489.2	332.6	315.2	425.3	312.9	218.9
2016	518.2	467.3	322.5	314.2	409.3	304.6	220.2
2017	492.6	446.9	317.4	309.1	394.4	299.8	215.2
2018	495.0	445.5	297.2	282.1	389.6	282.1	209.5
2019	462.7	416.3	278.1	269.1	368.1	266.8	212.2
2020	449.1	400.3	259.8	255.0	353.6	251.2	211.1
2021	452.1	406.6	267.9	255.6	360.5	258.2	209.5
2022*	482.2	437.3	308.9	293.3	404.3	303.0	268.8

[1] Included electricity by bioenergy.
[2] Included renewable electricity, without production from pumped storage units.
[3] Included CO_2 emissions for heat production.
* Preliminary estimate.

From 1990 to 2007, the impact of renewable sources in terms of yearly avoided emissions changed around an average value of 30.7 Mt CO_2 in parallel with the variability observed for hydroelectric production. Subsequently, the development of non-traditional sources led to a surge of the impact with a peak recorded in 2014 when 69.4 Mt CO_2 were not emitted thanks to renewable production. In the following years there was a decrease in avoided emissions in parallel with the decrease in electricity production from renewable. In 2021, because of the increase in electricity production from renewable sources, the avoided emissions are 52.6 Mt CO_2.

The atmospheric emissions from power sector also involves other gases such as methane (CH_4) and nitrous oxide (N_2O) and other air pollutants. Although methane and nitrous oxide are emitted in extremely limited quantities compared to carbon dioxide, these gases are characterized by high global warming potentials (28 for methane and 265 for nitrous oxide). Methane and nitrous oxide emissions account for 0.4% to 0.7% of total greenhouse gas emissions from the power sector. Combustion in the power sector is also responsible for emissions of other atmospheric pollutants such as nitrogen oxides (NO_x), sulphur oxides (SO_x), non-methane volatile organic compounds (NMVOC), carbon monoxide (CO), ammonia

(NH_3) and particulate matter (PM_{10}). All pollutants considered have decreased the emissions in 2021 compared to 2005 levels, from -13.5% for CO to -92.7% for SO_x. Only for NMVOC has been registered the increase of emissions (+59% in 2021 compared to 2005).

Table 1.14 – Emissions of GHG in the power sector for electricity and heat production (Mt CO_2eq). * Preliminary estimate

Gas	2005	2010	2015	2016	2017	2018	2019	2019	2021	2022*
CO_2	157.85	134.77	106.63	106.30	106.46	98.08	93.99	84.89	88.98	100.69
CH_4	0.18	0.19	0.25	0.26	0.26	0.25	0.25	0.24	0.24	0.28
N_2O	0.44	0.46	0.50	0.50	0.47	0.45	0.42	0.39	0.38	0.45
GHG	**158.46**	**135.42**	**107.39**	**107.05**	**107.19**	**98.78**	**94.66**	**85.53**	**89.60**	**101.41**

Table 1.15 – Emission factors of GHG in the power sector for electricity and heat production (g CO_2eq/kWh). * Preliminary estimate

Gas	2005	2010	2015	2016	2017	2018	2019	2019	2021	2022*
CO_2	450.39	379.61	312.86	304.59	299.82	282.15	266.81	251.24	258.16	302.99
CH_4	0.51	0.54	0.74	0.74	0.73	0.72	0.72	0.72	0.69	0.83
N_2O	1.24	1.29	1.47	1.42	1.32	1.29	1.18	1.16	1.10	1.34
GHG	**452.14**	**381.45**	**315.07**	**306.76**	**301.87**	**284.16**	**268.71**	**253.12**	**259.95**	**305.17**

Table 1.16 – Emissions of atmospheric pollutants in the power sector for electricity and heat production (kt).

Pollutant	2005	2010	2015	2016	2017	2018	2019	2019	2021
NOx	129.13	102.27	86.27	82.94	80.57	75.89	74.07	67.90	68.62
SOx	183.91	78.98	32.52	25.03	22.48	20.30	16.86	14.44	13.38
COVNM	18.57	26.01	27.84	30.29	30.40	30.08	31.24	30.71	29.53
CO	36.97	35.90	32.15	33.60	34.66	32.46	33.33	31.25	32.03
NH_3	0.23	0.23	0.24	0.21	0.19	0.17	0.13	0.11	0.11
PM_{10}	5.93	2.85	1.41	1.24	1.17	1.01	0.94	0.80	0.83

Table 1.17 – Emission factors of atmospheric pollutants in the power sector for electricity and heat production (mg/kWh).

Pollutant	2005	2010	2015	2016	2017	2018	2019	2019	2021
NOx	368.44	288.07	253.12	237.66	226.91	218.32	210.27	200.97	199.11
SOx	524.75	222.46	95.41	71.72	63.31	58.41	47.86	42.73	38.82
COVNM	52.97	73.26	81.69	86.78	85.62	86.54	88.69	90.90	85.67
CO	105.49	101.11	94.31	96.29	97.60	93.37	94.63	92.49	92.93
NH_3	0.66	0.65	0.71	0.60	0.54	0.50	0.37	0.32	0.31
PM_{10}	16.91	8.03	4.12	3.54	3.31	2.91	2.66	2.37	2.42

The reduction of sulphur oxides emission factor is very important. The emission of sulphur oxides is basically due to solid fuels which in recent years have been used by high-efficiency plants equipped with emission abatement systems. Abatement systems have also contributed to a significant reduction of PM_{10} emissions, -86% compared to 2005.

1.3.3 Decomposition analysis

The variation in GHG emissions from thermoelectric production is due to several factors such as electricity generation technology, the fossil fuel used, the contribution of renewable sources and electricity demand. Decomposition analysis was applied to assess the relative contribution of these components. This technique is widely used in the analysis of environmental data. The Statistical Institute of Germany adopted decomposition analysis to assess the driving factors of carbon dioxide emissions (Seibel, 2003).

As already seen the starting point of decomposition analysis is the construction of an identity in which the examined variable is indicated as a product of the components considered determinants. The identity factors must be defined as relationships, where the denominator of one factor is the numerator of the next factor. The identity is provided *a priori* in relation to the available data and the objective of the analysis considering a conceptual model that explains the factors that can reasonably influence the variable considered. The identity identified in this study is as follows:

$$CO_2 = \sum_{i=1}^{n} \frac{CO_{2i}}{E.E._i} \times \frac{E.E._i}{E.E._F} \times \frac{E.E._F}{E.E._T} \times E.E._T$$

Where:

CO_{2i} is the carbon dioxide emitted by the type of fossil fuel i;

$E.E._i$ is the electricity produced by the type of fossil fuel i;

E.E.F is the electricity produced from fossil fuels;

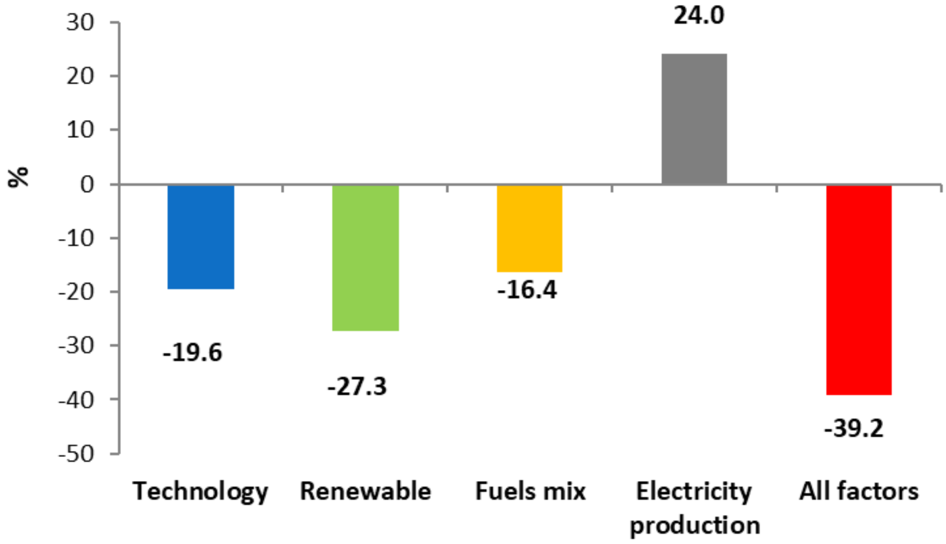
$E.E._T$ is the total electricity produced, including renewable sources.

The first factor of the equation evaluates the technological effect, in terms of the temporal variation of the emission factors of the different types of fossil fuels. This variation is an indicator of the increase in efficiency of thermoelectric plants in the process of transformation of fossil fuels into electricity. In other words, the effect of the variation in carbon intensity in electricity generation is assessed. The second factor considers the effect of the change in the fuel mix, i.e., the variation in the relative frequency of different fuels with different carbon content and therefore different emission factors. The third factor assesses the effect of electricity production from renewable sources by considering the variation in the ratio between fossil electricity and total electricity. Finally, the fourth factor considers the effect of the change in total electricity produced.

According to the equation shown, emissions can be decomposed into different factors with the two methodologies previously illustrated, to evaluate the effect of the variation of one factor while leaving the other factors unchanged. In the decomposition analysis carried out, an independent contribution of the four factors to the variation of atmospheric emissions was assumed. The final effect shall be evaluated in additive terms for the factors considered. The *structural decomposition analysis* (SDA) approach has been applied (Seibel, 2003; APAT, 2007).

The factors considered in the analysis (technology, type of fuel, renewable sources) contribute to CO_2 emissions reduction where the increase in electricity production has the opposite effect. The results of the analysis show that technological, renewable sources, and fuel mix factors contribute to the reduction of CO_2 emissions from 1990 to 2021 respectively for 19.6%, 27.3% and 16.4%, while the increase in electricity production leads to an increase in emissions of 24%. The cumulative effect of the four factors led to a reduction in atmospheric CO_2 emissions in 2021 of 39.2% compared to emissions observed in 1990 (-49.5 $MtCO_2$).

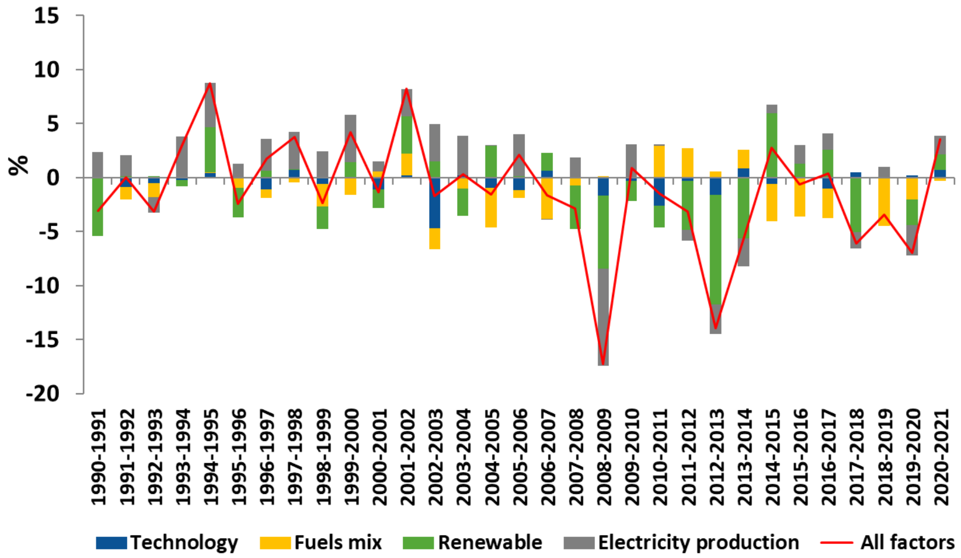
Figure 1.42 – Decomposition analysis of CO_2 emissions in the period 1990-2021 with the contribution to the emissions change for the four factors identified.



In other words, the reduction due to the change in the technological factor (decrease in the specific emission factors of fossil fuels) over the period 1990-2021 would have been 24.8 Mt CO_2 if the other factors remained unchanged. The reduction due to the fuels mix change would have been 20.7 Mt CO_2, while the increasing renewable share would have led to a reduction in emissions of 34.5 Mt CO_2. These effects are offset by a net increase in electricity production which would have resulted in an increase in emissions of 30.4 Mt CO_2 without the contribution of the other factors.

The year-by-year decomposition analysis (Figure 1.43) shows the role of each factor on a year basis. The renewable effect played the largest role from 2007 to 2014. The great variability observed for this factor reflects the uncertainty of the hydroelectricity production due to weather conditions. As concerns the technological factor the largest reduction in atmospheric emissions was recorded in the period 2000-2003 when several combined cycle plants powered by synthesis gases and natural gas started the activity. Such plants are characterized by greater efficiency than traditional steam cycles. Regarding the fossil fuels shift over the whole period examined, the increase of natural gas and the corresponding decrease of petroleum products, leads to reduction in emissions in almost all years.

Figure 1.43 – Year by year decomposition analysis of CO_2 emissions in the period 1990-2021 with the contribution to the emissions change for the four factors identified.



Since 2007 the role of renewable sources becomes more relevant than the other factors. Moreover, it should be underlined that since 2007 the economic crisis has significantly reduced the consumption of fossil fuels while increasing the share of renewable sources as result of the priority of dispatching renewable electricity. In any case, each unit of renewable electricity contributes far more to the reduction of atmospheric emissions than any other factor, if an equivalent amount of fossil electricity is replaced.

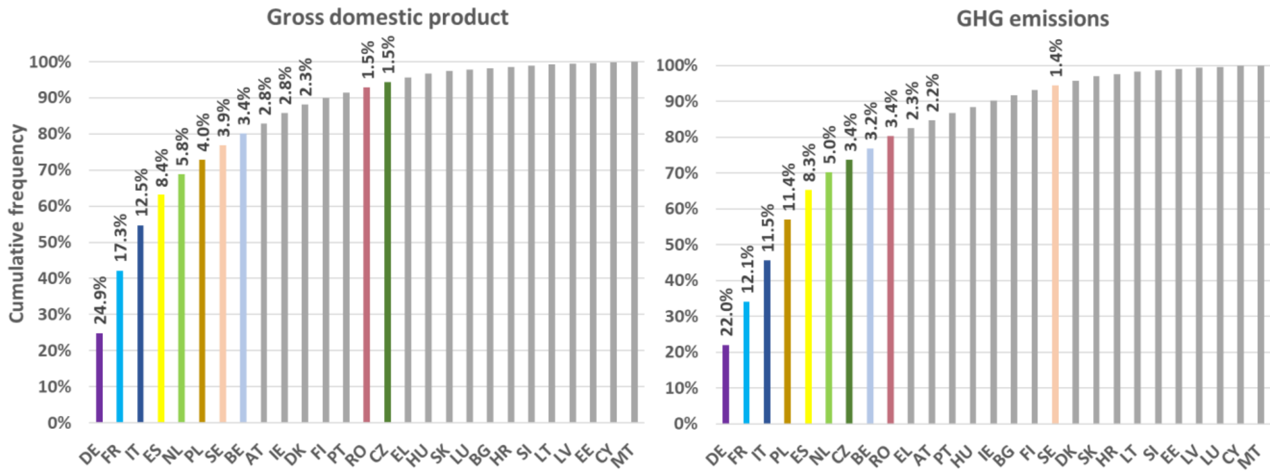
2 ITALY AND THE BIGGEST EUROPEAN COUNTRIES

This chapter will examine the trends of efficiency and decarbonization indicators in the biggest European Member States. The indicators are elaborated using the most updated data of energy balances from the EUROSTAT database (https://ec.europa.eu/eurostat/data/database, last update 24 March 2023). As concern the greenhouse gas (GHG) emissions CRFs (Common Reporting Formats) submitted in 2023 are downloaded from UNFCCC (https://unfccc.int/), last download on 27 April 2023.

2.1 Efficiency and decarbonization indicators

Comparison of decarbonization and efficiency indicators is carried out among Italy and the largest European Countries. The EU Member States with more than 3% of EU27 GHG emissions or more than 3% of EU27 GDP in 2020 are considered for comparison. The Member States examined (Germany, France, Italy, Spain, Poland, the Netherlands, Belgium, Romania, and Sweden) represented 81.5% of the population in EU27 in 2020, 81.6% of GHG emissions and 83.1% of GDP. The gross inland energy consumption accounted for 82.5% of the energy consumption of EU27.

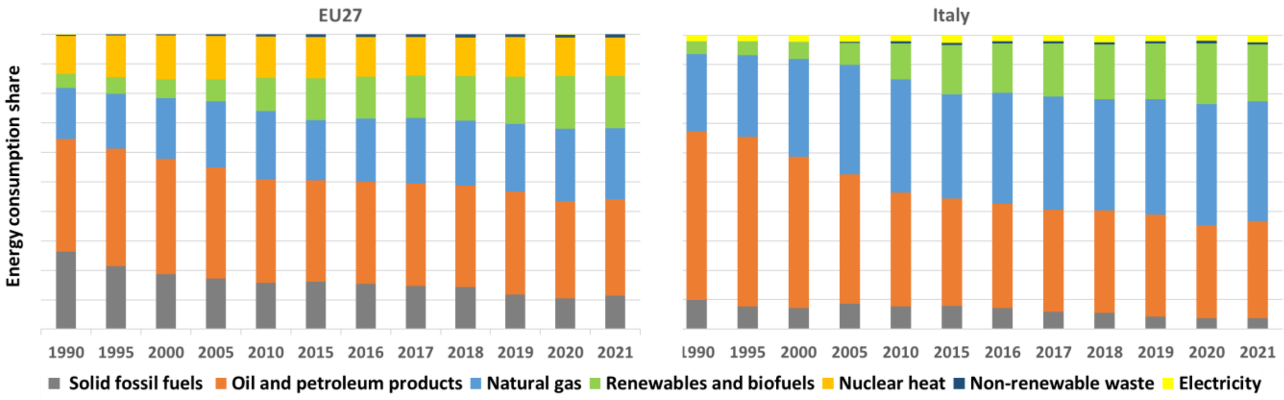
Figure 2.1 – Cumulative frequencies for gross domestic product and greenhouse gas emissions in the EU27 Countries (data 2020). Labels of selected Member States or higher than 2% are reported.



2.1.1 Energy consumption and gross domestic product

Since 1990, European environmental policies have led to a significant change of the energy mix in the Member States. The nuclear energy represents 13.1% of EU27 gross inland consumption in 2021, quite stable since 1990 (12.9%). On the other hand, solid fuels energy faces significant contraction since 1990. EU27 share decreased from 26.3% to 11.4% from 1990 to 2021, higher than 2020 (10.5%). There are still significant shares in some of the largest States such as Germany (18%), Poland (41.9%) and Czechia (30.2%). Oil and petroleum products, on the other hand, show a modest reduction at European level (from 38.3% in 1990 to 32.7% in 2021) with different trends among the States. Natural gas energy consumption shows a considerable increase in almost all States and at EU27 level ranges from 17.1% in 1990 to 23.9% in 2021. Renewable energy shows a significant increase in EU27 from 4.9% in 1990 to 17.7%.

Figure 2.2 – Fuel energy share in gross inland consumption for EU27 and Italy.



The following graphs show the fuel energy share in gross inland consumption for each member State considered. It is evident the great heterogeneity in the European Countries' energy mix and a common shift toward renewable sources and lower carbon content fuel as natural gas.

Figure 2.3 – Share of energy sources in gross inland energy consumption in the selected European states.

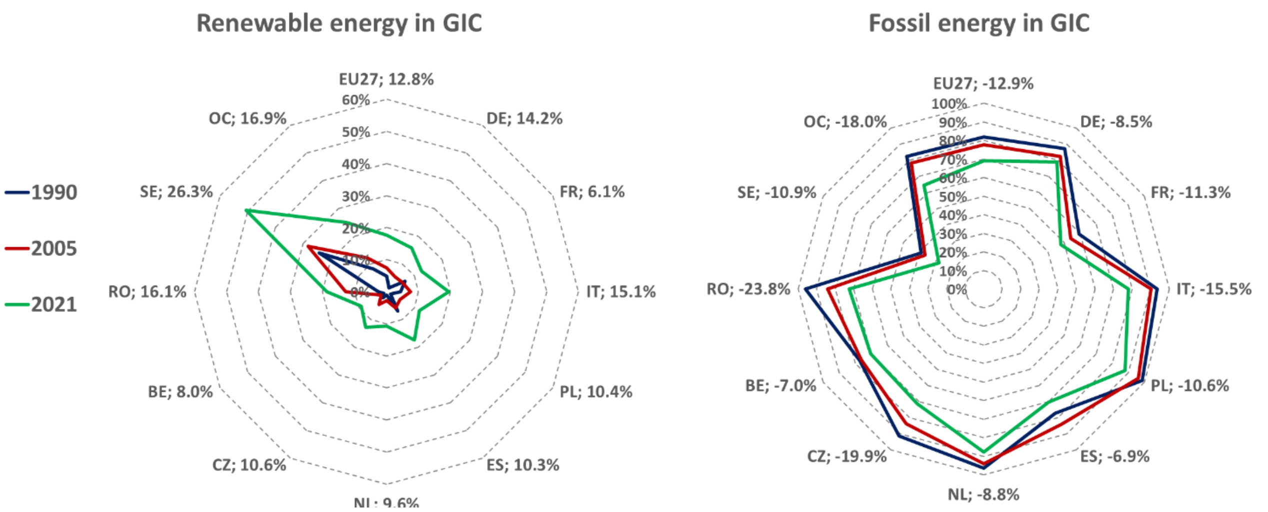
Figure 2.4 – Share of energy sources in gross inland energy consumption in the selected European states.

Figure 2.5 – Share of energy sources in gross inland energy consumption in the selected European states.

The Italian share of solid fuels, mainly coal, in gross inland consumption decreased from 9.9% in 1990 to 3.6% in 2021. On the other hand, the share of natural gas for Italy goes from 26.3% to 40.6%. The share of oil and petroleum products goes from 57.3% to 33.2% and renewable share grew from 4.4% to 19.4%, below the 2020 level of 20.7%. Italy's renewable share is among the highest in the Countries examined, only Sweden's share is higher than the Italian one. The share of fossil fuels is significantly reduced in almost all European Countries. The EU27 average decreased from 82% in 1990 to 69.1% in 2021. Among the examined Countries, the Netherlands and Poland shares are still higher than 85%, respectively 87.7% and 88%.

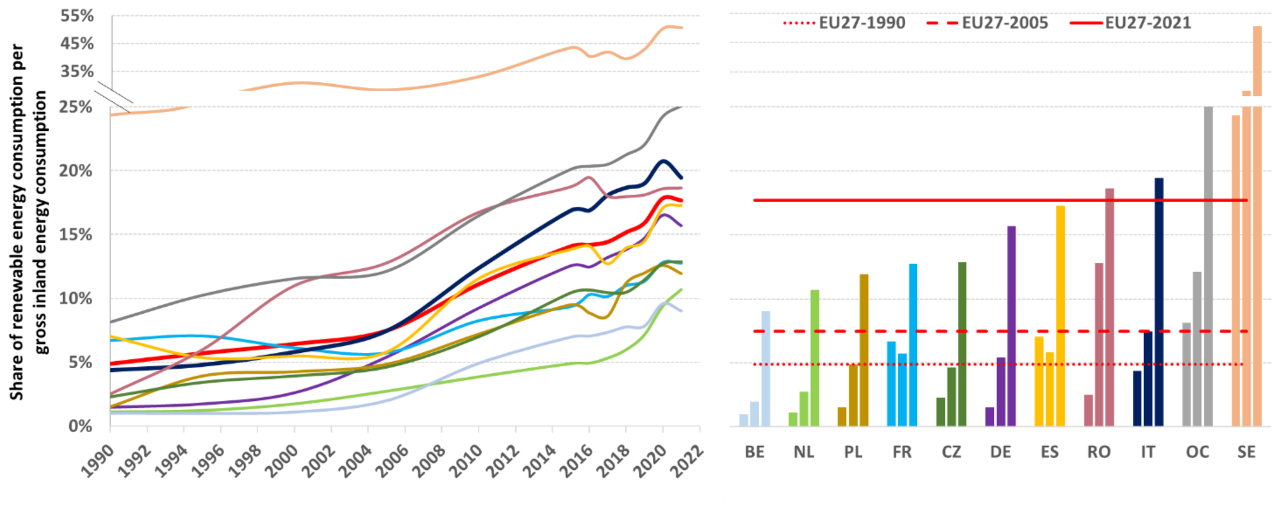
The Countries' trends on the path of decarbonization of the energy mix can be summarized by the following graph showing the change of renewable and fossil shares from 1990 to 2021. The picture makes clear the widening area of renewable energy opposed to the shrinking area of fossil energy since 1990. As shown the increasing rate of renewable share as well as the decreasing rate for fossil share are very different for each Country.

Figure 2.6 – Share of renewable and fossil energy in gross inland energy consumption. The label for each Country is the difference between the share in 2021 and 1990.



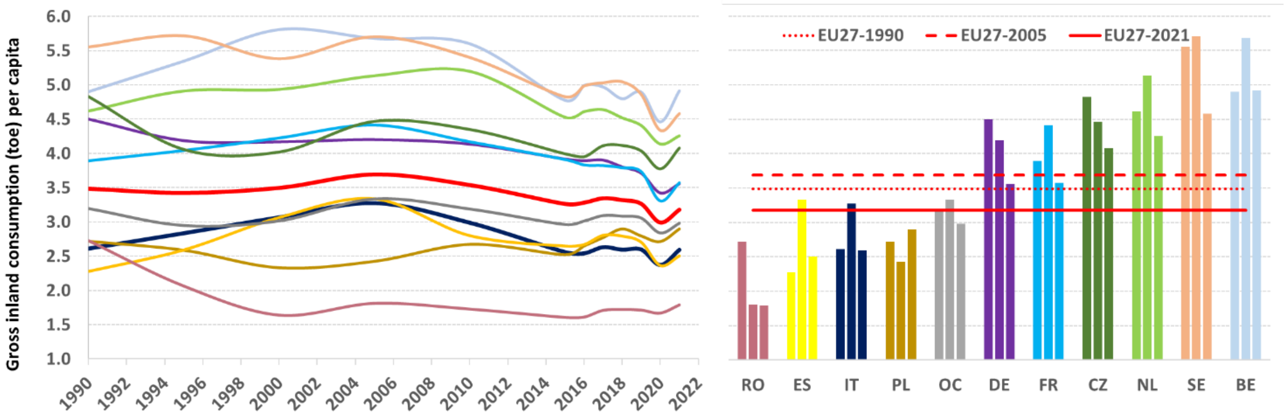
As for the renewable sources a detail is provided in the following graph with the trend for each examined Country.

Figure 2.7 – Share of renewable energy in gross inland energy consumption. For each Country the bars on the right graph are 1990, 2005, and 2021 values. Data in ascending order of 2021 value. OC – Other Countries.



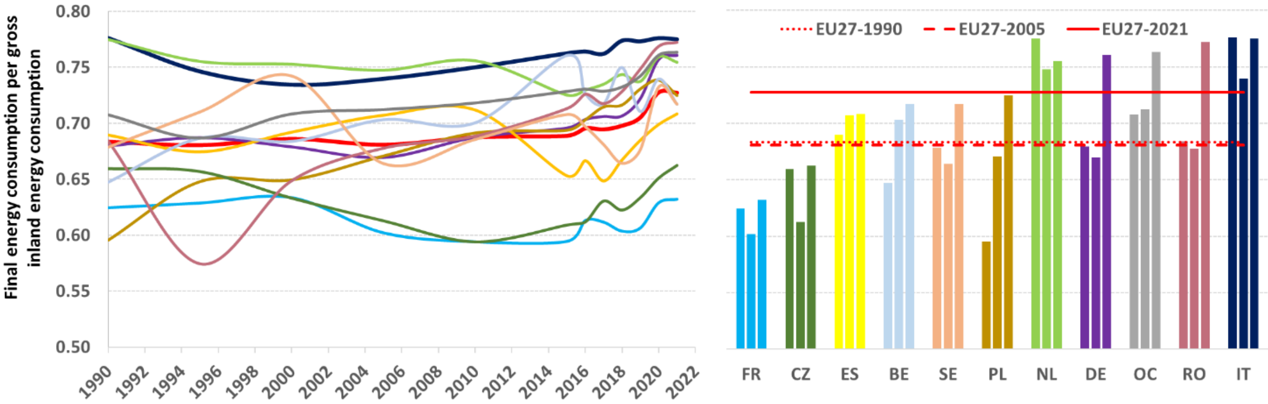
Gross inland energy consumption per capita shows very different values in the European Countries. Italian value is well below the European average. The average Italian consume increased from 2.61 toe (tonnes of oil equivalent per capita) in 1990 to 3.27 toe in 2005. After 2005 the consumption falls to 2.59 toe per capita in 2021, while the EU27 average is 3.18 toe per capita. In 2021 Italy has one of the lowest consumptions per capita among the Countries examined, only Romania (1.79 toe per capita) and Spain (2.5 toe per capita) registered lower values. Germany, France, Czechia, the Netherlands, Belgium, and Sweden have higher figures than EU27 averages. The trends show that energy consumption has decreased everywhere since 2005 up to 2015 with some fluctuations in the last years. In 2020 data was heavily affected by measures adopted by all Countries to contain SARS-CoV-2 pandemic diffusion. As compared to 2005 values Spain shows the highest rates of reduction (-25% from 2005 to 2021), followed by Italy (-20.8%), Sweden (-19.7%), and France (-19%) among the biggest Countries. Poland is the only exception to the observed trend for the Countries examined, with a 19.4% increase of energy consumption per capita from 2005 to 2021.

Figure 2.8 – Gross inland energy consumption per capita. For each Country the bars on the right graph are 1990, 2005, and 2021 values. Data in ascending order of 2021 value. OC – Other Countries.



