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Renewable energy in Europe — 2020

Recent growth and knock-on effects



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Executive summary

This report outlines the progress made in 2018 and 2019 in the deployment of renewable energy sources (RES) since 2005 in the European Union (EU-27) as a whole, and at country, market and technology level.

Using data reported by Member States to Eurostat and early estimates from the European Environment Agency (EEA), the assessment confirms that the EU RES share continues to be in line with the indicative trajectory designed to achieve the mandatory 20 % EU RES consumption target for 2020. However, to achieve the 2020 targets with certainty and prepare for their transition towards climate neutrality, countries need to prioritise the deployment of renewable energy sources as part of their energy mix, and invest in energy efficiency improvements nationally and across the EU. This is particularly important in the context of the post-COVID-19 recovery. For the transport sector, the RED sets a target of 10 %. At current pace this target would not be met by 2020. However, due to the COVID-19 crisis energy use fell significantly in 2020, especially in transport, which may contextually facilitate the achievement of the 10 % target set for the transport sector.

The increase in RES use throughout Europe since 2005, has had many co-benefits. This includes a cut in the annual demand for fossil fuels ([1]) of more than 13 % in 2018, associated with a drop in greenhouse gas (GHG) emissions of 11 % across the EU in that year, than if RES use had remained at the same level of 2005. This is almost as much as the gross final energy consumption and the total GHG emissions of France. Overall, interactions with air pollutant emissions were also beneficial, leading year on year to decreases in the emissions of NO_x and SO_2, by 6 % and 1 % in 2018, respectively, than if RES use had remained at the same level of 2005. However, the emissions of $PM_{2,5}$, PM_{10}, and VOCs were estimated to have increased, mainly due to increases in the combustion of biomass since 2005, by 12 %, 7 % and 4 %, respectively.

Seen globally, between 2005 and 2018 the EU has transformed its electricity production base faster than other world regions. However, even though the EU is still the world leader in renewable electricity capacity installed per capita, in terms of total installed capacity China surpassed the EU already in 2013.

The renewable energy share has been continuously increasing at EU level. However, increases in gross final energy consumption are slowing down the pace of growth of the RES share

The EU wide share of renewable energy in gross final energy use increased from 10.2 % in 2005 to 18.9 % in 2018 and to 19.5 % in 2019, according to the EEA's early estimates. Accordingly, the EU has met its indicative trajectory for 2018 as set out in the Renewable Energy Directive (RED). RES are a major contributor to the transition of Europe's energy sector. The rapid development of some renewable energy technologies has already allowed these technologies to achieve high market shares. Today, for solar photovoltaic (PV) electricity, biogas electricity and solid biomass used for heating and cooling, these shares are above, or close to, the 2020 levels anticipated by countries in their national renewable energy action plans (NREAPs), drafted in 2010. This has led to GHG emission reductions in the EU electricity sector, in the heating and cooling sector, and, to a lesser extent, in transport.

However, despite installed renewable capacity continuing to grow, the average yearly growth in the RES share slowed down in 2015-2019 (average growth of 0.4 percentage points per year), compared to performances recorded between 2005 and 2015 (average growth of 0.8 percentage points per year). This is related to the evolution of gross final energy consumption, which decreased between 2005 and 2014 (by 1.1 percentage points on average), it increased between 2014 and 2017 (by 1.8 percentage points on average) and remained stable in 2018 and 2019 (preliminary estimate).

([1]) Gross inland consumption of fossil fuels

Today, the shares of RES in gross final energy consumption continue to vary widely between countries, ranging from over 35 % in countries such as Denmark, Finland, Latvia and Sweden to 10 % or less, in Belgium, Luxembourg, Malta, and the Netherlands.

Renewable energy sources are mostly used for heating and cooling

In absolute terms, **renewable energy for heating and cooling** remains the dominant RES market sector in Europe, comprising nearly half of all the renewable energy consumption. RES made up more than one fifth for this sector: 21.1 % in 2018 and 21.7 % in 2019, according to reported data and early EEA estimates. Since 2005, despite biogas and heat pumps sources having increased faster on average, solid biomass-based technologies prevailed in this market sector.

In absolute terms, **renewable electricity** is the second largest RES market sector in the EU. Growth in this sector was driven especially by growth in onshore and offshore wind power and solar PV electricity generation, but also by other RES, such as an increase in biogas for electricity purposes. Around a third of all electricity consumed in the EU in 2018 and in 2019 (32.2 % and 34.1 % respectively) originated from renewable sources.

The bulk of renewable energy use in transport comes from biofuels

In the **EU transport sector**, renewable energy made up 8.3 % of all energy use in 2018 and 8.4 % in 2019, according to reported data and the EEA's early estimates. With renewable electricity currently playing only a small role in transport, the bulk of renewable energy use in this sector comes from biofuels. To prevent potential negative impacts on climate, the environment and interactions with food production from land-use (such as when natural forests and food crops are displaced by biofuels), only certified biofuels that comply with the sustainability criteria under the RED can be counted towards the RED targets. Certification is carried out through voluntary schemes recognised by the European Commission and through national systems set up by the Member States.

Transport biofuels grew fastest over the period 2005-2018 (at 30 percentage points increase per year, on average), as they increased from a very low level in 2005. Nevertheless, considerable efforts are needed in this market sector in the run-up to 2020 to reach the 10 % RES target at the national and at the EU level.

The increased use of renewable energy sources since 2005 allowed the EU to cut its fossil fuel use and the associated greenhouse gas emissions by, respectively, 145 Mtoe and 478 Mt CO2 in 2018

The additional consumption of renewable energy compared with 2005 levels, allowed the EU- to cut its demand for fossil fuels by 145 million tonnes of oil equivalent (Mtoe) in 2018. This is equivalent to 13 % of the EU's gross inland consumption of fossil fuels. As a comparison, this amount corresponds to almost the gross final energy consumption of France in 2018 (151 Mtoe). In 2019, the amount of substituted fossil fuels is estimated to have increased by 10 Mtoe to 155 Mtoe.

These fossil fuel savings due to the additional use of renewable energy after 2005 helped the EU achieve an estimated gross reduction in CO_2 emissions of 478 Mt CO_2 (12 %) in 2018, compared with a counterfactual scenario in which RES consumption would have stayed the same as in 2005. The estimated reduction in GHG emissions attributed to renewables in 2018 was similar to the total GHG emissions of France the same year. In 2019, the effect on CO_2 emissions increased further, resulting in a gross emission reduction of 513 Mt CO_2 (a 12 % gross reduction in the EU). Most of these changes took place in energy-intensive sectors covered by the EU Emissions Trading System (ETS), as the increase in renewable electricity decreased the reliance on fossil fuels and made up roughly three quarters of the estimated total EU reductions.

In 2018, the largest relative reductions in the consumption of fossil fuels compared to 2005 were made by Estonia (56 %), Sweden (42 %), Denmark (35 %) and Finland (28 %), in proportion to their gross domestic fossil fuel use. In absolute terms, the greatest quantities of fossil fuels were avoided in Germany, Italy, France and Spain, where most renewable energy was consumed.

The increased use of renewable energy sources since 2005 allowed the EU to cut its emissions of NOx and SO_2, but caused an increase of PM and VOC emissions

At the EU level, for 2018, the total estimated RES effect results in a decrease of air pollutant emissions of 44 kt for NO_x and 129 kt for SO_2, compared with a counterfactual scenario in which RES consumption would have remained at the levels of 2005. However, for PM_{10}, $PM_{2.5}$ and VOCs emissions, the result is an increase of respectively 122, 120 and 248 kt, compared with 2005. On the relative level, this has led to a decrease of SO_2 and NO_x emissions in 2018, by 6 % and 1 %, respectively, compared to air pollutant emissions if RES use had remained at the same level of 2005. In contrast, an indicative increase of EU-wide emissions for PM and VOCs took place in 2018, following the increase in biomass use since 2005 (by 12 % for $PM_{2.5}$, 7 % for PM_{10} and 4 % for VOCs).

Globally, 2019 was a strong year for renewable energy, reaching 34 % of the world's total installed power capacity and one quarter of total generation

In 2019, the world has added 177 GW in net renewable electricity capacity, almost the same as in 2018 and representing a 7 % growth of total installed capacity. As such, renewables accounted for an estimated 71 % of net power generation capacity additions. Since 2012, every year except for 2014, more than half of all newly installed power capacity worldwide was of renewable origin.

In 2019, China was a clear leader regarding net renewable capacity additions (63 GW). Yet, the EU continued to rank second, after China, as regards total installed renewable electricity capacity, having installed as much as 26 GW of net capacity in 2019 – a record since 2012 (IRENA 2020b).

Trends in renewable electricity capacity across the EU show a sharp increase between 2009 and 2013, , coinciding with the adoption of the RED (IRENA 2020b, EU 2009). The upward trend continued between 2014 and 2018 although less steeply.([2]) The agreement on the revised RED (EU 2018a) sets the binding EU target at 32 % renewable energy sources consumption in gross final energy by 2030, subject to a potential upward revision in 2023. It is expected thus that the growth in installed capacity will be high in this period to cope with the demand.

An increase in investments accompanied the growth in net installed capacity in renewable power. After a reduction in 2018, global renewable energy investments increased again in 2019, amounting to EUR 252 billion. Yet, this was still below the peak reached in 2015([3]). In Europe (including the Commonwealth of Independent States), investments amounted to EUR 49 billion in 2019. Since 2013, annual renewable energy investments have varied between 40 and EUR 65 billion in Europe, being significantly lower than the peak achieved in 2011 (EUR 92 billion) (Frankfurt School-UNEP 2020).

Wind and solar PV systems remain the fastest growing technologies worldwide. More flexibility needs to be added to the energy system to make the most of their variable generation.

In 2019, wind power represented 22 % of the renewable generation worldwide, while solar PV represented 10 %. New RES capacity additions continued to be dominated by solar PV and wind power

([2]) The UK was an important contributor to RES growth in the period 2014-2018 concerning the EU-28, but is no longer accounted for in the current analysis, which concerns the EU-27.

([3]) In 2015 the all-time high of EUR 287 billion was invested.

(IRENA 2020b) These technologies accounted for over 95 % of total global RES investments (Frankfurt School-UNEP 2020). At the other end, investments in new biofuel dropped drastically in 2019, possibly because of policy uncertainty and limitations for first generation biofuels, for example in Europe, and a still immature market for second generation biofuels.

The expected future growth of these technologies, which generate independently of the level of consumption, will require more flexibility to be built into the energy system, so as to absorb their variable and inflexible nature and avoid high costs.

The EU remains a global leader in renewable electricity capacity per capita, but faster activity is visible in other parts of the world

The average renewable electricity capacity per capita for the EU was two and a half time larger in 2018 compared with 2005 (1 kW per person in 2018), with large differences between Member States. The EU retains its global lead, being closely followed by the United States (at 0.8 kW per capita), the UK and Brazil (both at 0.7 kW per capita). The fastest progress in the last five years can be observed in China, followed by the Middle East and ASOC (except China and India).

Jobs in renewables continued to increase with China as the main employer, while EU comes second

Jobs remain concentrated in a few countries worldwide, but this was more decentralised in 2019 than 2018. An estimated 11.5 million direct and indirect jobs were related to renewables in 2019, up 4 % from 2018. This is roughly 0.55 % of the total labour force (IRENA 2020c, World Bank 2020). China provided 4.4 million jobs, around 38 % of the global renewable employment. The EU is the second employer in the renewable energy sector with 1.2 million jobs, at the same level as Brazil. Jointly with India, the United States of America as well as Japan, Malaysia, Bangladesh and UK follow, these countries host 78 % of the global renewable jobs. Compared to 2017, when these countries summed 84 % of the global renewable workforce, the employment has distributed to other countries.

In terms of proportion of renewable energy-related jobs in the labour force, Malaysia and Brazil were leaders at 1.2 % and 1.1 % respectively. They were followed by the EU, with 0.66 % of the labour force dedicated to renewable energy, outpacing China at a 0.56 %. Within the EU, Germany remains the number one employer in terms of RES-related jobs.

Globally, solar PV and bioenergy are the largest employers for direct and indirect jobs in renewables, with a large growth in bioenergy jobs. In Europe, this trend is somewhat reversed, with 62 % of employment coming from bioenergy, followed by wind representing 25 % of renewables jobs, while solar only represents an 11 %.

To reach the raising 2030 ambitions, Member States and the EU need to intensify their climate and energy efforts

In the context of the Paris Agreement and to reach the EU climate and energy targets for 2030 and to become a sustainable, carbon neutral economy by 2050, Member States need to overcome a number of important challenges. In their 2019 NECPs, Member States have proposed indicative efforts contributing to the 32 % EU binding target for renewable energy for 2030. The European Commission's assessment of these national RES contributions shows that the EU's share of renewable energy could surpass the 2030 target by approximately 1 % (ranging between 33.1 % and 33.3 %)(EC 2020c). However, reaching a higher EU greenhouse gas emission reduction target of net 55 % by 2030 ([4]) as proposed by the European

([4]) To achieve climate neutrality in 2050, the European Commission has proposed a target to reduce EU-wide net GHG emissions by at least 55 % by 2030, compared to 1990 levels.

Commission under its 2030 Climate Target Plan will require higher shares of renewables, in the range of 38 % to 40 %, in the energy system (EC 2020c).

To maintain momentum, EU Member States must reinforce and build existing, home-grown expertise and innovation capacity in renewable energy and energy efficiency solutions and radically transform their energy systems. This will also help retain Europe’s global competitiveness in these growing knowledge-intensive sectors.

1 Introduction

1.1 Background: international and European context

On a global scale, the Paris Agreement ([5]) (UNFCCC 2015) is the most important driver for fossil fuel divestment. This requires fundamentally transforming our energy system and adjusting our production and consumption patterns on a short term.

Increased deployment of renewable energy sources (RES) plays an important role in transitioning in a cost-effective way to a resilient carbon neutral economy. With long-term energy demand overall stable in Europe, increasing the share of RES triggers the displacement of non-renewable sources (especially fossil fuels) in power supply, heat production and transport, thereby reducing greenhouse gas (GHG) emissions across all sectors. Renewables are a key pillar in delivering the European Energy Union's decarbonisation priority (see Box 1.1), achieving the EU's climate commitments under the Paris Agreement.

Progress achieved in EU-wide renewable energy deployment since 2005 is largely attributed to the presence of binding national targets for 2020 under the Renewable Energy Directive, or RED (EU 2009), and to national support instruments put in place in response to these targets, such as feed-in tariffs, feed-in premiums, auction/tender systems, quotas, tax credits and grants. A broad set of complementary climate and energy policies support low-carbon energy developments and aim to spur innovation in this field. This process of target setting and the policy response to that, not only on EU level but also on a global level, led to technological advances, the scaling up of production volumes and a reduction in costs, especially of wind power and solar photovoltaic (PV) technologies. Nevertheless, the rapid initial developments also triggered frequent adaptation of Member States' policies to establish cost-effective support and, in some cases, even to abrogate that support.

In 2017-2018, however, the annual pace of growth in the EU has stagnated for most RES technologies. This loss of speed initially took shape in the aftermath of the financial crisis, when many support mechanisms were scaled back, sometimes cut entirely or were retroactively changed. Subsequently, economic growth resumed across countries and, since 2015, energy consumption from non-renewable sources increased by more than that from renewable ones, as a result of increased energy use in the transport sector and low carbon prices in the EU's electricity market till 2018. The increasing number of countries getting closer to, or having reached their renewable energy targets for 2020 ahead of time, may offer a further explanation.

In 2019, energy consumption from all the sources stayed stable in the EU, increasing only 0.1% compared to 2018, while energy consumption from renewables increased by 3.2%. RES-E sector had the highest increase by 1.9% to 34.1% due to growth in electricity generation from wind and photovoltaics. RES share increased by 0.6% to 19.5% in 2019.

Despite the slower pace, the EU-27 is on track to meet its 2020 RES target. However, underperformance in RES-T continued (EEA 2020).

([5]) The Paris Agreement's central aim is to strengthen the global response to the threat of climate change by keeping the global temperature rise this century well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 °C. The Paris Agreement requires all Parties to put forward their best efforts through 'nationally determined contributions' (NDCs) and to strengthen these efforts in the years ahead (UNFCCC 2015).

In 2020, the Covid-19 crisis has had an enormous impact on Europe's energy system. Despite its resilience, it is expected that the crisis will negatively impact the renewable energy industry as well. Renewable energy investments therefore need to play a key role in the recovery after the crisis. This report focuses on developments in renewable energy in 2018 and proxy estimates for 2019, and therefore it does not reflect the impact of the COVID-19 pandemic on the energy system.

Box 1.1 EU renewable energy policies up to 2020 and 2030

The EU was an early adopter of renewable energy starting with the implementation of EU-wide policies from the mid-nineties. After the first directive on electricity production from renewable energy sources (2001) with indicative targets, the review (in 2005) of Member States' supporting schemes led to a period of debate and negotiations between Member States and the EU institutions. This resulted, in 2009, in the RED (2009/28/EC), which set legally binding national targets contributing to an EU-wide target of 20 % renewable energy in the total energy needs by 2020.

The binding national targets are set at different levels to reflect national circumstances. The EU's renewable energy target for transport (i.e. a 10 % share by 2020) is divided equally for all countries into 10 % national targets, with biofuels produced from energy crops grown on agricultural land limited to a maximum of 7 %. The RED also sets out options for cooperation to help countries achieve their targets cost-effectively.

In the run-up to 2020, two interim trajectories are of interest in assessing the EU's and Member States' progress towards their binding targets:

- The minimum **indicative RED trajectories** for each country. These trajectories concern only the total RES share. They run until 2018, ending in 2020 with the binding national RES share targets. They are provided in the RED to ensure that the national RES targets will be met.
- The **expected trajectories** adopted by Member States in their national renewable energy action plans (NREAPs) under the RED. These NREAP trajectories concern not only the overall RES share but also the shares of renewables in the electricity, heating and cooling, and transport sectors up to 2020.

For 2030, the RED II sets a binding EU-wide target of 32 % RES in gross final energy consumption. Member States have proposed national targets contributing to the EU binding target for renewables in their final NECPs including existing and planned policies and measures. The assessment of NECPs shows that the share of renewable energy could reach, under existing and planned measures, a range of 33.1 to 33.7 % in 2030, surpassing the EU's 2030 RES target (ref COM assessment).. Additionally, the RED II also includes:

- guiding principles concerning financial support schemes for RES-E;
- the requirement for Member States to set up 'one-stop shops' to coordinate the entire permit-granting process for new RES generation, transmission and distribution capacity;
- principles of renewable self-consumption and (local) renewable energy communities;
- enhancement of existing provisions on cross-border cooperation;
- provisions to improve the sustainability and GHG emissions-saving criteria for biofuels, bioliquids and biomass;
- mainstreaming of renewable heating and cooling (RES-H&C) applications, in particular by asking Member States to increase the share of renewable energy supplied for heating and cooling by a fixed rate (by an indicative 1.3 percentage points for 2021-2025 and higher thereafter) per year, starting from the level achieved in 2020.

Outlook beyond 2020

In June 2018, European countries gave their endorsement to a binding EU-wide renewable energy target of a minimum of 32 % of gross final consumption by 2030, which is included in the recast Renewable Energy Directive (RED II) that entered into force at the end of 2018. Building on the Energy Union strategy of 2015 (EC 2015), as well as on the Regulation on the Governance of the Energy Union (EU 2018b) ([6]), Member States had to propose an indicative level of effort contributing to the EU binding target for renewable energy as part of their final integrated national energy and climate plans, by the end of 2019, taking into account the Commission's recommendations of June 2019 on their draft plans. The assessment of NECPs shows that the share of renewable energy could surpass the target of 32 % (see also Box 1.1).

In September 2020, the Commission presented its 2030 Climate Target Plan proposing an EU-wide net greenhouse gas (GHG) emissions reduction target of at least 55% by 2030, compared to 1990 levels. The analysis for the accompanying Communication on stepping up Europe's 2030 climate ambition shows that higher shares of renewables are fundamental to achieve higher GHG emissions reduction targets. As set out in the impact assessment, reducing GHG emissions by at least 55 % would require a share of renewable energy in the EU of 38-40% by 2030 (EC 2020a). These levels of renewable energy are not yet translated in Member State's NECPs of 2019.

Since the renewable energy target is defined as the share of renewable energy in gross final energy consumption it is clear that the role of energy savings and improved energy efficiency in gross final consumption cannot be underestimated.

In the run-up to 2030, the indicative RES trajectory of the EU-27 (based on the collective efforts of the Member States) should reach at least the following reference points for the total increase in the RES share between the binding 20 % RES share target for 2020 and the binding 32 % RES share target for 2030: 18 % by 2022; 43 % by 2025; 65 % by 2027. For EU-27, this would be equal to a RES share of 22 %, 25 % and 28 % in respectively 2022, 2025 and 2028. Should Member States fall behind similar reference points in relation to their RES trajectories in the integrated national energy and climate plans, they will need to implement additional measures to cover the gap within 1 year (EU 2018b). The RED II intends to mainstream renewable energy in heating and cooling and thus includes a trajectory for this purpose. Member States are urged to make an effort to increase the share of renewable energy by an indicative 1.3 percentage points as an annual average calculated for the periods 2021 to 2025 and 2026 to 2030, starting from the share of renewable energy in the heating and cooling sector in 2020, expressed in terms of national share of final energy consumption. The increase shall be limited to an indicative 1.1 percentage points for Member States where waste heat and cold is not used (EU 2018a).

Beyond Europe

In the past, the EU has been a frontrunner in renewable energy. Nevertheless, with developing countries investing more in green energy than developed economies, the situation may be changing in the short run (see Chapter 4).

1.2 About this report

This EEA report depicts changes in RES in Europe since 2005, at the level of individual technologies and countries (Chapter 2) and outlines key global developments to put European progress in perspective

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([6]) The Regulation on the Governance of the Energy Union, which entered into force at the end of 2018, is a horizontal piece of legislation that aims to streamline monitoring and reporting of progress, and increase synergies and cooperation across all dimensions of the Energy Union, so as to obtain a high level of policy coherence through integrated national energy and climate plans.

(Chapter 1). It also illustrates the co-benefits of growing RES consumption in Europe, notably the replacement of fossil fuels by a growing share of renewables and the resulting effects on the reduction in GHG emissions and air pollutant emissions (Chapter 0). This chapter sets the overall context.

The assessment uses Eurostat data for the period 2005-2018, complemented by early EEA estimates regarding GHG emissions and energy developments in 2019

1.2.1 Geographical scope

The assessment focuses on the 27 EU Member States (EU-27) in Chapter 2 and 3, whereas an EU-27 plus UK format is applied in Chapter 4 due to data limitations. Reason for the focus on EU-27 is the withdrawal of the United Kingdom from the EU in 2020. The target for 2020 will have to be achieved by the 27 other Member States.

In Chapter 2 (section 2.1.2) and 4, capacities and investments in RES-E, population and GDP are aggregated into relevant world regions to facilitate a comparison of the EU's progress with international developments. Details of the geographic aggregation are presented in the glossary.

1.2.2 Data sources and methodologies

Approximated estimates for the share of gross final consumption of renewable energy resources (RES share proxies)

The EEA 2019 RES shares are, ultimately, estimated values. Although the 2019 RES shares proxies formed the basis of a specific EEA country consultation, carried out in October 2020 ([7]), these values are not a substitute for data that countries officially report to Eurostat.

The methodology applied for approximating RES values in the year *t*-1 was described in a previous EEA report (EEA 2015) — see also Annex 3. Confidence in the estimated RES share proxy values is greatest in the electricity sector. The dynamics in the renewable heating and cooling market sector may be underestimated due to the more limited data available for this sector. Finally, the specific accounting rules in the RED concerning renewables consumed in transport remain difficult to replicate. Despite these challenges, the estimation of RES share proxies yields plausible results in most cases and should be further improved, especially as more timely information and data that are relevant for the estimations become available.

Gross avoided greenhouse gas emissions due to avoided fossil fuel use

Chapter 3 estimates the gross effects of renewable energy consumption on GHG emissions based on data available from Eurostat for primary energy consumption in 2018. The term 'gross avoided GHG emissions' illustrates the theoretical character of the GHG effects estimated in this way, as these contributions do not necessarily represent 'net GHG savings per se' or are not based on life-cycle assessment or full carbon accounting ([8]). Considering life-cycle emissions could lead to substantially

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([7]) The approximated GHG emissions, energy consumption and RES proxy data were sent for consultation to the European Environment Information and Observation Network (Eionet) of environmental bodies and institutions active in the EEA member countries. These proxies were finalised in October 2020, after the Eionet consultation.

([8]) In the absence of specific information on current bioenergy systems, CO_2 emissions from the combustion of biomass (in solid, liquid and gaseous forms) were not included in national GHG emission totals in this report, and **a zero emission factor** had to be applied to all energy uses of biomass. This should not be interpreted, however, as an endorsement of default biomass sustainability or carbon neutrality. It should be noted that, according to the United Nations Framework Convention on Climate Change (UNFCCC) different results. It is important to note that, because the base year of this analysis is 2005, the development of renewable energy from only that point in time is considered. Section 0 illustrates the avoided fossil fuel use at the Member State level. The relative effects are shown with respect to gross inland fossil fuel use per country (see Figure 22). Section 0 also estimates the effects on energy consumption. A detailed description of the methodology applied for approximating these effects was provided in a previous EEA report (EEA 2015).

Gross effect of renewable energy on air pollutant emissions

Chapter 3 also estimates the gross effect of renewable energy consumption on air pollutant emissions. Based on the gross final energy consumption of renewable energy technologies (RETs), the attributes of individual RETs, the primary energy use per unit of electricity or heat, the implied emission factors calculated with GAINS data, an estimate is made of the gross effect of renewable energy on air pollutant emissions for the EU-28 and per Member State (ETC/CME 2019a; ETC/CME 2019b).

Renewable energy investments

To date, a central, publicly available source of information on global RES technology investments is missing. The comprehensive information used in this assessment is sourced from the Global trends in renewable energy investment annual report (Frankfurt School-UNEP 2020). The period covered is 2005-2019 and the focus is on new renewable energy investments per region. While analysing investments, the report includes projects on renewable power and fuels — wind, solar, biomass and waste, biofuels, geothermal and marine projects, and small hydro-electric dams of less than 50 MW. It does not cover larger hydro-electric dams of more than 50 MW. Investment figures were originally supplied in nominal billions of US dollars. Full comparability across regions and time remains limited, as nominal values include inflation ([9]).

For the purpose of this report, figures in US dollars have been converted to euros using the Eurostat data set on exchange rates (Eurostat 2020c).

Renewable energy employment

The renewable energy sector requires specific skills and value chains, which lead to the creation of new jobs. Job numbers can be estimated using various methods with different levels of detail. As data availability varies across regions and data differ about quality and methods, a consistent time series is not yet available. For these reasons, only a snapshot of the recent past (2019), by available region and technology, can be shown. Direct and indirect jobs related to renewable energy per region for 2019 are presented below and stem from the International Renewable Energy Agency (IRENA 2020c).

Newly introduced Eurostat codes and descriptions since 2019

In January 2019, Eurostat introduced a novel methodology for the energy balances, mostly to harmonise codes and labels with international statistics. To ensure continuity of indicators necessary to assess

reporting guidelines, these emissions have to be reported separately in GHG inventories as a memorandum item (mainly to avoid double counting of emissions from a reporting perspective), with the assumption being that unsustainable biomass production would show as a loss of biomass stock in the land use, land use change and forestry (LULUCF) sector and not in the energy sector.

([9]) To adjust for inflation one would need to consider individual inflation rates — or deflators — for each of the regions. As the regions are composed of heterogeneous countries, probably experiencing different levels of inflation, it is not possible to make this conversion. This needs to be taken into account when interpreting the data.

progress towards the Energy Efficiency Directive, Eurostat therefore established new specific indicator codes: Gross Inland Consumption (Europe 2020-2030); Primary Energy Consumption (Europe 2020-2030); Final Energy Consumption (Europe 2020-2030) ([10]).

The "Europe 2020-2030" indicators have been used exclusively when referring to total amounts, to check the trend towards the 2020 targets. The other indicators have been used when breaking down the analysis for specific fuels, e.g. fossil fuels. This distinction was needed for both the lack of data for single fuels in the "Europe 2020-2030" indicators, as well as a more scientifically correct analysis for the fossil fuels themselves. Where relevant, tables and figures in this report state which indicators were used.

In addition, the "Combustible fuels" label does not exist anymore as a single indicator. Instead, it is now possible to calculate the indicators for the desired fuels. The full list of fuels included in the calculations is presented below:

Table 1 List of fuels included in the calculations of Eurostat indicators.

C0110	Anthracite	**O4300**	Refinery feedstocks
C0121	Coking coal	**O4610**	Refinery gas
C0129	Other bituminous coal	**O4620**	Ethane
C0210	Sub-bituminous coal	**O4630**	Liquefied petroleum gases
C0220	Lignite	**O4640**	Naphtha
C0311	Coke oven coke	**O4652XR5210B**	Motor gasoline (excluding biofuel portion)
C0320	Patent fuel	**O4661XR5230B**	Kerosene-type jet fuel (excluding biofuel portion)
C0330	Brown coal briquettes	**O4671XR5220B**	Gas oil and diesel oil (excluding biofuel portion)
C0340	Coal tar	**O4680**	Fuel oil
P1100	Peat	**O4694**	Petroleum coke
P1200	Peat products	**O4695**	Bitumen
G3000	Natural gas	**W6100**	Industrial waste (non-renewable)
O4100_TOT	Crude oil	**W6220**	Non-renewable municipal waste
O4200	Natural gas liquids		

([10]) For the exact definition, please refer to the official documentation (Eurostat 2019e, Eurostat 2018).

Other observations

For offshore wind, 2005-2017 data are calculated based on capacities reported by EurObserv'ER, while 2018 and 2019 data are calculated on capacities reported by WindEurope. The decision to go for these sources instead of Eurostat SHARES values came from the incompleteness of the information in the latter source. All the production calculations are based on an assumption of 4 000 full load hours of operation. The offshore wind production is then subtracted from the total wind production reported by Eurostat (Eurostat 2019b) and the result is attributed to onshore wind production. The total of onshore and offshore wind power generation is equal to the total for wind power reported by Eurostat. Data for 2020 originate from table 10 in each country's NREAP, where there is separate reporting for onshore and offshore wind power.

In the context of renewable energy use in transport the terms 'other biofuels' and 'all biofuels' are understood to also include biogas and other liquid biofuels used in transport. Similarly, in the context of RES-E generation, the term 'solid biomass' is understood to also include renewable municipal waste.