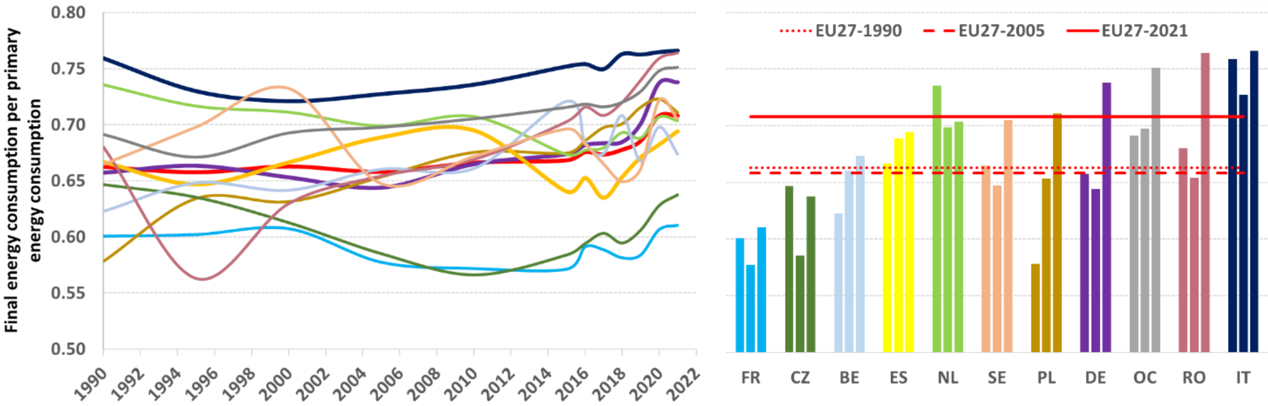
The ratio between the final energy consumption (including non-energy uses) and gross inland consumption is an indicator of energy efficiency. Since 1990 the ratio for Italy has been around the average of 0.76 vs 0.7 the average EU27. This indicator has always been higher for Italy than for the European average and shows values which, among the biggest Countries, are comparable only with those of the Netherlands up to 2015, while in the following years the Italian efficiency increase, and the Netherlands efficiency shows a sensible decrease with a recovery in the last years. As concerns the other States, except France and Czechia with the lowest values since 2000, their efficiency fluctuates around the European average. The lowest values for France and Czechia are due to the low electrical conversion efficiency of nuclear power plants and the significant weight that the nuclear source has in the energy balance of such States (40.9% and 17.9% of gross inland consumption in 2021, respectively for France and Czechia). A sharp increase in efficiency made Poland reach and overcome the European average in recent years. It should be noted that also Germany, Spain, the Netherlands, Romania, Belgium, and Sweden have shares of nuclear heat in their energy consumption in 2021 (from 1.2% for Netherlands to 26% for Sweden).

Figure 2.9 – Ratio between final energy consumption (including non-energy uses) and gross inland energy consumption. For each Country the bars on the right graph are 1990, 2005, and 2021 values. Data in ascending order of 2021 value. OC – Other Countries.



To evaluate energy transformation efficiency, it is useful to consider energy consumption without non-energy uses. In other words, the ratio between final energy consumption and primary energy. The Italian energy transformation efficiency is higher than any other Countries examined. Only Romania approaches the Italian value in 2021. The trend of this indicator is quite like that of the previous one, although it highlights some differences between Member States concerning the share of non-energy uses. This indicator reveals that the value of Netherlands' energy transformation efficiency is lower than in Italy. In the Netherlands, the average share of non-energy uses is more than 16% of gross inland consumption with a slight increasing trend since 1990, while for Italy the average is less than 5% with a decreasing trend. The Netherlands' share of non-energy consumption in 2021 is the highest in Europe, followed by Belgium (13.3%) and Lithuania (12.8%). Among the biggest Countries Germany recorded 8.7%. All the other States range from 0.8% of Luxembourg to 8.8% of Hungary. The EU27 average in 2021 is 6.6%.

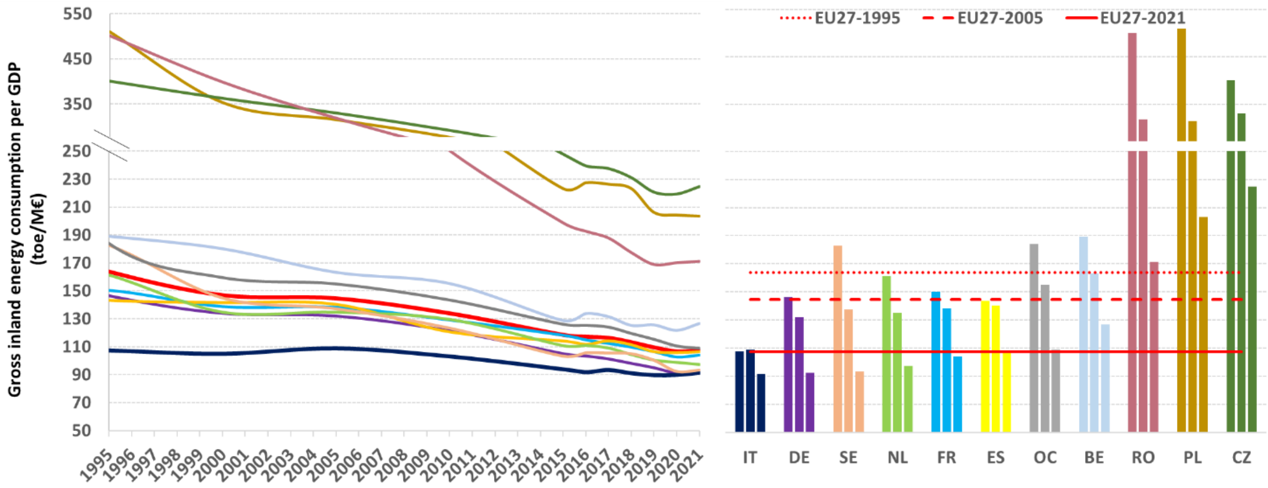
Figure 2.10 – Ratio between final energy (w/o non-energy uses) and primary energy consumption. For each Country the bars on the right graph are 1990, 2005, and 2021 values. Data in ascending order of 2021 value. OC – Other Countries.



The gross inland energy consumption per unit of gross domestic product (GDP - chain linked volumes, reference year 2015) is an indicator of the Country's economic and energy efficiency (energy intensity). Such indicator is sensible to the Country's energy mix and economy structure, in terms of industry-service share. Without considering the efficiency improvement an industry-based economy is generally more energy intensive than a service-based economy. Moreover, the GDP is also determined by activities related to international bunkers, such as international maritime bunkers, whose energy consumption is not included in gross inland energy consumption. The role of international bunkers will be considered in the paragraph 2.1.2.1.

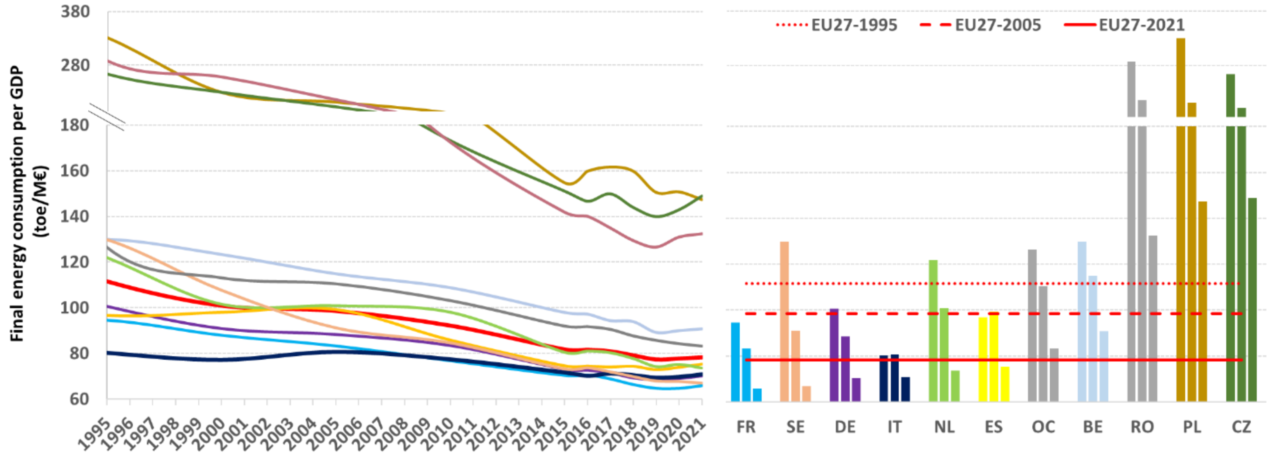
Italy was one of the European Countries with lower energy intensity until 1995, when it was behind only to Denmark, then lost positions and in 2021 has the 5th lower values, upper than Ireland, Denmark, Malta and Luxembourg. Among the biggest EU27 Countries, Italy continues having the lowest energy intensity followed by Germany and Sweden.

Figure 2.11 – Gross inland energy consumption per unit of GDP (chain linked volumes, reference year 2015). For each Country the bars on the right graph are 1995, 2005, and 2021 values. Data in ascending order of 2021 value. OC – Other Countries.



The final energy intensity (ratio between final energy consumption, including non-energy uses, and gross domestic product) follows similar trends of energy intensity with a sudden reduction in the European Countries which, starting from higher levels than Italy, reach Italian figures and in some cases exceed them. Since 1995 Italy shows considerable energy and economic efficiency, the final energy intensity reduced by 11.6% from 1995 to 2021; much higher reductions have occurred in the other European Countries (-29.9% in EU27). The reasons for the reduction in energy intensity observed are manifold such as the increase in building efficiency, industrial efficiency improvement, the electrification of final consumption and the shift of economy towards high value added and low energy consumption activities of services to the detriment of industrial sectors. The last aspect is particularly relevant considering the long-term growth of GDP in the Countries and the increasing share of the value added from services, which in EU27 represents 72.7% of the value added of all economic activities in 2021, while in1995 it represented 69.4%. On the other hand, the share of value added in industry (except construction), the most energy-intensive sector, was 28.4% in 1995 and 25.6% in 2021.

Figure 2.12 – Final energy consumption per unit of GDP. For each Country the bars on the right graph are 1995, 2005, and 2021 values. Data in ascending order of 2021 value. OC – Other Countries.



European Countries show a wide range of electrification of final energy consumption (energy uses only) in 2021 ranging from 14.6% in Latvia to 41.6% in Malta. Italy is just below the EU27 average with 22.2% *vs* 22.8%. Among the biggest Countries, Sweden, France, and Spain have higher levels of electrification than Italy, respectively 34.3%, 26.7%, and 24.9%. At the lowest end there are Romania and Poland with 15.7% and 16.7% respectively.

Figure 2.13 – Share of final electricity consumption in total final energy consumption in EU27 Countries (2021).

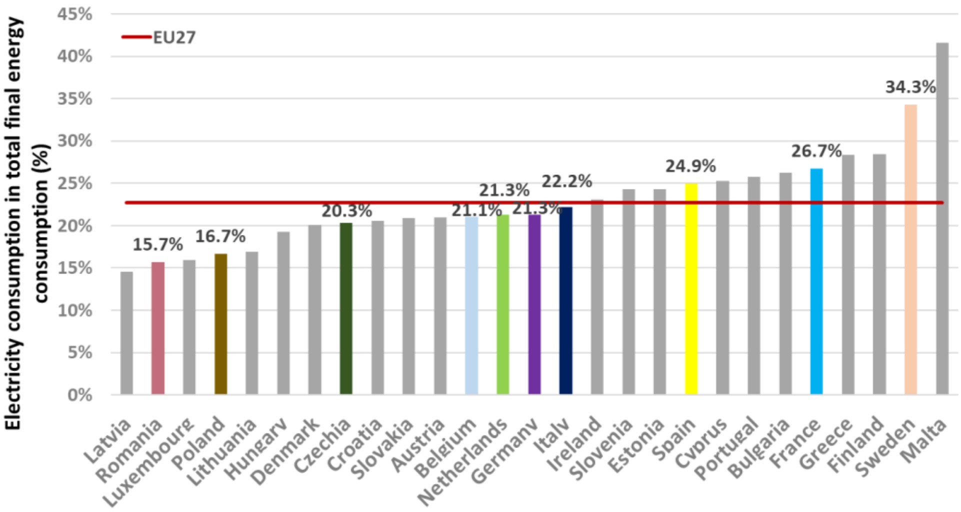
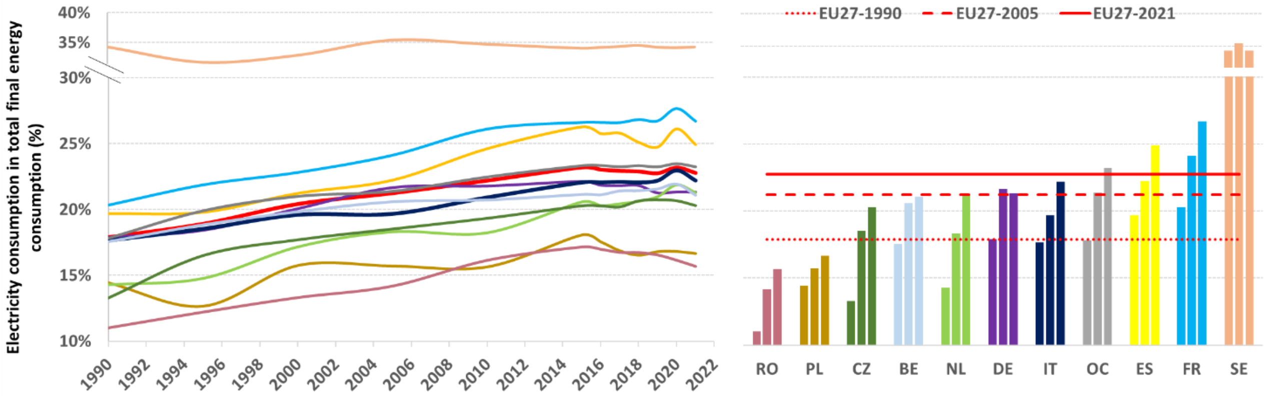


Figure 2.14 shows the increasing trends of electrification in almost all the European Countries except Sweden whose highest level is quite constant.

Figure 2.14 – Trend of final electricity consumption share in total final energy consumption. For each Country the bars on the right graph are 1990, 2005, and 2021 values. Data in ascending order of 2021 value. OC – Other Countries.

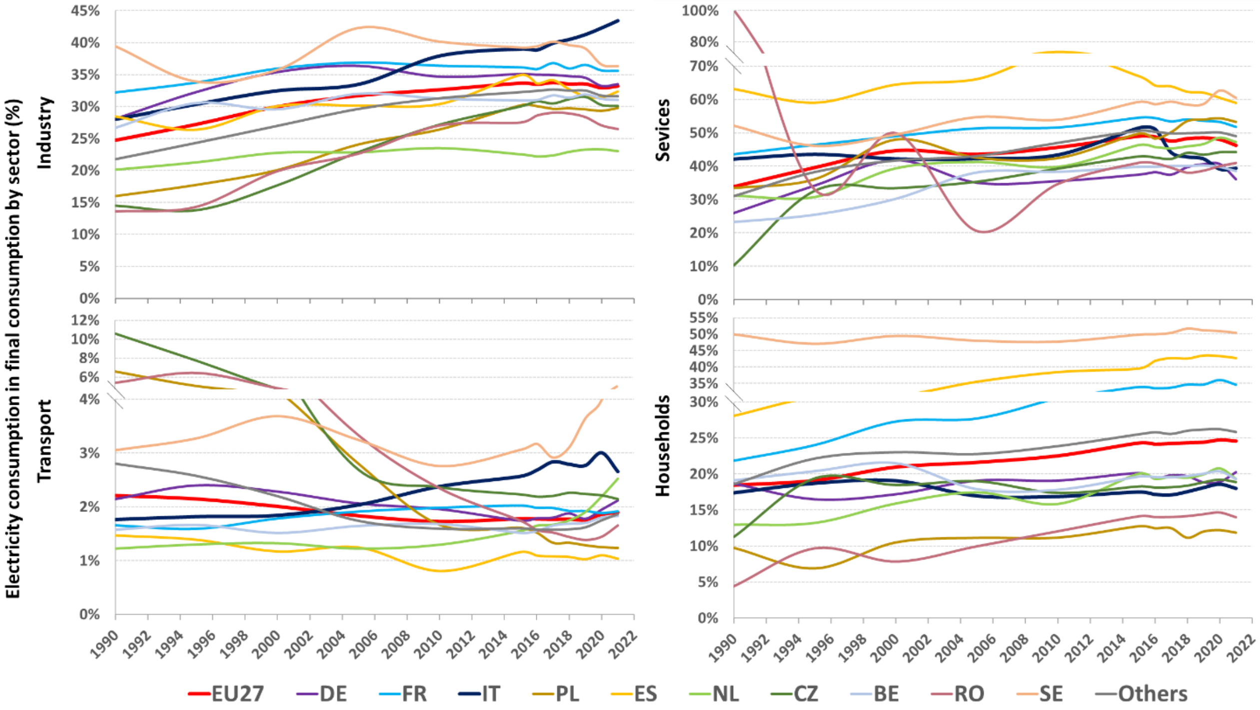


At sectoral level, the Member States' electrification of final energy consumption shows different shares although with a common growing trend. The electrification of industry final consumption in Italy is among the highest in Europe (43.4% in 2021). Only three States in EU27 have higher rates: Malta (70.4%), Ireland (49.5%), and Luxembourg (42.9%). The sharp boost of industry electrification recorded in Poland, Czechia and Romania is particularly interesting, the Countries are approaching the EU27 average (33.2%). Equally notable is the reduction recorded in Germany from 36.4% in 2005 to 33.5% in 2021. The electrification of final consumption in the most emission intensive sector, such as industry, is an important strategy to mitigate greenhouse gas emissions if pursued in parallel with the spread of renewable energy for electricity production.

Services show the highest percentages of electrification among sectors. The Italian share in 2021 is 39.4%, well below the EU27 average (46.3%), as well as the electrification in households (18% in Italy *vs* 24.6% in EU27). Among the largest Countries Sweden and Spain show the highest electrification shares in services in 2021, 60.5% and 59% respectively, although in Spain there has been a sudden reduction since 2010, when the share of electricity consumption was 73.8%. Germany, Romania, Belgium, and Italy are at the lower end with shares from 36.1% to 41%.

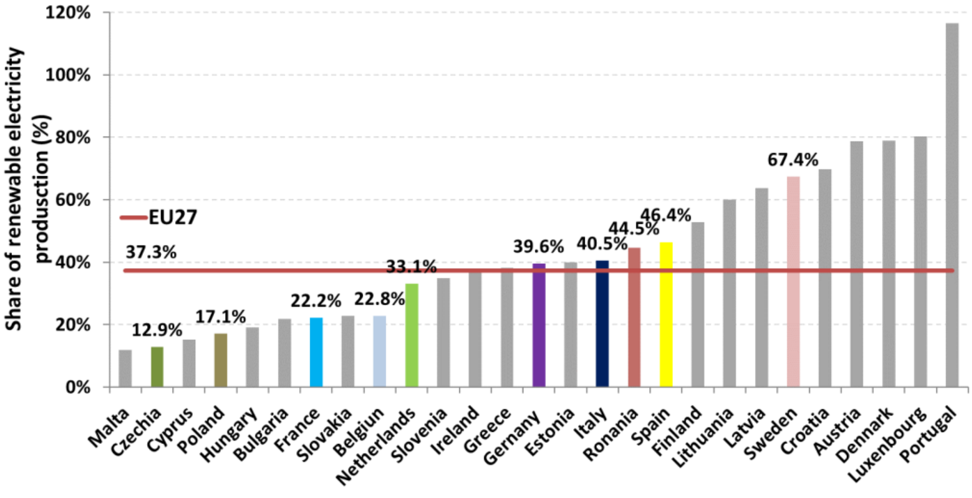
The transport sector shows the lowest percentages of electrification and in 2021 Italy is one of the three EU27 Countries with the highest share (2.7%), after Sweden (5%) and Austria (3.5%). Electricity consumption in the mobility sector has been limited so far to public transport (train, tram, metro), while for private mobility the electricity plays a marginal role. The decline in the electrification rate in Poland, Czechia and Romania is explained by the strong growth of final consumption in this sector, especially due to road transport, and decreasing consumption of electricity as consequence of decrease of public transport demand.

Figure 2.15 – Trend of final electricity consumption share in total final energy consumption. For each Country the bars on the right graph are 1990, 2005, and 2021 values.



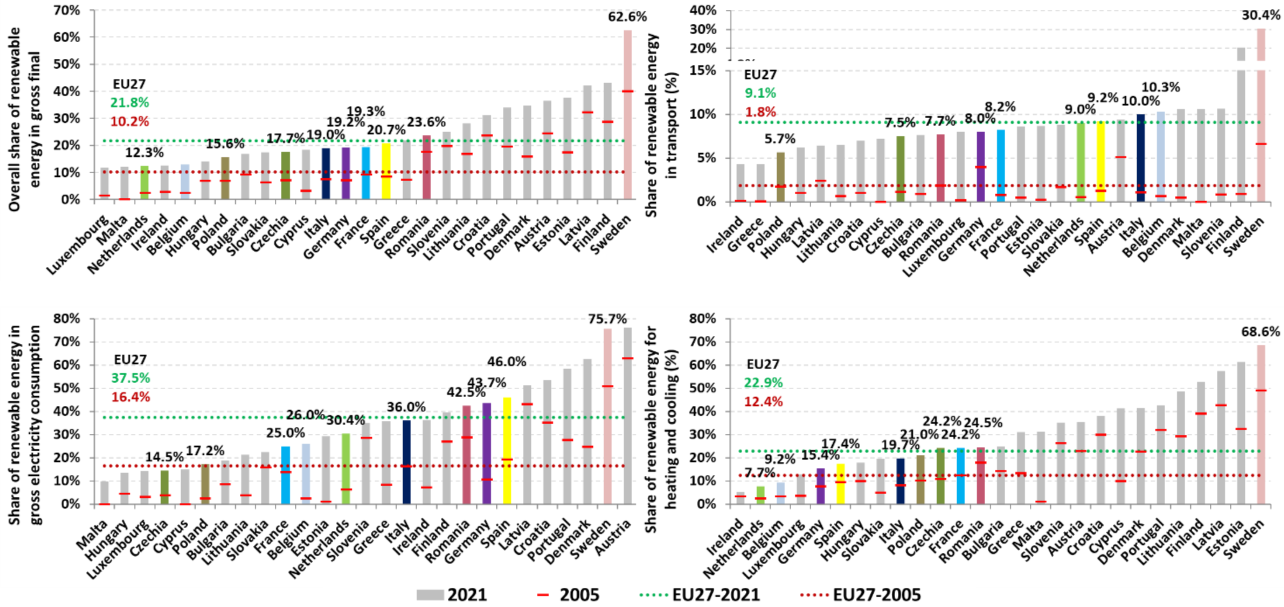
The share of sectoral electricity consumption can provide indications on the emission mitigation performance of each sector reading the figures together with sectoral consumption of renewable energy and above all with the share of renewable electricity production and consumption.

Figure 2.16 – Share of renewable electricity production in the EU27 Countries (2021).



As for the renewable energy consumption the following graph shows the overall and sectoral shares of renewable energy recorded in 2021 in the EU27 Countries according to the Directive (EU) 2018/2001. The EU27 average share of renewable energy in gross final electricity consumption is more than doubled from 2005 to 2021 (16.4% *vs* 37.5%).

Figure 2.17 – Share of renewable energy in the EU27 Countries (2021). Directive 2009/28/EC until 2020 and Directive (EU) 2018/2001 for 2021.



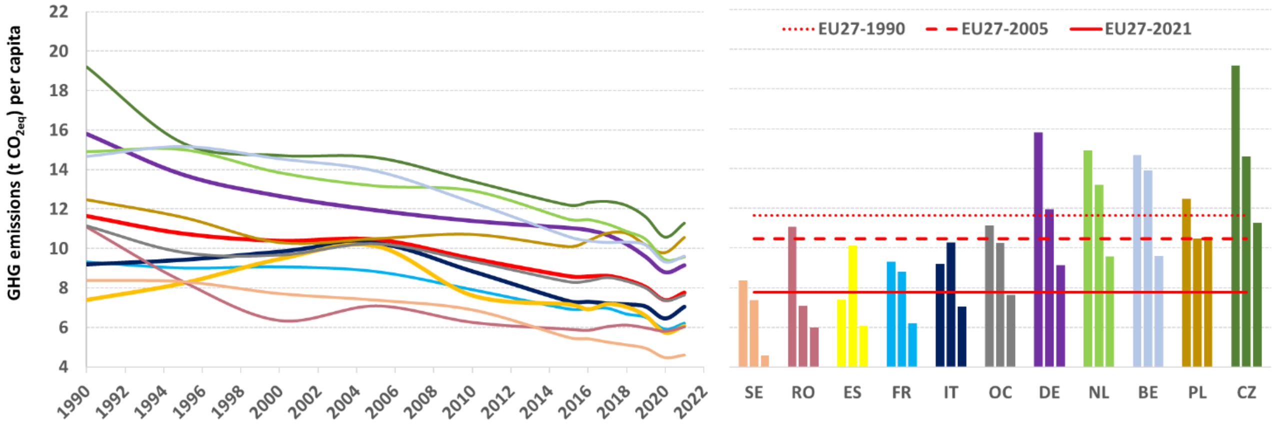
The Countries examined for comparison with Italy represent 78.9% of EU27 renewable energy in gross final electricity consumption in 2021. Such outcomes show clearly that the electrification of the final consumption in the biggest Countries, such as Germany, France, Italy, and Spain, collectively accounting 56.9% of EU27 renewable electricity consumption, involve a significant contribution to the mitigation of GHG emissions in Europe.

2.1.2 Greenhouse gas emissions and energy consumption

Italy's GHG emissions per capita from 1990 to 2021 is 8.8±1.2 t CO_2eq (ISPRA, 2023a). Emissions per capita increased until 2004 when the maximum value of 10.3 t CO_2eq was reached, then a reduction of up to 6.4 t CO_2eq was observed in 2020. In 2021 the emissions per capita are 7 t CO_2eq. Italian emissions per capita have always been below the European average. EU27 average emissions per capita in 2021 are 7.8 t CO_2eq.

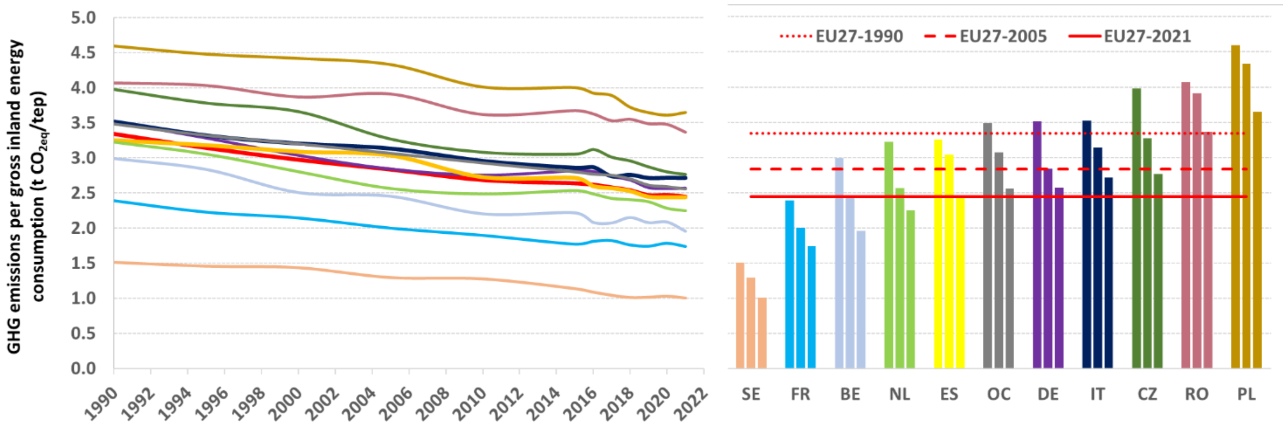
Apart for Italy and Spain, the trend of emission reductions in the other Countries began as early as 1990. Emissions per capita in Spain increased with higher rate than in Italy until 2005, when the emissions per capita of the two Countries reached the same level. After 2005 the emissions per capita decreased also in Italy and Spain. In recent years, emissions in France, Spain, Romania, and Italy are very close and below the EU27 average. Sweden has the lowest GHG emissions per capita. All other examined Countries have higher emissions than the EU27 average.

Figure 2.18 – Greenhouse gas emissions per capita. For each Country the bars on the right picture are 1990, 2005, and 2021 values. Data in ascending order of 2021 value. OC – Other Countries.



As for carbon intensity, GHG emissions by energy consumption, all Countries have reduced the emissions per unit of gross inland energy consumption since 1990. Such indicator is sensible to the Country's energy mix. It should be considered that sources of energy, as renewables and nuclear heat, do not contribute to GHG emissions, so Countries with higher share of such sources are more likely to have low carbon intensity. Moreover, the share of net imported electricity plays a positive role in reducing the indicator because the emissions to generate such electricity are allocated to the Countries which produce it. The Country economy structure is another relevant factor to be considered to correctly interpret such indicator. The industry activities are generally more energy consuming than service activities, so the Countries' economy structure is a relevant parameter for such indicator. Carbon intensity of Italy is higher than the European average, also for the contribute of nuclear power in all other Countries except Poland (Figure 2.19). By unbundling nuclear power from gross inland consumption, Italy's figures are below the EU27 average (2.7 t CO_2eq *vs* 2.8 t CO_2eq in 2021).

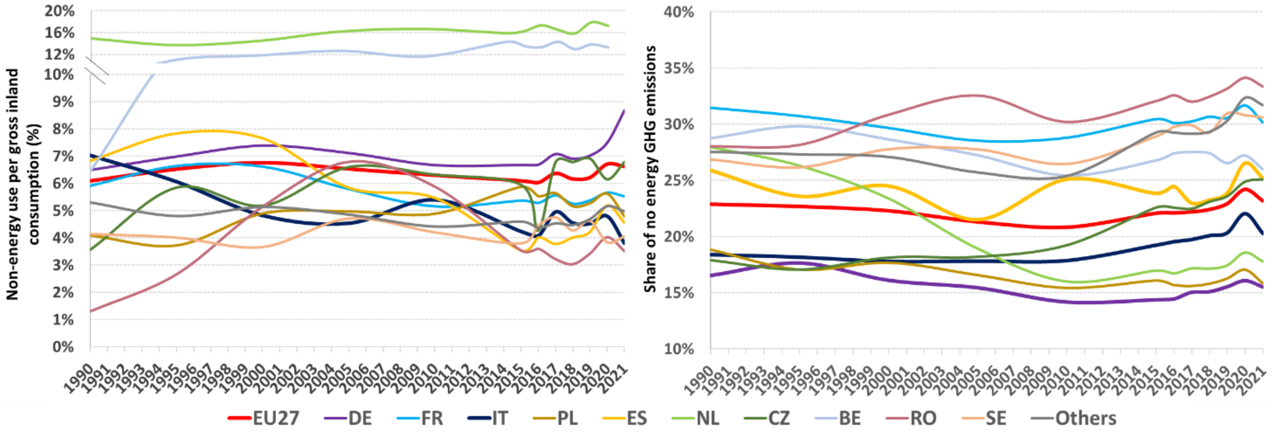
Figure 2.19 – Greenhouse gas emissions per gross inland energy consumption. For each Country the bars on the right picture are 1990, 2005, and 2021 values. Data in ascending order of 2021 value. OC – Other Countries.



Countries with lower carbon intensity than Italy have higher cumulated share of renewable, nuclear energy, and electricity with the only exception of the Netherlands and Germany whose cumulated shares are lower than the Italian one (the Netherlands, 11.9%; Germany, 21.2%; Italy, 21.8%). On the complementary side of the fossil share the only Countries with higher values than Italy (78.2%) are Germany, Poland, and the Netherlands, respectively 78.8%, 88%, and 87.7%. It is worth noting that despite the lower fossil share in Czechia (71.4%) and Romania (72.4%) compared to Italy the two Countries have higher carbon intensity due to the much lower share of natural gas in their fossil mix.