The methods applied in this report to estimate the impact of the uptake of renewable energy on energy consumption and GHG emissions cannot be used to assign these effects to particular drivers, circumstances or policies, other than the increased consumption of renewable energy itself. These methodologies provide valuable insights, but as the assumptions are static (i.e. the same set of assumptions is applied to all years in the period), assumptions need to be re-adjusted at times to reflect real-life conditions. A detailed description of the methods was given in a previous report (EEA 2015).

2 Developments in renewable energy sources in Europe

Key messages:

- Since 2005, renewable energy increased significantly across the EU, from 10.2 % in 2005 to 18.9 % in 2018. According to preliminary estimates calculated by the EEA, the RES share continued to grow in 2019, reaching an estimated 19.5 % share in gross final consumption ( ). If the UK is taken into account too, the RES share across the EU-28 would have increased from 9.1 % in 2005 to 18.0 % in 2018. The EU-28 RES share would have reached to 18.7 % according the EEA early estimates. This would be almost 1 % lower than the current EU share.
- In 2018, the RES share exceeded the trajectory that can be ascribed to the EU on the basis of the indicative trajectories of the Member States under the RED (16.6 % in 2018(12)). The EU almost reached the trajectory level of 19.2 %, expected in accordance with the NREAPs. For 2019, again EU almost reached its indicative trajectory which was determined at 20.2 %.
- Considering the strong contractions in GDP and energy use during 2020, it appears likely that the EU will meet its 20 % RES target in 2020. If so however, much will have been due to the drastic measures taken to contain the spread of the Covid-19 virus, than solely to the success of domestic policies and measures to promote renewable energy use.
- At the current pace of growth of 0.7 percentage points annually, the 32 % target by 2030 will not be met. To reach that target, the RES share across the EU will have to grow by an average of 1.1 percentage points, per year, between 2018 and 2030.
- Across the EU, in absolute terms, the largest market sector for renewable energy use remains heating and cooling. Renewables made up more than one fifth of all final energy consumed in this market sector in 2018 and 21.7% in 2019. In 2018, the largest contributions came from solid biomass (80.0 Mtoe, or 81 % of all RES-H&C), heat pumps (11.4 Mtoe, or 12 % of all RES-H&C) and biogas (3.5 Mtoe, or 4 % of all RES-H&C).
- Electricity is the second largest market sector for RES in the EU (RES-E share of 32.2 % in 2018 and 34.1 % in 2019 according to the early EEA estimates). In 2018, the largest contributions came from hydropower and wind power (37 % and 34 % of all RES-E, respectively), solar PV systems (12 % of all RES-E) and solid biomass (10 % of all RES-E). All the other technologies made smaller contributions, ranging from 0.1 % (tidal, wave and ocean energy) to 6 % (biogas).
- Transport is the third and smallest market sector for renewables (8.3 % in 2018 and 8.4 %in 2019, according to the early EEA estimates). Renewable energy use in transport (including only biofuels certified in accordance with the existing sustainability criteria) varied significantly among Member States.

2.1 Recent progress in deployment of renewable energy sources

2.1.1 Renewable energy shares at the EU level and in individual Member States

The RED (EU 2009) sets minimum indicative trajectories for each country, which end in binding national RES share targets for 2020. Progress towards these 2020 targets is assessed by comparing the most recent developments with these interim trajectories. The indicative RED target for the EU is 16.6 % ([11])

([11]) Since Annex I of the RED (EU 2009) does not include the share of energy from renewable sources in gross final consumption of energy, 2005 and 2020 (S_{2005} and S_{2020}) for EU-27 this indicative target is calculated by taking for S_{2005} the value from SUMMARY results SHARES 2018 (10.24 %) and for S_{2020} 20 %. The indicative trajectory is then calculated according to the formula of Annex I.

for the years 2017 and 2018. Having achieved a RES share of 18.9 % in 2018 and an estimated share of 19.5% in 2019, the EU has surpassed its indicative target for 2018. Considering the strong contractions in GDP and energy use during 2020, it appears likely that the EU will meet also its 20 % RES target in 2020 (EU 2009). If so however, two major events could be of influence: Brexit and the outbreak of the Covid-19 virus. Including the UK, the RES share would have been 18.0 % in 2018 (and an estimated 18.7 in 2019) – almost one percentage point less than for the EU-27. The Covid-19 outbreak this spring lead to unprecedented decreases in final energy consumption for the target year 2020. Given the lower operational costs of RES compared to traditional power sources, the reduction in consumption probably translates in lower generation from fossil fuels, pushing the share of RES up in the energy mix. The higher CO_2 allowances costs for fossil power generators also contribute to this effect. These higher costs are due to the measures the European Commission took in recent years to address the surplus in allowances.

Compared to its expected NREAP trajectory ([12]), the EU-27 almost reached its expected NREAP level in 2018 which was determined at 19.2 %. If the UK is considered, the expected NREAP level of 18.2 % for the EU-28 was again almost reached.

Between 2005 and 2018, the RES share increased annually by 0.7 percentage points, on average, with the pace of growth below this average since 2015, but remaining stable in 2017 and 2018 (0.4 percentage points). It is worth noting that gross final energy consumption decreased between 2005 and 2014 by 1.1 percentage points, on average, but it increased again between 2014 and 2017, by 1.8 percentage points on average and remained stable in 2018. According to early EEA estimates, final energy consumption in 2019 increased 0.1% compared to 2018.

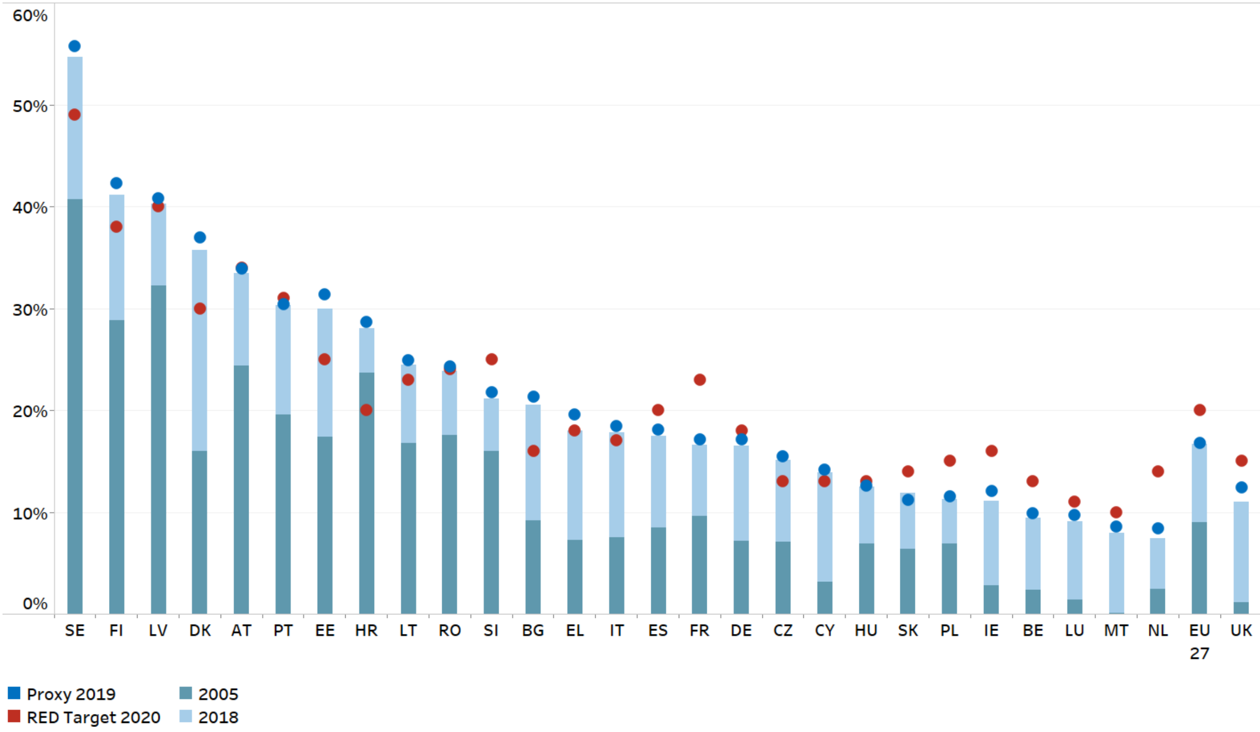
As shown in the he EEA's annual report on Trends and Projections in Europe, the drop in gross final energy consumption from all sources recorded between 2005 and 2014 coincided with a progressive substitution of fossil and nuclear fuels by renewables. But the steady growth in total final energy consumption recorded between 2014 and 2018 slows down progress to enhance the share of renewable energy use (EEA 2020b).

The current pace of 0.7 percentage point annually is not sufficient to meet the target of 32 % by 2030. To meet that target, the EU's RES share must grow by an average of 1.1 percentage points per year between 2018 and 2030 (EEA 2020b).

Figure 1 shows the actual RES shares in the EU Member States and for the EU for 2005 and 2018. The RES shares vary widely among countries. In 2018, the highest shares of renewable energy were attained by Sweden (54.6 %), followed by Finland (41.2 %) and Latvia (40.3 %). Netherlands (7.4 %), Malta (8.0 %) and Luxembourg (9.1 %) realised the lowest shares. Figure 1 also shows the RED target share for 2020. This overall target takes into account individual national circumstances, such as RES potentials and starting points as well as GDP.

([12]) In paragraph 2.2 more explanation on NREAPs of the Member States is provided. For the EU-27 or EU-28 as such, no NREAP was made up, only the individual Member States did. The EU-27 and EU-28 expected NREAP trajectories are constructed by summing up the estimations of the contributions of the individual renewable energy technologies per market sector, for compliant fuels (from table 10, 11 and 12 of the NREAPs) and dividing them by the expected GFEC per market sector (additional energy efficiency) (from table 1 of the NREAPs).

Figure 1 **Actual and approximated RES shares in the EU and its Member States and the UK.**



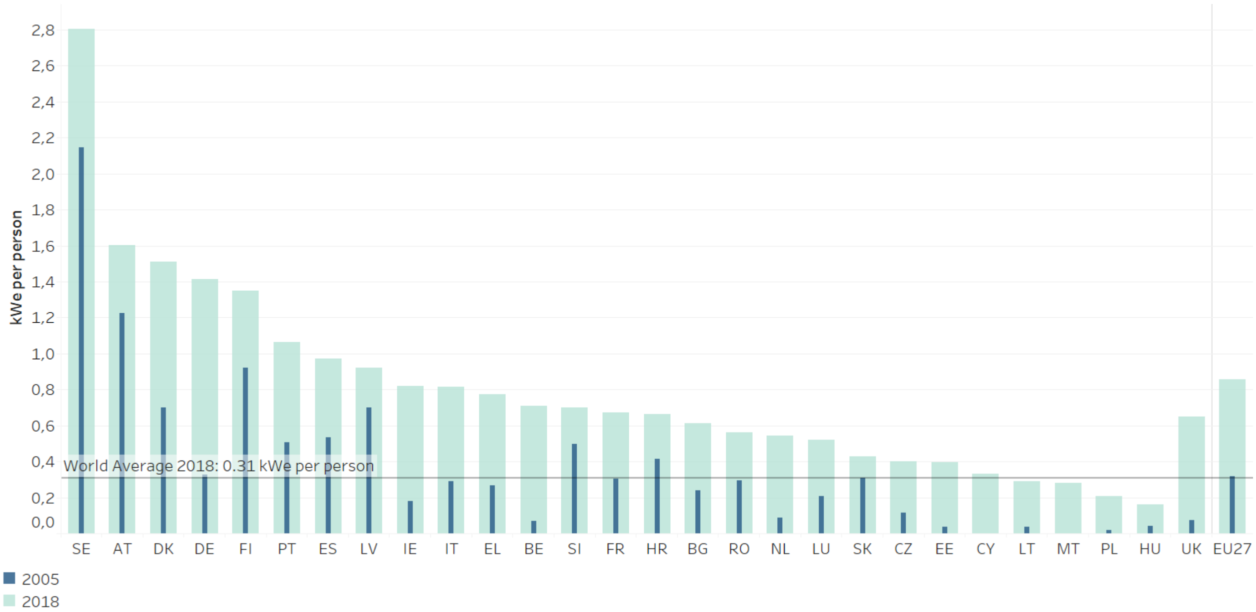
Notes: The dark green bars show the RES shares in 2005. The tops of the light blue bars show the levels that the RES shares reached in 2018.

Sources: ETC/CME, (Eurostat 2020a); RED (2009/28/EC).

2.1.2 Renewable electricity capacities per capita and per unit of gross domestic product

The average RES-E capacity per capita for the EU was two and a half time larger in 2018, compared with 2005, from 0.35 kW in 2005 to 0.89 kW in 2018. Sweden had the largest installed capacity per person in 2018 (2.80 kW), followed at a distance by Austria, Denmark, Germany and Finland (1.35 to 1.60 kW). However, since 2005, the largest growth in RES-E capacity per capita has been observed in Cyprus, Estonia, Poland, Belgium, Lithuania, Netherlands, Ireland, Germany, Hungary, Czech Republic (all more than 300 % growth), followed by Greece, Italy, Bulgaria, Luxembourg, France, Denmark, Portugal (growth between 200 % and 300 %). The remaining countries (Romania, Spain, Croatia, Finland, Slovenia, Slovakia, Latvia, Austria, Sweden showed lower growth rates (< 200 %). Only in four EU countries (Lithuania, Malta, Poland and Hungary) the installed capacity per capita remained below the world average (see Figure 2 and Figure 34). It must be noted that the RES-E capacity per capita is just one indicator and that it does not necessarily reflect the local conditions for RES development in a country well. It is included here however to make the comparison with the global RES-E capacity and with other world regions (see Chapter 4).