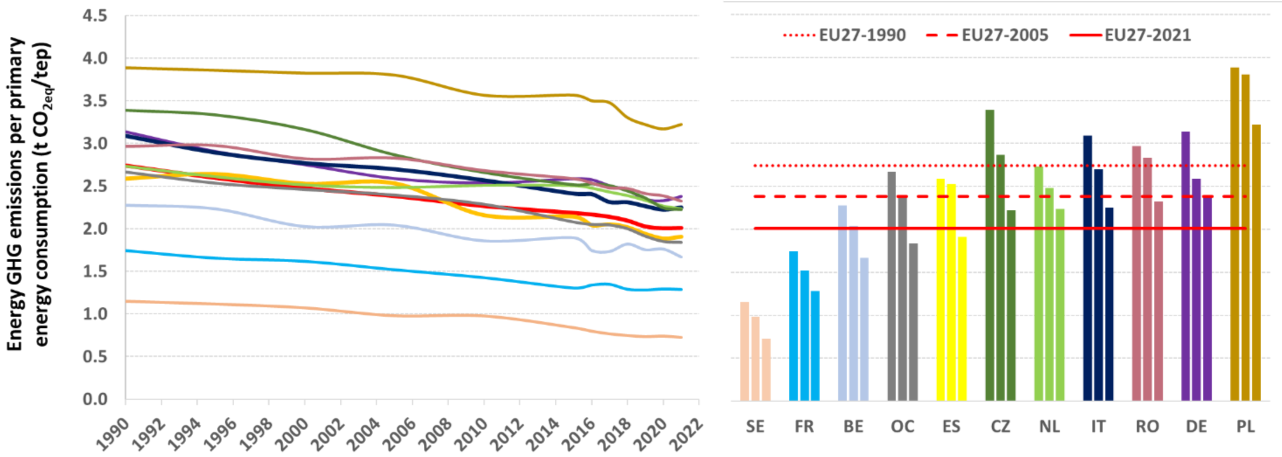
The carbon intensity in the Netherlands and Germany is in apparent contrast to what was previously said about the energy mix of the Countries. To overcome the apparent contrast, Figure 2.19 should be read considering the role of non-energy consumption in the energy mix of Countries. The share of non-energy consumption in the Netherlands (17.3%) and Germany (8.7%) are significantly higher than in Italy (3.8%). While primary energy consumption has a direct relationship with greenhouse gas emissions, the same is not true for non-energy uses. These consumptions include industrial processes in sectors such as the petrochemical, pharmaceutical, etc., where oil and its products are not used as fuels, but for transformation into other products. Moreover, the role of no energy GHG emissions must be considered with large source of emission as waste and agriculture not related to energy consumption. The GHG emissions from no energy sectors show a wide range in the European Countries with an average for EU27 of 23.2% in 2021. Among the biggest Countries here considered the range goes from 15.5% in Germany to 33.4% in Romania.

Figure 2.20 – Trends of non-energy use per gross inland energy consumption and trends of share of greenhouse gas emissions from no energy sectors.



The comparison of decarbonization indicators among Countries with significantly different shares of non-energy uses and no energy emissions can be corrected by considering the energy GHG emissions per unit of primary energy consumption: primary energy carbon intensity. This indicator highlights the decarbonization of a Country's energy sector. In general terms Countries with higher shares of renewable or nuclear energy have lower primary energy carbon intensity. This indicator shows that the carbon intensity of the Netherlands and Italy are very close, the primary energy carbon intensity of Germany is higher than Italian one also due to the lower amount of no energy emissions in Germany (15.5%) compared to Italy (20.3%). As for the gross inland consumption of energy Czechia has higher carbon intensity than Italy, while as for primary energy carbon intensity there is a shift in the Countries’ position which can be explained by the higher share of no energy emissions in Czechia than Italy (25.1% vs 20.3%).

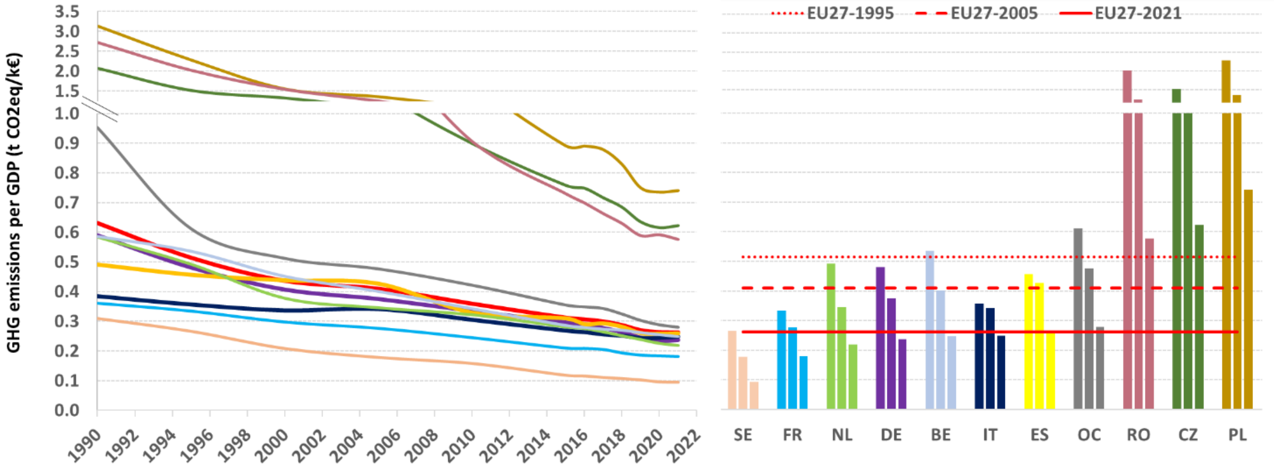
Figure 2.21 – Greenhouse gas emissions from energy sector per primary energy consumption. For each Country the bars on the right picture are 1990, 2005, and 2021 values. Data in ascending order of 2021 value. OC – Other Countries.



The ratio between GHG emissions and gross domestic product is the carbon intensity related to economy. Such indicator is sensible to the Country's energy mix, as the intensity related to energy, and even more sensible to economy structure: share of services and industry. Moreover, the Countries' GDP is also determined by activities related to international bunkers, whose emissions are memo items in the emissions inventories. The GHG emissions in the following graphs do not include memo items. The role of such items will be considered in the next paragraph. The indicator shows a reduction for all European Countries and Italy's figures are just below the EU27 average in 2021 (0.26 t CO_2eq/k€ *vs* 0.25 t CO_2eq/k€). Sweden and France have the lowest values: 0.09 t CO_2eq/k€ and 0.18 t CO_2eq/k€, respectively. Poland is at the upper end with 0.74 t CO_2eq/k€, followed by Czechia and Romania with 0.62 t CO_2eq/k€ and 0.58 t CO_2eq/k€.

The reduction since 1995 for EU27 is -49% and range from -30.4% for Italy to -71.5% for Romania. The causes of such reductions are manifold and concern both the common increase in efficiency of industry and the increasing share of value added from services, whose carbon intensity is far lower than those of manufacturing industries.

Figure 2.22 – Greenhouse gas emissions per unit of GDP. For each Country the bars on the right picture are 1995, 2005, and 2021 values. Data in ascending order of 2021 value. OC – Other Countries.



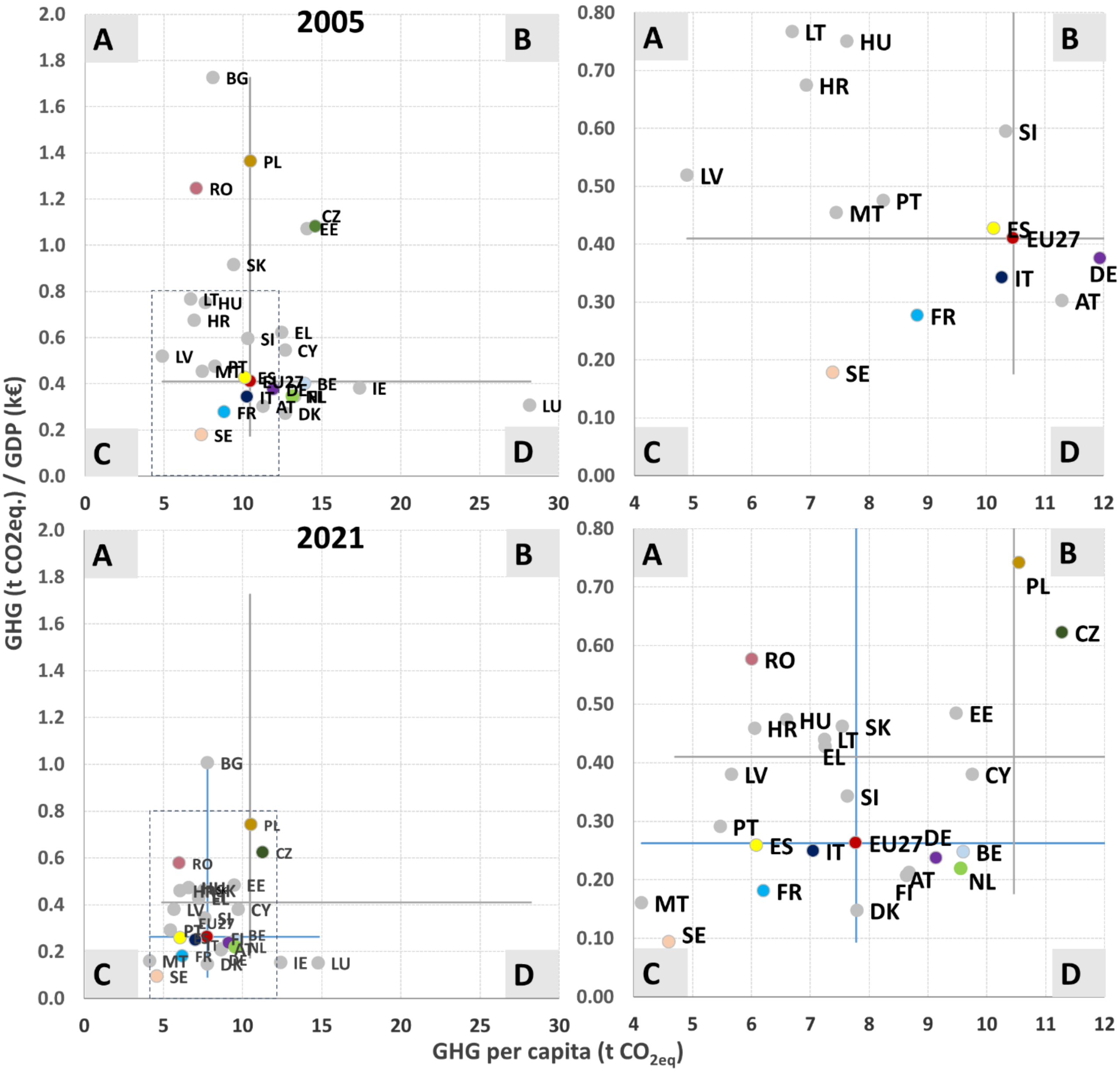
The following graphs show how the Countries "moved" in the phase space defined by GHG emissions per capita and GHG emissions per unit of GDP from 2005 to 2021. EU27 average is the centroid of the Countries' cloud. The crossed axes on EU27 value separate four quadrants with different performances. The pictures on the right are the zoomed box which inscribes the biggest Member States in 2021. In the quadrant C, at the bottom left corner, there are the best performing Countries with lower GHG emissions per capita and GHG emissions per GDP than EU27 average, while in the quadrant B, at the upper left corner, there are the worst performing Countries, with higher GHG emissions per capita and GHG emissions per GDP than EU27 average. The Countries' cloud became more and more "concentrated" moving toward the bottom left corner. Italy, France, and Sweden were in the C quadrant since 2005. Spain passed from A quadrant to B quadrant, while the Poland and Czechia are in the B quadrant both in 2005 and in 2021. Germany, Belgium, and the Netherlands are positioned in the quadrant D, with higher GHG emissions per capita but lower GHG emissions per unit of GDP than EU27 average.

The distance that each Country travelled since 2005 in the phase space provides a measure of the progress made in the decarbonization process. The distance of two points in the two-dimension Euclidean space, P = (p_x , p_y) and Q = (q_x , q_y), is calculated as:

$$\sqrt{(p_x - q_x)^2 + (p_y - q_y)^2}$$

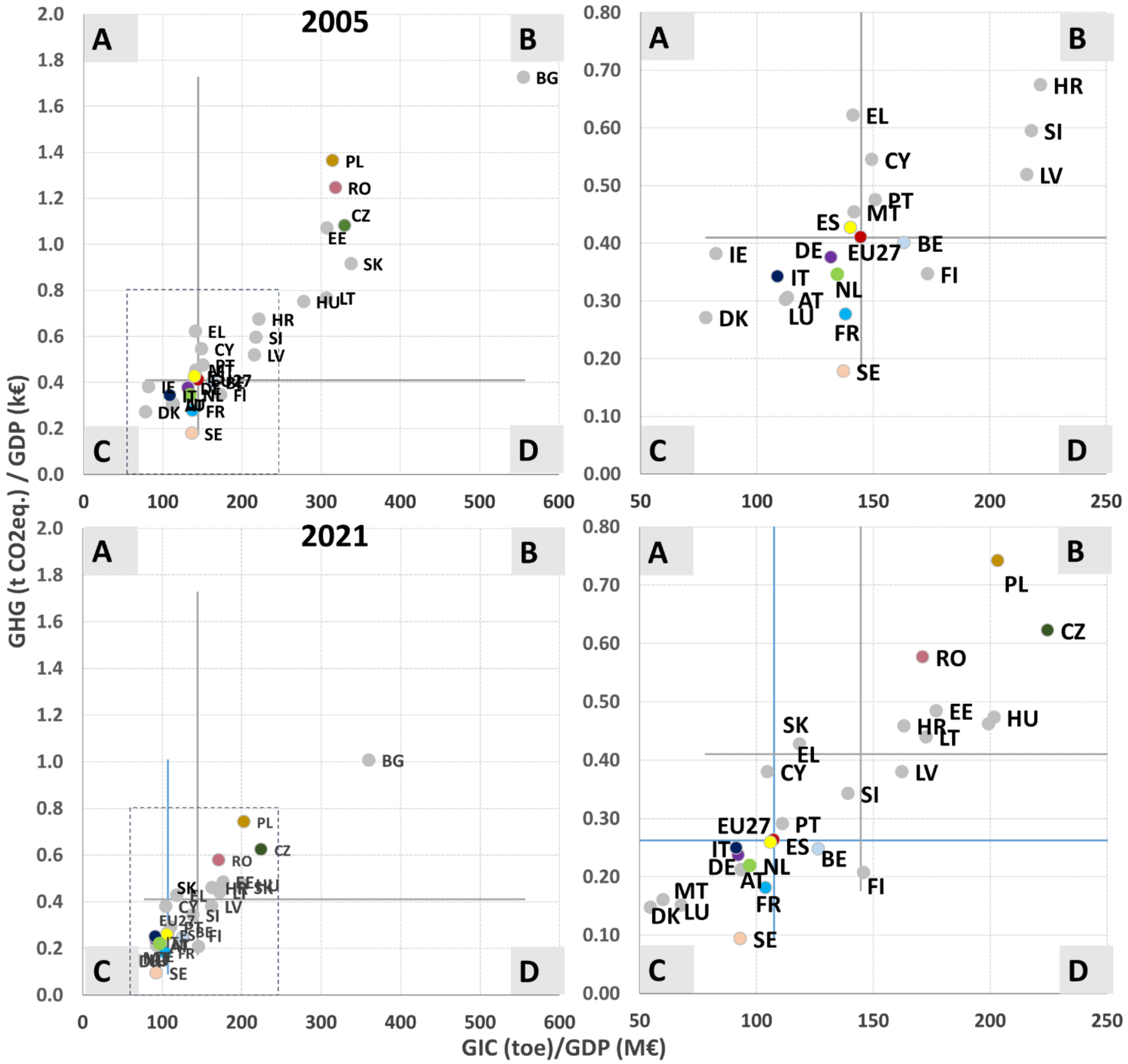
Among the examined Countries Belgium and Spain travelled the longest distances, followed by the Netherlands, Czechia, and Italy. Poland moved the shortest distance reducing only the GHG emissions per GDP without any relevant change of GHG emissions per capita.

Figure 2.23 – In the phase space defined by emissions per capita (abscissa) and economy carbon intensity (ordinate) is shown the position for each Member State on the left. On the right the enlarged box that inscribes the biggest Member States in 2021 is shown. The grey axes in the bottom graphs are those plotted in 2005.



Even more interesting is the positioning of Countries in the space defined by GHG emissions per GDP and gross inland energy consumption per GDP (Figure 2.24). In such picture both abscissa and ordinate report intensities indicators. Among the examined Countries only Poland, Czechia, and Romania are in the quadrant B with the worst performances, although travelling in this phase space longer distances than any other Countries since 2005. On the other end Italy travelled the shortest distance. Such phase space makes clear how Germany and other Countries, as Spain and the Netherlands, approached Italy from 2005 to 2021.

Figure 2.24 – In the phase space defined by economy energy intensity (abscissa) and economy carbon intensity (ordinate) is shown the position for each Member State on the left. On the right the enlarged box that inscribes the biggest Member States in 2021 is shown. The grey axes in the bottom graphs are those plotted in 2005.



The trends of indicators such as GHG emissions per capita, energy, carbon, and economy intensities show that Italy had some of the lowest values since 2005 and the biggest Countries are gradually moving toward the quadrant that Italy, together with few other Countries, occupied already in 2005.

The indicators show that Italy, compared to the biggest EU27 Countries, has historically high energy and economy efficiency with a significant share of renewable energy and natural gas in the energy mix, and one of the lowest emissions per capita in Europe. The gross energy intensity per unit of GDP in Italy is higher only to those of Ireland, Denmark, Malta, and Luxembourg, while the carbon intensity per unit of GDP is just below the EU27 average and very close to carbon intensities recorded in Germany, Belgium, and Spain, among the biggest Countries. The carbon intensity per gross energy consumption is higher than the European average because of the significant share of nuclear heat in EU27. The carbon intensity per gross energy consumption without the nuclear heat shows that Italy's intensity is higher only than those of Sweden, the Netherlands, and Belgium, among the biggest Countries. Although some indicators show that many Countries have improved their GHG emissions performance, sometimes achieving better results than Italy, the following factors need to be considered:

- Countries with high shares of solid fuels or oil and petroleum products have greater potential for reducing emissions from fossil fuels than those available in Italy, where the fossil mix is mainly represented by natural gas and further GHG emissions reductions are possible only increasing the renewable share and improving efficiency.
- In several Countries there is a relevant contribution of nuclear power with emissive advantages, a source of energy which is not without controversy and which some Countries intend to phase out gradually (Germany, Belgium), even though recent events, such as Russian-Ukrainian war from February 2022 determined revisions of the nuclear plants decommissioning planning. Moreover, the uncertainty about the timing of the nuclear power plant maintenance program remains considerable also in France which is currently suffering from the shutdown of 25 out of 56 reactors (TERNA, 2023b).
- The emissive performance of a Country depends closely on its economic structure. Countries with a predominance of productive activities in the service sector or with significant shares of non-energy consumption, such as the Netherlands, show lower emissions per GDP and energy consumed.

2.1.2.1 International bunkers

The decarbonization and efficiency indicators with GHG emissions from international bunkers (international flights and shipping) require a premise on the composition of national emission inventories and energy balance.

GHG emission inventories submitted to the UNFCCC Secretariat include emissions from international aviation and maritime activities. Such emissions, although methodologically consistent with IPCC guidelines (2006), are reported as "memo" items and are not included in total national emissions.

Similarly, for energy consumption, the items that make up a Country's gross inland energy consumption must be considered in relation to GHG emissions from international bunkers. In EUROSTAT's energy balance, gross inland energy consumption includes the consumption of international aviation but not those of international maritime activities.

In particular, the main items in the budget can be explained by the following equations:

GAE= PPRD + RCV_RCY + IMP – EXP + STK_CHG (1)

where

GAE: gross available energy;

PPRD: primary production;

RCV_RCY: recovered or recycled products;

IMP: import;

EXP: export;

STK_CHG: stock changes.

GIC = GAE – INTMARB (2)

where

GIC: gross inland energy consumption;

INTMARB: international maritime bunkers;

NRGSUP = GIC – INTAVI (3)

where

NRGSUP: total energy supply;

INTAVI: international aviation;

AFC = NRGSUP – (TI_E – TO) – NRG_E – DL (4)

AFC = FC_E + FC_NE (5)

where

AFC: energy available for final consumption;

TI_E: transformation input of energy:

TO: transformation output;

NRG_E: energy consumption in the energy sector;

DL: distribution losses;

FC_E: energy uses of final energy;

FC_NE: non-energy uses of final energy.

Equations (2) and (3) show that in the gross inland energy consumption is not considered the energy consumption by international maritime bunkers, while the consumption by international aviation is included. Therefore, a decarbonization indicator that considers total emissions reported in the inventories should be the ratio between GHG emissions to total energy supply (NRGSUP), as both terms are without international bunkers. Similarly, decarbonization indices can be drawn up with gross inland energy consumption (GIC) or with gross available energy (GAE) considering the contribution of international aviation in the first case and of all international bunkers in the second case.

The energy available for final uses (AFC) consist of energy and non-energy uses. The former component is directly related to greenhouse gas emissions from combustion, while the latter is involved in transformation processes not directly related to atmospheric emissions. Final uses consist of total energy without transformation losses, energy branch sector consumption and distribution losses.

This report has not the aim to examine in detail the components of gross domestic product, but in the first approximation it can be considered that GDP is also determined by activities related to flights and international navigation.

The biggest European Countries have very different contributions from international bunkers regarding GHG emissions. The GHG emissions from such sectors are relevant in some Countries and the EU27 average share in total emissions with bunkers in 2021 is 5.4% and, for the biggest Countries, it ranges from 0.3% in Romania and Czechia to 21.5% in Belgium.

In the light of such different contributions, it is reasonable to investigate the dynamics of decarbonization and efficiency indicators considering the role of international bunkers. Carbon intensity related to gross domestic product and energy consumption will be considered. The first indicator is equal to the ratio between GHG emissions including contribution from international bunkers and gross domestic product (GDP). The second indicator is equal to the ratio between energy GHG emissions including contribution from international bunkers and gross available energy (GAE) without final consumption for non-energy uses (FC_NE), a measure that can be defined as gross available primary energy. Regarding the efficiency indicator, carbon and energy intensities will be calculated through the ratio between gross available energy (GAE) and gross domestic product (GDP).

Figure 2.25 – Share of national emissions in the inventories and international bunkers emissions (2021 data). Countries in descending order of international bunkers emissions share.

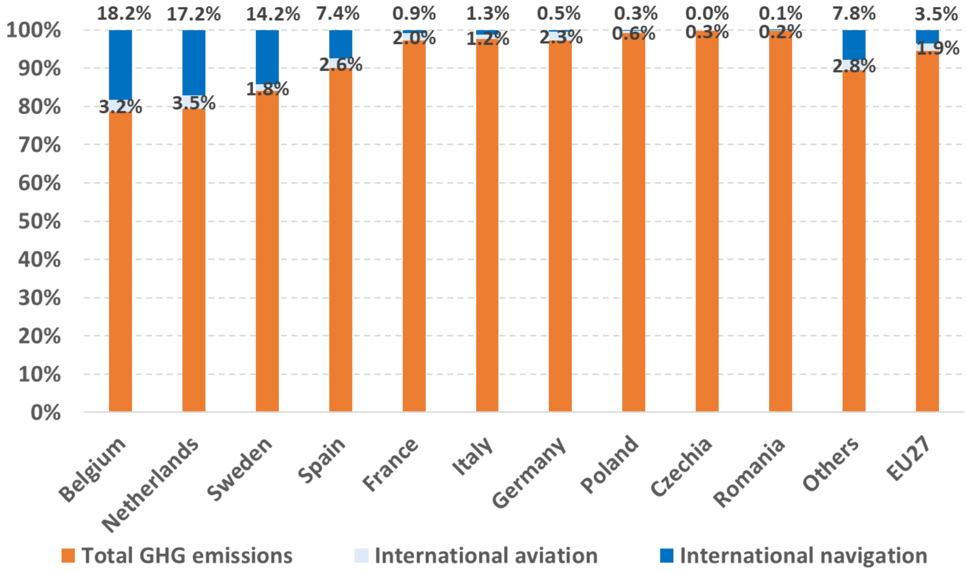
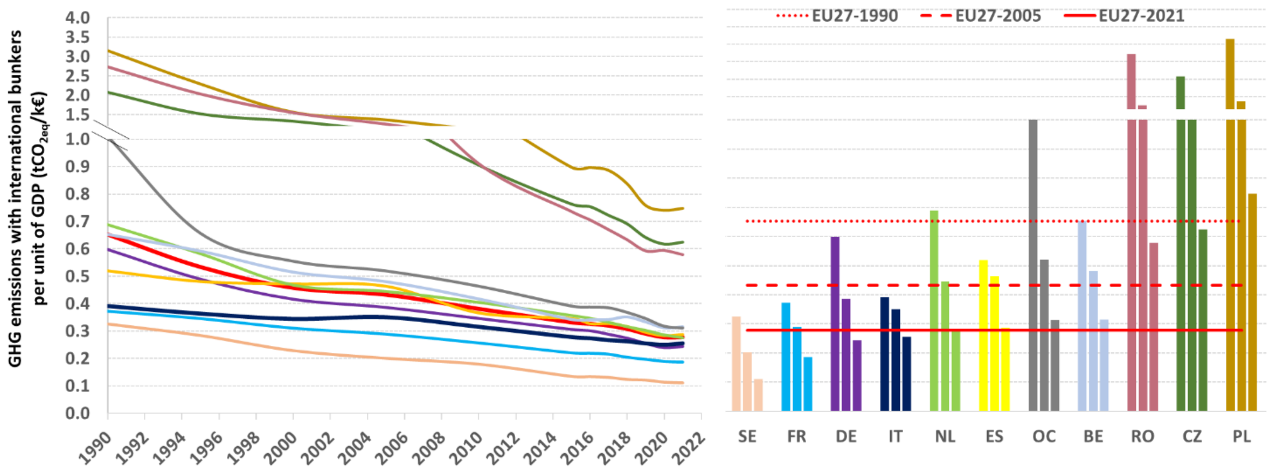


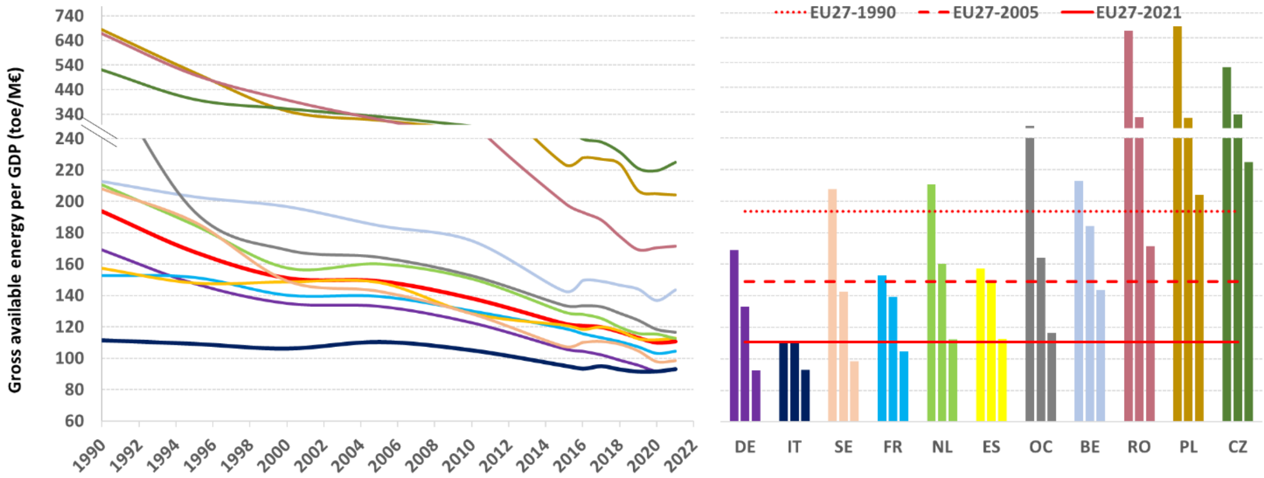
Figure 2.26 shows the GHG emissions per unit of GDP and should be compared with Figure 2.22. The indicator is affected by the role of bunkers and highlights the increase in carbon intensity per GDP in Countries where bunkers have a significant share, such as Belgium and the Netherlands. Whereas in Figure 2.22 the intensities of Belgium and the Netherlands are quite below the EU27 average, in Figure 2.26 the intensity of Belgium is greater than the European average and the intensity of the Netherlands is close to the EU27 average.

Figure 2.26 – Greenhouse gas emissions including international bunkers per unit of GDP. For each Country the bars on the right picture are 1995, 2005, and 2021 values. Data in ascending order of 2021 value. OC – Other Countries.



The gross available energy per unit of GDP shown in Figure 2.27 highlights the role of international bunkers energy consumption (cf. Figure 2.11) and confirms that Italy and Germany values are the lowest among the largest Countries. The relevant amount of energy consumed by international bunkers in the Netherlands and Belgium increases the indicators shown in Figure 2.11 by 15.4% and 13.3% respectively. moves these Countries toward higher values of the indicator.

Figure 2.27 – Gross available energy per unit of GDP. For each Country the bars on the right picture are 1995, 2005, and 2021 values. Data in ascending order of 2021 value. OC – Other Countries.



The gross available energy, which include the contribution of international bunkers, per unit of GDP highlights the different role of international bunkers energy consumption and shows that Italy, together with Germany, have the lowest values among the largest Countries.

2.1.2.2 Sectoral efficiency and decarbonization

The comparison of efficiency and decarbonization indicators at sectoral level among Member States shows a rather heterogeneous situation (Figure 2.28). As for industry in Italy, the final energy intensity, ratio between final energy consumption and value added, has been comparable to that of Germany since 2005 and shows a decreasing trend from 2005 to 2021. Among the European Countries only Ireland, Denmark, Malta, and Estonia have lower industry energy intensities than Italy in 2021. Among the Countries examined the Netherlands and Belgium show the highest energy intensities for industry. The average annual rate of the sector energy intensity from 2005 to 2021 decreased of -1.9% for Italy against -1.5% for European average.

In commercial and public services Italy shows a countertrend of energy intensity compared to other European Countries in recent years. Italy is the only Country, among the biggest ones, whose energy intensity in the sector increased since 2005. The outcome is also due to the accounting of energy consumed by heat pumps whose data for Italy started from 2017 in EUROSTAT database, such item has significantly increased the sector energy intensity. The average annual rate of energy intensity from 2005 to 2021 shows an increase of 0.8% for Italy against a decrease of -1.3% for European average.

The agriculture sector shows a general decrease of energy intensity in EU27. In 2021, among the considered Countries, only Romania and Sweden have lower energy intensity than Italy. The average annual rate of sector energy intensity from 2005 to 2021 decreased of -0.6% for Italy against -0.4% for European average. The trend of Germany's indicator appears quite unrealistic.

Figure 2.28 – Final energy consumption per unit of sectoral value added.

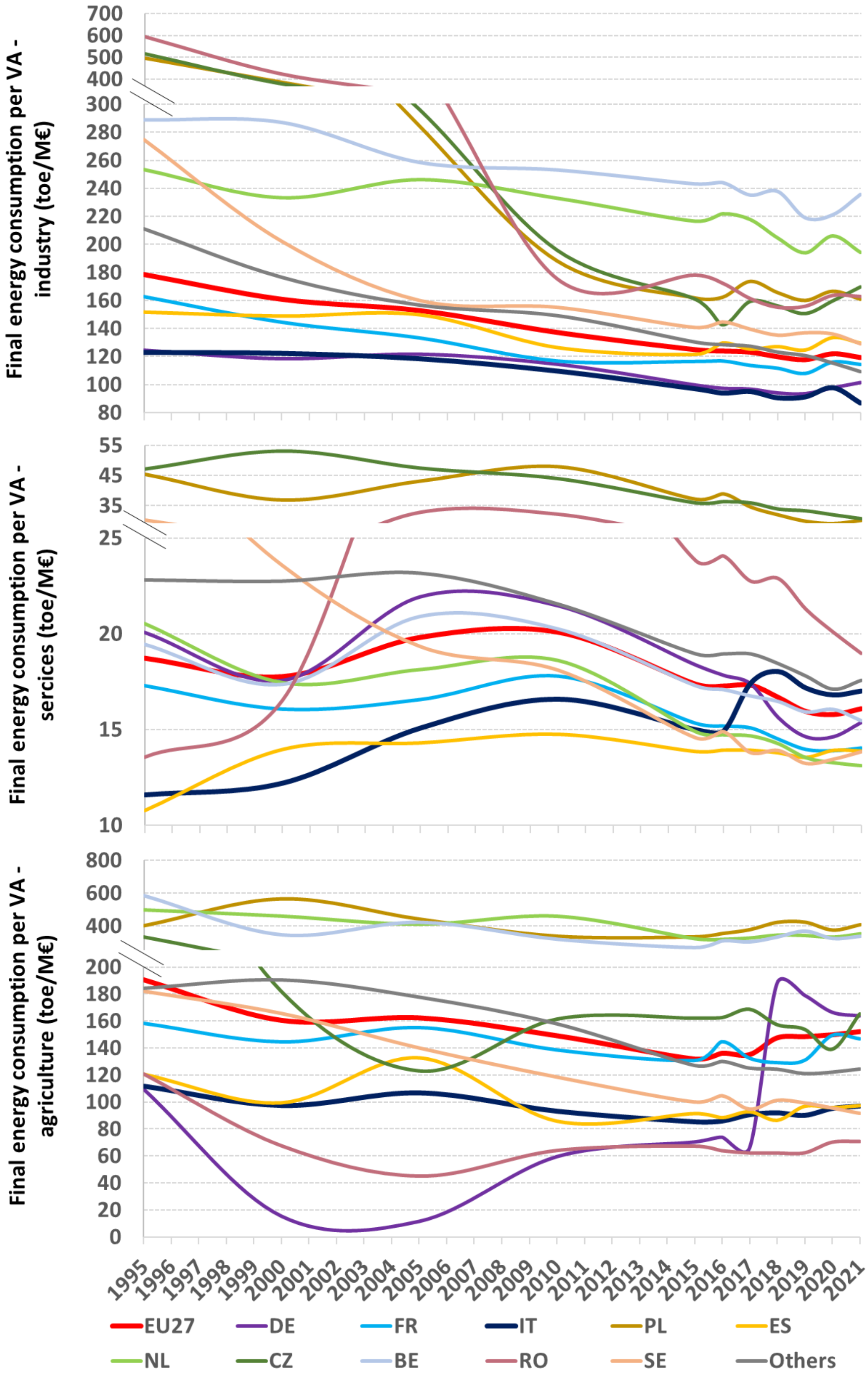
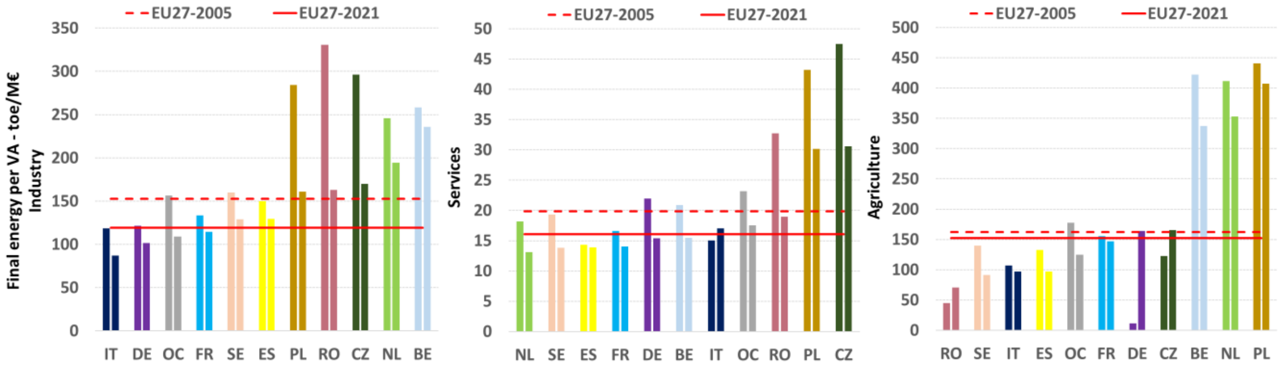


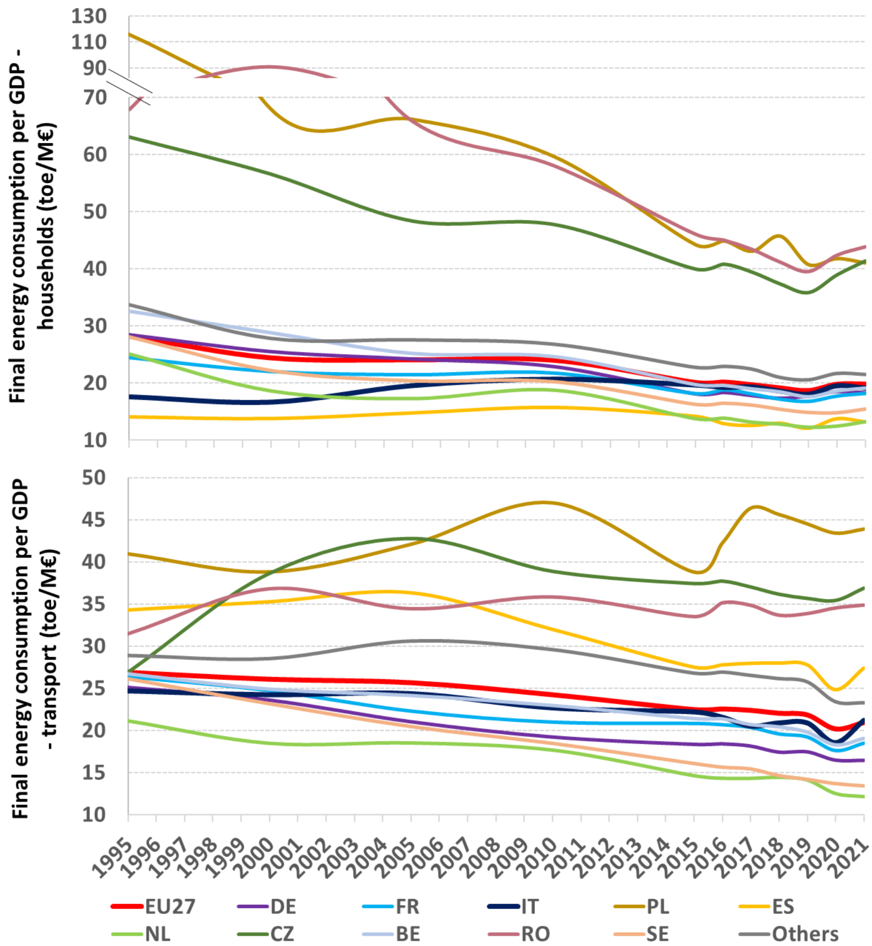
Figure 2.29 compares the final energy intensity in 2005 and 2021 for the examined Countries for the three sectors. It makes quite evident how Italy can improve the energy intensity in services.

Figure 2.29 – Final energy consumption per unit of sectoral value added in 2005 and 2021. Countries in ascending order. OC = other Countries.



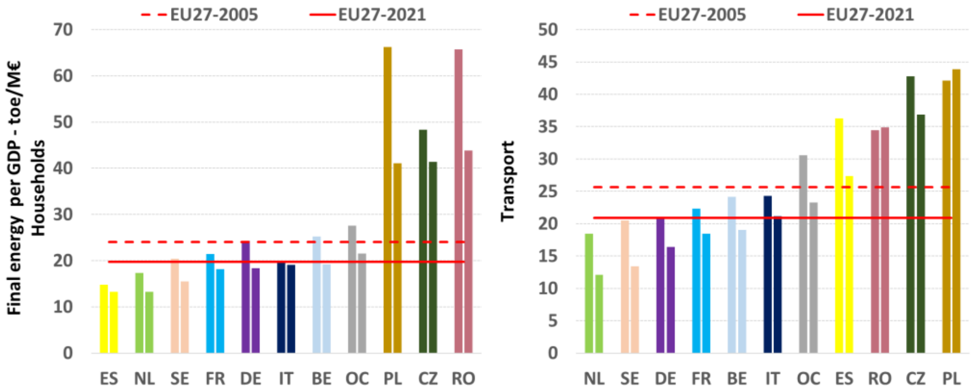
The GDP will be considered to assess the energy intensity of those sectors not directly related to value added output, such as households and transport (Figure 2.30). In the household sector, from 2005 to 2021 the biggest Countries show significative reductions of energy consumption per unit of GDP (from -0.7% per annum in Spain to -2.9% per annum in Poland), while Italy do not show any relevant change (-0.1%). The energy intensity trend for Italian transport is broadly comparable to EU27 average.

Figure 2.30 – Final energy consumption per unit of GDP.



The ranking of the examined Countries for households and transport shows that in 2021 the Italian energy intensity is near the European average and that there is wide room to improve the sectors' performance.

Figure 2.31 – Final energy consumption per unit of GDP in 2005 and 2021. Countries are in ascending order. OC = other Countries.



What is seen for energy intensity is reflected in the carbon intensity (t CO_2eq/M€), but this indicator is sensible to the role of renewable energies, nuclear power and electricity import in the Countries' energy balance because such sources do not generate GHG emissions. Among the biggest Countries, the Italian industry in 2021 has carbon intensities higher only than those of Sweden and Germany. For agriculture, the Italian carbon intensity is among the lowest in Europe, after Malta, Sweden, and Greece. The European average is 74.1% higher than the Italian intensity.

Figure 2.32 – Greenhouse gas emissions per unit of sectoral value added.

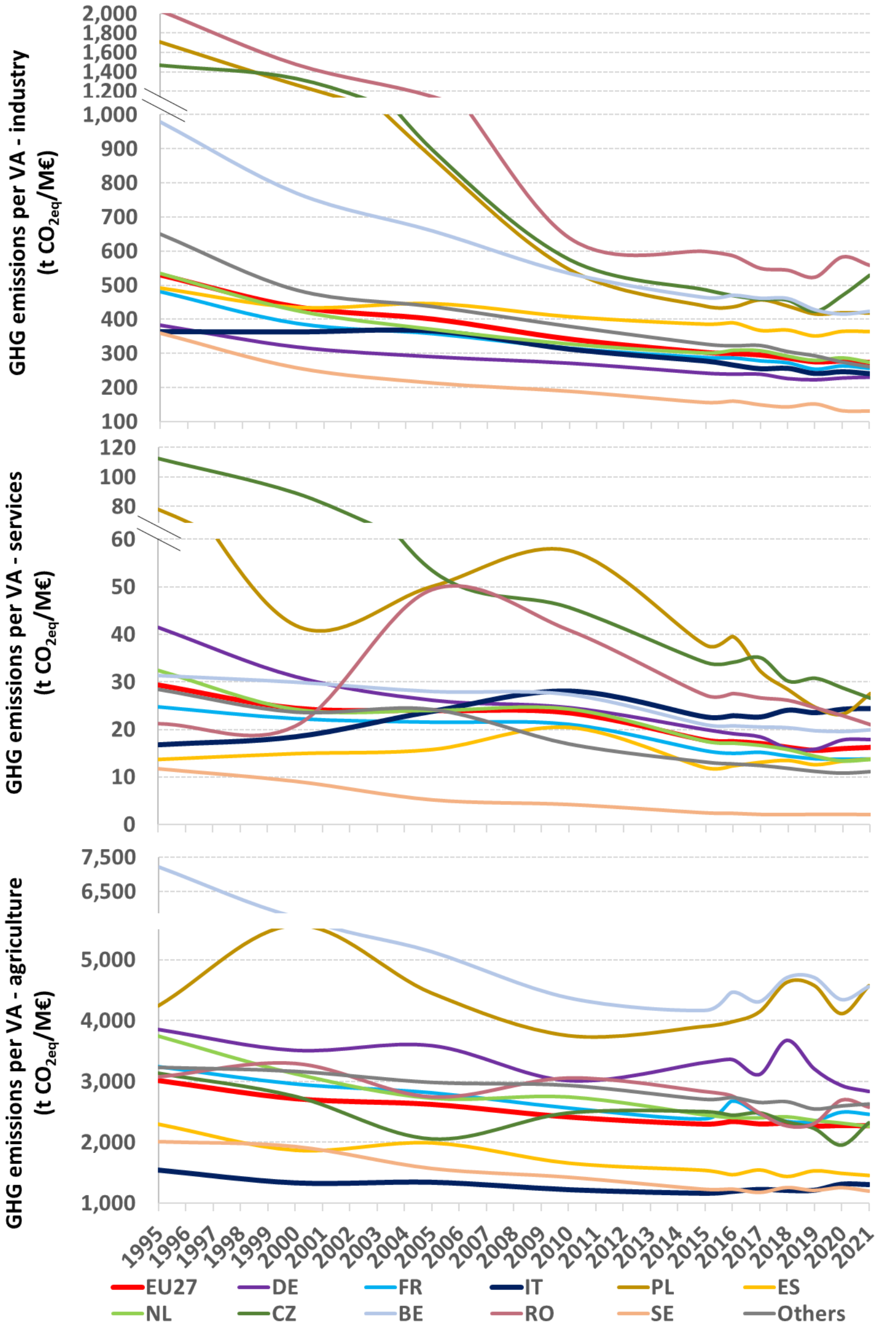
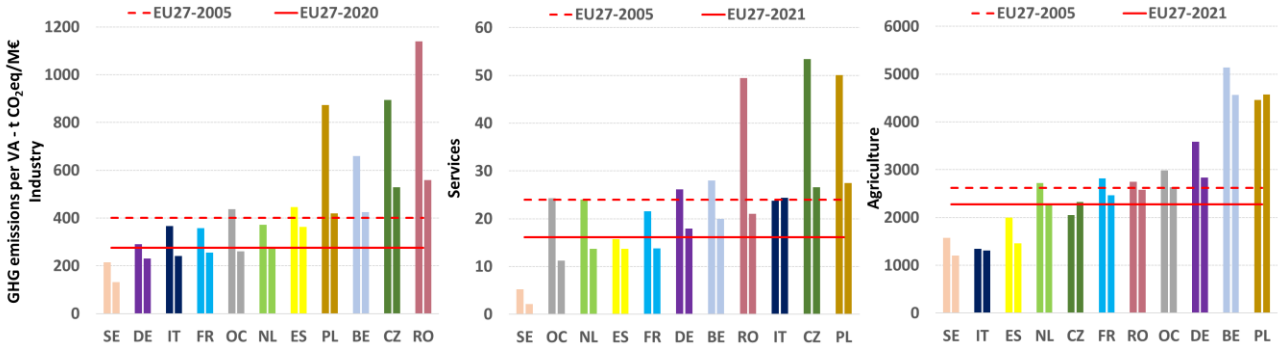
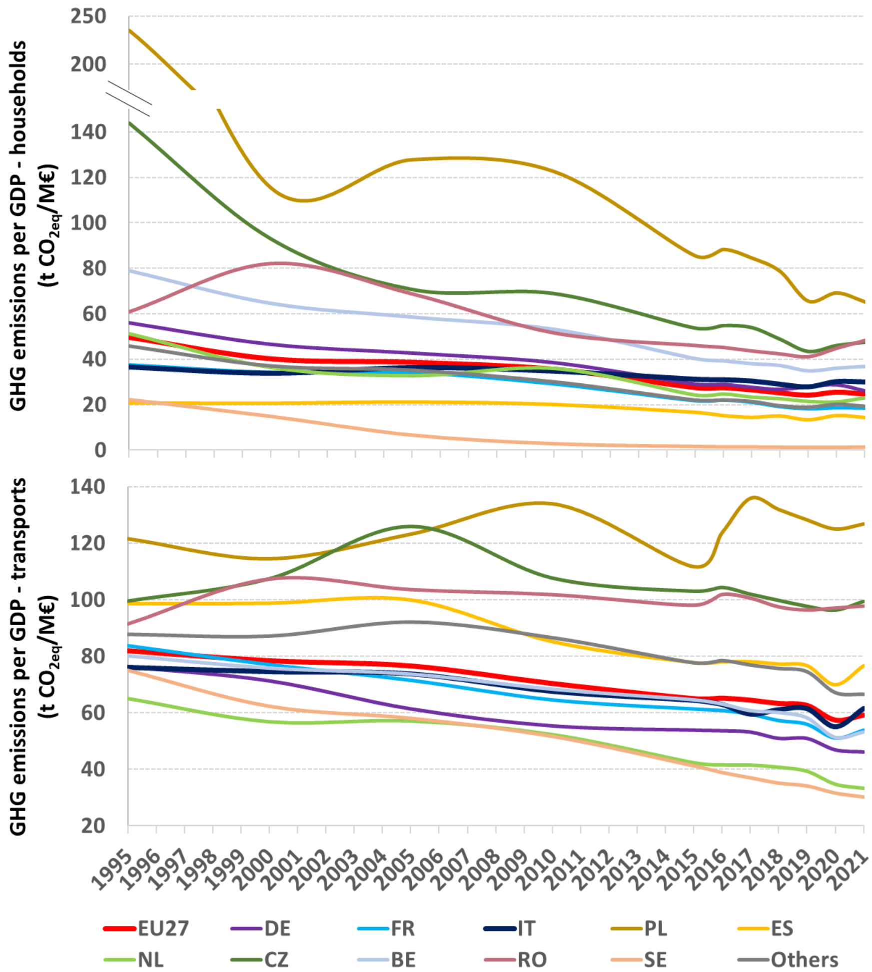


Figure 2.33 – GHG emissions per unit of sectoral value added in 2005 and 2021. Countries are in ascending order. OC = other Countries.



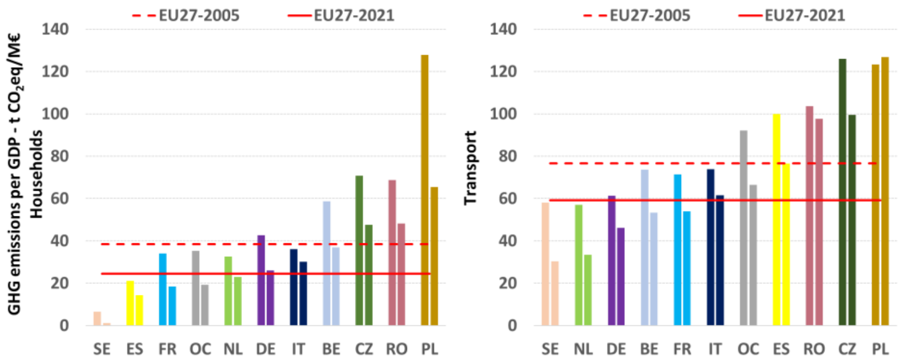
On the other hand, the civil sector (households and services) in Italy shows wide room for improvement with values higher than the EU27 average (+22.3% for households and +50.8% for services). The Italian civil sector therefore shows very wide emission reduction potentials, especially considering the sectoral electrification of final consumption in 2021 is much below the EU27 average (households: 18% *vs* 24.6%; services: 39.4% *vs* 46.3%).

Figure 2.34 – Greenhouse gas emissions per unit of GDP.



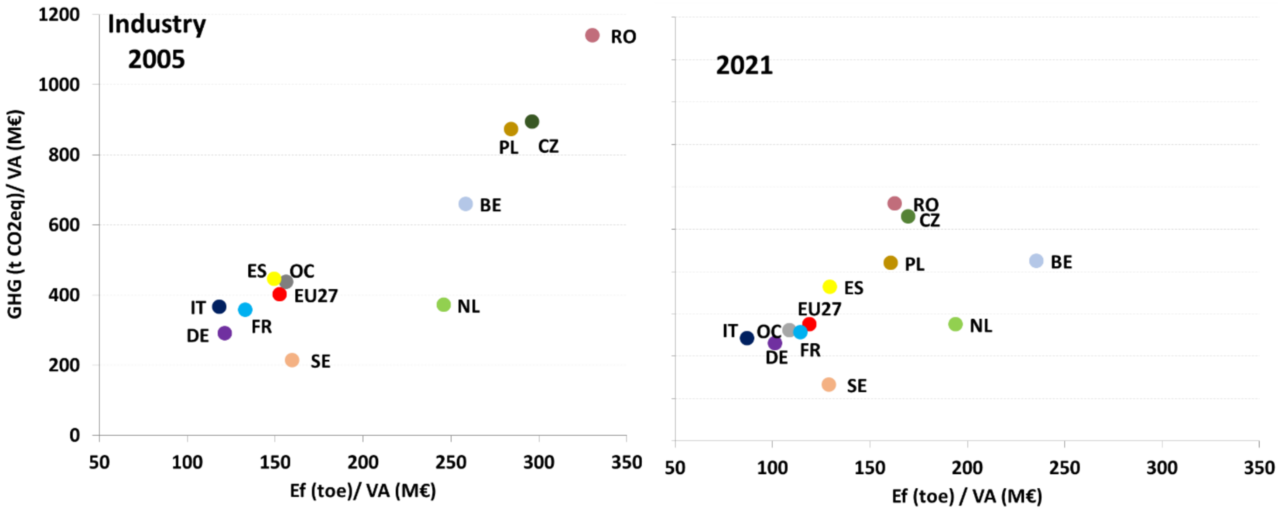
The ranking of carbon intensity in the examined Countries shows that Italy has wide room for better performances in the civil sector and transport.

Figure 2.35 – Greenhouse gas emissions per unit of GDP in 2005 and 2021. Countries are in ascending order. OC = other Countries.



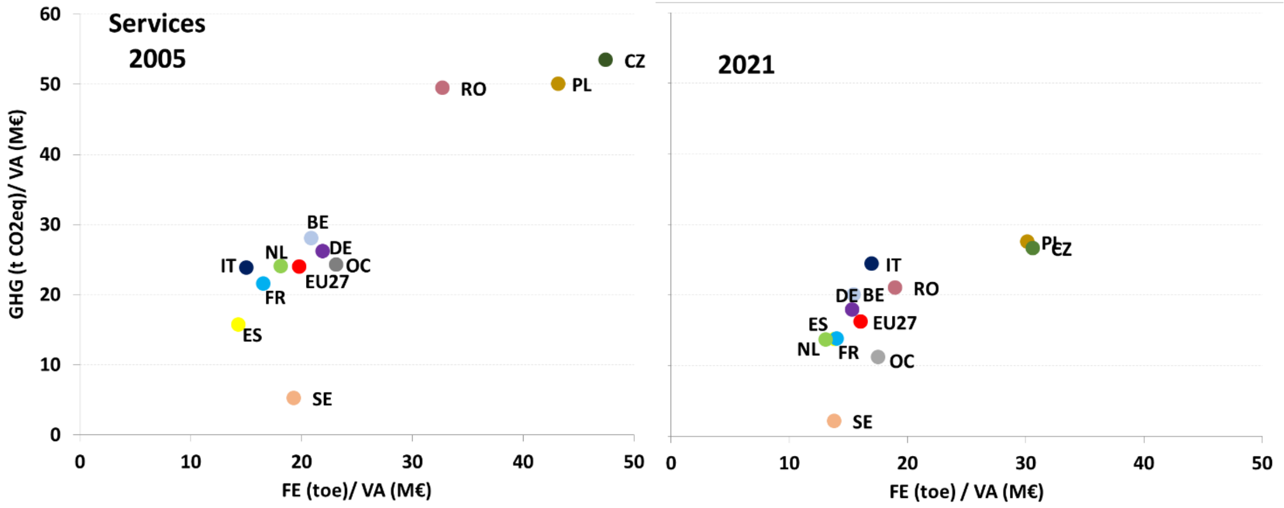
The following graphs show the position of the biggest EU States in the space defined by the carbon and final energy intensities by sector added value. For each sector, it is evident that all Countries move to the lower left corner from 2005 to 2021.

Figure 2.36 –Member States' position in the phase space defined by energy (abscissa) and carbon intensities (ordinate) by value added of industry for the biggest European Countries and for the groups of other Countries.



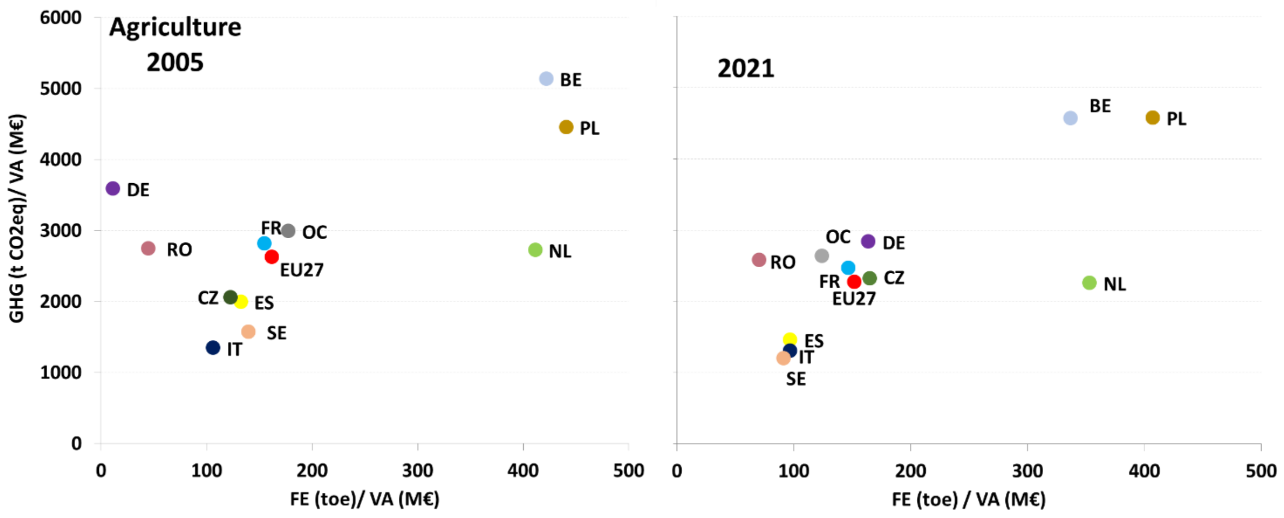
Unlike industry, the intensity for services shows that Italy has lost many positions compared to other Countries. Energy intensity increased from 15.1 toe/M€ to 17 toe/M€ from 2005 to 2021 and carbon intensity increased from 23.8 t CO_2eq/M€ to 24.4 t CO_2eq/M€, while all other Countries and EU27 show significative decreases.

Figure 2.37 –Member States' position in the phase space defined by energy (abscissa) and carbon intensities (ordinate) by value added of services for the biggest European Countries and for the groups of other Countries.



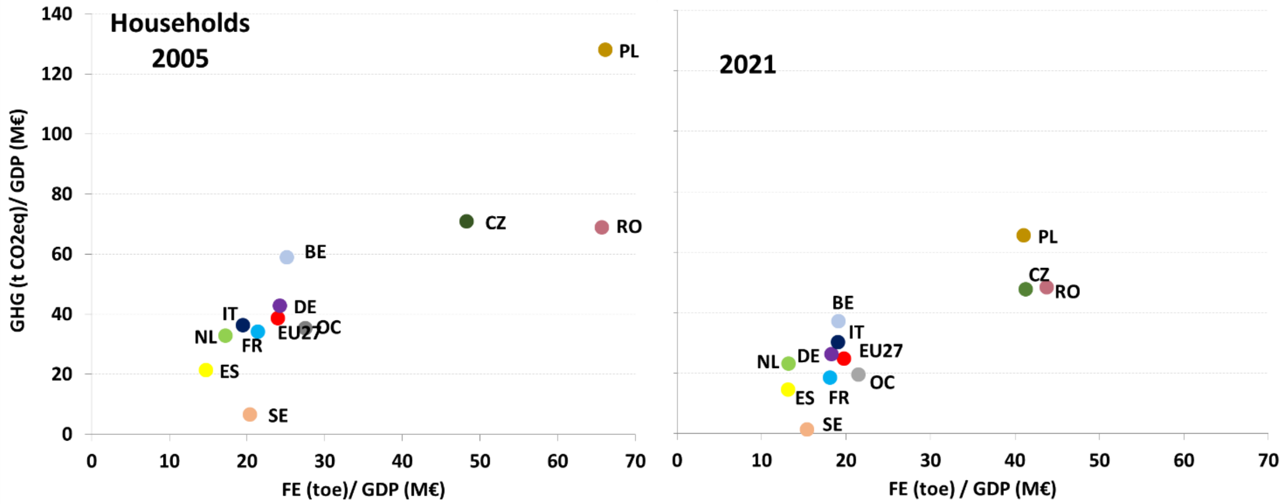
The agriculture is the sector with highest intensities and the following graph shows that in 2021 Italy occupies the position at the lower left corner of the graph, together with Sweden and Spain.

Figure 2.38 –Member States' position in the phase space defined by energy (abscissa) and carbon intensities (ordinate) by value added of agriculture for the biggest European Countries and for the groups of other Countries.