Figure 2 **RES-E capacities, excluding pumped storage, per capita in the EU and its Member States and the UK.**

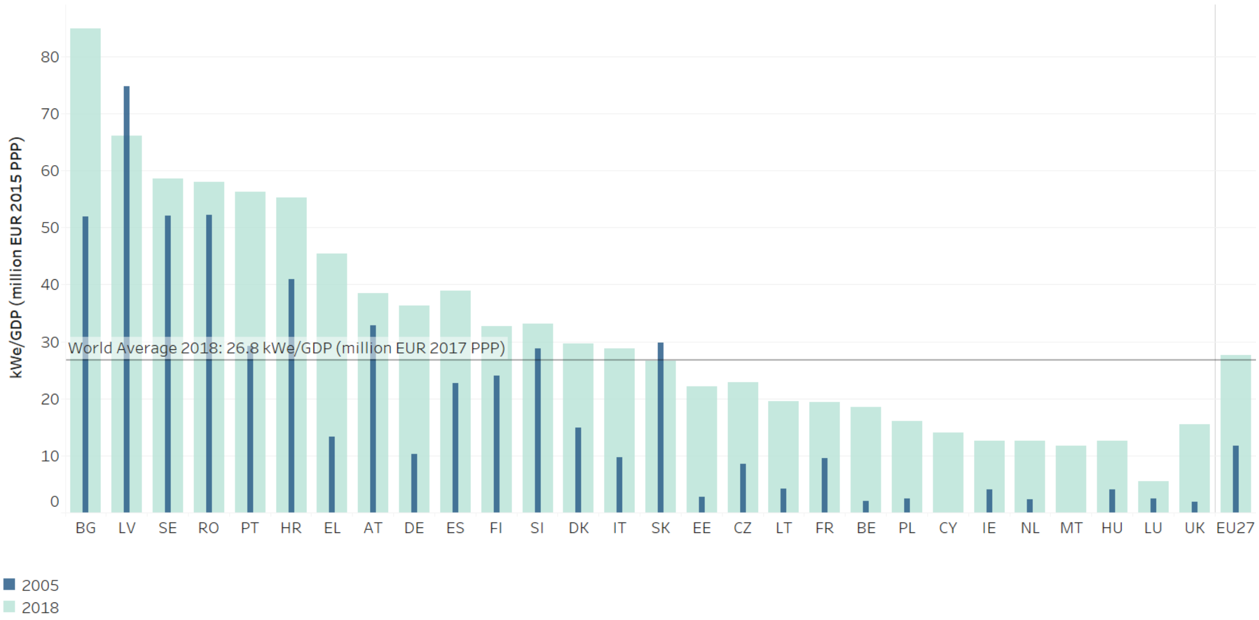


Sources: ETC/CME, (Eurostat 2020e); (Eurostat 2020d); (IRENA 2020b)

Similar to the average RES-E capacity per capita, the average RES-E capacity per unit of GDP for the EU has more than doubled since 2005, reaching 28 kW/GDP ([13]) in 2018. Bulgaria, Latvia, Sweden and Romania had the largest installed capacities per unit of GDP (58 kW/ million EUR_{2015} (PPP) or more) followed by Portugal, Croatia, Greece, Spain, Austria and Germany (35 to 57 kW/million EUR_{2015} (PPP)). The largest growth in RES-E capacity per GDP since 2005 can be observed in Malta, Cyprus, Belgium, Estonia, Poland and the Netherlands (all more than 450 % growth), followed by Lithuania, Germany, Greece, Hungary, Ireland, Italy and Czech Republic (between 150 % and around 250 % growth). The remaining countries (Luxembourg, France, Denmark, Portugal, Spain, Bulgaria, Finland, Croatia, Austria, Slovenia, Sweden and Romania) showed lower growth rates (< 130 %) while Slovakia and Latvia showed negative growth rates per unit of GDP. Per unit of GDP, installed capacities in 2018 were below the world average (26.8 kW per unit of GDP EUR_{2017} (PPP)) in 13 of the 27 EU Member States (Slovakia, Czech Republic, Estonia, Lithuania, France, Belgium, Poland, Cyprus, the Netherlands, Ireland, Hungary, Malta and Luxembourg).

([13]) GDP expressed in constant 2017 euro value (EUR_{2017}) at PPP.

Figure 3 **RES-E capacities, excluding pumped storage, per GDP in the EU and its Member States and the UK.**



Sources: ETC/CME;(Eurostat 2020e); (EEA 2020a); (IRENA 2020b).

2.2 Contributions of renewable energy sources by energy market sector and technology

In 2010, Member States submitted NREAPs in which they outlined their expected national paths to meet their binding 2020 RES targets and included separate trajectories for RES-E, RES-H&C and RES-T. The expected paths in the NREAPs are, overall, more ambitious than the indicative RED trajectories. This section shows the progress achieved by RES within the three energy market sectors and compares it with the expected (NREAP) development in these market sectors.

The expected (NREAP) trajectories of individual technologies enable progress to be monitored, but they become increasingly outdated as conditions and policies change ([14]). In fact, because of steep learning curves, the rapid development and consequent cost reductions achieved by some renewable energy technologies have already led to higher shares of these technologies than anticipated in the NREAPs for 2020.

At EU level, in absolute terms RES-H&C remains the dominant RES market sector (see Section 2.2.3), followed by RES-E (see Section 2.2.2) and RES-T (see Section 2.2.4).

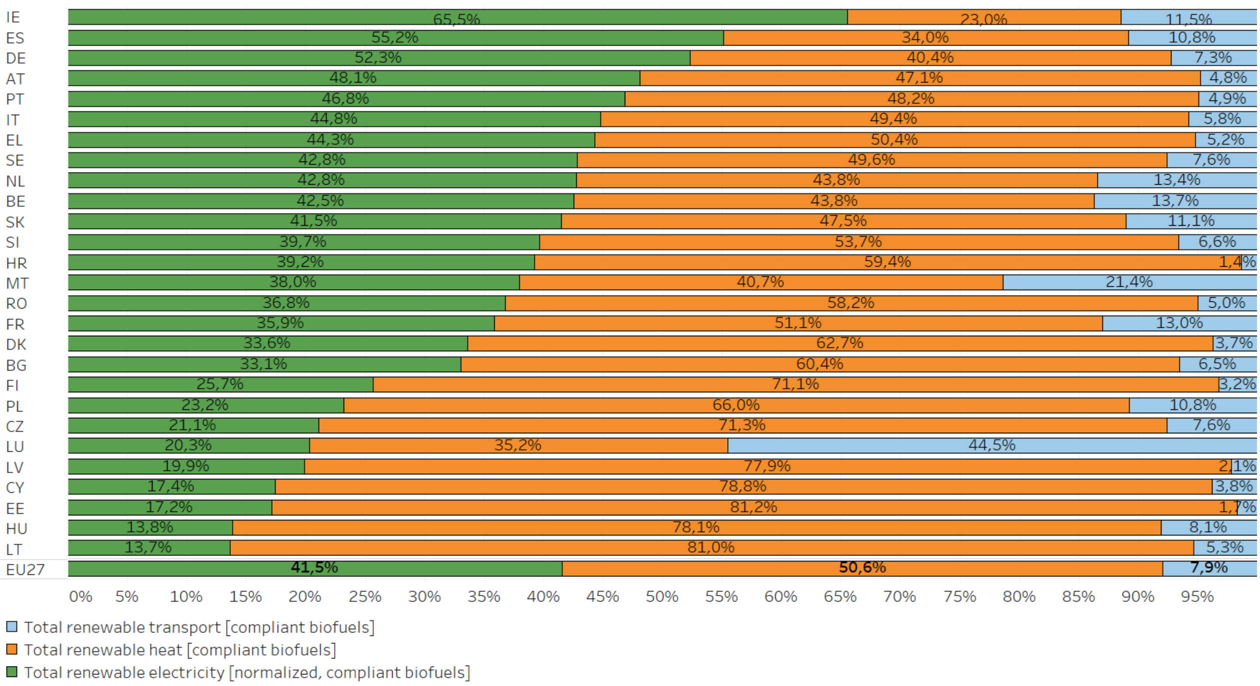
2.2.1 Contribution of renewable energy sources to various energy market sectors in Member States

At the country level, the significance of each energy market sector, and the role renewable energy plays therein, differs considerably. Figure 4 illustrates these differences by showing the split of gross final renewable energy consumption by market sector in each country.

([14]) Some countries have updated their NREAPs since 2010. The most recent versions were used for this report. Austria, Bulgaria, Czech Republic, Denmark, Estonia, Ireland, Poland, Spain and Sweden updated their overall RES shares, or their RES shares per technology, for one or several years, as additional information to the Commission's questions or in a resubmission of their NREAP. The latest version of Malta's NREAP is from 2017 and this version was used for this report.

- **Renewable heating and cooling** represented more than half of all gross final consumption of renewables in 15 Member States (Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Greece, Hungary, Latvia, Lithuania, Poland, Romania and Slovenia).
- **Renewable electricity** represented over half of all RES consumption in only three countries (in descending order: Ireland, Spain and Germany).
- The contribution of **renewable transport fuels** (certified biofuels) was on average 7.9 %, but varied significantly among Member States from a maximum of 45 % of all RES consumption (Luxembourg) to less than 2 % (Estonia and Croatia)

Figure 4 **Total RES consumption in 2018 by market sector in the EU and its Member States.**



Notes: This figure shows how actual final renewable energy consumption in 2018 is distributed over RES-E, RES-H&C and biofuels in transport. Wind power and hydropower are normalised ([15]). The consumption of RES accounts for only biofuels complying with the RED sustainability criteria.

Source: Compiled from data in (Eurostat 2020e).

The variations observed across countries in the relative importance of each market sector are due to specific national circumstances, including different starting points in terms of the deployment of RES, different availability of low-cost renewables, country-specific demand for heating in the residential sector and different policies to stimulate the deployment of renewable energy.

([15]) Under the accounting rules in the RED, electricity generated by hydro- and wind power needs to be normalised to take into account annual climatic variations (hydro for 15 years and wind for 5 years).

2.2.2 Renewable electricity

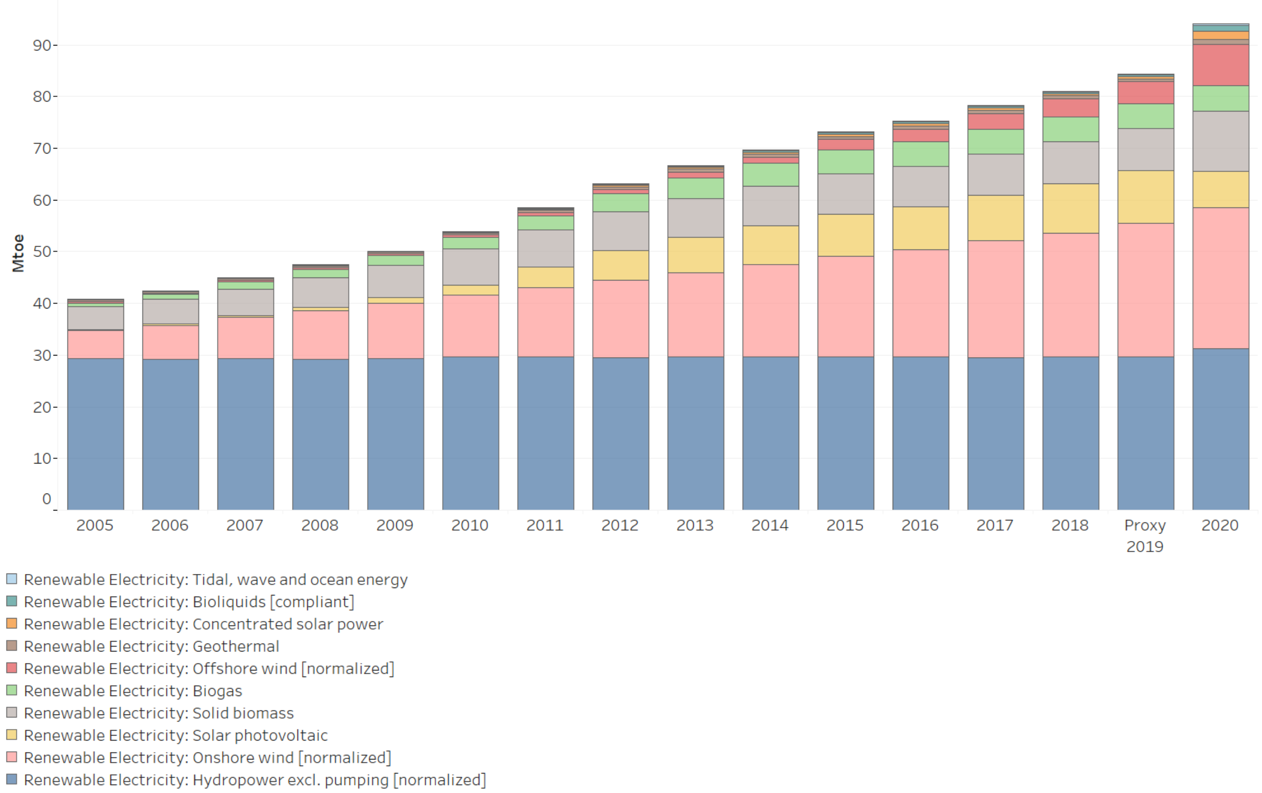
In 2018, the EU-wide share of RES-E amounted to 32.2% — almost twice the level in 2005. Figure 5 and Table 2 show the consumption of RES-E up to 2018, approximated estimates for 2019 and the expected NREAP developments by 2020.

- The gross final energy consumption of RES-E continued to increase, reaching 81.6 Mtoe in 2018.
- In 2018, the largest contributions came from hydropower and wind power (37 % and 34 % of all RES-E, respectively) ([16]), solar PV systems (12 % of all RES-E) and solid biomass (10 % of all RES-E). All the other technologies made smaller contributions, ranging from 0.1 % (tidal, wave and ocean energy) to 6 % (biogas).
- Over the period 2005-2018, the RES-E consumption increased by 8 percentage points per year, on average. To achieve the expectations for 2020 in the NREAPs, an increase by 8 percentage points per year, on average, will be required over the period 2018-2020. For 2005-2018, the increase was the highest for solar PV systems, offshore wind, biogas and onshore wind with respectively 573, 129, 45 and 26 percentage points increase per year, on average. For the same period, hydropower and tidal, wave and ocean energy had the lowest increase with 0 percentage points per year, on average.

According to EEA early estimates, RES-E generation increased in 2019 to 84.4 Mtoe, while total electricity generation from all sources increased to 247.7 Mtoe, resulting in a RES-E share of 34.1 %. Most of the increase in RES-E generation in 2018 was due to the greater contribution of wind energy (+3.1 Mtoe) and solar energy (+0.7 Mtoe). In 2018, electricity consumption in Europe remained at the same level as in 2017 after three years of increase since 2015.

([16]) The SHARES tool contains only total offshore and onshore wind energy production. In this report, it is assumed that offshore wind turbines realise 4 000 full load hours per year. Accordingly, onshore and offshore wind reached each a share of 28 % and 6 % of all RES-E, respectively.

Figure 5 **RES-E in the EU.**



Notes: This figure shows the actual final RES-E consumption for 2005-2018, approximated estimates for 2019 and the expected realisations in the energy efficiency scenario of the NREAPs for 2020. Wind power and hydropower are normalised. The consumption of RES accounts for only biofuels complying with the RED sustainability criteria.

Sources: ETC/CME; (Eurostat 2020e); NREAP reports.

Table 2 RES-E in the EU by RES technology.

Technology	Final energy (ktoe) 2005	2017	2018	Proxy 2019	NREAP 2020	Percentage increase per year 2005 - 2018	2017 - 2018	2018 - 2020
Hydropower excl. pumping (normalised)	29 320	29 461	29 640	29 653	31 239	0%	1%	3%
Onshore wind (normalised)	5 554	22 669	23 984	25 860	27 367	26%	6%	7%
Solar PV systems	125	8 776	9 468	10 131	6 870	573%	8%	-14%
Solid biomass ([a])	4 401	7 996	8 191	8 189	11 689	7%	2%	21%
Biogas	695	4 813	4 791	4 852	5 014	45%	0%	2%
Offshore wind (normalised)	199	3 037	3 545	4 170	7 946	129%	17%	62%
Geothermal energy	464	577	572	572	943	2%	-1%	32%
Concentrated solar power	0	506	418	489	1 633	n.a.	-17%	146%
Bioliquids (certified)	0	415	409	409	1 096	n.a.	-2%	84%
Tidal, wave and ocean energy	41	45	41	41	220	0%	-8%	216%
Total RES-E (normalised, certified biofuels)	40 800	78 292	81 061	84 366	94 016	8%	4%	8%
Total RES-E (normalised, including all biofuels) ([b])	40 952	78 306	81 075	84 385	94 016	8%	4%	8%

Notes: This table shows the actual final renewable energy consumption for 2005, 2017 and 2018, approximated estimates for 2019 and the expected realisations in the energy efficiency scenario of the NREAPs for 2020. Also shown are the average percentage point increase per year for the period 2005-2018, the percentage point increase from 2017 to 2018 and the average percentage point increase per year required to reach the expected realisations in the NREAPs for 2020. Wind power and hydropower are normalised.