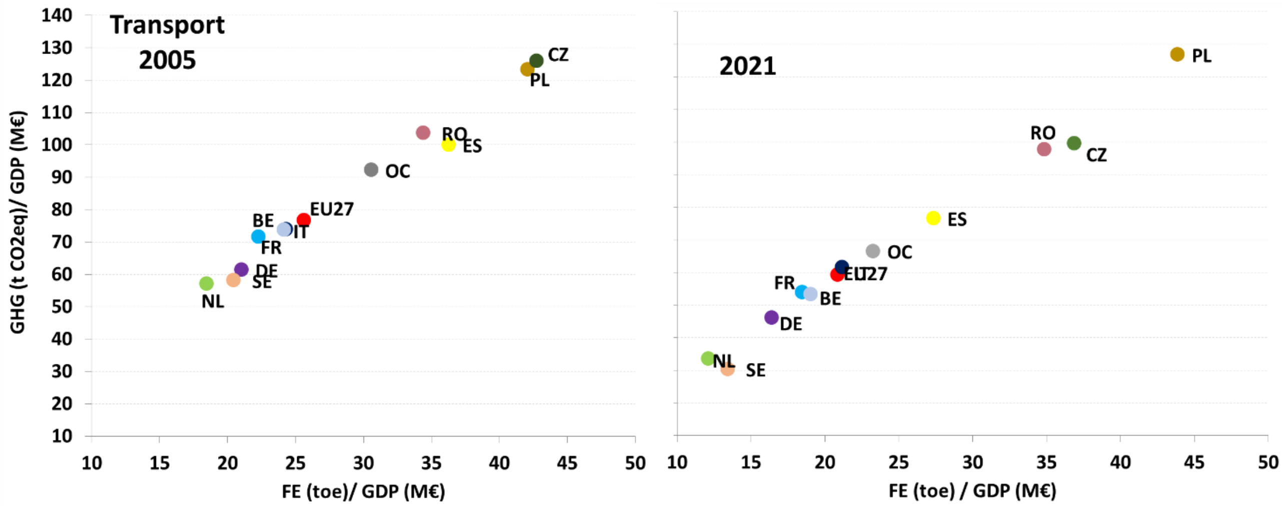
For the household and transport sectors, the intensities related to GDP are reported in the following graphs. For the household sector, too, the Italian intensity has been overcome or reached by Countries that had higher values in 2005, such as Germany and Belgium.

Figure 2.39 –Member States' position in the phase space defined by energy (abscissa) and carbon intensities (ordinate) by GDP of households for the biggest European Countries and for the groups of other Countries.



The sector of transport shows the high linear correlation between GHG emissions and energy consumption, mainly made up of fossil fuels. For this sector too, it is possible to observe the shift of Countries towards lower carbon and energy intensities, except for Poland, which recorded an increase of both intensities.

Figure 2.40 –Member States' position in the phase space defined by energy (abscissa) and carbon intensities (ordinate) by GDP of transport for the biggest European Countries and for the groups of other Countries.



2.1.3 Material flow accounts

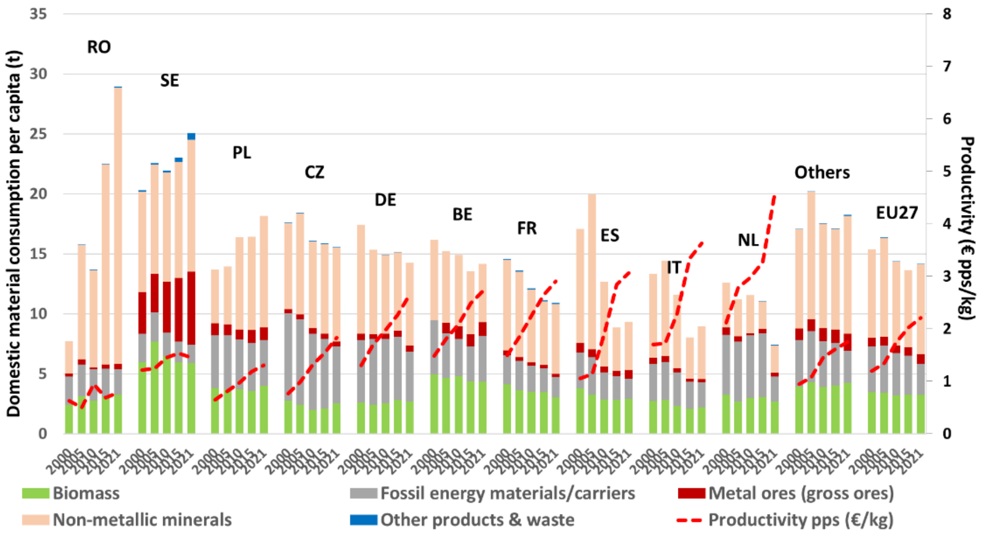
This paragraph compares material flow accounts among Countries *(EW-MFA Economy Wide - Material flow Accounts)*. The material flows for Italy are processed by ISTAT (2022) and communicated to EUROSTAT in whose database the material flows of the other Member States are also available (last update on 1st July 2022). For Italy, the historical series is drawn up from 1990 to 2021 (provisional data). The availability of data from other Countries allows comparison only from 2000.

The EW-MFA is a measure of the interactions between the environment and the anthropogenic system, that is, the exploitation of resources used in human activities. EW-MFA provides an aggregate measure (mass) of material flows in and out of an economic system. In Eurostat's EW-MFA material inputs to the economy cover extractions of natural resources (excluding water and air) from the natural environment and imports of material products (goods) from the rest of the world economy. Material outputs are disposals of materials to the natural environment and exports of material products and waste to the rest of the world. EW-MFA is a satellite account of national accounts prepared by ISTAT in accordance with the European Regulation 691/2011 on environmental accounting and is developed with harmonized methodologies at European and international level (ISTAT, 2022).

Indicators of *direct material inputs (DMI)* and *domestic material consumption (DMC)* describe, in aggregate terms, the direct use and provenance of natural resources and products. The first indicator includes all materials which have an economic value and are used for production and consumption activities and the indicator is calculated as the sum of internal extractions and imports. The second indicator represents domestic consumption of matter in the national economy net of exports and is calculated by subtracting from direct material inputs the share of physical exports. The indicators make possible to analyse the material aspects of socio-economic metabolism related to the environmental sustainability of production and consumption patterns, and - in conjunction with the traditional national accounts, with which they are consistent - allow economic activity to be dissociated from environmental pressures and the intensity/efficiency of resource use (Femia and Paolantoni, 2012; Paolantoni and Femia, 2016). One economic system which, with the same flow of matter, produces more wealth than another is a more efficient system.

Since 2000, there has been a decrease of average DMC per capita in the European Countries. In 2021 the Netherlands has the lowest consumption per capita of matter among all EU27 Countries followed by Italy with the 2nd lowest value. As for resource productivity there is a general increase since 2000, although the absolute values of the Countries are very different. The average annual growth rates among the biggest Countries range from 0.8% for Sweden to 5.2% for Spain; Italy's annual rate is 3.7%. The Netherlands shows the highest value (5.7 €/kg in 2021), followed by Italy (3.4 €/kg). Germany and France productivities are 2.7 €/kg and 3.1 €/kg, respectively.

Figure 2.41 – Domestic material consumption per capita by type of material and resource productivity at purchasing power standard. Countries sorted in descending order by DMC per capita in 2021.

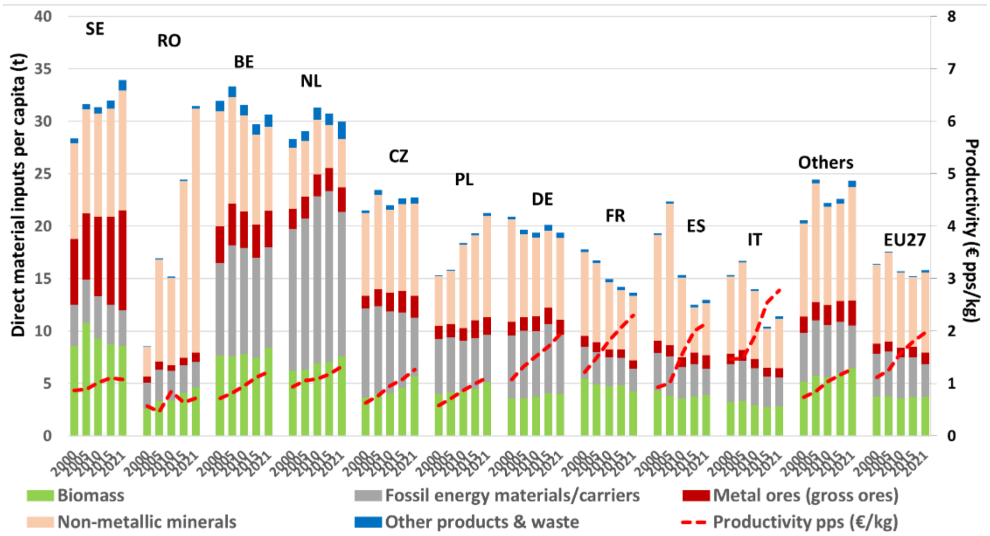


As already reported, direct material inputs (DMI) include all materials which are economically valued and are directly used in production and consumption activities. Such indicator is equal to the sum of internal extractions and imports. Since this indicator represents domestic consumption without exports, it is useful for assessing actual material consumption, including that not used in domestic production and consumption activities and addressed to exports.

The following graph, realized in the same way as the previous one, shows the direct material inputs per capita and the resource productivity. Sweden, Romania, Belgium, and the Netherlands have high share of fossil extraction, biomass, and metal ores destined for exports and shows the highest DMI per capita among the biggest European Countries, far above the European average. It is also clear the increasing DMI per capita recorded in Romania. Italy recorded in 2021 the lowest value among all European Countries (11.4 t per capita *vs* EU27 average of 15.8 t per capita).

As for resource productivity Italy have the 2nd highest value among the European Countries (2.67 €/kg), the 1st one is recorded for Ireland (2.72 €/kg). The productivity of the Netherlands for this indicator (1.4 €/kg) do not show high performance as for DMC.

Figure 2.42 – Direct material inputs by type of material per capita and resource productivity at purchasing power standard. Countries sorted in descending order by DMI per capita in 2021.



The direct material inputs are far greater than the domestic material consumption due to the amount of material exported. The surplus percentage of DMI per capita relative to DMC per capita is on average 11.7% for EU27 in 2021, and ranges from 8.6% in Romania to 303.1% in the Netherlands. The share of export is quite relevant also for Belgium with a surplus of 119.3%. The Italian figure is 28.6%, in line with the other biggest Countries (France 25.3%; Germany 36.2%; Spain 41.9%).

It should be noted that the productivity reciprocal is an indicator of material intensity (Fischer-Kowalski *et al.*, 2011), *i.e.,* a measure of the exploitation of material resources. The Countries with the lowest productivity are therefore the Countries with the greatest pressure on their material reserves.

Although productivity provides information on the economic efficiency of the whole system, it is nevertheless necessary to consider that efficiency depends not only on maximizing the performance of the material used but also on structural factors. In this sense, the Country's economy structure plays a decisive role as concerns the material consumption. A service-based economy will have lower material consumption than an economy based more on manufacturing industry. Industrial activities are more energy-intensive than service activities. This is true to a greater extent for the material consumption which is the subject of extraction and transformation of industrial activities.

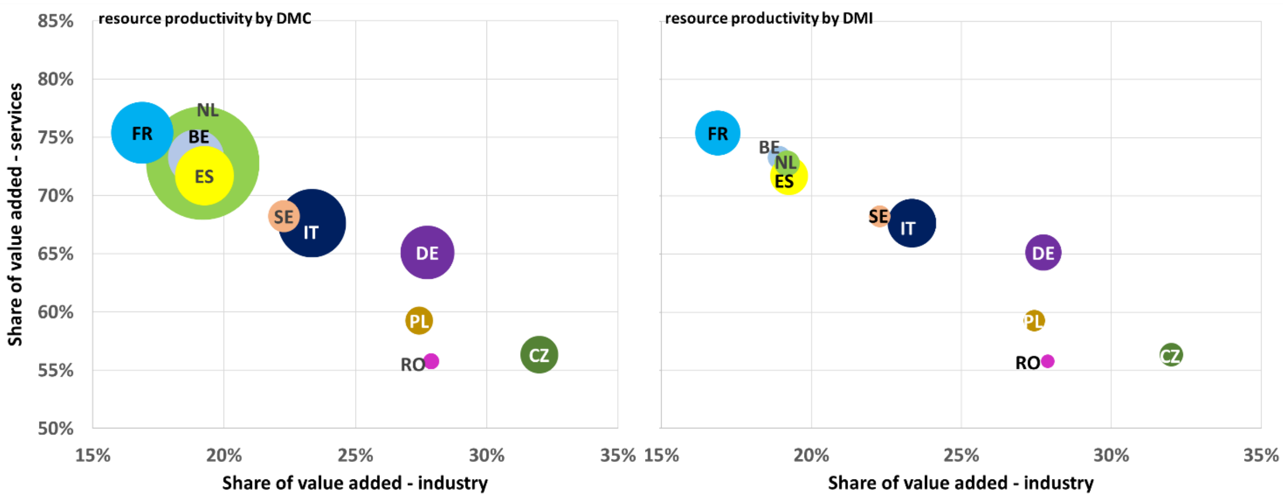
The resource productivity depends jointly both on the efficiency of resource use in each sector and on sector's share for each State. Material consumption at sectoral level is not available but it is possible to assess the role of each sector using *proxy* variables to unbundle material consumptions at the sector level. To assess the impact of economic sectors on the productivity index, final energy consumption was used as a proxy to disaggregate the material consumption among sectors. The material consumption, like energy consumption, also takes place in sectors that do not have a corresponding value added, such as the households and transport sectors. In addition, transport is a cross-cutting sector which contributes to the value added of the productive sectors. No breakdown of transport energy consumption in the economic sectors was made for the following elaboration. The purpose of the breakdown is to assess the productivity range of the following economic sectors: industry (including construction), services and agriculture.

Domestic material consumption of each Country has been broken down into sectors (including households and transport) according to their share of final energy consumption. The value added for industry and construction, services and agriculture has been divided by their estimated material consumption. Sectoral productivity highlights the contribution of each sector to total productivity. The following graph makes it clear that a predominantly service-based economy has a higher resource productivity than an industry-based economy regardless of the efficiency of individual sectors. The median sector productivity in 2021 is € 1/kg in the industry and construction as well in agriculture, and € 7/kg in services.

The sectoral productivities in the Countries examined range from 0.3 €/kg (Romania) to 2.6 €/kg (Italy) for industry and construction, 2.5 €/kg (Romania) to 32.9 €/kg (the Netherlands) for services and 0.3 €/kg (Poland) to 2.3 €/kg (Italy) for agriculture. Such values should be read considering the share of value added from services and industry in the Countries' economy.

The following graph summarize the resource productivity for each Country considering the relative positioning of the Countries' economy in the industry/service space. The left side graph shows that Italy, despite having a higher share of industrial value added than France and Spain, has higher productivity (DMC), a clear result of greater efficiency in the use of resources, mainly in the industrial sector. This result is in line with what was previously seen for energy intensity indicators. Considering the DMI the right side graph shows that the productivity is significantly lower than for DMC. Productivity in the Netherlands falls by 75.2% compared to DMC productivity. For the other Countries the decrease ranges from 7.9% for Romania to 54.4% for Belgium. The Italian figure is 22.2%.

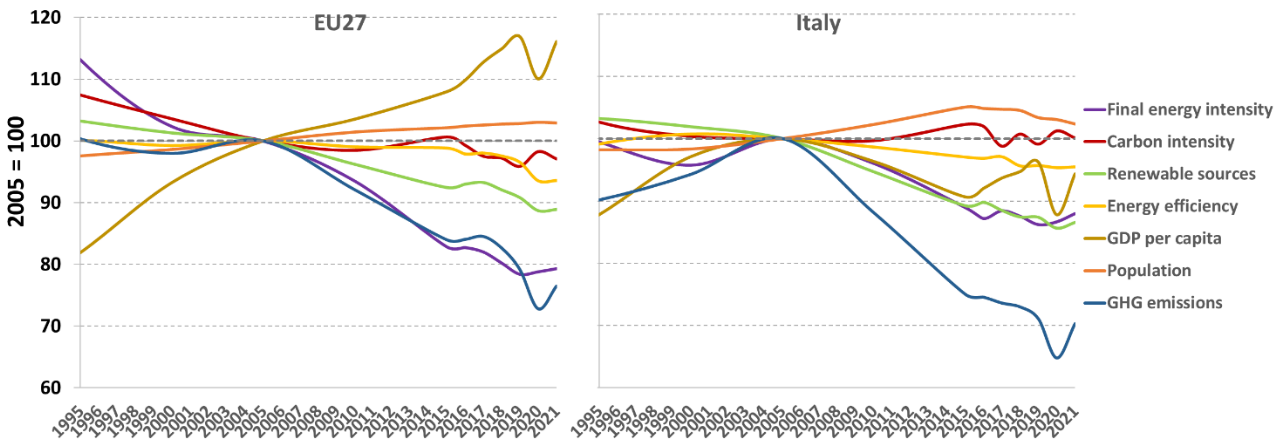
Figure 2.43 – Examined Countries arranged in the space defined by the percentage of added value of industry (abscissa) and services (ordinate). For each Country the circle size is proportional to the resource productivity for the domestic material consumption (left) and direct material inputs (right).



2.1.4 Kaya Identity and decomposition analysis

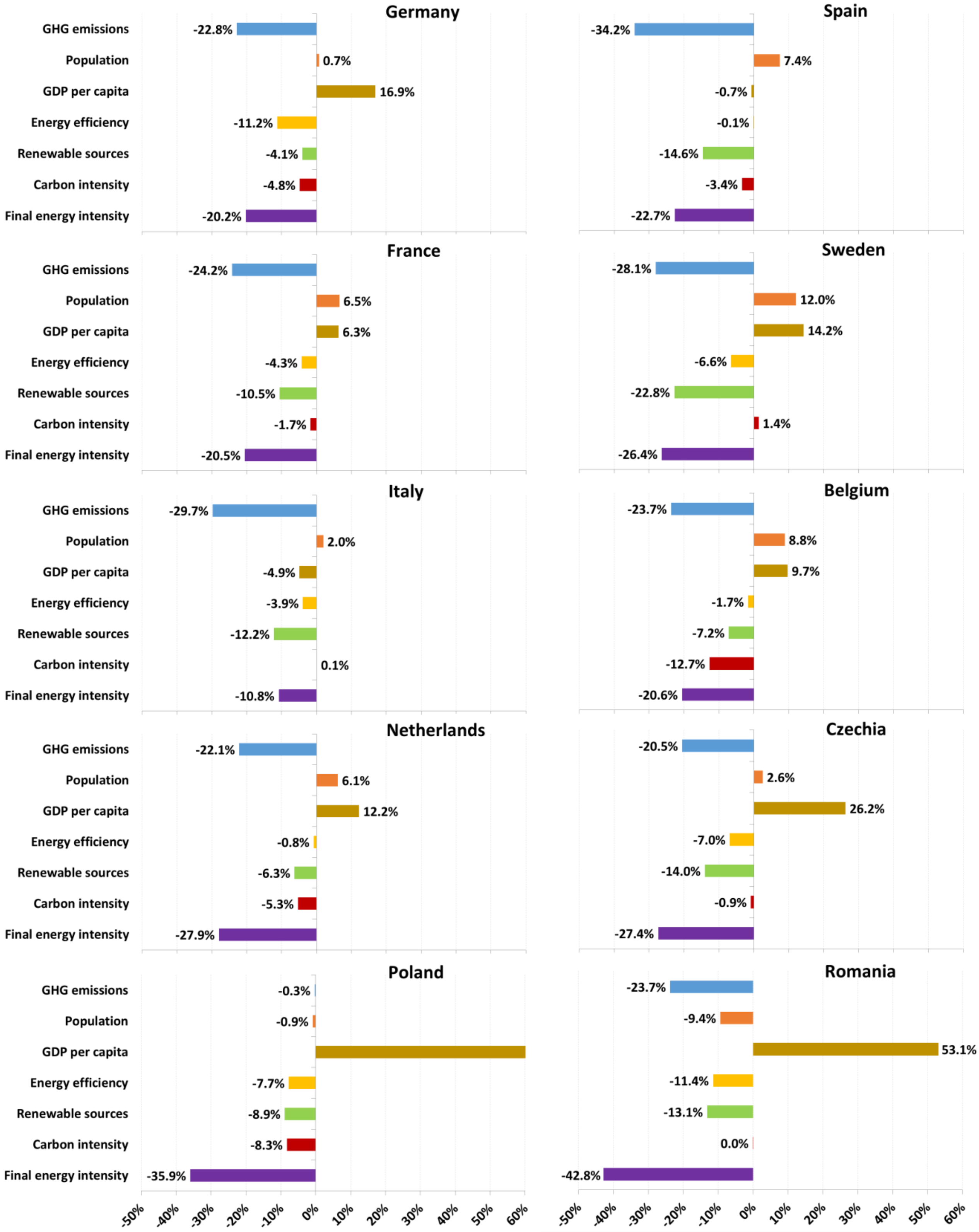
The same factors considered to carry out the analysis on Italian data are considered for the European data. The trend of *kaya identity* parameters for EU27 and Italy in the period 1995-2021 shows a quite different pattern as for the driving factors in GHG reductions. Whereas in EU27 the most powerful factor seems to be the final energy intensity, in Italy both renewable sources and final energy intensity (final energy consumed per unit of GDP) are the driving factors. Moreover, in EU27 population and GDP increase their trend, while in Italy such factors have downward trend. The GHG emission change is the integrated result of the driving factors change. So, in EU27 is evident an absolute decoupling between economy and GHG emissions while in Italy only a relative decoupling is recorded.

Figure 2.44 – Trend of Kaya identity parameters normalized to 2005 in EU27 and Italy.



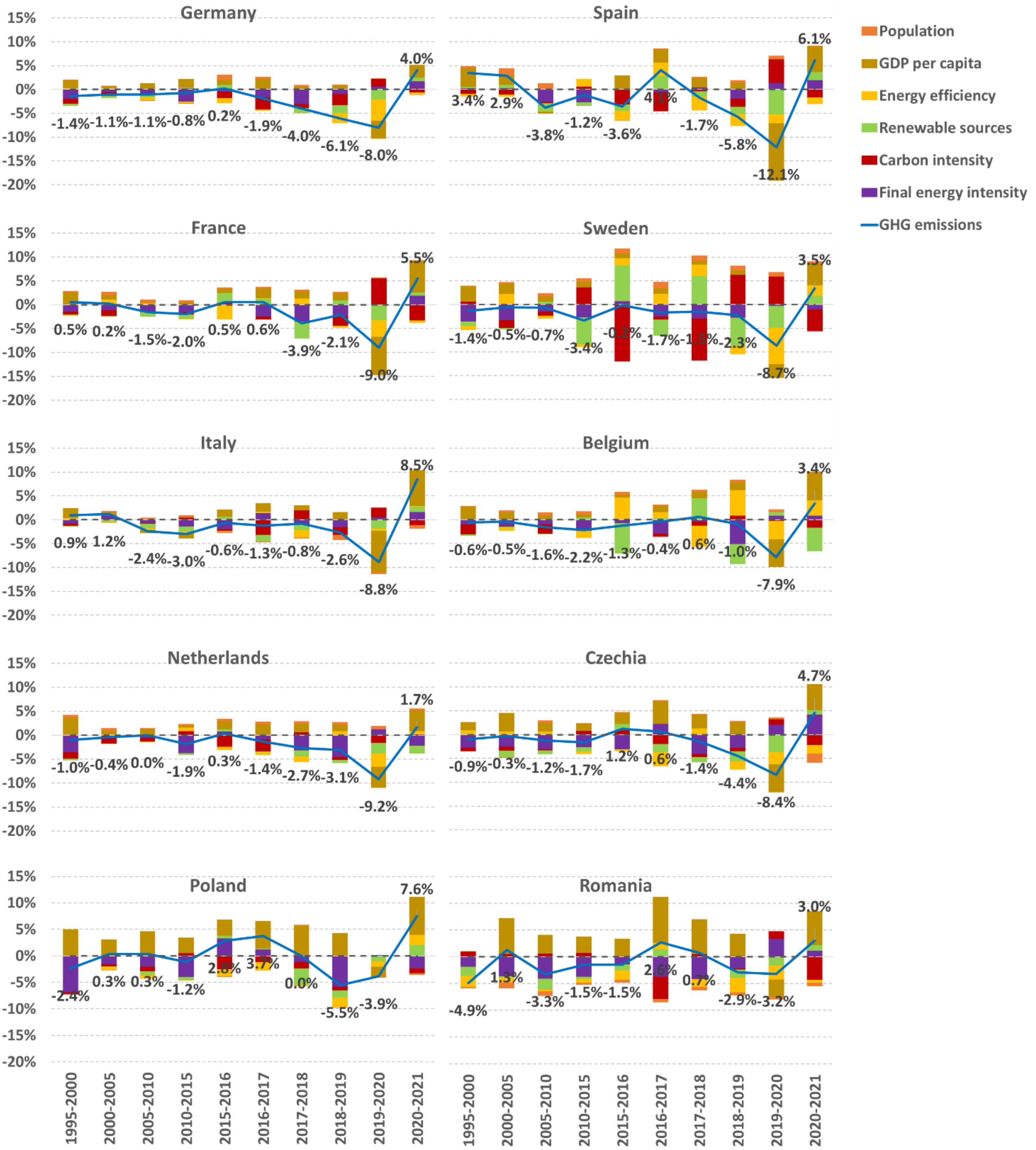
Decomposition analysis for the EU biggest Countries and Italy, carried out according *Logarithmic mean Divisia index* (Ang, 2005), allows to quantify the role of each factor to reduce the GHG emissions. The outcome of the analysis in Italy has been shown in paragraph 1.2.2. The outcomes of decomposition analysis show that in Italy the improvement of final energy efficiency played a less important role than in other Countries because of the better performance of the indicator in Italy already in 2005. Moreover, unlike Italy most Countries recorded the sensible increase of GDP per capita since 2005.

Figure 2.45 – Decomposition of GHG emissions in the period 2005-2021 in the biggest Countries.



The following graph provides the detail of decomposition analysis in the time frame considered since 1995. The analysis up to 2015 has been carried out on five years basis, while after 2015 a year-by-year GHG emission change has been decomposed in the driving factors. The examined Countries show differentiated patterns and different GHG trends, but it is possible to find a quite common frame as the relevant acceleration of GHG reduction since 2018 compared to 2017. The further decrease in 2020 compared to 2019 was mainly due to the economy factor which faced the sharp contraction because of the effect of the measures adopted to contrast the pandemic. The economy rebound in 2021 determined the GHG emissions increase in all Countries, although with different rate.

Figure 2.46 – Decomposition of GHG emissions in the biggest Countries since 1995 for the shown time frame. The average annual rate of GHG emissions is reported.



In summary, higher decoupling between economy factor and GHG emissions has been observed in any Countries than that recorded in Italy and the contraction of economy played a role to decrease the emissions in Italy more relevant than in other Countries.

The decoupling does not necessarily correspond to emission reductions in line with the targets. According to EEA (2022), among the largest Countries, in Germany the effort sharing emissions exceeded the available national annual emission allocations; regarding renewable energy, France do not meet the 2020 renewable share target outlined in its national renewable energy action plans; as for efficiency target Germany, Belgium, and Sweden, among the biggest Countries, had not reduced their final energy consumption enough to meet their 2020 final energy targets. In relation to the indicative targets for primary energy consumption, Belgium and Poland had not met their 2020 targets. Moreover, it should be emphasized that the decomposition analysis focuses on the relative change of the parameters, without assigning any weight to the starting points. The absolute values of parameters and relative trends in the biggest European Countries have been investigated in the previous paragraphs. As already mentioned, the economic and energy efficiency of the Italian system is among the highest in Europe. The last edition of the *International Energy Efficiency Scorecard*, issued by ACEEE in 2022, reported for Italy the drop of four ranks since the previous edition in 2018, mainly due to buildings section, but Italy managed to rank within the top five, after France, UK, Germany, and the Netherlands. The ACEEE International Energy Efficiency Scorecard evaluates the efficiency policies and performance of 25 of the most energy-consuming Countries globally. ACEEE used 36 metrics, both policy and performance-oriented metrics, to score each Country's efforts to save energy and reduce greenhouse gas emissions across four categories: buildings, industry, transportation, and overall national energy efficiency progress. "*Policy metrics highlight best practices in government actions and can be either qualitative or quantitative. Examples include national targets for energy efficiency, building and appliance labelling, and fuel economy standards for vehicles. The performance-oriented metrics are quantitative and measure energy use per unit of activity or service extracted. Examples include the efficiency of thermal power plants, energy intensities of buildings and industry, and average on-road vehicle fuel economy.*" (Subramanian *et al*., 2022).

The efficiency improvement cannot be separated from the assessment of the potentials and cost effectiveness of the energy system change, as well as a mindful assessment of the economy structure must be considered, especially concerning the role of services and industry.

2.2 Power sector

Data of power sector are from EUROSTAT database as for §2.1. Fuels are considered according to EUROSTAT nomenclature. Default emission factors for CO_2, CH_4, and N_2O (IPCC, 2006, 2019; Table 2.1) and GWP from AR5 (IPCC, 2013) have been applied to esteem GHG emissions.

Table 2.1 – List of fuels used in the thermoelectric sector according to the EUROSTAT classification and default emission factors of CO2, CH4, and N2O for stationary sources in the energy industries (IPCC, 2006).

Type	Fuels	Emission factors		
		CO_2 t/TJ	CH_4 kg/TJ	N_2O kg/TJ
Solid	Patent fuels	97.5	1.0	1.5
	Anthracite	98.3	1.0	1.5
	Coking coal	94.6	1.0	1.5
	Other bituminous coal	94.6	1.0	1.5
	Sub bituminous coal	96.1	1.0	1.5
	Coke oven coke	107.0	1.0	1.5
	Gas coke	107.0	1.0	0.1
	Coal tar	80.7	1.0	1.5
	Lignite	101.0	1.0	1.5
	Brown coal briquettes	97.5	1.0	1.5
	Peat	106.0	1.0	1.5
	Peat products	106.0	1.0	1.5
	Oil shale and oil sands	107.0	1.0	1.5
Oil	Crude oil	73.3	3.0	0.6
	Natural gas liquid	64.2	3.0	0.6
	Refinery gas/Refinery feedstocks	57.6	1.0	0.1
	Liquefied petroleum gas	63.1	1.0	0.1
	Other kerosene	71.9	3.0	0.6
	Kerosene-type jet fuel (excluding biofuel portion)	71.5	3.0	0.6
	Naphtha	73.3	3.0	0.6
	Gas oil and diesel oil (excluding biofuel portion)	74.1	3.0	0.6
	Fuel oil	77.4	3.0	0.6
	Bitumen	80.7	3.0	0.6
	Petroleum coke	97.7	3.0	0.6
	Other oil products n.e.c.	73.3	3.0	0.6
Natural gas	Natural gas	56.1	1.0	0.1
Derived gases	Coke oven gas	44.4	1.0	0.1
	Blast furnace gas	260.0	1.0	0.1
	Gas works gas	44.4	1.0	0.1
	Other recovered gases	50.3	1.0	0.1
Other non-renewable	Industrial waste (non-renewable)	143.0	30.0	4.0
	Non-renewable municipal waste	91.7	30.0	4.0
Other renewables	Renewable municipal waste	-	30.0	4.0
	Primary solid biofuels	-	30.0	100.0
	Biogases	-	1.0	0.1
	Pure biodiesel	-	3.0	0.6
	Other liquid biofuels	-	3.0	0.6

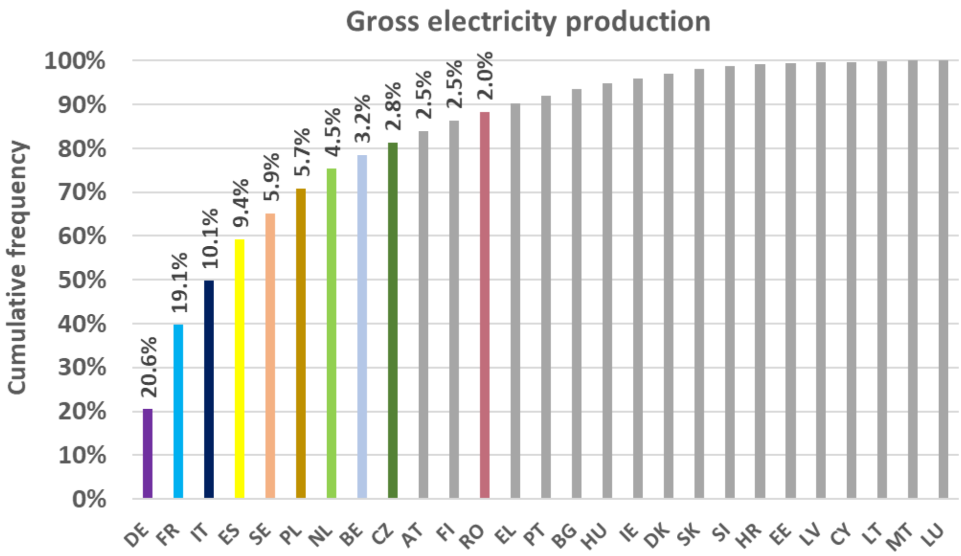
The power sector is one of the largest GHG emission sources in Europe. Sector 1.A.1.a., according to the classification adopted by the Common Reporting Formats submitted to UNFCCC, represents emissions from "Public electricity and heat production", i.e. thermoelectric plants that supply electricity to the grid.

The sector's GHG emissions in 2005 in EU27 were around 33.5% of the energy emissions and about 26.4% of total emissions, both shares sharply decreasing to 26.9% and 20.7% in 2021, respectively. However, it should be noted that sector 1.A.1.a does not represent the whole electricity system, since emissions from auto producers shall be allocated/accounted for in the specific categories and subcategories (refineries, other energy industries, iron and steel plants and other manufacturing industries) of the Energy sector. In 2005, auto produced electricity from fossil energy in EU27 accounted for 12.3% with an increasing share up to 19.1% in 2021. GHG emissions due to electricity generation are therefore higher than the figures reported in sector 1.A.1.a. of CRF.

The sector is therefore one of the main targets for measures aimed to decarbonize the economy, both for the amount of emissions and for the renewable energy potential. The Countries examined for comparison with Italy account for 83.4% of EU27 gross electricity production in 2021. Since 2005, such sources have more than doubled their share of electricity production in EU27 from 15.5% to 37.3% in 2021. Moreover, the power sector is characterized by a relatively small number of large point sources, unlike other sectors, such as transport, which is equally relevant in emissive terms although characterized by millions of small and mobile sources with greater inertia as far as the deployment of renewable energies is concerned. Therefore, the electrification of final consumption is a key strategy to achieve the decarbonization.

The analysis of the main parameters of the electricity sector will concern the selected European Countries, as illustrated in the previous chapter, and at aggregate level the group of other Countries and EU27. The Countries examined for comparison with Italy account for 83.4% of EU27 gross electricity production in 2021.

Figure 2.47 – Cumulative frequencies for gross electricity production in the EU27 Countries in 2021. The labels of Country frequencies higher than 2% are reported.



The amounts of energy allocated to the production of electricity and heat in cogeneration plants have been calculated according to the methodology proposed by EUROSTAT (2016) for the compilation of national questionnaires by Member States.

The following equation defines the total efficiency (ε):

$$\varepsilon = (H + E) / F \qquad (1)$$

where H is the heat produced, E is the electricity produced and F is the fuel energy.

The fuel used for electricity production, F*e*, and that used for heat production, F*h*, are given by the equations:

$$Fe = F - (H / \varepsilon = F \times [E/ (E + H)] \quad (2)$$

$$Fh = F - (E / \varepsilon = F \times [H/ (E + H)] \quad (3)$$

In this way it is possible to allocate the fuel energy used in cogeneration plants for the production of electricity and heat in order to calculate the emission factor for electricity production.

The total efficiency (ε_t) and the electrical efficiency (ε_{el}) are calculated with the equations:

$$\varepsilon_t = (H + E) / F \quad (4)$$

$$\varepsilon_{el} = E / F \quad (5)$$

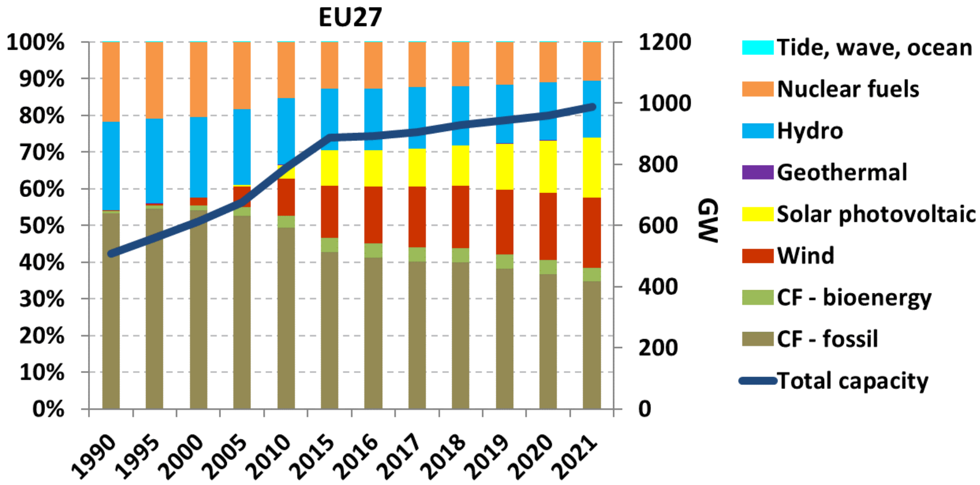
Another way for comparing the electrical efficiency of different Countries considers only the share of fuel allocated to electricity generation after having parted the share of fuel for heat generation (according to equations 2 and 3). The electrical efficiency thus defined (equivalent electrical efficiency), ε'_{el}, will be given by the equation:

$$\varepsilon'_{el} = E / Fe \quad (6)$$

2.2.1 Power capacity and electricity production

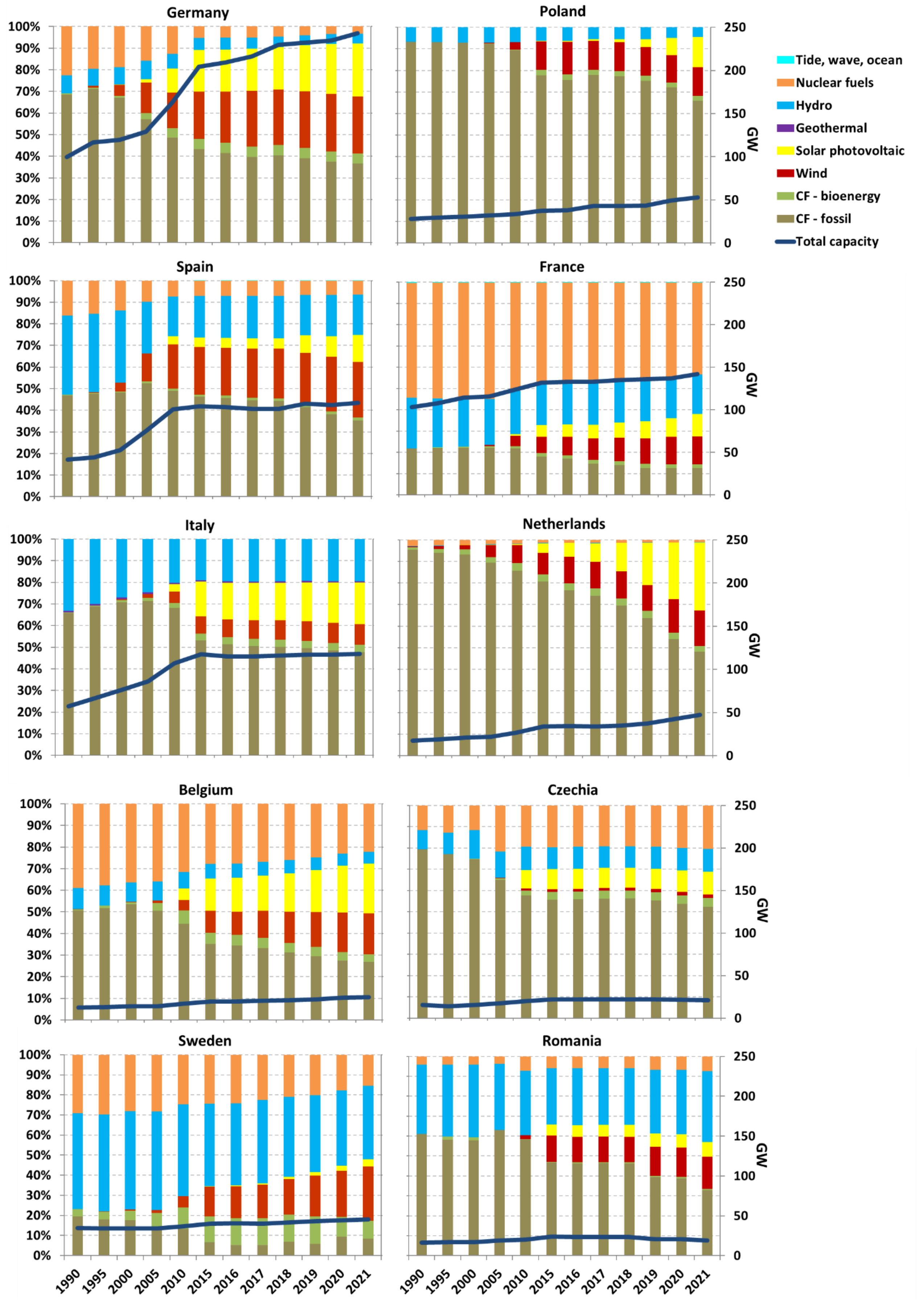
The installed capacity in 1990 consisted mainly of thermoelectric plants (54% in EU27), nuclear (21.8%) and hydroelectric (24%). Wind and photovoltaic sources had marginal shares. In 2021 the thermoelectric capacity was 38.5%, 10.6% nuclear, 15.3% hydroelectric, 19.1% wind, and 16.4% photovoltaic. The total capacity has increased by 46.3% in 2021 compared to 2005, from 676 GW to 989 GW. The nuclear capacity is the only one with a relevant reduction, from 123 GW to 105 GW (-14.6%). It is also noteworthy the increase of bioenergy net capacity from 15.8 GW in 2005 to 36.3 GW in 2021, representing 9.5% of total thermoelectric capacity.

Figure 2.48 – Power capacity trend (blue line – right axis) and share by source in EU27 (bars – left axis). CF=Combustible fuels.



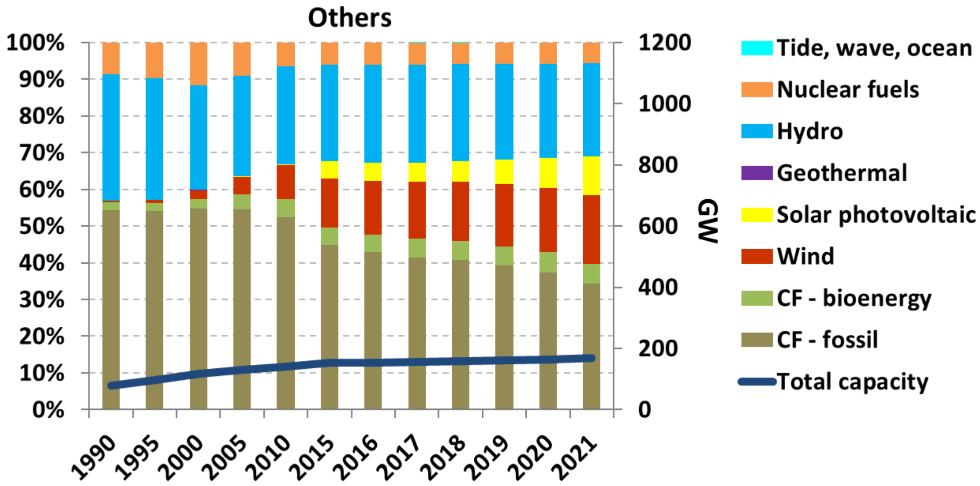
There is considerable heterogeneity of power capacity among Countries. In Poland, there is a clear prevalence of thermoelectric plants with a minor role for bioenergy. The nuclear plants, which are not present in Italy and Poland among the considered Countries, make up significant share of the capacity in France (43.3%), Sweden (15.4%), Belgium (22.3%), and Czechia (20.4%), although the shares of other Countries are not negligible (from 1.1% in the Netherlands to 7.5% in Romania). Since 1990, hydroelectric capacity has accounted for a considerable proportion of traditional renewable sources in Romania, Spain, France, Italy and Sweden. In all the Countries examined, the share of thermoelectric and nuclear capacity shows a considerable reduction. Wind power has increased in all Countries since 2005. Photovoltaic plants begun to have significant shares only after 2010.

Figure 2.49 – Power capacity trend (blue line – right axis) and share by source in the biggest European Countries (bars – left axis). CF=Combustible fuels.



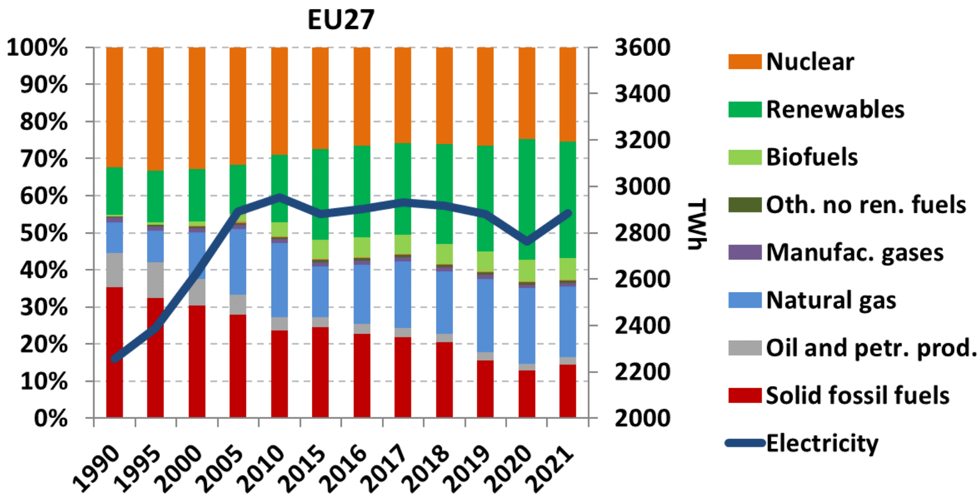
As for the group of other Countries it is worth noting the relevant share of hydro, 25.3% in 2021, while the combustible fuels plants are just below 40%.

Figure 2.50 – Power capacity trend (blue line – right axis) and share by source in the others European Countries (bars – left axis). CF=Combustible fuels.



Gross electricity production in Europe has shown a marked increase from 1990 to 2010, followed by stability up to 2019 and a sharp decrease in 2020 due to measures adopted to contain SARS-CoV-2 pandemic. In 2021 the electricity production comes back to the 2019 level; 14.5% of EU27 electricity production without pumping comes from solid fuels and 19.1% from natural gas. Oil and petroleum products account for 1.8%. Nuclear source accounts for 25.4% and 37.3% comes from renewable energy (renewables and biofuels). All considered Countries increased the electricity production since 1990, from 6.5% in Germany to 79.3% in Spain, except Romania whose electricity production decreased by 8%.

Figure 2.51 – Gross electricity production (blue line – right axis) and share by source in EU27 (bars – left axis).



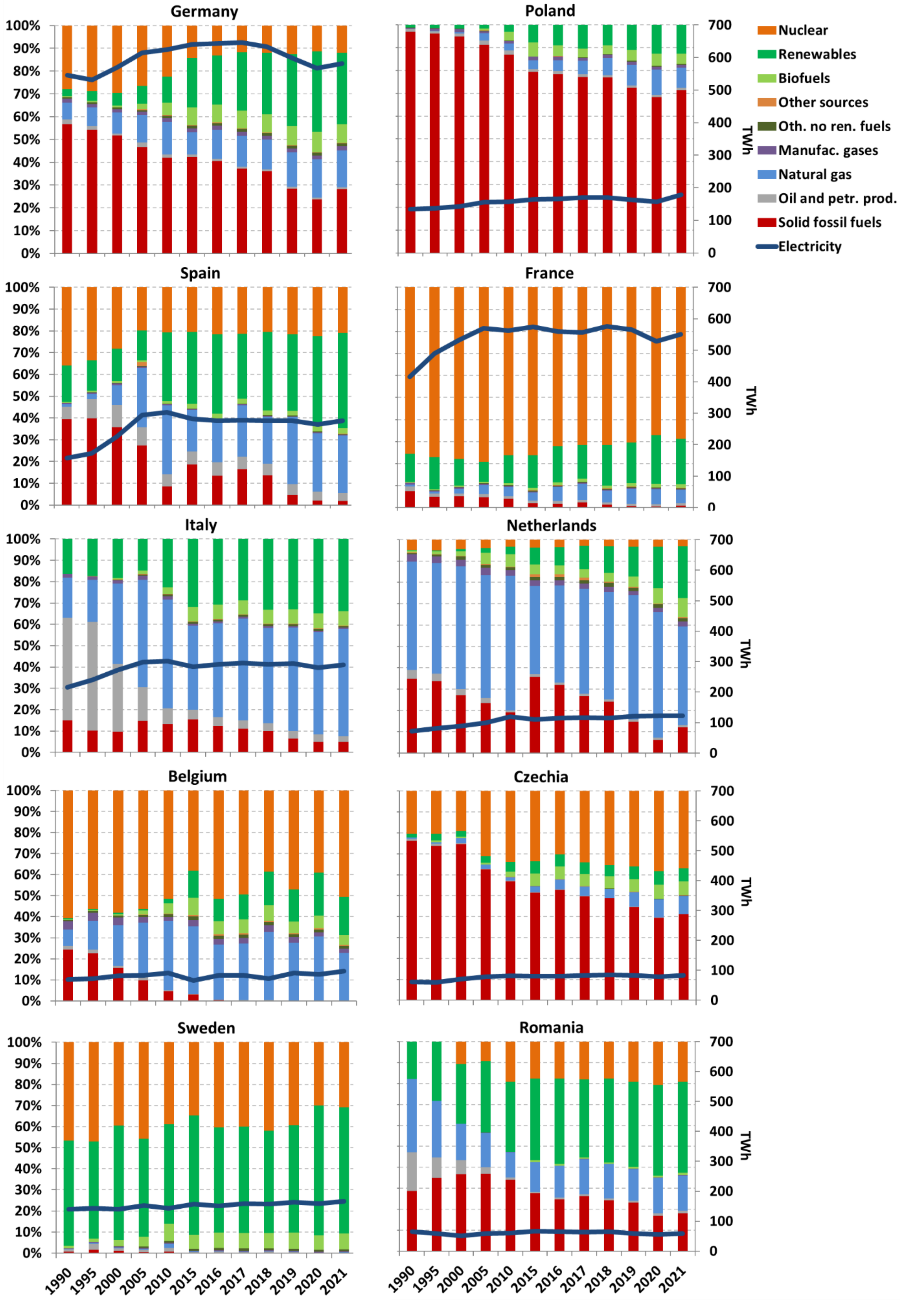
The energy mix in the examined Countries is quite heterogeneous, mainly as far as fossil fuels are concerned. In 2021, solid fuels make up 71.3% of electricity production in Poland, 41.1% in Czechia, and 28.2% in Germany. Even more interestingly, 54% of EU27 electricity production from solid fuels originates from lignite. Germany, Poland, and Czechia are the main users of such fuel for electricity production and account collectively for 82.5% of the EU27's electricity production by lignite (48.1% Germany, 20.5% Poland, and 13.9% Czechia). Romania accounts for 4.7% and the group of smallest Countries accounts collectively for the remaining 17.5% (mainly Bulgaria, Greece, and Slovenia). The electricity produced from lignite in Germany, Poland and Czechia is 66.1%, 36.4%, and 91.9% of electricity from solid fuels respectively.

France has the highest electricity production from nuclear plants in Europe (68.9% in 2021), followed by Belgium (50.6%), Czechia (36.9%) and Sweden (30.8%), among the examined Countries. In the other Countries the nuclear electricity ranges from 11.9% in Germany to 19.1% in Romania, while the Netherlands have the lowest end share of electricity from nuclear source (3.1%). Poland and Italy do not have nuclear plants. At EU27 level, the nuclear source provides around a quarter of electricity production (25.4%).

Italy and the Netherlands have the highest share of electricity by natural gas in 2021, 50.2% and 46.4% respectively. Italy shows a massive conversion of its thermal power plants since 1990 with a sharp contraction of oil and petroleum products and the corresponding expansion of natural gas. Solid fuels show significant contractions in all Countries although some Countries as Germany, Poland, and Czechia still have relevant shares of such fuels.

As regards electricity production from renewable sources, the share in EU27 has increased from 13.4% to 37.3% since 1990 to 2021. Since 2005 the renewable share has shown a steady increasing trend except in 2021 which recorded a decrease compared to 2020 (38.4%). In all the Countries examined there is a marked increase of renewable electricity production with a strong acceleration since 2005. After 2015 the growth slowed down and has resumed in recent years, although with different rates among the States. Sweden has one of the highest renewable shares in Europe.

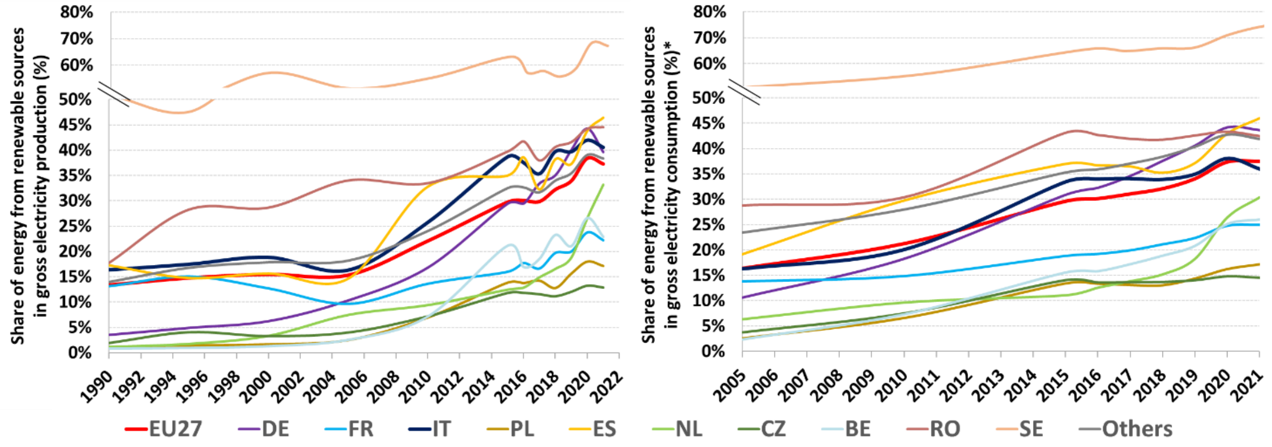
Figure 2.52 – Gross electricity production (blue line – right axis) and share by source in EU27 (bars – left axis).



The following graph shows the trend of renewable share in gross electricity production without pumping and gross electricity consumption as required by targets achievement. Sweden has one of the highest shares in Europe. At European level the share has been growing rapidly since 2005. The Italian figures, as for electricity production, are higher than the EU27 average and Italy's renewable share of electricity production n 2021 (40.5%) is one of the highest among the biggest Countries. In 2021 Sweden (67.4%), Spain (46.4%), and Romania (44.5%) exceeded the Italian share.

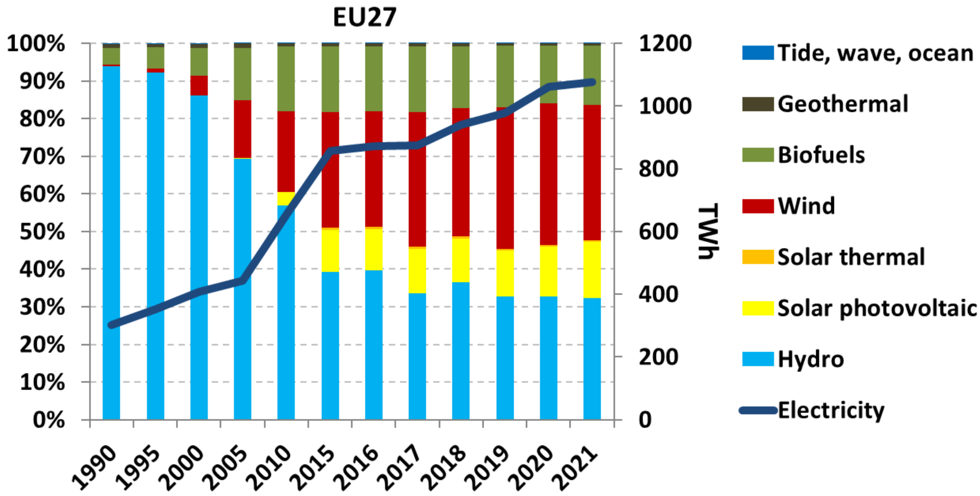
The renewable share for the achievement of the European 2020 targets, in accordance with the Directive 2009/28/EC, refers to gross inland consumption of electricity, i.e., electricity production without electricity from pumping plus the net import of electricity. For net importing Countries, the share of renewable electricity consumption will therefore be lower than renewable electricity production. In other words, the electricity importing Countries, such as Italy, face a relatively greater effort than exporting Countries to achieve the renewable targets in the electricity sector.

Figure 2.53 – Renewable share in gross electricity production (left side) and gross electricity consumption since 2005 (right side). * Data until 2020 are calculated according to Directive 2009/28/EC, data for 2021 follow Directive (EU) 2018/2001.



The following graph shows in more details the electricity production without pumping from renewable sources and the mix of sources. In all the Countries examined there is a marked increase of renewable electricity production with a strong acceleration since 2005. After 2015 the growth slowed down and has resumed in recent years although with different rates among the States.

Figure 2.54 – Renewable share in gross electricity production by source (left side), and total renewable gross electricity production in EU27 (right side).



In 1990, almost all electricity from renewable sources was from hydroelectric (94% in EU27). Countries show different development dynamics for the renewable sources related to the specificities of their electrical systems and national circumstances. Hydropower continues to cover more than 30% of Europe's renewable production in 2021 (32.4%). Among the examined Countries, hydroelectric power supplies 66.1% of renewable production in Romania and 63.8% in Sweden, but the shares recorded in France, Italy, and Spain are not less important (48.7%, 39%, and 23.6% respectively). The wind source shows considerable development in Germany, Spain, Poland, the Netherlands, and Belgium, with shares ranging from 44.5% to 53.1%. Photovoltaic electricity production plays a significant role in Germany, Italy, the Netherlands, and Czechia with shares from 21.4% to 28.4%. Among the biggest Countries lower shares are recorded in Poland and France for photovoltaics and solar thermal (both with 12.9%). Bioenergy covers over 50% of renewable production in Czechia, followed by Poland with 26.4%. The shares for the other Countries range between 2.5% in Romania and 26.9% in the Netherlands. The electricity from this source represents 16.4% in Italy. Among the Countries under examination, the geothermal source is present significantly only in Italy (5.1%).

Figure 2.55 – Renewable share in gross electricity production by source (left side), and total renewable gross electricity production in the selected Countries (right side).