(a) Renewable municipal waste has been included in solid biomass.

(b) The series includes all biofuels and bioliquids consumed for electricity purposes, including uncertified ones after 2011.

Sources: ETC/CME; (Eurostat 2020e); NREAP reports.

Hydropower

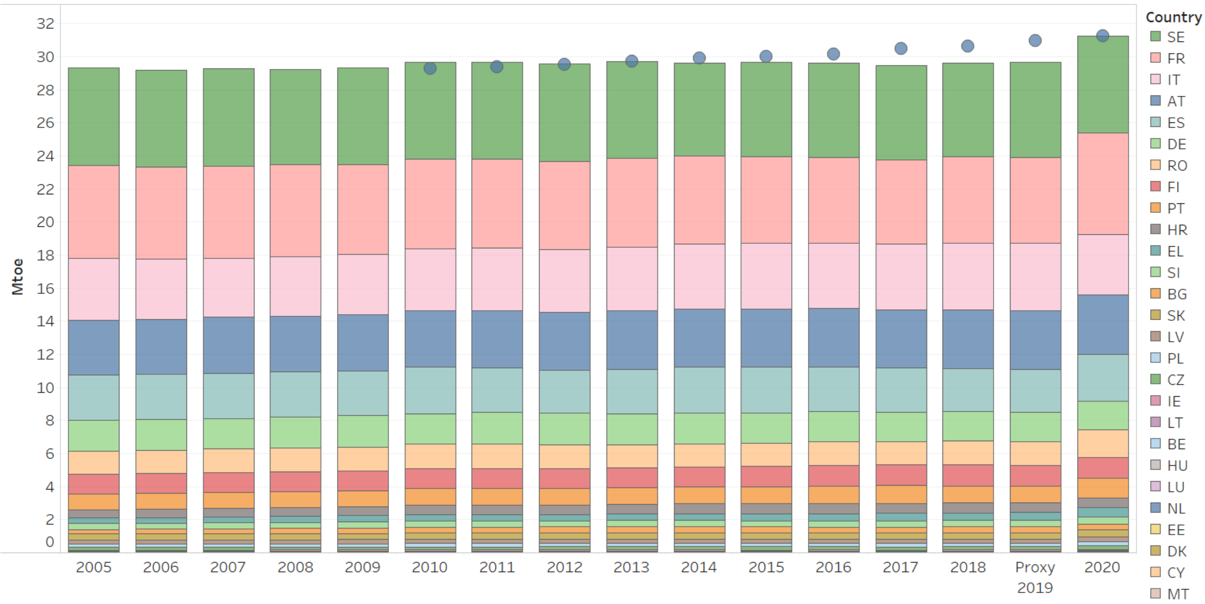
Rainfall patterns determine annual changes in hydroelectricity production. That is why normalised production data are taken into account. The normalised ([15]) production of renewable hydroelectric power remained quite stable over the period 2005-2018, as illustrated in Figure 6. According to the NREAPs, limited growth, from 29.6 to 31.2 Mtoe, is expected for the period 2018-2020. In 2018, the five countries with the most hydropower (Sweden, France, Italy, Austria and Spain) had a share of more than 70 % of all hydropower generation in the EU. In 2019, the normalised production of hydroelectricity is likely to slightly increase in absolute value (from 29.6 Mtoe in 2018 to 29.7 Mtoe in 2019), but decreasing its share (from 37 % in 2018 to 35 % in 2019).

Hydropower is a flexible, mature technology for power generation, and hydropower reservoirs (dams) can provide energy storage. Investments in large-scale hydropower (> 10 MW) were mainly made before 2000. Most of the best sites have already been developed (amounting to about half of the technically feasible potential; Pedraza, 2014), which is why hydropower capacities evolved only a little across the EU. In 2019, the largest capacities (including pumped storage) have been added in Italy, Spain and

Austria (respectively 95, 38 and 29 MW). Larger capacities were added outside the European Union, in Turkey and Norway (respectively 212 and 134 MW in 2019) (International Hydropower Association 2019).

Hydropower projects may negatively impact water bodies, adjacent wetlands and the habitats where they are installed, their operation impacting directly certain rare and threatened species protected under EU nature legislation. To minimise such impacts, measures targeting fish migration, habitat restoration or sediment management need to be implemented in accordance with the Water Framework Directive. Moreover, the European Commission has published guidance for use by competent authorities, developers and consultants 'The requirements for hydropower in relation to EU Nature legislation' (EC 2018).

Figure 6 RES-E in the EU: hydropower excluding pumping (normalised).



Notes: This figure shows the actual final RES-E consumption for 2005-2018, approximated estimates for 2019 and the expected realisations in the energy efficiency scenario of the NREAPs for 2020.

Sources: ETC/CME; (Eurostat 2020e); NREAP reports.

Onshore wind

Onshore wind power generation increased from 5.6 Mtoe in 2005 to 24.0 Mtoe in 2018. The largest generations could be observed in Germany (6.9 Mtoe in 2018) and Spain (4.3 Mtoe in 2018).

In 2019, the normalised [15] onshore wind production of electricity is estimated to reach 25.9 Mtoe (Figure 7).

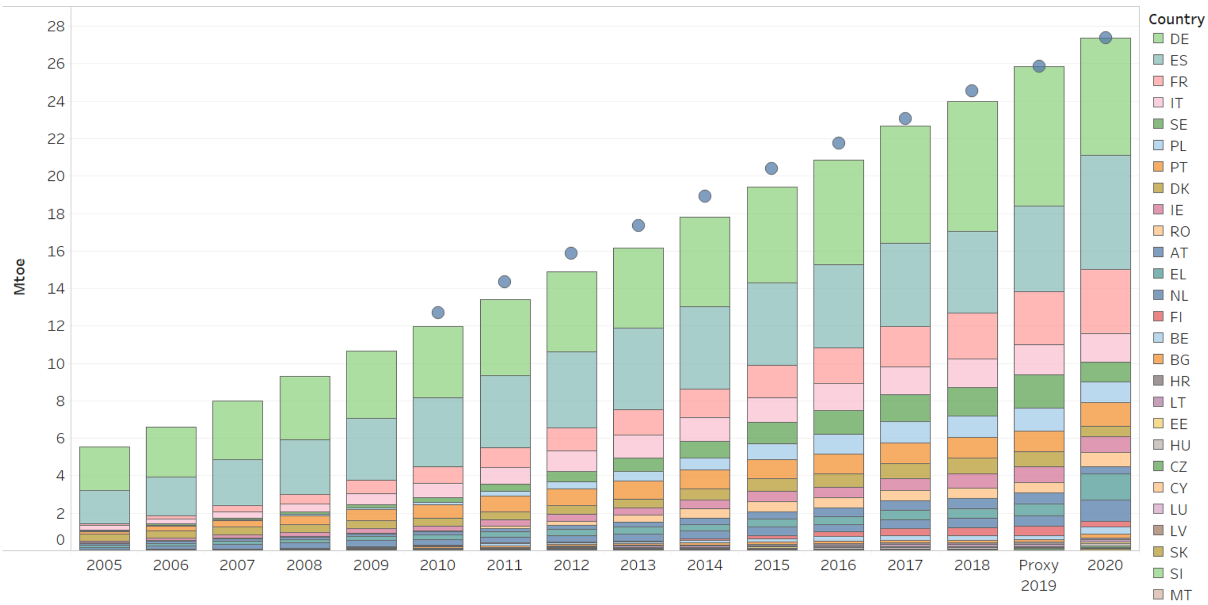
Onshore wind is a proven, mature RES technology (IEA 2020). The NREAPs indicate that onshore wind could increase to 27.4 Mtoe in 2020. Over the period 2005-2018 onshore wind increased by 26 percentage points per year, on average. Although an increase of 7 percentage points per year, on average, in the period up to 2020 would be sufficient to meet expectations in the NREAPs, in reality wind power could continue to grow more rapidly until 2020, given the cost reductions that have taken place over the past 10 years.

In 2018, the greatest increase in normalised onshore wind production, in absolute terms was recorded in Germany, followed by France and Ireland (respectively 0.66, 0.28 and 0.10 Mtoe) while the largest increases, in relative terms, could be observed for Finland, Ireland, France and Luxembourg (respectively 20 %, 15 %, 13 % and 12 %).

In 2019, Spain was the largest installer, with 2.15 GW additional onshore capacity, followed by Sweden and France (respectively 1.68 GW and 1.36 GW). Germany with 0.96 GW, not including 0.08 GW decommissioned, again installed less than in 2017 and 2018 (respectively 2.4 and 5.3 GW installed). The main reasons for the considerable slowdown in deployment in Germany were the new regulatory requirements which led to delays in permitting. The principal requirement slowing down the process is the requirement of siting onshore wind turbines more than 1000 metres from residential areas. A few years ago, the lead time for a license was only 10 months while this nowadays runs up till more than two years. In 2019 the Spanish market revived due to the launch of two renewable energy tenders in 2017. In France the addition of new capacity again decreased compared to 2018 (1.5 GW net installed In 2018) (EurObserv'ER 2020c). Sweden more than doubled its capacity in 2019 compared to 2018 (from 0.72 GW in 2018 to 1.59 GW in 2019). This trend is expected to remain in the next years, but the joint Swedish-Norwegian electricity certificate is set to phase out after 2021 and it remains to be seen what the impact will be. In September 2020, after several years of amendments and negotiations, Sweden and Norway announced that the system will close to new participants of both countries from 1st January 2022, effectively terminating the scheme at the end of 2035, ten years earlier than planned (ETC/CME 2020).

To overcome the barrier of siting wind projects in such a way that they are compatible with protecting biodiversity and Europe's natural heritage, the European Commission developed the guidance 'Wind energy developments and Natura 2000'(EC 2011, EC 2001). It includes guidelines on how best to ensure that wind energy developments are compatible with the provisions of the Habitats and the Birds Directives (EC 2014b).

Figure 7 RES-E in the EU: onshore wind (normalised).



Notes: This figure shows the actual final RES-E consumption for 2005-2018, approximated estimates for 2019 and the expected realisations in the energy efficiency scenario of the NREAPs for 2020.

Sources: ETC/CME; (Eurostat 2020e); NREAP reports.

Solid biomass

Electricity generation from solid biomass grew from 4.4 Mtoe in 2005 to 8.2 Mtoe in 2018, driven by, inter alia, the expansion in biomass cogeneration and the conversion of coal-fired power plants to biomass installations ([17]). The increase per year for the period 2005-2018 was by 7 percentage points per year, on average (Figure 8).

In 2018, Germany had the largest share, with 18 % of total electricity generated from solid biomass across the EU; Finland and Sweden followed with shares of 13 % and 12 % respectively. Preliminary estimates for 2019 show solid biomass staying at 8.2 Mtoe.

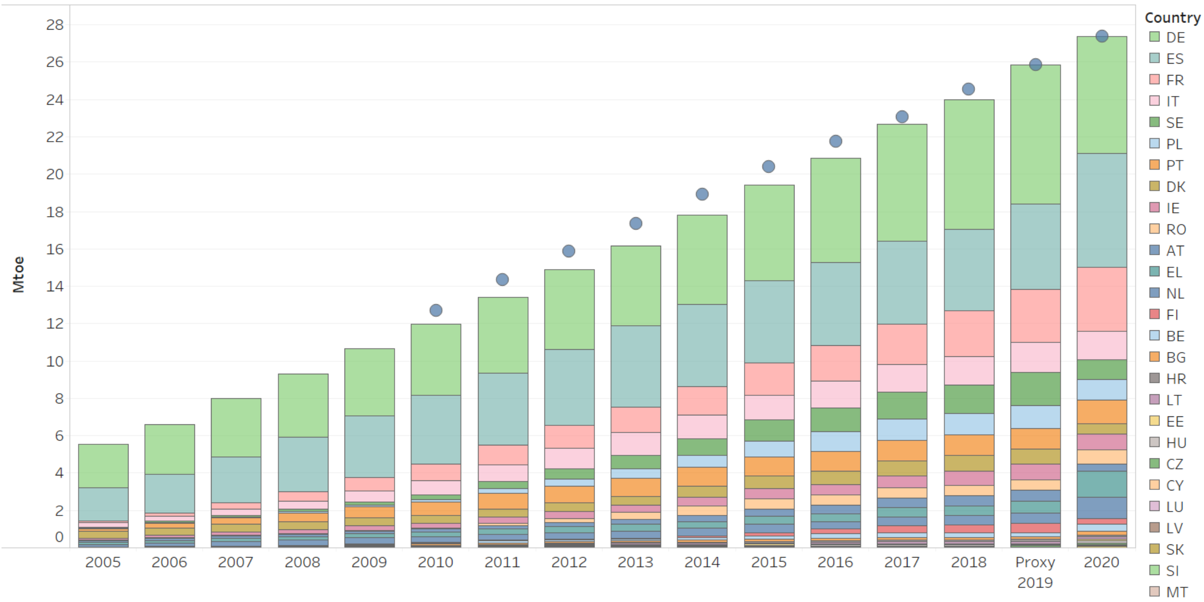
Until 2020, the European Commission leaves it to Member States to decide whether to introduce sustainability criteria for solid (and gaseous) biomass fuels. For the post-2020 period, the RED II, which entered into force by the end of 2019, strengthens the existing EU criteria regarding the sustainability of biofuels and bioliquids and extends them to the conversion of biomass and biogas to heat and power in plants with a capacity of at least 20 MW. Default GHG emission values and calculation rules are provided in Annex V (for liquid biofuels) and Annex VI (for solid and gaseous biomass for power and heat production). The RED II also includes new sustainability criteria for forestry feedstocks and requires that harvesting takes place with legal permits, the harvesting level does not exceed the growth rate of the forest, and that forest regeneration is ensured. Further, it requires that biofuels and bioenergy from forest materials comply with requirements which mirror the principles from the EU Land Use, Land Use Change and Forestry (LULUCF) Regulation (EU 2018a). The new approach is essential to address emissions from indirect land-use change (ILUC) associated to the production of biofuels, bioliquids and biomass fuels.

For 2018, at EU-level, an underachievement of 23 % compared to the expected NREAP trajectory is observed for this technology.

To meet NREAP expectations, an increase of 21 percentage points per year, on average, in electricity generated from solid biomass would need to be sustained over the period 2018 to 2020.

([17]) Municipal solid waste has been included in solid biomass.

Figure 8 **RES-E in the EU: solid biomass.**



Notes: This figure shows the actual final RES-E consumption for 2005-2018, approximated estimates for 2019 and the expected realisations in the energy efficiency scenario of the NREAPs for 2020.

Sources: ETC/CME; (Eurostat 2020e); NREAP reports.

Solar photovoltaic systems

Solar PV electricity production reached 9.5 Mtoe in 2018 (Figure 9), exceeding by more than 38 % (2.6 Mtoe) the level that was expected for 2020, according to the NREAPs (6.9 Mtoe). In 2018, 42 % of all solar PV electricity across the EU was generated in Germany. Italy too had a large share, 21 %, followed by France and Spain with shares of 10 % and 7 % respectively.

In 2019, early EEA estimates suggest that the production of solar PV electricity increased 8%, overtaking the NREAP levels for 2020 by 46 % and reaching 10.1 Mtoe.