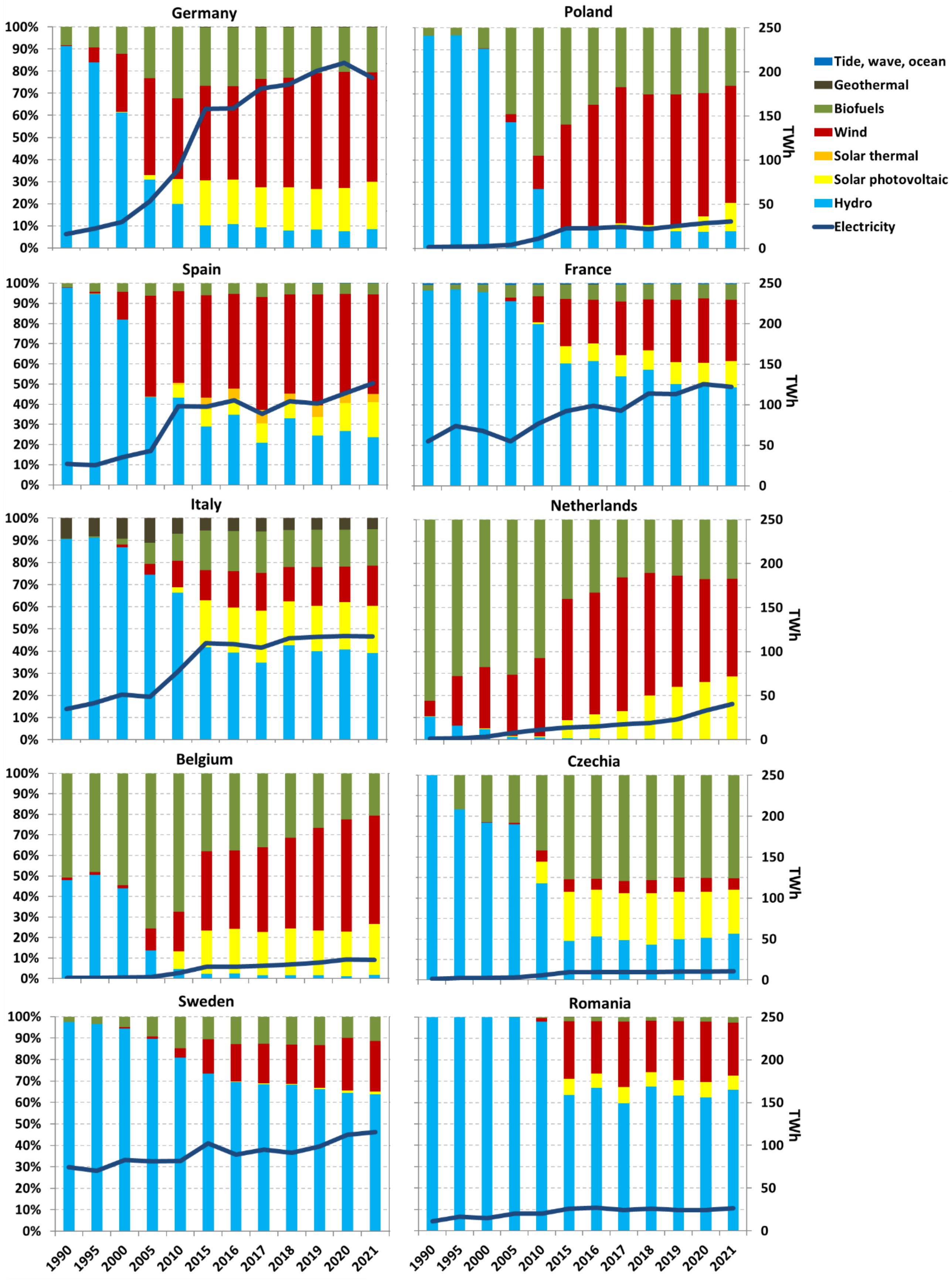
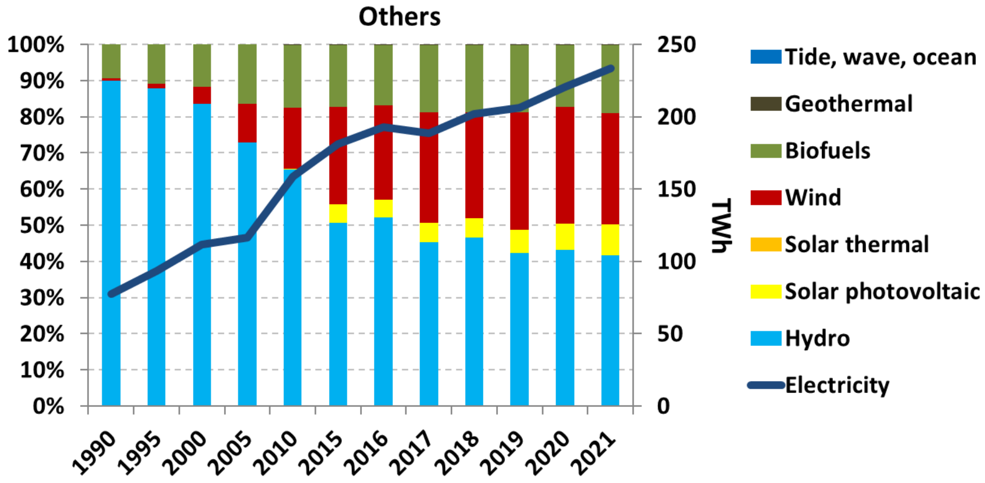


Figure 2.56 – Renewable share in gross electricity production by source (left side), and total renewable gross electricity production in the other Countries (right side).



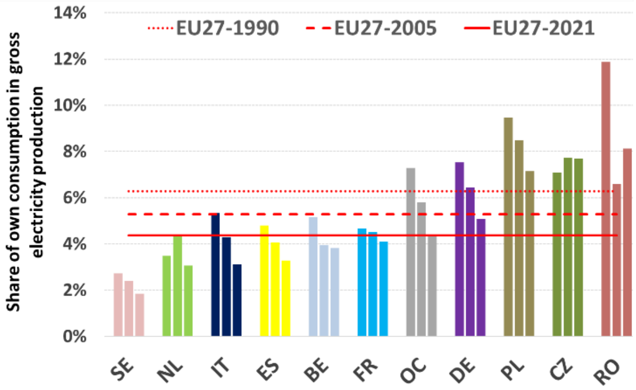
2.2.2 Efficiency of thermal power plants

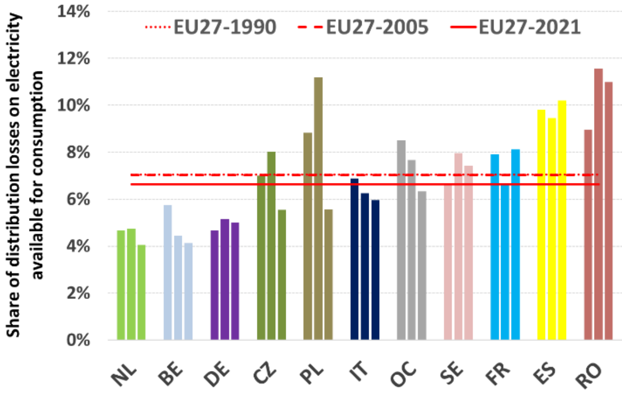
The performance of the Countries' electrical systems will be compared through parameters such as the share of own consumption, the distribution losses and above all the transformation efficiency of the fuel energy for electricity and heat generation. In the case of cogeneration plants, it should be considered that not all the electricity and heat produced in such plants can be regarded to as cogeneration production. However, it is reasonable to compare the overall efficiency of the thermoelectric plants in different Countries in terms of the transformation of the fuel energy into the final products regardless of the way in which the plants were used. In this respect, the distinction between cogeneration and non-cogeneration plants was made by considering the activities classified by Eurostat: "combined heat and power" and "electricity only".

Own consumption is the consumption of electricity utilities functional to the electricity production and is an indicator of the energy required by the electricity generation system. The share of own consumption in Italy has always been below the EU27 average and in 2021 it is higher only than that recorded in the Netherlands and Sweden. In general terms, thermoelectric, geothermal and nuclear generation are the sources with the greatest demand of energy, while renewable sources, such as hydroelectric, wind and photovoltaic, have very low own consumption. The greatest own consumption in thermoelectric plants is related to plants powered by solid fuels and bioenergy, less energy is required by plants fuelled by oil and petroleum products and even less energy is required by plants fuelled by natural gas. Therefore, in addition to the efficiency, a decisive parameter is represented by the fuel mix used by each Country.

On the other hands, distribution losses give insight on the network performance, higher losses determine higher electricity production to supply the electricity demand. In 2021 the distribution losses compared to the energy required for final consumption in Italy are higher than the EU27 average.

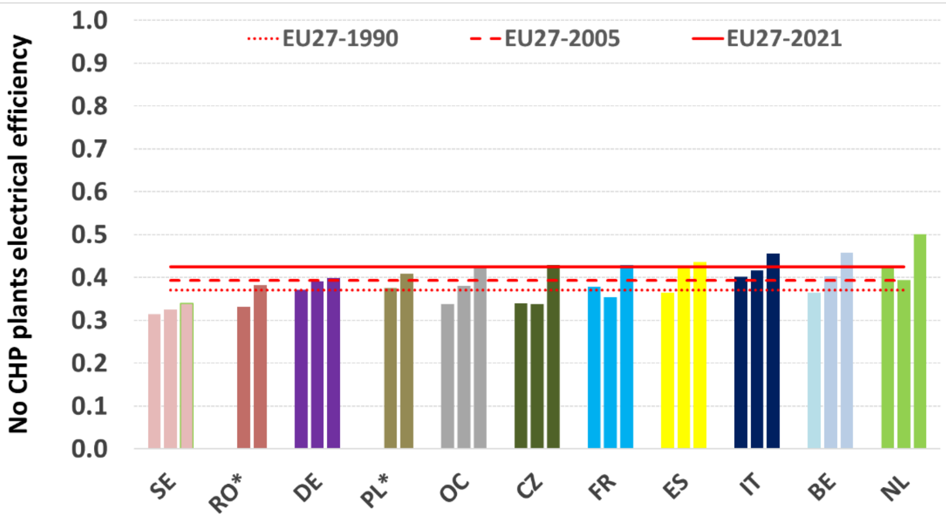
Figure 2.57 – Own consumption compared to gross electricity production (left side) and distribution losses on electricity available for final consumption (right side). For each Country the three bars refer to 1990, 2005, and 2021. Data in ascending order of 2021 value. OC – Other Countries.





The most important parameter for assessing the efficiency of an electricity generation system is the transformation efficiency of fuels into electricity and heat. The electrical efficiency of Italian non-cogeneration plants (0.456 in 2021) is among the highest in the biggest European Countries after Belgium (0.458) and the Netherlands (0.501). In 2021, the Italian average is over the EU27 average (0.425).

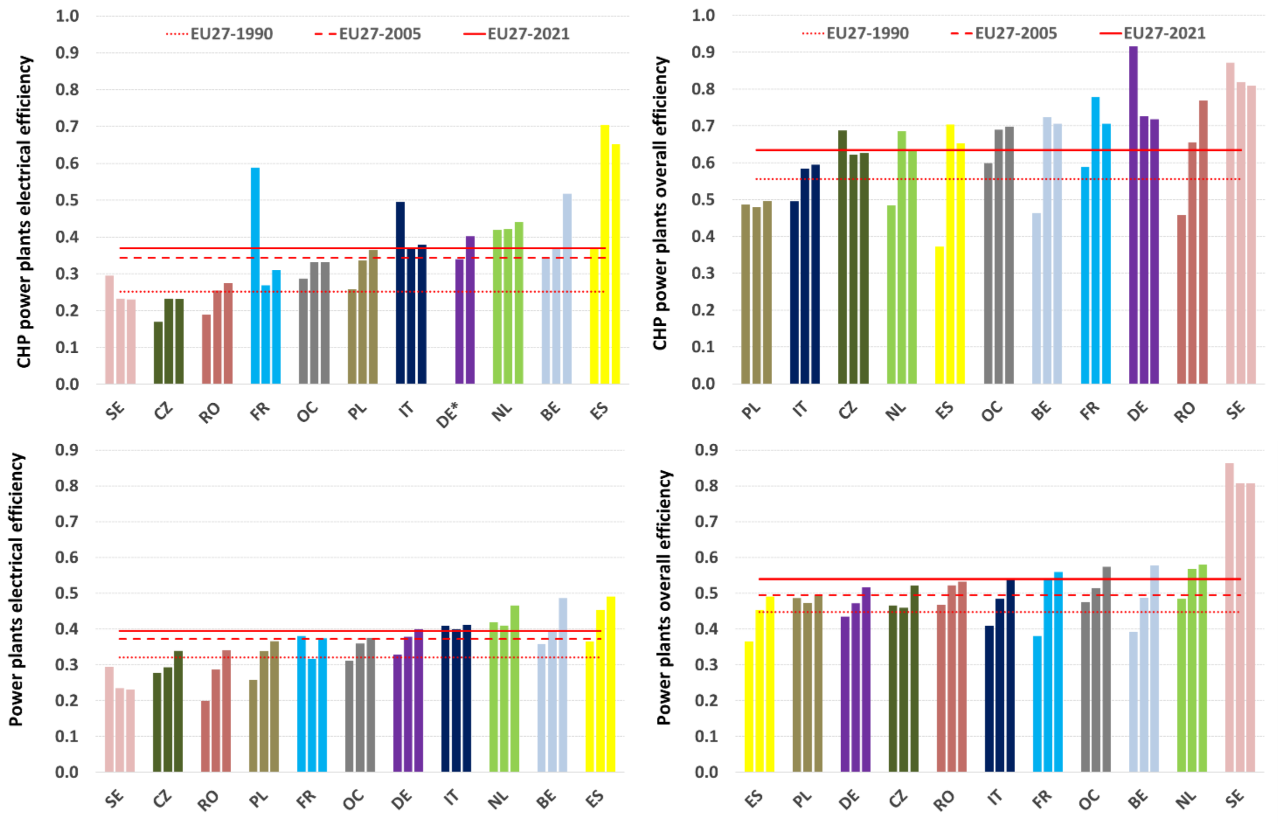
Figure 2.58 – Electrical efficiency of no CHP plants. For each Country the three bars refer to 1990, 2005, and 2021. Data in ascending order of 2021 value. OC – Other Countries. * 1990 not available.



As concerns the electrical efficiency of CHP plants, in 2021 Spain shows the highest value among the main European Countries (0.652), far higher than the EU27 average (0.37). Italy's electrical efficiency is 0.38. The total efficiency, for electricity and heat production, of the Italian cogeneration plants (0.595) is below the EU27 average (0.635) and increased of 20.1% since 1990.

The Italian electrical efficiency for all power plants (CHP and electricity only) in 2021 is 0.411, exceeded by Spain, Belgium, and the Netherlands, from 0.466 to 0.491. Sweden has the lowest electrical efficiency among the examined Countries (0.231), well below the EU27 average (0.395). The overall efficiency of Italian plants, for electricity and heat production, is 0.537, just below the EU27 average (0.539). Sweden shows the highest value (0.807) due to the highest ratio between heat and electricity recorded in this Country in CHP plants (more than 2.5), followed by Romania (1.79).

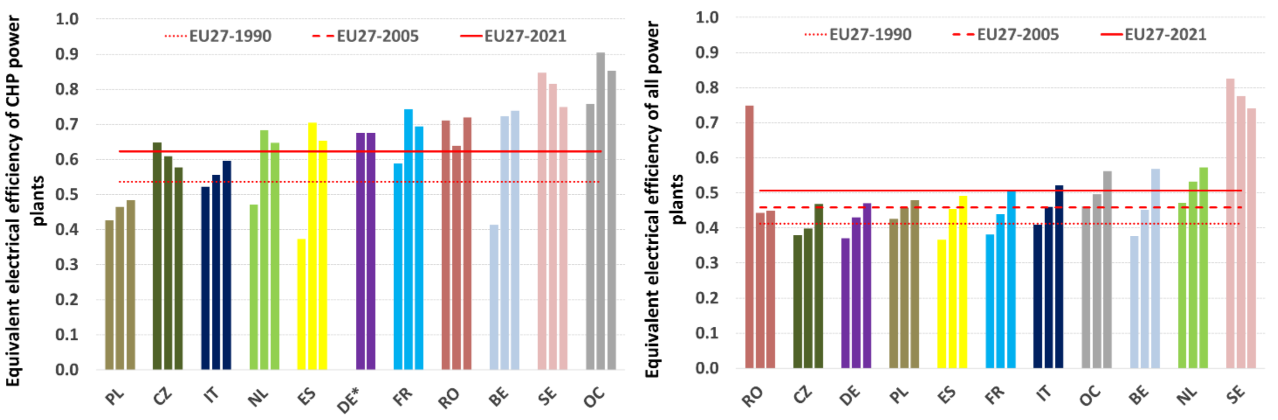
Figure 2.59 – Electrical and overall efficiency of CHP plants (up) and all power plants (down). For each Country the three bars refer to 1990, 2005, and 2021. Data in ascending order of 2021 value. OC – Other Countries. * 1990 not available.



The equivalent electrical efficiency of CHP plants, calculated after unbundling the share of fuels for heat production, is 0.597 for Italy, below the EU27 average (0.622), with a growing trend (+7.4% since 2005). The equivalent electrical efficiency ranges from 0.483 in Poland to 0.749 in Sweden. The average for group of smallest Countries is 0.856.

As for the equivalent electrical efficiency for all power plants in 2021, Italy (0.522) is exceeded Belgium (0.568), the Netherlands (0.578) and Sweden (0.741), among the biggest Countries. The EU27 average is 0.507 and the average for group of smallest Countries is 0.563.

Figure 2.60 – Electrical and overall equivalent electrical efficiency for CHP plants (left) and all thermal plants (right). For each Country the three bars refer to 1990, 2005, and 2021. Data in ascending order of 2021 value. OC – Other Countries. * OC – Other Countries. * 1990 not available.

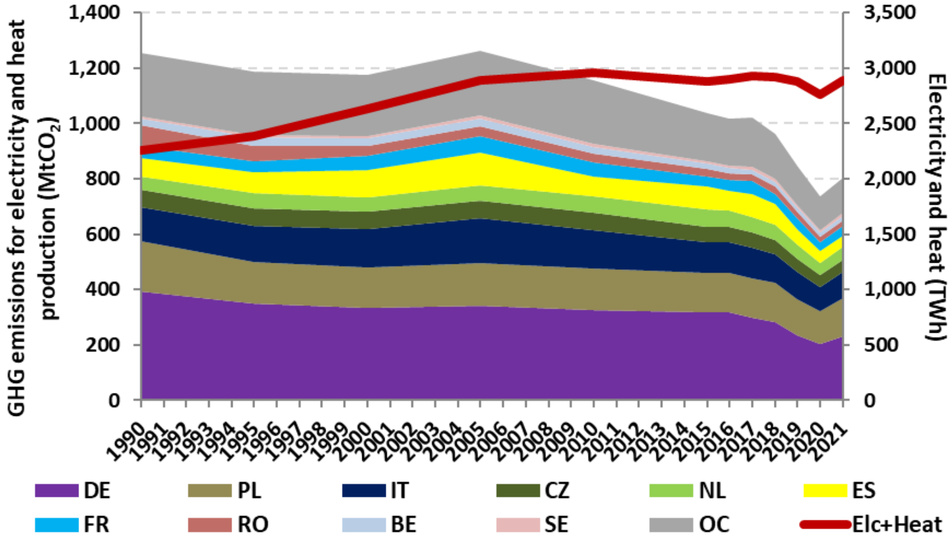


2.2.3 Greenhouse gas emissions from the electricity sector

The Tier 1 approach has been adopted to estimate the GHG emissions for the power sector of Countries and comparing the GHG emission factors. Tier 1 methodology with default emission factors is adopted only to carry out international comparison. Such purpose requires a common methodology for the States. A more detailed approach, with national emission factors, is available for Italy (see chapter 1).

Since 1990 there has been a decoupling between electricity production and GHG emissions by power sector in almost all European Countries, although emissions show a significant decrease only after 2005, with an increasing decoupling mainly due to the growing share of renewables. The following graph shows the cumulated contribution of each Member State to the EU27 GHG emissions by power plants and the trend of gross electricity and heat production.

Figure 2.61 – GHG emissions (Mt CO_2eq) in thermal power plants (left axis) and gross electricity and heat production in EU27 (right axis).



GHG emissions from the 27 European Countries to produce electricity and heat are 804.1 Mt CO_2eq in 2021, 35.9% lower than 1990 level and 36.3% lower than 2005 level. Since 2005 a significant reduction of GHG emissions in the electricity sector begun to take place. Overall, 2021 GHG emissions from power sector in the selected Countries (676.2 Mt CO_2eq) account for 84% of EU27 sector's emissions and Italy's share is 11.8%.

Table 2.2 – Estimation of GHG emissions (Mt CO_2eq) for electricity and heat production in thermal power plants. Countries in descending order of 2021 value.

Source	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
EU27	**1256.6**	**1187.7**	**1177.5**	**1264.2**	**1157.5**	**1037.7**	**1018.5**	**1020.4**	**963.5**	**848.2**	**734.8**	**804.9**
Germany	393.3	350.5	333.1	341.5	327.5	318.3	318.0	298.3	282.7	235.0	201.5	229.9
Poland	181.4	150.2	146.7	154.5	149.4	142.9	141.9	143.5	141.9	129.9	119.8	138.9
Italy	123.3	130.4	137.0	160.1	137.0	110.6	110.2	110.5	102.7	97.9	88.8	95.3
Czechia	63.8	64.1	64.0	64.5	63.0	53.8	54.9	53.3	52.9	48.9	42.3	45.3
Netherlands	45.0	52.5	53.6	57.7	61.0	62.0	60.9	58.0	54.0	50.8	43.3	44.3
Spain	66.4	77.5	98.1	117.7	71.4	84.3	70.1	82.6	73.6	56.4	42.3	42.7
France	46.4	38.4	48.7	59.1	49.9	37.3	39.8	44.3	37.4	37.0	33.4	35.2
Romania	73.2	56.8	37.5	36.2	31.2	27.5	25.5	26.4	25.4	23.5	18.1	19.1
Belgium	26.2	28.3	26.0	25.9	23.8	18.0	16.8	16.7	16.8	17.3	16.4	15.3
Sweden	5.3	9.0	8.3	10.7	13.4	9.2	10.2	10.4	10.8	10.3	9.2	10.3
Others	232.1	230.0	224.5	236.4	229.9	173.7	170.3	176.4	165.3	141.1	119.7	128.7

GHG emission factors for electricity and heat production due to fuel combustion in thermal power plants reduced since 1990. In 2021 the emission factor in Italy (386.3 g CO_2eq/kWh) is higher only than that of Sweden (182.4 g CO_2eq/kWh), where the thermal power plants are mainly fuelled by bioenergy. Spain, Sweden, Belgium, and the group of smallest Countries have the largest reductions since 2005 (from -28% to -28.9%), followed by Italy (-26.3%). Germany reduced the emission factor by 20.5%. At the lowest end of reduction rate there are Romania (-6.4%), Poland (-8.9%), and the Netherlands (-9.3%).

Table 2.3 – GHG emission factors for electricity and heat production by thermal power plants (g CO_2eq/kWh). Countries in descending order of 2021 value.

Source	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
EU27	**726.9**	**706.8**	**655.6**	**600.8**	**557.7**	**565.5**	**542.2**	**533.5**	**528.4**	**485.8**	**457.9**	**474.4**
Poland	723.4	760.6	749.4	723.5	713.3	704.0	696.4	693.4	681.9	656.4	633.8	659.1
Czechia	791.5	790.7	760.1	792.0	774.8	721.1	703.5	697.5	706.8	673.5	633.5	626.2
Romania	587.9	548.3	562.3	589.0	615.0	595.5	575.0	590.8	610.0	650.9	561.5	551.4
Germany	784.9	779.8	745.4	681.2	638.3	635.8	619.5	599.0	585.3	546.3	515.5	541.4
Spain	928.8	893.6	780.2	628.6	501.6	653.8	616.6	620.7	623.2	481.9	451.1	447.1
Belgium	877.6	818.6	649.0	583.5	455.4	446.4	434.6	431.0	422.9	429.4	400.8	420.1
Netherlands	572.6	505.8	448.8	445.6	411.4	496.8	476.5	457.8	447.2	408.4	373.7	404.2
France	951.5	855.7	547.0	519.2	576.7	507.7	444.4	446.1	447.6	411.4	394.2	404.0
Italy	691.7	666.3	623.8	523.9	477.8	441.1	424.4	409.5	407.9	383.4	370.0	386.3
Sweden	340.3	276.1	267.4	254.5	217.7	181.7	187.1	191.7	198.4	188.8	189.7	182.4
Others	665.1	655.9	594.7	557.4	518.8	508.7	479.4	484.1	475.8	430.9	396.4	398.8

GHG emissions for electricity production have been estimated after unbundling the fuel energy consumption for heat production in CHP plants according to the methodology proposed by EUROSTAT (2016) for the compilation of national questionnaires by Member States already adopted in ISPRA 2022. EU27 emissions in 2020 are 660.4 Mt CO_2eq and the Countries examined account for 84.7%.

Table 2.4 – Estimation of GHG emissions (Mt CO_2eq) for electricity in thermal power plants. Countries in descending order of 2021 value.

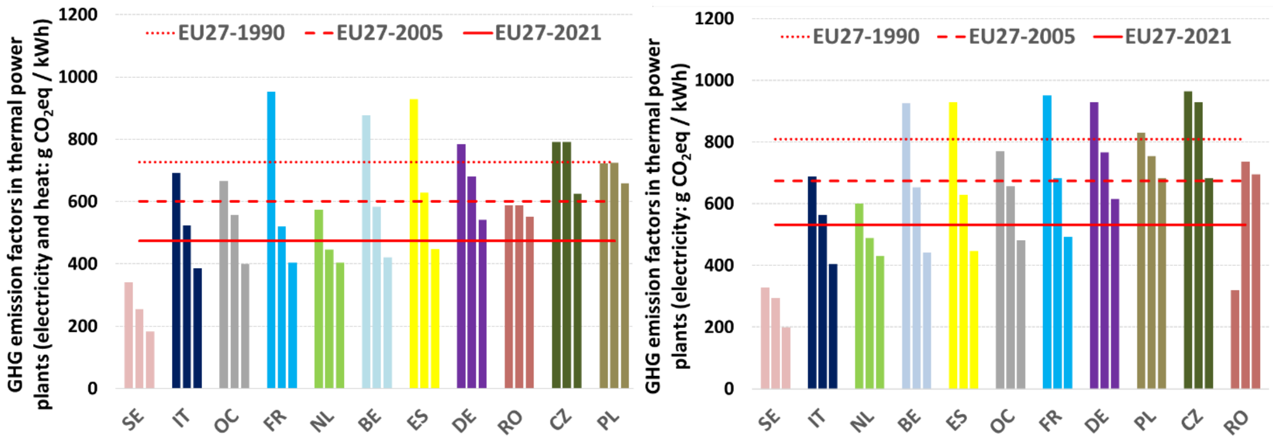
Source	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
EU27	**1003.9**	**998.1**	**1014.7**	**1068.5**	**966.2**	**879.6**	**856.3**	**861.0**	**811.6**	**702.0**	**599.4**	**660.4**
Germany	350.5	322.8	306.4	308.1	293.4	288.1	287.0	267.2	253.6	207.2	176.8	202.3
Poland	110.5	108.0	109.9	115.2	112.3	109.2	107.9	108.9	108.4	98.0	90.0	106.7
Italy	122.7	129.8	134.4	141.7	116.7	91.2	89.7	90.3	83.3	78.3	70.0	76.5
Spain	66.4	77.5	98.1	117.7	71.4	84.3	70.1	82.6	73.6	56.4	42.3	42.7
Netherlands	40.9	42.1	42.0	45.6	48.2	53.4	52.6	49.7	46.3	43.4	36.9	38.0
Czechia	46.2	43.3	49.8	48.4	46.5	41.5	42.1	41.5	41.4	38.0	31.8	32.2
France	46.4	37.0	40.9	45.6	43.1	31.7	33.5	38.0	31.1	30.3	26.8	28.6
Romania	16.9	25.5	20.6	24.8	23.0	21.1	19.3	20.8	20.4	19.1	14.2	15.4
Belgium	25.2	27.3	24.9	23.5	21.3	15.9	14.7	14.8	14.8	15.4	14.7	13.5
Sweden	1.7	3.4	3.3	3.6	4.9	2.7	2.8	3.0	3.2	3.4	2.7	3.2
Others	176.4	181.4	184.4	194.3	185.4	140.6	136.6	144.2	135.5	112.4	93.4	101.3

Italian emission factor by thermal plants in 2021 (404.3 g CO_2eq/kWh) is second only to that of Sweden (198.8 g CO_2eq/kWh), where the share of bioenergy in the thermoelectric plants is much higher. The Italian factor is well below the EU27 average of 531.6 g CO_2eq/kWh. Czechia, Romania, Poland, and Germany have the top four emission factors, from 695.1 g CO_2eq/kWh to 616.1 g CO_2eq/kWh, well above the European average.

Table 2.5 – GHG emission factors for electricity production by thermal power plants (g CO_2eq/kWh). Countries in descending order of 2021 value.

Source	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
EU27	**809.6**	**790.6**	**729.4**	**674.5**	**621.5**	**637.7**	**608.9**	**595.8**	**594.6**	**542.9**	**509.8**	**531.6**
Romania	319.4	601.7	657.1	736.3	797.4	739.2	719.4	723.9	747.0	803.0	705.7	695.1
Czechia	963.8	944.6	900.0	928.2	917.2	857.3	830.7	824.9	827.5	785.0	734.1	683.8
Poland	830.8	799.0	779.3	754.5	736.9	721.0	713.8	714.8	701.8	674.8	655.6	682.9
Germany	928.1	906.0	824.6	767.1	710.7	702.1	684.0	661.0	657.9	620.0	584.7	616.1
France	951.5	917.0	770.4	683.4	693.8	618.6	524.2	521.0	540.0	488.0	470.9	491.5
Spain	928.9	893.5	780.0	628.6	501.6	653.8	616.6	620.7	623.2	481.9	451.1	447.1
Belgium	924.8	858.9	730.4	652.4	497.2	479.3	464.6	453.7	447.1	447.5	415.4	440.4
Netherlands	600.4	550.6	497.5	487.9	434.7	556.1	525.8	500.1	483.7	434.0	389.3	430.8
Italy	688.3	663.0	611.6	562.4	506.4	476.6	451.2	432.5	433.8	401.4	387.3	404.3
Sweden	327.3	339.6	368.0	294.7	237.4	192.8	187.3	195.2	205.5	206.9	199.1	198.8
Others	769.7	750.9	693.5	655.4	616.9	621.8	581.6	583.1	575.5	519.7	472.4	481.0

Figure 2.62 – GHG emission factors in thermal power plants (g CO_2eq/kWh). For each Country the three bars refer to 1990, 2005, and 2021. Data in ascending order of the 2021 value. OC – Other Countries.



The emission factors for total electricity and heat production by the whole power sector, including renewable and nuclear power production, in Italy are higher than the European average (276.6 *vs* 241 g CO_2eq/kWh). All Countries with lower emission factors than Italian one (Figure 2.59) have relevant amount of electricity by nuclear plants. The average EU27 emission factor shows a reduction of 34.9%, compared to the 2005 level, while Italy reduced its emission factor by 39.4% ranking the 3rd higher reduction rate among the biggest Countries. Spain and Belgium recorded the highest rates of reduction since 2005, -61.3% and -48% respectively, on the other side Poland and Sweden have the lowest ones, -16.7% and -14.7% respectively. The emission factor in Germany, which has the highest share of European GHG emissions by power sector, decreased by -29% since 2005.

Table 2.6 – GHG emission factors for total electricity and heat production (g CO_2eq/kWh). Countries in descending order of 2021 value.