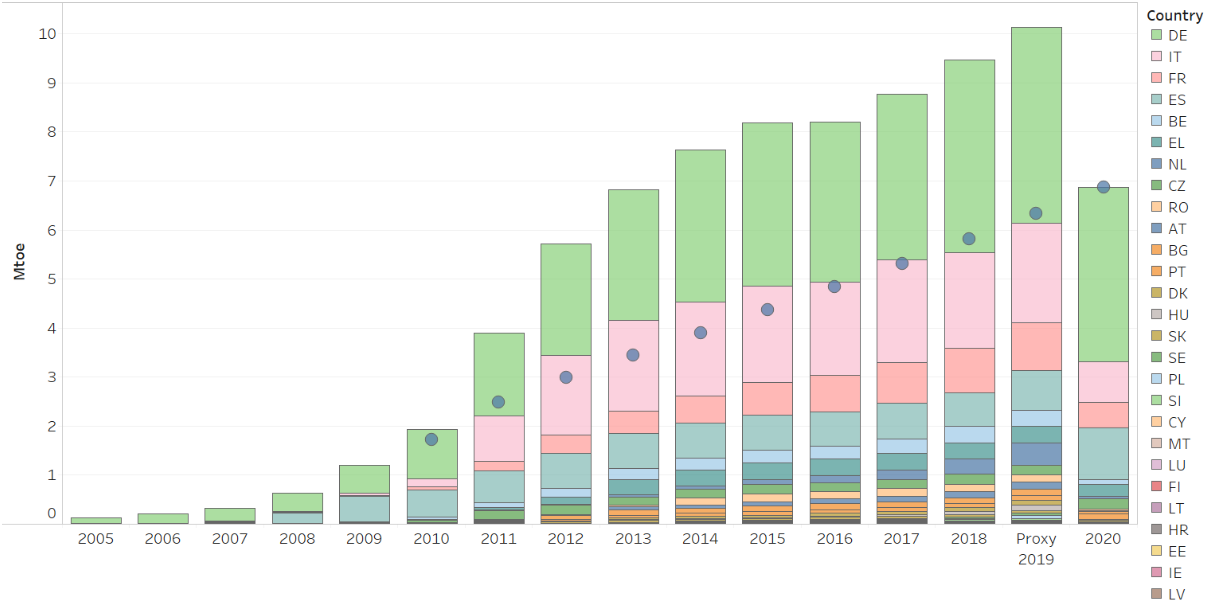
After the slower growth in 2017 and 2018 newly installed capacity surged in 2019 to 15.1 GW (EU). The largest newly installed solar PV capacities at the Member State level were recorded in Spain (4.0 GW), and Germany (3.9 GW) followed by the Netherlands (2.4 GW) ([18]). A further five Member States (France, Italy, Poland, Hungary and Belgium) added between 0.5 GW and 1 GW in 2019 (EurObserv'ER 2019a). Key drivers for this positive development in 2019 were a more intensification of auctioning policies by countries, the capacity build-up of PPA – Power Purchase Agreements (especially in Spain) – and the achievement of grid parity by some countries that gives distributed photovoltaic and self-consumption a boost. Moreover, European legislation strongly encourages the development of solar self-consumption (EurObserv'ER 2020a).

Rapid technological progress, cost reductions and the relatively short project development times were among the key drivers for the growth of solar PV energy in the period 2005-2014 (Ecofys 2014). After the peak years, 2011 and 2012, the market slowed down because of increased taxes on self-consumption

([18]) For 20182019, capacity data for all Member States are taken from EurObserv'ER and, in some cases, they might vary slightly from national data.

and new policies reducing financial support. As a result, annually installed solar PV capacities are lower since 2011 than installation levels before this year. But in 2019 the market is again growing faster. For PV, the EU NREAP expected trajectory is overachieved in the short-term by 63 % in 2018.

Figure 9 RES-E in the EU: solar PV energy.



Notes: This figure shows the actual final RES-E consumption for 2005-2018, approximated estimates for 2019 and the expected realisations in the energy efficiency scenario of the NREAPs for 2020.

Sources: ETC/CME; (Eurostat 2020e); NREAP reports.

Biogas

Electricity generation from biogas grew from 0.7 Mtoe in 2005 to 4.8 Mtoe in 2018 (Figure 10), reaching the level expected for 2020 in the NREAPs (5.5 Mtoe). On average, over the period 2005-2018, the increase for biogas was by 45 percentage points per year. At the EU level, over half of the electricity sourced from biogas is recorded in Germany (53 %). Italy and the United Kingdom both accounted for 13 % of the EU total.

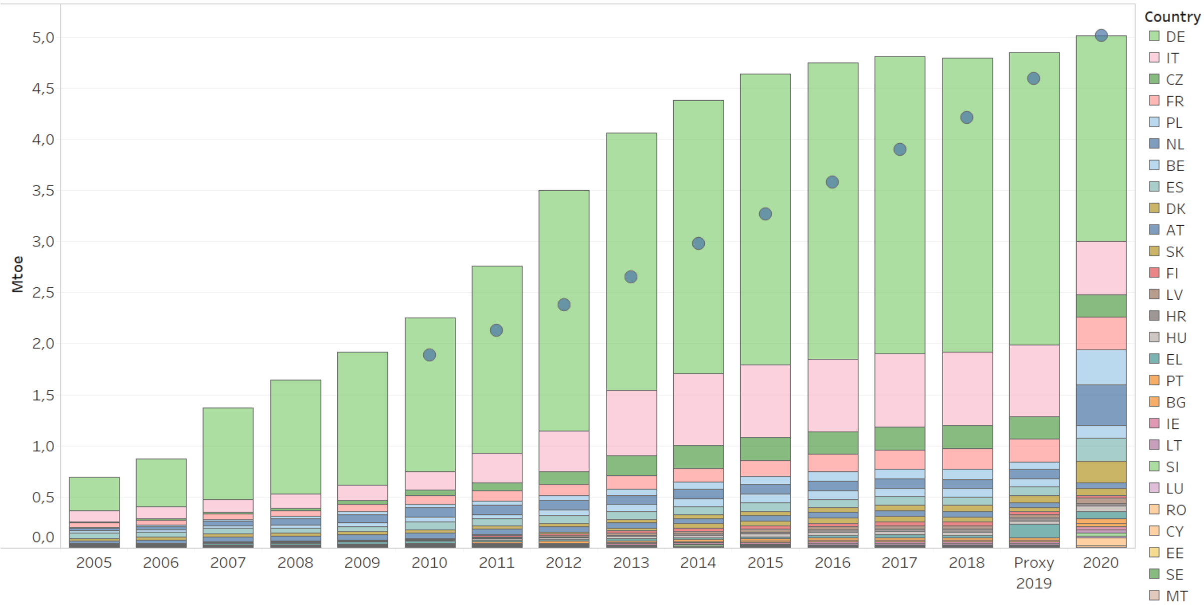
In 2019, electricity generation from biogas increased slightly, according to early EEA estimates, up to 4.9 Mtoe. After a period of strong growth between 2005 and 2013, more moderate growth could be observed in 2014 and 2015, and a plateauing generation in 2016-2018. The trend is caused by policy changes to reduce incentives and discourage the use of food crops for energy. At the Member State level, slight to moderate decreases of generation can be observed in 2018 compared to 2017 in ten countries: Austria, Czech Republic, Germany, Hungary, Ireland, Latvia, the Netherlands, Portugal, Slovakia, Slovenia and Spain. On the contrary France, Denmark and Croatia increased their generation with percentage increases ranging 10% to 15% and absolute increases ranging 4 to 22 ktoe. France continued its incentive framework with a feed-in tariff for biomethane injected into the grid and an improved feed-in tariff for biogas electricity for small installations (EurObserv'ER 2019b).

For several years, most of the EU's primary biogas energy production has been taken up by the 'other biogas' ([19]) category which potentially use food crops. Its share has constantly risen compared with the landfill and sewage plant biogas categories in the period before 2016. In 2018 this category has risen

([19]) 'other biogas' = raw plant material and non-hazardous waste (EurObserv'ER 2019b) again but moderately (EurObserv'ER 2017). At the European level, discussions on sustainability criteria are similar to those concerning solid biomass.

Contrary as to electricity production from solid and liquid biomass, biogas electricity production overachieved the EU NREAP expected trajectories for the year 2018 by 14 %.

Figure 10 RES-E in the EU: biogas.



Notes: This figure shows the actual final RES-E consumption for 2005-2018, approximated estimates for 2019 and the expected realisations in the energy efficiency scenario of the NREAPs for 2020.

Sources: ETC/CME; (Eurostat 2020e); NREAP reports.

Offshore wind energy

Offshore wind power grew from 0.2 Mtoe in 2005 to 3.5 Mtoe in 2018, adding approximately 0.5 Mtoe from 2017 to 2018 (Figure 11). The largest increase in normalised offshore wind power generation at the Member State level occurred in Germany, with a recorded increase of 0.3 Mtoe, from 2017 to 2018. Other countries with considerable increases are Belgium, the Netherlands and Denmark (respectively 106, 55 and 22 ktoe). For the remaining countries deploying this technology, a standstill or slight decrease can be observed. After the top year 2015 with an increase of almost 70 % in total generation, the yearly increase slowed down continuously.

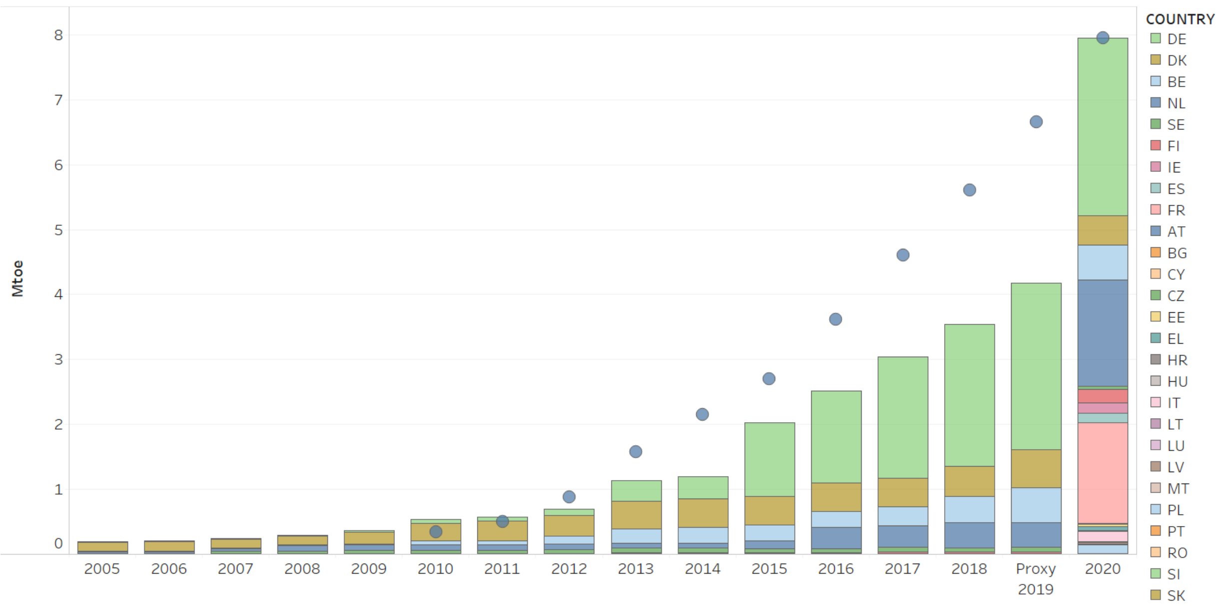
According to preliminary estimates from WindEurope, 1.8 GW of additional offshore wind capacity was installed in 2019 in the EU 27, compared to 1.5 GW in 2018 (Wind Europe 2020). At the EU level, more than 61 % of the total normalised electricity generation from offshore wind power in 2019 was recorded in France.

According to early EEA estimates, European offshore wind generation in 2019 was 4.2 Mtoe, an increase of 18 % compared with 2018.

Comparing the early EEA estimates for this technology to the expected trajectories for 2018 as laid down in the NREAPs, a significant gap of about 27 % is expected at the EU-level.

Offshore wind power would need to grow to 8 Mtoe by 2020 to reach the expected realisations in the NREAPs. This corresponds to an increase of 62 percentage points per year, on average, from 2018 to 2020. To be successful, the offshore wind sector needs to deliver the objectives of the EU integrated maritime policy's Blue Economy agenda and comply with nature and marine-related legislation and objectives. The guidance for siting wind projects compatible with protecting biodiversity and Europe's natural heritage developed by the European Commission also applies to offshore wind energy (EC 2011).

Figure 11 RES-E in the EU: offshore wind (normalised).



Notes: This figure shows the actual final RES-E consumption for 2005-2018, approximated estimates for 2019 and the expected realisations in the energy efficiency scenario of the NREAPs for 2020.
Sources: ETC/CME; Eurostat, (Eurostat 2020e); NREAP reports.

Other sources of renewable electricity

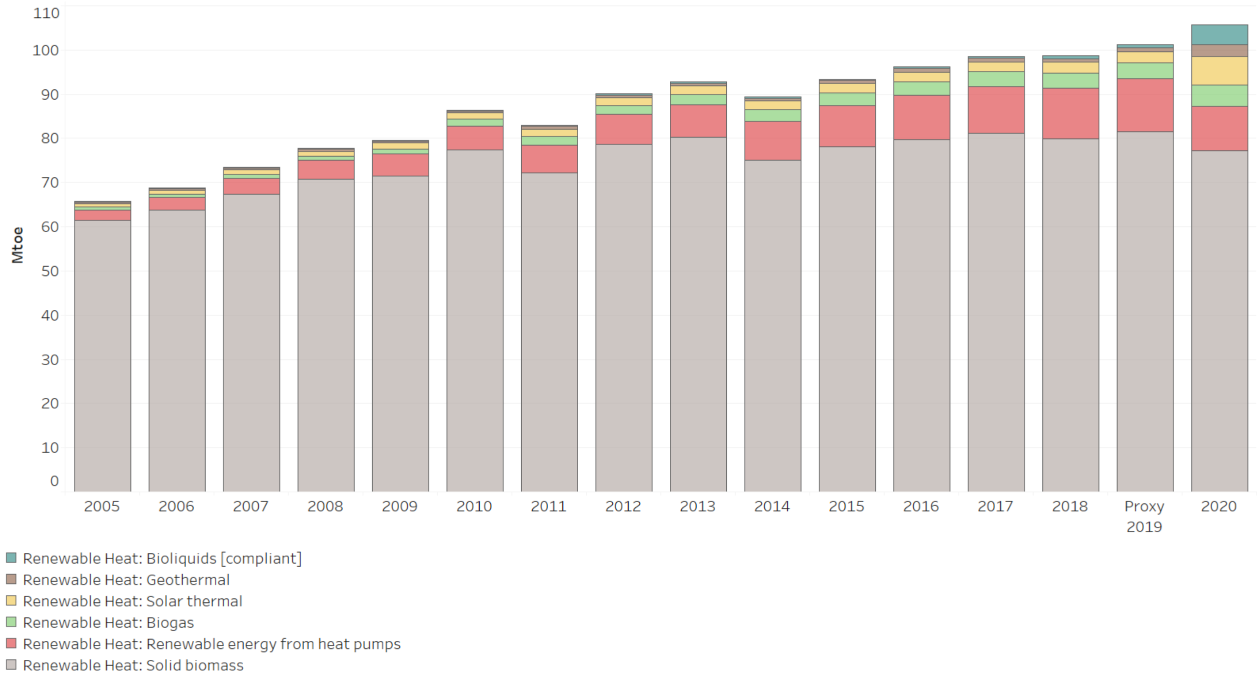
- Concentrated solar power (CSP) technology is currently only realistically applicable in southern Europe. CSP provided 0.4 Mtoe of renewable energy in 2018, which is a decrease of 17% compared to 2017. A 1% increase is expected in 2019. At the end of 2019, a new CSP installation with approximately 9 MW capacity came into operation in the French Pyrenees and brought the total capacity to 2 323 MW (EurObserv'ER 2020b).
- Geothermal electricity grew by only 2 percentage points per year, on average, to reach 0.6 Mtoe in 2018. No significant change was expected in 2019.
- Electricity generation from tidal, wave and ocean energy remained at only 41 ktoe in 2018, and no significant change was expected in 2019.
- Electricity production from certified bioliquids decreased by 2 % from 2017 to 2018 and remained at a moderate level, 0.4 Mtoe, in 2018. The EEA estimates the same level of generation in 2019.