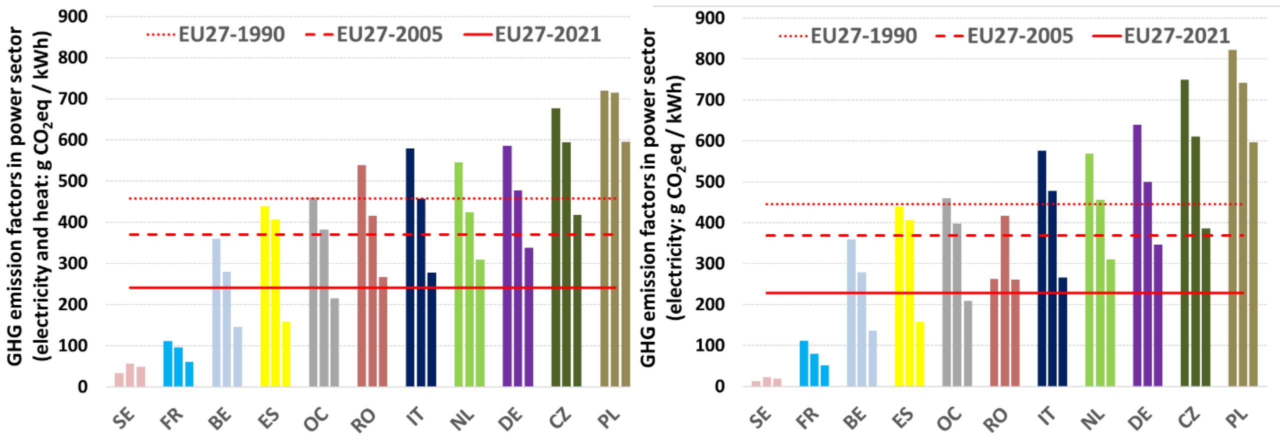
Source	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
EU27	**457.3**	**423.1**	**388.0**	**370.3**	**333.0**	**311.2**	**301.9**	**300.1**	**285.5**	**254.4**	**230.3**	**241.0**
Poland	719.2	753.4	741.4	714.6	697.7	662.1	648.9	638.7	635.5	601.6	573.3	595.3
Czechia	676.2	672.7	642.9	594.2	556.8	506.8	513.6	486.7	483.1	452.6	414.3	417.3
Germany	585.1	559.6	514.4	476.9	450.5	434.4	430.6	402.3	386.3	337.2	306.5	338.4
Netherlands	546.1	483.9	430.2	424.4	389.7	446.0	425.9	401.4	387.9	348.4	299.9	308.6
Italy	578.6	549.5	507.6	456.8	385.9	324.5	315.9	311.3	295.4	277.9	262.9	276.6
Romania	538.6	472.1	431.4	415.1	377.8	329.5	310.7	330.1	322.3	328.6	267.2	266.5
Spain	439.0	468.2	444.0	406.8	239.5	303.6	258.2	302.4	270.7	208.2	162.8	157.4
Belgium	359.9	370.7	293.4	279.2	231.8	237.5	183.2	182.2	208.8	175.3	174.2	145.2
France	111.5	77.7	85.5	95.7	84.9	62.5	68.0	76.0	62.1	62.3	60.1	60.7
Sweden	33.8	52.6	49.5	56.9	70.8	46.2	52.2	51.4	53.6	49.8	46.3	48.5
Others	460.1	445.2	396.8	382.9	350.5	302.0	284.0	292.8	278.1	243.0	209.6	215.2

Also considering only the total electricity generation the average EU27 emission factors have always been lower than the Italian ones, thanks also to the contribution of nuclear power in the European Countries with lower emission factor than the Italian one. The increasing share of renewable electricity significantly reduces the emission factors.

Table 2.7 – GHG emission factors for total electricity production (g CO_2eq/kWh). Countries in descending order of 2021 value.

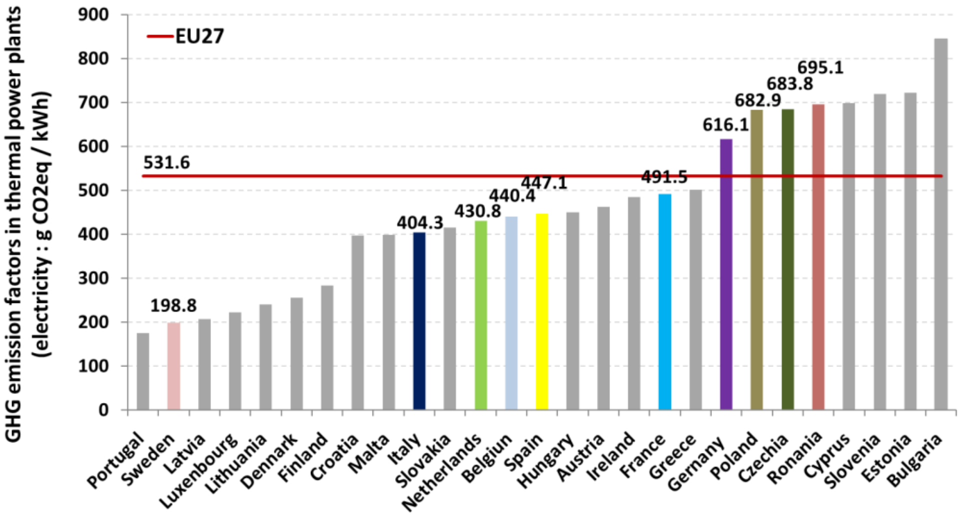
Source	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
EU27	**444.7**	**418.0**	**385.9**	**369.3**	**327.0**	**305.5**	**295.2**	**293.6**	**278.3**	**243.6**	**217.1**	**228.9**
Poland	822.0	788.0	767.8	741.7	715.0	664.6	649.7	640.4	638.9	600.4	572.3	596.7
Czechia	749.1	720.7	704.6	610.4	563.3	518.9	529.3	497.5	488.7	453.2	404.1	386.5
Germany	640.0	605.8	535.4	499.9	468.1	448.4	445.1	412.6	399.8	344.8	310.7	346.9
Netherlands	568.5	518.7	468.9	456.4	404.5	484.2	456.6	424.3	405.6	357.3	299.3	311.1
Italy	575.8	546.8	497.7	477.4	390.6	324.1	311.4	307.2	289.4	268.1	251.4	266.5
Romania	262.7	431.7	399.2	417.1	378.9	320.7	299.3	324.6	316.6	322.7	254.9	260.5
Spain	438.9	468.2	443.9	406.8	239.5	303.6	258.2	302.4	270.7	208.2	162.8	157.4
Belgium	359.1	371.7	301.2	278.2	228.5	231.2	173.5	173.1	200.4	166.4	165.8	135.7
France	111.5	75.6	76.7	80.0	76.5	55.1	60.0	68.2	54.0	53.6	50.8	52.0
Sweden	11.9	23.3	22.5	22.8	33.1	16.6	18.2	18.5	19.6	20.1	16.6	18.7
Others	459.4	445.9	406.7	397.3	361.2	305.9	285.2	297.2	280.7	239.5	200.0	208.5

Figure 2.63 – GHG emission factors in power sector (g CO_2eq/kWh). For each Country the three bars refer to 1990, 2005, and 2021. Data in descending order of the 2021 value. OC – Other Countries



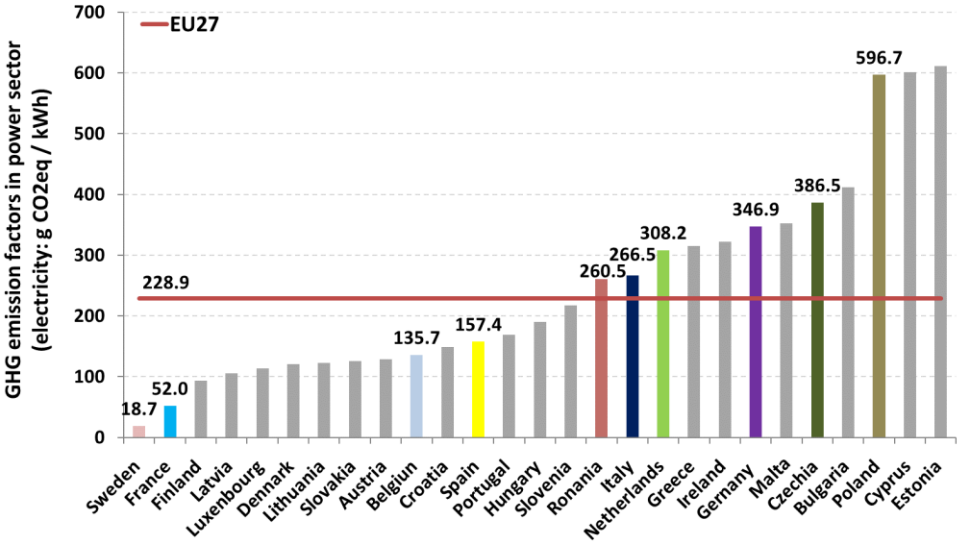
The outcomes allow to conclude that Italy have one of the lowest GHG emission factor for electricity production by fuel mix combustion among the biggest European Countries. Italian GHG emission factor by thermal plants occupies the 10th position, well below the European average. The Italian fuels mix, with greater share of natural gas than other Countries and the contribution of bioenergy, is a driving factor for the emission factor in thermal power plants.

Figure 2.64 – GHG emission factors in thermal power plants for electricity production (g CO_2eq/kWh) in 2021. States in ascending order.



As for the whole power sector, therefore also considering the no thermal renewables and nuclear power plants, the Italian emission factor loses positions compared to other Countries. Countries with nuclear power have a benefit in terms of avoided GHG emissions. France has a relevant amount of energy from nuclear power plants, which allows the drastically reduction of the emission factor. Apart from Italy and Poland, the other Countries have significant shares of electricity from nuclear power (from 3.1% in the Netherlands to 50.6% in Belgium). Overall, nuclear electricity in EU27 was 25.4% in 2021. In 2021, 89.4% of EU27 nuclear electricity comes from the Countries examined, with France accounting for 51.8%. The nuclear electricity plays a decisive role for the correct interpretation of the emission factors in Spain, Belgium, and France. The effect of nuclear energy is particularly evident for France: although the renewable share of electricity production is almost half than the Italian one and the emission factor in thermal plants is higher, France has the lowest emission factor in Europe, second only to that recorded for Sweden. Germany has 11.9% of nuclear electricity and 39.6% of renewable electricity but the relevant presence of solid fuels in the fossil mix (28.2% of electricity production), mainly high-carbon content fuel as lignite, results into a higher emission factor than the Italian one.

Figure 2.65 – GHG emission factors in power sector for total electricity production (g CO_2eq / kWh) in 2021. States in ascending order.

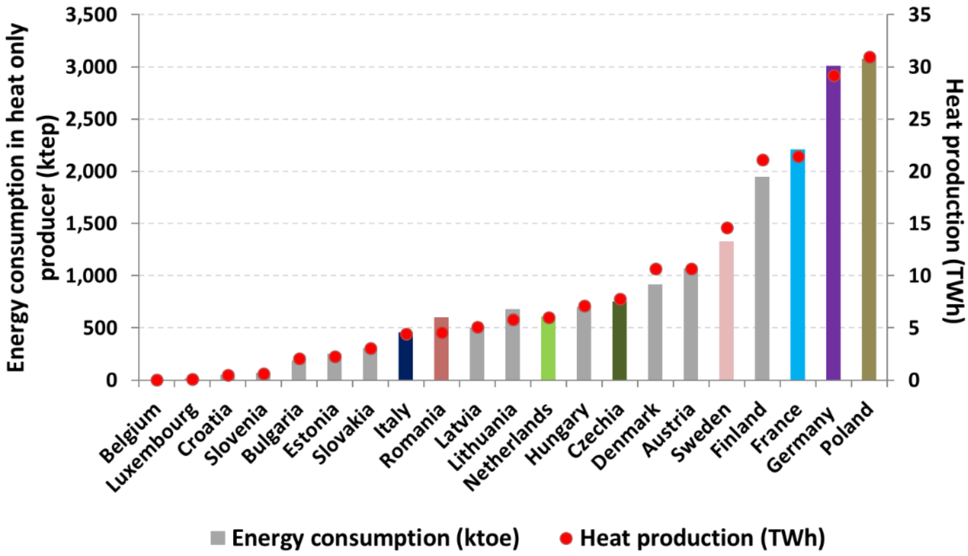


As a result of many factors (fuel mix shift, efficiency, share of renewable) Italy reduced the emission factor for electricity production by 53.7% from 1990 to 2021 (-44.2% since 2005), against a reduction of 42.1% in Germany (30.6% since 2005) and 27.4% in Poland (19.6% since 2005). The reduction rate in Poland is the lowest among the biggest emitters in Europe. If Germany and Poland had reduced their GHG emission factors since 1990 at the same rate of Italy, it would have led (with the same electricity production) to avoid around 68 Mt CO_2eq in 2021 (about 103 Mt CO_2eq considering also heat production), about 11% of EU27 emissions from power sector. The power plants in Germany and Poland are still fuelled by significant shares of high-carbon content solid fuels, such as lignite, and the transition to natural gas has been much slower than in Italy.

2.2.4 Heat-only producers

Heat production accounts for a significant share of energy transformation processes. Plants dedicated to heat production for district heating and other uses (mainly for industry) consume an important share of the energy in the European balance. In 2021 the energy consumption of plants for heat production in EU27 was 18.7 Mtoe of which 0.67 Mtoe from geothermal and solar thermal, and 0.29 Mtoe from heat pumps. The energy consumption of fuels was 17.8 Mtoe, of which 6.2 Mtoe from bioenergy. Bioenergy consumption shows a rapidly growing share: the consumption in 2021 is more than double the 2005 level and is more than 8 times the consumption in 1990.

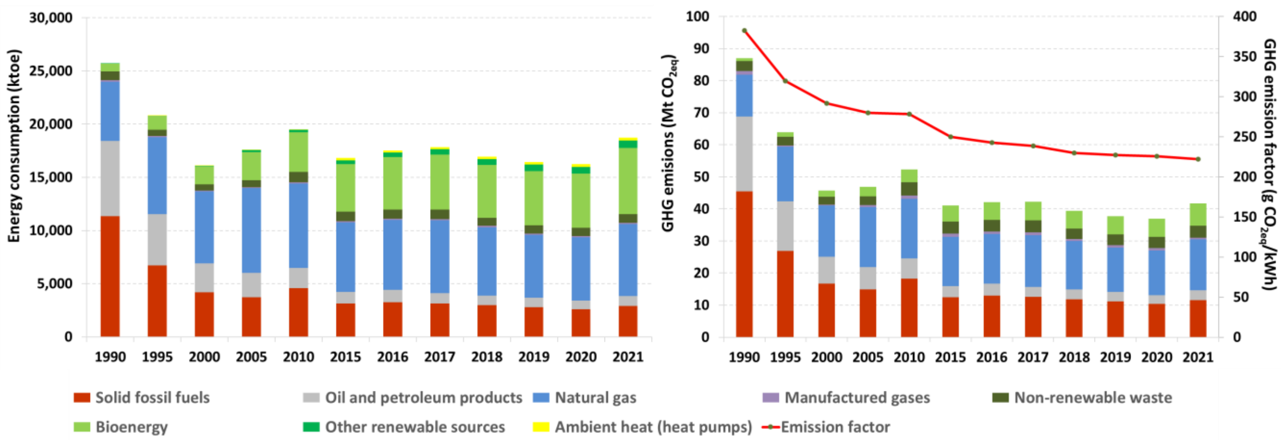
Figure 2.66 – Energy consumption and heat produced by heat only producer plants in European Countries (2021). Data in ascending order for energy consumption.



Total energy consumption in 2021 is less than that recorded in 1990 and a marked fuel shift has occurred with decrease of solid fuels and, to a greater extent, of oil and petroleum products being replaced by natural gas and bioenergy. The contribution of other renewable sources (more than 90% from geothermal energy and the rest from solar thermal) and heat pumps recorded an increasing trend and in 2021 represent 5.6% of total consumption.

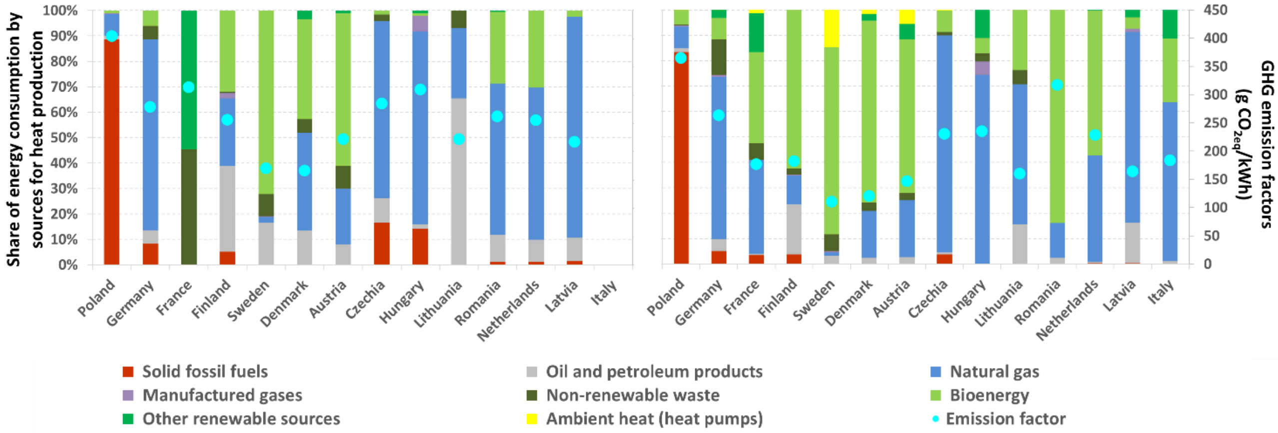
As a result of fuel shift and decreasing energy consumed (-27.1%) and heat production (-17.2%), GHG emissions registered a sharp decrease by 52% since 1990. GHG emission factor decreased by 42%. At EU27 level the GHG emissions from these plants were 41.8 Mt CO_2eq in 2021. Since 2005 the emission factors decreased by 20.7% in EU27 (from 279.7 to 221.9 g CO_2eq/kWh).

Figure 2.67 – Energy consumption (left side), GHG emissions, and average GHG emission factor (right side) by source in heat only producer in EU27.



Italy's emission factor in 2021 is 17.4% lower than the EU27 average. The relevant solid fuels or non-renewable waste consumption in Poland and Germany results in higher emission factors, respectively 98.8% and 43.8% higher than the Italian one.

Figure 2.68 – Share of energy sources for heat only producer plants and GHG emission factor in the greatest heat producers in 2005 (left) and 2021 (right). Countries in descending order of heat produced in 2021.



CONCLUSIONS

National data

The main outcomes of this report can be summarized as follows:

- Gross inland energy consumption increased from 1990 until 2005 when it peaked at 189.4 Mtoe, then there was a reduction accelerated by the effects of the economic crisis with the minimum value of 149.8 Mtoe reached in 2014. In 2020 there was a further contraction of energy consumption due to measures implemented to contain SARS-CoV-2 pandemic (-8.9% lower than 2019 level and -4.4% lower than 1990 level). In 2021 followed a rebound of consumption (+8.5% higher than 2020), with 153.7 ktoe. Renewable gross inland consumption has more than quadrupled from 6.5 Mtoe in 1990 to 29.9 Mtoe in 2021 (19.4% of gross inland consumption).
- Total GHG emissions increased until 2005, the following decrease was accelerated by the economic crisis. In 2020 GHG emissions was heavily affected by lockdown measure to contain SARS-CoV-2 pandemic. In 2021 a rebound was recorded for all sectors, although total emissions remained below the 2019 level. The 2021 GHG emissions fell by 19.9% compared to 1990 and by 13.9% compared to 2005.
- National methane emissions, without the contribution of natural sources, represent on average 10.5%$\pm$0.8% of CO2eq emissions from 1990 to 2021, with a rather variable trend. Methane emissions without LULUCF decreased from 55 to 47.1 Mt CO2eq from 1990 to 2021 (-14.3%). The reduction of methane emissions is much lower than the reduction of total GHG (-19.9%). Agriculture contributes with 45.1% of methane emissions, while the waste sector accounts for 39.4%. Fugitive emissions make up 8.3%, and unburned methane in the energy sector accounts for 7.2%.
- The trends of gross inland energy consumption (GIC), gross domestic product and GHG emissions show an increasingly decoupling among between energy consumption, economy and GHG emissions. Such decoupling is mainly due to fuel shift towards lower carbon content fuels, such as natural gas, and, most of all, to the increasing share of renewable energy.
- The energy and carbon intensities by GDP decreased since 1995. The gross inland energy consumption per unit of GDP decreased from 107.5 toe/M€ in 1995 to 91.5 toe/M€ in 2021 (-14.8%). Over the same period, GHG emissions per unit of GDP fell by 30.4%, from 357.3 t CO_{2eq} / M€ to 248.8 t CO_{2eq}/M€, while energy emissions per primary energy unit goes from 2.81 t CO_{2eq}/toe to 2.21 t CO_{2eq}/toe, with a reduction of 21.1%. The average carbon intensities by sector shows notable differences between sectors depending upon the different deployment of renewable sources and electrification of final energy consumption. The transport carbon intensity, including international aviation, recorded the highest value in the last years with the lowest change since 1990 among sectors.
- The decrease in energy intensity per unit of value added at national level until 2014 is partly due to increased efficiency in industry and the decline in the share of value added of this sector compared to services which have significantly lower energy intensity. The aggregate energy intensity in 2020 increased by 6.4% compared to the 2014 value.
- The analysis of decomposition shows that the reduction of GHG emissions since 2005 is mainly driven by renewable share increase and energy intensity decrease. The reduction of economic activities played a minority, though not nil, role until 2019. On the other hand, the contraction of economic activities in 2020 assumed a dominant role in reducing emissions compared to the previous year.
- The renewable sources in the power sector had a significant boost since 2007 following the adoption of policies to reduce GHG emissions and to achieve the renewable target in final consumption. The increase in renewable energy in the sector has been achieved through many measures such as subsidies and priority dispatching renewable electricity.
- CO_2 emission factor in power sector decreased since 1990 with a strong decoupling between electricity generation and emissions. The renewable electricity on total electricity production went from 16% in 2005 to the top of 43.1% in 2014, in 2021 the share is 40.2%, with a particularly significant

increase in wind and photovoltaic sources. The contribution of hydropower remains decisive also in relation to the intrinsic variability of this source. Preliminary estimate shows an abrupt contraction of renewable share in 2022 (35.5%), mainly due to the sharp reduction of hydroelectric generation.

- The analysis of the decomposition shows that historically the increase in technological efficiency in the thermoelectric sector and the related increase in the share of natural gas have played a dominant role in the reduction of CO_2 emissions, while since 2007 the significant increasing share of renewable electricity assumes the main role compared to the other factors considered.
- The electric carrier in final consumption shows a faster increase in gross domestic energy consumption, indicating an increasing electrification of final consumption destined to further growth to pursue the carbon neutrality. Therefore, power sector's emission factors are useful to plan and monitor initiatives aimed at reducing GHG emissions. In practical terms, the emission factors allow to calculate the avoided emissions by replacing fossil sources with renewable sources on the production side or saving electricity on the consumption side.

Italy and the biggest European Countries

The main outcomes can be summarized as follows:

- Italy's ratio between final and primary energy consumption has been historically higher among the biggest European Countries, showing high energy transformation efficiency. Italy is one of the largest European Countries with the lowest gross inland energy consumption per unit of GDP.
- The renewable energy per unit of gross inland consumption in Italy is greater than the EU27 average since 2005. The Italian renewable share accelerated sharply since 2007, with an increase in the distance between the Italian and European average. In 2021 Italy is, among the Countries considered, second only to Sweden.
- Italian emissions per capita increased until 2004, unlike other European Countries, which have seen decreasing emissions per capita since 1990. Italian emissions per capita were always below the EU27 average and in 2021 are higher to those recorded in France, Romania, Spain, and Sweden where the nuclear energy represents a not negligible share of inland consumption.
- At sectoral level, the final energy and carbon intensities per unit of value added show that Italian industry has one of the lowest values among the 27 European States with the highest levels of electrification among the biggest Countries. The agriculture intensities are among the lowest in Europe. On the other hand, the Italian civil sector shows wide margins for reducing emissions if compared with other Countries, especially considering the level of electrification of final consumption that is among the lowest in Europe both for households and for services.
- The energy intensity per unit of GDP also considering the energy consumption by international bunkers confirms that among the largest Countries Italy and Germany have the lowest values.
- Italy's resource productivity per direct material inputs is the highest among the biggest Countries, despite the relevant share of energy intensive industrial activities.
- The results of decomposition analysis on GHG emissions change since 2005 show that, among the driving factors, the decreasing final energy intensity and the increasing renewable energy have played a key role to reduce European emissions. The outcomes of decomposition analysis show that in Italy the improvement of final energy efficiency played a less important role than in other Countries because of the better performance of the indicator in Italy already in 2005.
- The comparison of the largest Countries of the European Union shows greater decoupling between GDP and GHG emissions in other Countries than the one observed in Italy, although indicators as energy efficiency, energy consumption per GDP, and GHG emissions per GDP performed better in Italy than European average since '90s and many Countries with much higher values are approaching Italian values.

- The Italian GHG emission factors in thermal power sector for electricity and heat production is one of the lower among the biggest Countries, second only to Sweden. The emission factors calculated also considering the nuclear and renewable energy shows Italian values are higher than the EU27 average because of the zero emissions benefit of nuclear plants. Italian share of renewable electricity production in 2021 is higher than the European average.

The results show that Italy has one of the most efficient energy and economic systems among the biggest Countries in Europe. The figures show that energy intensity per unit of GDP as well as resource productivity are among the lowest in Europe despite a relevant role of industry in the Italian economy. Low energy intensity often corresponds to more service-based economies with a minor role of industrial activities. EU27's carbon intensity per unit of energy consumption is on average lower than Italian one, since in several Countries is present a not negligible share of nuclear energy.

GHG emissions trends depend on many factors. The emission reductions in European Countries are mainly due to the decreasing energy intensity and increasing renewable energy consumption. In 2020 the measures adopted to contain the diffusion of SARS-CoV-2 pandemic heavily affected the European economy and GHG emissions. Independently from contingencies there is a clear decoupling between GDP and GHG emissions in the European Countries, although decoupling does not necessarily correspond to the emission reductions in line with the 2020 targets for some Country, as for Germany. The potential for reducing emissions must be assessed also considering the starting points of the driving factors and the costs to change the energy system, as well as the economy structure, especially concerning the services and industry assets.

Sectoral decarbonization indicators in Italy show sectors such as industry and agriculture with energy intensities among the lowest in Europe and sectors such as households and services occupying the last positions among European Countries with very wide emission reduction potentials, especially considering the level of electrification of final consumption that for such sectors is among the lowest in Europe. Also for transport the Italian energy and carbon intensity per GDP is near or over the European average showing wide improvement margins. Such outcomes are consistent with the worrying distance of Italian projections from the target to be achieved in 2030 (ISPRA, 2023b). More than the energy system overall performance the emission targets are centred on the partition between biggest energy and manufacturing industries (subject to emissions trading system, ETS) and other sectors (ruled by Effort Sharing Regulation, ESR). The Country's emission targets are only for sectors not subject to the ETS, i.e. transport, civil, agriculture, waste and small industry, while emissions from large plants as thermal power plants, refineries, cement plants, steel plants, etc. are in the European cap and trade system of emissions trading. The projections, carried out with the existing measures up to 31st December 2021, show that Italy would reduce the ESR emissions by 28.4% compared to 2005 level against the current target of -33%. The distance is even greater with the more challenging target of -43.7% proposed by the European Commission and approved by the European Parliament.

As for the power sector Italy reduced its emission factor for electricity production by 53.7% from 1990 to 2021, compared with a reduction of 42.1% in Germany and 27.4% in Poland (the lowest reduction rate among the biggest emitters in Europe). Poland and Germany have the highest share of lignite consumption and the highest emission factors among the biggest Countries. In such Countries the transition to natural gas has been slower than in Italy. The reduction of GHG emission factors since 1990 in Germany and Poland with the rate recorded for Italy, at parity of electricity production, would have avoided around 68 Mt CO_2eq in 2021 (about 103 Mt CO_2eq considering also heat production), about 11% of the EU27's GHG emissions from power sector.

BIBLIOGRAPHY

AA.VV., 2019. Piano nazionale integrato per l'energia e il clima. Ministero dello Sviluppo Economico, Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Ministero delle Infrastrutture e dei Trasporti, dicembre 2019. https://www.mise.gov.it/

AA.VV., 2021. Strategia italiana di lungo termine sulla riduzione delle emissioni dei gas a effetto serra. https://www.mase.gov.it/

Ang B.W., 2005. The LMDI approach to decomposition analysis: a practical guide. Energy Policy 33, 867–871.

EEA, 2022 - Trends and projections in Europe 2022. EEA Technical report No 10/2022.

European Commission, 2018a. A Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. COM(2018) 773.

European Commission, 2018b. In-depth analysis in support of the commission communication COM(2018) 773. A Clean Planet for all. A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy.

European Commission, 2022a. REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition. 18 May 2022.

European Commission, 2022b. Commission staff working document – Implementing the RePower EU action plan: investment needs, hydrogen accelerator and achieving the bio-methane targets. 18 May 2022.

EUROSTAT Database, http://ec.europa.eu/eurostat/data/database

EUROSTAT - Electricity and heat annual questionnaire 2015 and historical revisions.

Femia A., Paolantoni C., 2012. I principali conti ambientali della statistica ufficiale in Italia. Energia, Ambiente e Innovazione. Speciale - Verso la green economy: strategie, approcci e opportunità tecnologiche. https://www.enea.it/it/seguici/pubblicazioni/EAI/anno-2012/verso-la-green-economy

Fischer-Kowalski, M., Krausmann, F., Giljum, S., Lutter, S., Mayer, A., Bringezu, S., Moriguchi, Y., Schütz,H., Schandl,H. Weisz, H., 2011. Methodology and indicators of Economy-Wide Material Flow Accounting. Journal of Industrial Ecology 15, 855–876.

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC, 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Calvo Buendia, E., Tanabe, K., Kranjc, A., Baasansuren, J., Fukuda, M., Ngarize, S., Osako, A., Pyrozhenko, Y., Shermanau, P. and Federici, S. (eds). Published: IPCC, Switzerland.

IPCC, 2021. Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

IPCC, 2022. Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA.

ISPRA, 2022. Efficiency and decarbonization indicators for total energy consumption and power sector. Comparison among Italy and the biggest European Countries. Rapporti 366/2022.

ISPRA, 2023a. Italian Greenhouse Gas Inventory 1990-2021. National Inventory Report 2023. Rapporti 383/2023.

ISPRA, 2023b. Le emissioni di gas serra in Italia: obiettivi di riduzione e scenari emissivi. Rapporti 384/2023.

ISTAT, 2023. Conti dei flussi di materia. http://dati.istat.it/

Piano Nazionale di Ripresa e Resilienza, #NextGenerationItalia, 2021. https://www.governo.it/sites/governo.it/files/PNRR.pdf

UNFCCC, National Inventory Submissions 2023. https://unfccc.int/

Paolantoni C., Femia A., 2016. Una chiave di lettura dello sviluppo umano nell'Antropocene: il metabolismo socioeconomico misurato attraverso i conti dei flussi di materia. Culture della Sostenibilità - N. 18/2016 - II semestre, 46-84.

SNAM, 2023. Trend dal 2005. https://www.snam.it/it/trasporto/dati-operativi-business/2_Andamento_dal_2005/

MASE, 2023. Statistiche energetiche e minerarie. https://dgsaie.mise.gov.it/

Subramanian S., Bastian H., Hoffmeister A., Jennings B., Tolentino C., Vaidyanathan S., and Nadel S. 2022. 2022 International Energy Efficiency Scorecard. Washington, DC: American Council for an Energy-Efficient Economy. www.aceee.org/research-report/i2201.

Terna, 2023a. Monthly Report on the electricity system, December 2022.

Terna, 2023b. Rapporto di adeguatezza Italia 2022. https://download.terna.it/terna/Terna_Rapporto_Adeguatezza_Italia_2022_8db050a8496bbb3.pdf

RAPPORTI

386/2023