2.2.3 Renewable heating and cooling

At the EU level, the gross final consumption of renewable energy in the heating and cooling market sector (RES-H&C) reached a share of 21.1 % in 2018. Figure 12 and Table 3 show the development of RES-H&C from 2005 to 2018, approximated estimates for 2019 and the expected NREAP development by 2020.

- At 98.7 Mtoe, the gross final consumption of RES-H&C in 2018 remained at the same level as 2017.
- In 2018, the largest contributions came from solid biomass (80.0 Mtoe, or 81 % of all RES-H&C), heat pumps (11.4 Mtoe, or 12 % of all RES-H&C) and biogas (3.5 Mtoe, or 4 % of all RES-H&C).
- Over the period 2005-2018, the RES-H&C increased by 4 percentage points per year, on average. To realise the expectations in the NREAPs for 2020, the same growth rate would be required over the period 2018-2020.
- According to early proxy estimates, RES-H&C increased from 98.7 Mtoe in 2018 to 101.1 Mtoe in 2019, while the amount of fuel consumed for heating and cooling stayed at 467 Mtoe, resulting in a renewable share of heating and cooling consumption of 21.7 % in 2019.

Figure 12 **RES-H&C in the EU.**



Notes: This figure shows the actual final RES-H&C for 2005-2018, approximated estimates for 2019 and the expected realisations in the energy efficiency scenario of the NREAPs for 2020. The consumption of RES accounts for only biofuels complying with the RED sustainability criteria.

Sources: ETC/CME; (Eurostat 2020e); NREAP reports.

Table 3 RES-H&C in the EU.

	Final energy (ktoe)					Percentage point increase per year		
Technology	**2005**	**2017**	**2018**	**Proxy 2019**	**NREAP 2020**	**2005-2018**	**2017-2018**	**2018-2020**
Solid biomass ([a])	61 460	81 134	79 976	81 518	77 274	2%	-1%	-2%
Renewable energy from heat pumps	2 289	10 600	11 352	11 993	10 035	30%	7%	-6%
Biogas	680	3 303	3 462	3 601	4 806	31%	5%	19%
Solar thermal	732	2 259	2 415	2 551	6 421	18%	7%	83%
Geothermal	559	833	867	887	2 646	4%	4%	103%
Bioliquids (certified)	0	440	588	592	4 416	n.a.	34%	325%
Total renewable heat (certified biofuels)	65 719	98 568	98 659	101 144	105 599	4%	0,1%	4%
Total renewable heat (including all biofuels) ([b])	65 938	98 960	99 110	101 594	105 599	4%	0,2%	3%

Notes: This table shows the actual final RES-H&C for 2005, 2017 and 2018, approximated estimates for 2019 and the expected realisations in the energy efficiency scenario of the NREAPs for 2020. Also shown are the average percentage point increase per year for the period 2005-2018, the percentage point increase from 2017 to 2018 and the average percentage point increase per year required to reach the expected realisations in the NREAPs for 2020. The consumption of RES accounts for only biofuels complying with RED sustainability criteria.

(a) Renewable municipal waste has been included in solid biomass.

(b) The series includes all biofuels and bioliquids consumed for heating and cooling, including uncertified ones after 2011.

Sources: ETC/CME; (Eurostat 2020e); NREAP reports.

Solid biomass

Solid biomass remains the largest source of renewable energy for heating (Figure 13) and since 2015 it exceeded the NREAP levels expected for 2020. The consumption of renewable heat originating from solid biomass decreased for the first since 2014, from 81.1 Mtoe in 2017 to 80.0 Mtoe in 2018. Heat from solid biomass increased by 2 percentage points per year, on average, over the period 2005-2018. In 2019, the consumption of solid biomass for renewable heat stayed in 81.5 Mtoe, according to the early EEA estimate, exceeding the expected NREAP level for 2019 by 6.7 Mtoe.

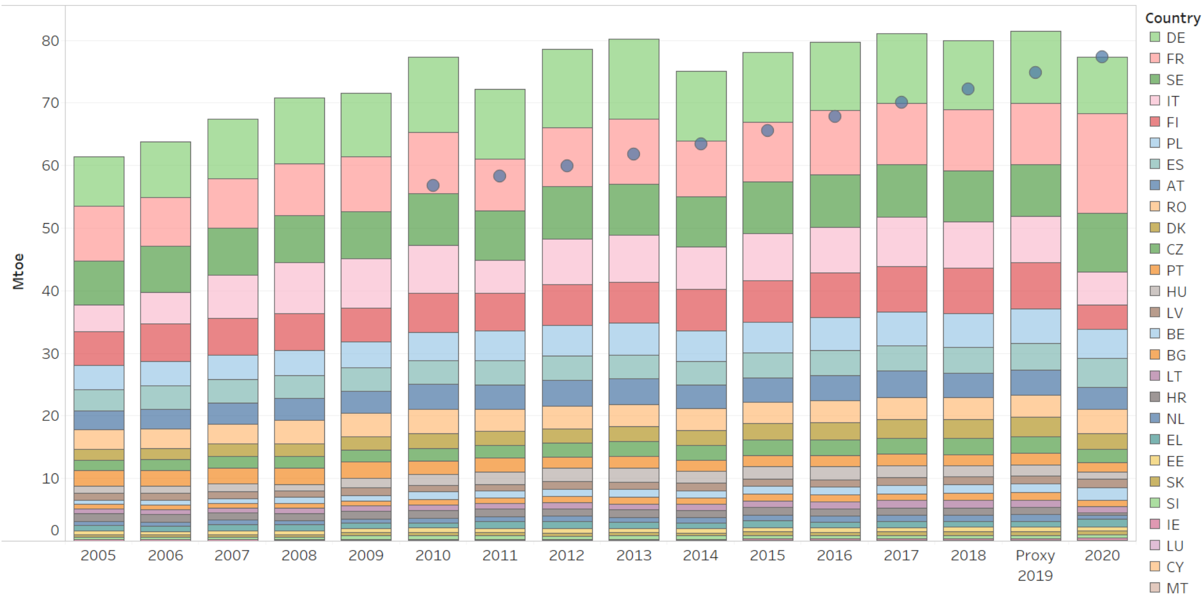
Climate has a strong impact on the burning of solid biomass for heat production. From 2010 on, for the years in which the heating degree days across the EU went down substantially year-on-year, compared to the year before (2011 and 2014), it can be observed that also the heat generation from biomass went down (Eurostat 2020b).

While heat from solid biomass sold to heating networks remained at the same level, the amount of heat from solid biomass directly used by final consumers across the EU decreased in 2018 (by 1.5 % compared to 2017 levels), because of the decrease in residential wood energy consumption in France, Italy and Sweden (EC 2019).

For the period starting with 2021, the new Renewable Energy Directive (RED II) (EU 2018a) has introduced sustainability requirements also for solid and gaseous bioenergy, in order to ensure robust

GHG emission savings and to minimize unintended environmental impacts from this energy source. It contains a new approach to address emissions from indirect land-use change (ILUC) caused by the production of biofuels, bioliquids and biomass fuels. Therefore, it sets national limits, which will gradually decrease to zero by 2030 at the latest, for high ILUC-risk biofuels, bioliquids and biomass fuels produced from food or feed crops. These limits will affect the amount of these fuels that can be taken into account when calculating the overall national share of renewable energy sources and the share of renewables in transport. However, the RED II also introduces an exemption from these limits for biofuels, bioliquids and biomass fuels that are certified as low ILUC-risk (EC 2019).

Figure 13 RES-H&C in the EU: solid biomass



Notes: This figure shows the actual final RES-H&C for 2005-2018, approximated estimates for 2019 and the expected realisations in the energy efficiency scenario of the NREAPs for 2020.

Sources: ETC/CME; (Eurostat 2020e); NREAP reports.

Heat pumps

Renewable energy from heat pumps grew from 2.3 Mtoe in 2005 to 11.4 Mtoe in 2018 (Figure 14). In northern Europe, most heat pumps are used for heating, but elsewhere there is also a market for cooling. In 2018, Italy and France contributed 23 % to final EU-wide RES consumption from heat pumps. Sweden (13 %) and Germany (10 %) also made significant contributions.

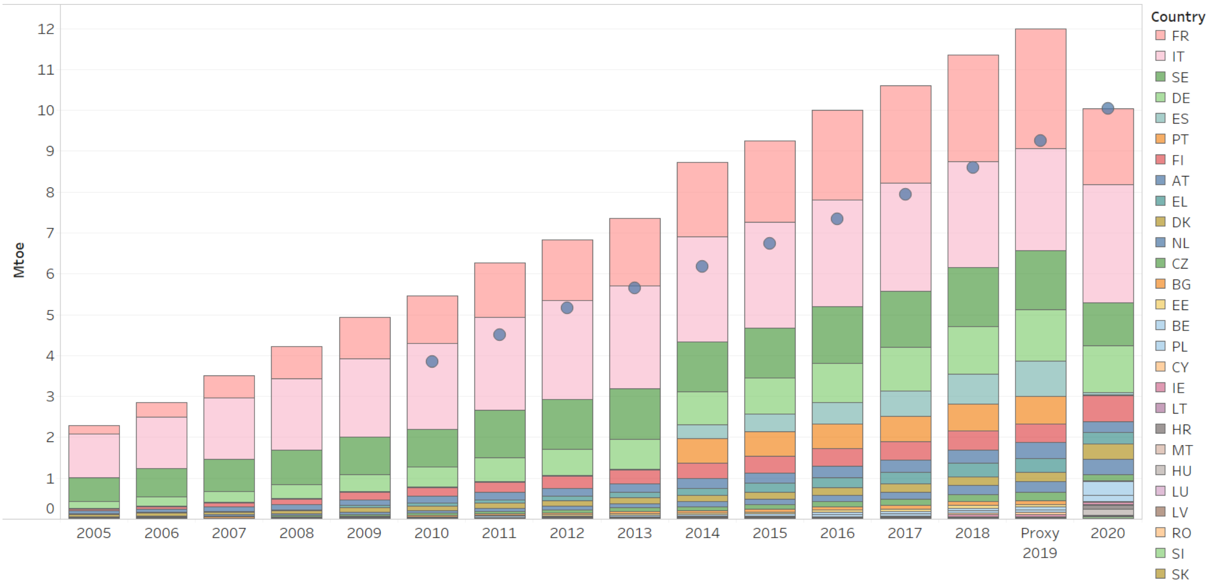
Four million systems were sold in 2018 in the EU, which amounts to a 10.5 % increase compared to 2017. However, in relative terms this is still less than the growth rates recorded in 2015 and 2016 (20 % and 26 %, respectively) but again more than the growth rate recorded in 2017 (4.4 %). The increased growth rate in 2018 can be explained by the increase in demand for reversible air-to-air heat pumps mainly used as cooling in Italy but also in Spain, Portugal and France which experience higher summer comfort needs. But also, for the waterborne systems mainly used for heating purposes sales have been increasing since 2013. Between 2017 and 2018 they increased by 21.5 % (more than 366 200 units) both in the historic markets for these systems as well as in less mature markets (EurObserv'ER 2018).

Reversible air-to-air heat pumps continue to lead sales (3.1 million units in 2017), being the preferred choice in home renovations. However, recent technological developments contributed to higher supplied temperatures, which also make them a solution for the renovation of the existing housing stock.

For the moment, the heat pump market share in renovation is rather moderate (less than 10 %, depending on the country) and that is why a significant potential for growth for heat pumps in this sector can be expected over the coming years.

In 2019, renewable heat from heat pumps increased to 12.0 Mtoe, according to early EEA estimates. With an increase of 30 percentage points per year, on average, over the period 2005-2018, the expectations in the NREAPs continue to be exceeded for 2018, as in previous years and even the projected expectation for 2020 is already met since 2017.

Figure 14 RES-H&C in the EU: renewable energy from heat pumps.



Notes: This figure shows the actual final RES-H&C for 2005-2018, approximated estimates for 2019 and the expected realisations in the energy efficiency scenario of the NREAPs for 2020.

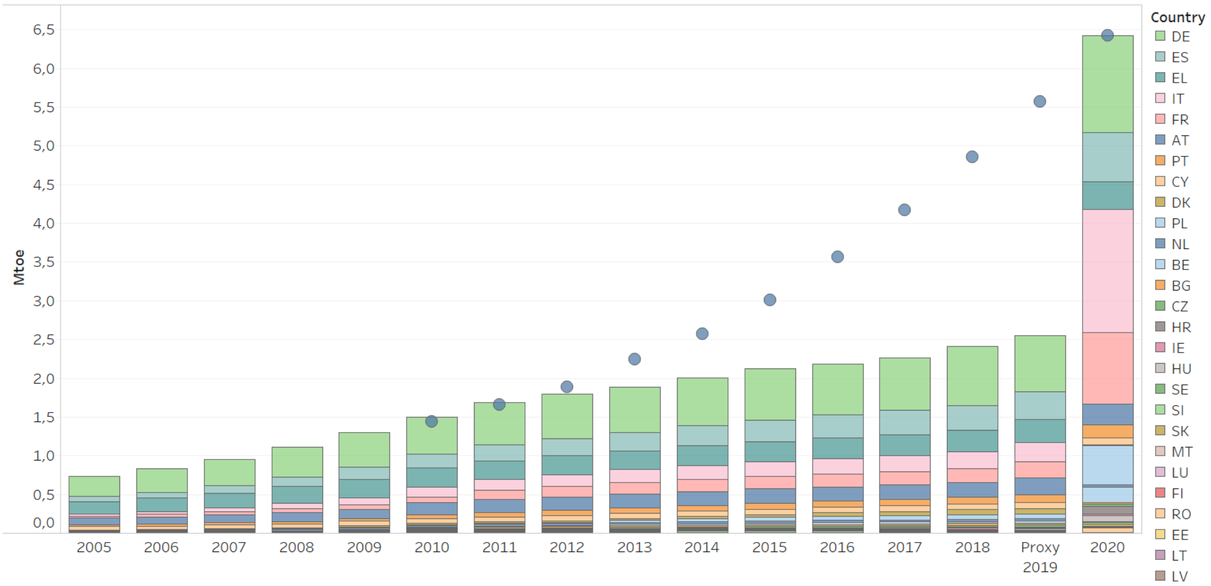
Sources: ETC/CME; (Eurostat 2020e); NREAP reports.

Solar thermal energy

The production of renewable heat from solar thermal technology realised an increase of 18 percentage points per year, on average, over the period 2005-2018, growing from 0.7 Mtoe in 2005 to 2.4 Mtoe in 2018 (Figure 15). However, despite a further estimated increase to 2.5 Mtoe in 2019, solar thermal energy has not been able to meet the expectations of the NREAPs.

Solar thermal collectors 'harvest' heat from the sun for hot water or space heating. After a decade of declining growth pace, the solar thermal market for hot water production and heating applications in the EU returned to increasing growth pace, as it grew from a total surface of 2.08 million m^2 in 2017 to 2.26 million m^2 in 2018 (by 8.6 %), (revised figures). However, the amounts of growth vary by country and market segment. The largest increases were realised in Poland, Greece and Spain. Another potential boost is the design of new systems identified in a number of countries (Denmark, Germany, Austria, Spain and France) which consists of collector surface connected to heating networks (EurObserv'ER 2020b).

Figure 15 RES-H&C in the EU: solar thermal energy.



Notes: This figure shows the actual final RES-H&C for 2005-2018, approximated estimates for 2019 and the expected realisations in the energy efficiency scenario of the NREAPs for 2020.

Sources: ETC/CME, (Eurostat 2020e); NREAP reports.

Other sources of renewable heating and cooling

- Renewable heat from biogas grew from 0.7 Mtoe in 2005 to 3.5 Mtoe in 2018. According to EEA estimates, it reached 3.6 Mtoe in 2019.
- Geothermal heat will have to bridge a large gap if it is to achieve the target of 2.6 Mtoe anticipated for 2020. In 2018, the production of geothermal heat was 0.87 Mtoe, the substantial growth in 2016 (+12 % compared to 2015) again slowed down in 2017 (+7 % compared to 2016) and 2018 (+4 % compared to 2017).
- The production of heat from liquid biofuels was 0.6 Mtoe in 2018.

2.2.4 Renewable transport fuels

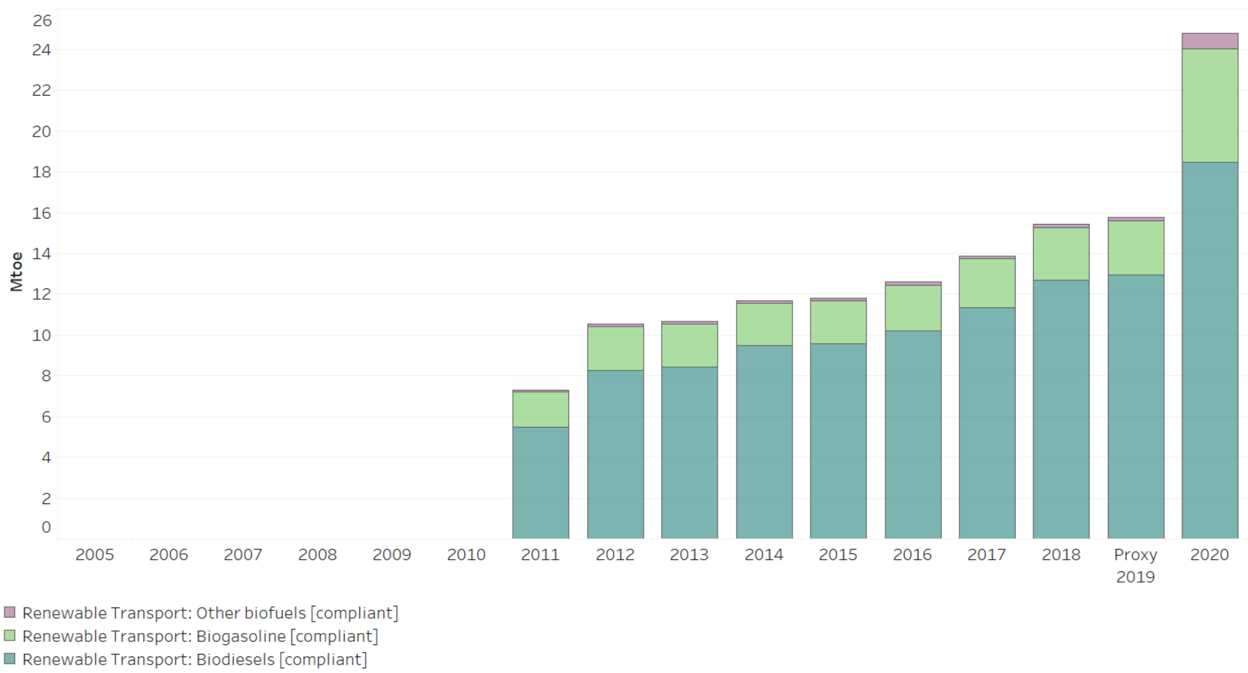
The share of RES-T([20]) in the EU was 8.3 % in 2018. Figure 16 and Table 4 show the development of the use of biofuels in transport up to 2018, approximated estimates for 2019 and their expected NREAP development by 2020. For the transport sector, the RED includes a target of 10 % and at current pace this target would not be met by 2020.

- The gross final consumption of certified biofuels was 15.4 Mtoe in 2018, which is a 11 % increase compared with 2017.
- According to proxy estimates, the RES-T share grew from 8.3 % in 2018 to 8.4 % in 2019.
- To realise the expectations in the NREAPs for 2020, an increase of 43 percentage points per year, on average, would be required over the remainder of the period 2018-2020.

([20]) RES-T shares are sourced from the Eurostat SHARES Results 2017; absolute values are from the nrg_bal_c Eurostat dataset (Eurostat 2020a).

The use of RES-E in road transport in the EU was 45.9 ktoe in 2018, an increase by more than 20% from 37.8 ktoe in 2017, and is estimated to be 49.0 ktoe in 2019. The amount of RES-E used in other transport modes was almost 1.8 Mtoe ([21]) in 2018 and is estimated to overcome 1.8 Mtoe in 2019.

Figure 16 RES-T in the EU: biofuels.



Notes: This figure shows the actual final RES-T for 2005-2018, approximated estimates for 2019 and the expected realisations in the energy efficiency scenario of the NREAPs for 2020. The consumption of RES accounts for only biofuels complying with the RED sustainability criteria.

Sources: ETC/CME; (Eurostat 2020e); NREAP reports.

From 2005 to 2010, the gross final consumption of biofuels increased strongly from 3.1 Mtoe to 12.0 Mtoe (all biofuels including non-compliant ones), followed by a moderate increase to 12.6 Mtoe in 2012 and then more or less plateaued until 2016 to increase again moderately in 2017 and 2018 to respectively 13.9 Mtoe and 15.4 Mtoe (Figure 17). The EEA estimates that the use of biofuels in transport was 15.8 Mtoe in 2019. Most countries' consumption of biofuels is below the expected realisations in their NREAPs, but there is no clear EU-wide trend.

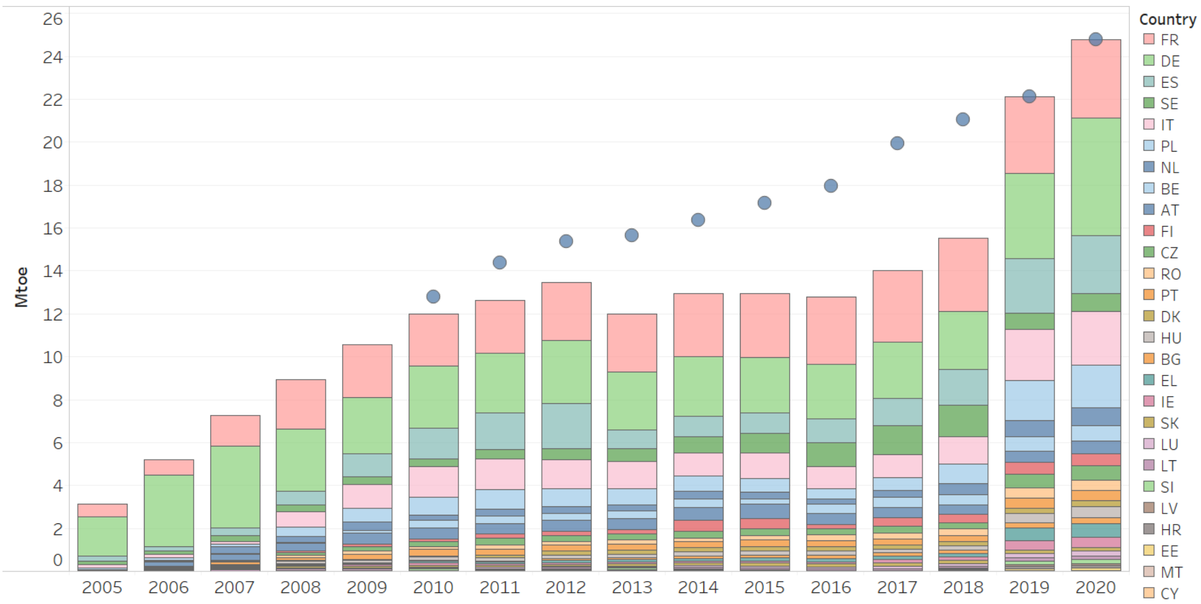
The transport sector has a separate RES target for 2020, which is equal to a 10 % share of renewable energy consumption in each Member State.

The RED (EU 2009) included sustainability criteria for biofuels that can be accounted towards the national targets. These criteria include minimum greenhouse gas emission savings and that raw materials for biofuels must not come from certain land areas, to avoid adverse environmental effects. For social and economic sustainability, it is requested that Member States report every two years to the European Commission on inter alia the impact on food prices, land rights, and ratification of main producer countries of international labour conventions. Since 2010, the share of non-certified biofuels decreased sharply, from 42 % in 2011 to less than 1 % in 2018.

([21]) This RES-E is produced by the energy technologies discussed in Section 2.2.2.

Concerns about the sustainability, and direct and indirect land use of first-generation biofuels led to a reconsideration of the role of food-based biofuels (Kampman et al. 2015). To reduce indirect land use impacts owing to biofuels and bioliquids, the Indirect Land Use Change (ILUC) Directive of 2015 (EU 2015a) attempted to tackle — among other things — these concerns. It limited the share of biofuels from crops grown on agricultural land to 7 % and obliged Member States to establish indicative national targets for advanced biofuels (second/third generation) for 2020, with a reference value of 0.5 %. Annex IX of the ILUC Directive also harmonised the list of feedstocks whose contribution would count double towards the 2020 national target of a 10 % share of RES-T. For electricity produced from RES and consumed by electric road vehicles and rail transport, the ILUC Directive increases the multiplier factors for calculating the market share of RES-T. It increased the minimum reduction threshold for GHG emissions applied to biofuels produced in new installations, and it obliged fuel suppliers to report annually the provisional mean values of the estimated ILUC emissions from biofuels traded (EU 2015b). The RED II (EU 2018a) further limits the use of high ILUC-risk biofuels, produced from food and feed crops that have a significant global expansion into land with high carbon stock such as forests, wetlands and peatlands. These additional requirements will affect the amount of fuels that Member States can take into account for their overall national share of renewables and the share of renewables used in transport. Member States still can use (and import) fuels covered by these limits, but these fuels will not be counted towards the national renewable energy targets, nor will they be entitled to receive any form of financial support. The requirements consist of a freeze at 2019 levels for 2021-2023 and the levels will gradually decrease from the end of 2023 to zero by 2030.

Figure 17 RES-T in the EU: biofuels including non-certified biofuels.



Notes: This figure shows the actual final RES-T for 2005-2018, approximated estimates for 2019 and the expected realisations in the energy efficiency scenario of the NREAPs for 2020.

Sources: ETC/CME; (Eurostat 2019b); NREAP reports.

In both 2018 and 2019, the EU's share of biofuels use in transport is lower than the trajectory expected based on the national NREAPs. Only Sweden and Malta reached their expected trajectories for 2018, while France almost reached it (0,5 % short).

Table 4 RES-T in the EU: biofuels.

	Final energy (ktoe)					Percentage point increase per year		
Technology	**2005**	**2017**	**2018**	**NREAP 2019**	**NREAP 2020**	**2005-2018**	**2017-2018**	**2018-2020**
Biodiesels (all)	2 446	11 432	12 762	16 179	18 458	32%	12%	22%
Bio gasoline (all)	543	2 416	2 599	5 281	5 581	29%	8%	103%
Other biofuels (all)	146	152	154	654	746	0%	1%	325%
Certified biofuels	0	13 891	15 441	22 113	24 784	n.a.	11%	43%
All biofuels	3 135	14 000	15 516	22 113	24 784	30%	11%	43%

Notes: This table shows the actual final RES-T for 2005, 2017 and 2018 (based on Eurostat nrg_bal_c data), approximated estimates for 2019 and the expected realisations in the energy efficiency scenario of the NREAPs for 2020. Also shown are the average percentage point increase per year for the period 2005-2018, the percentage point increase from 2017 to 2018 and the average percentage point increase per year required to reach the expected realisations in the NREAPs for 2020. The consumption of RES accounts for only biofuels complying with RED sustainability criteria.

Sources: ETC/CME; (Eurostat 2020e); NREAP reports.

2.3 Flexibility as a solution for variable renewable energy sources

Key messages:

- Having a digitalized and flexible energy system is essential to increase the uptake of variable renewable energy, notably from wind and solar sources, and to reach the EU binding targets for 2030 and the carbon neutrality goals for 2050.
- Many technologies that support flexibility and smart system management have become more affordable. This includes technologies for households. There are challenges that remain: it is key to foster research and development to further lower the costs and increase the efficiency of technology, and for regulators and system operators to incentivize the use of flexibility solutions.
- Challenges related to the behavior and trust of consumers, notably households and small businesses, are important to consider. This includes the effects of incentives to use and purchase flexible products such as dynamic tariffs, where prices change according to the day ahead price, or third party that manages remotely the consumption in exchange of payments.
- The European Commission is prioritizing flexibility to achieve the set RES targets. This is because wind and solar generation, both variable in nature, will remain in the foreseeable future the technologies dominating new renewable installations**.** The assessment by the European Commission of the NECPs highlights ***"****several shortcomings in the energy market (flexibility through smart grids, storage and limited demand-side response)".* In the meantime, the Electricity Regulation establishes network codes and guidelines to be adopted.

2.3.1 Consequences of high penetration of wind and solar energy

Experts and policy makers expect that solar and wind generating technologies will become the cheapest technologies to generate renewable electricity, dominating the growth of renewables in the electricity sector in the next years. This trend is likely to be underpinned by the provisions in the Clean Energy for all Europeans package, requiring that renewable energy targets are met through competitive processes that ensure that the energy transition is achieved at the lowest cost.

Wind and solar energy are variable in time and inflexible. This creates two main problems for the electricity systems:

- **Balancing of electricity demand and supply:** Supply and demand must remain identical at all times for the security of the electricity systems. The sun does not shine and the wind does not blow to match the electricity demand. This has two effects. On the one hand, supply can be higher than demand, e.g. in a residential area with solar panels during working hours. On the other hand, high installed capacity of RES-E cannot secure generation and requires back-up from flexible generation like gas- and coal-fired power plants. Unlike wind and solar, these plants have higher operational costs linked to the fuels' costs and thus are costlier for consumers. Moreover, investors might not get returns if they are mostly used as back-up. To ensure security of supply, some countries are paying to get availability on demand from these plants. Finally, using fossil fuel as a back-up reduces the carbon reduction from RES-E.
- **Grid congestion:** The most cost-efficient locations for solar and wind plants are not always near the areas with high demand for electricity. Transmission of electricity from generation to consumption can result in grid congestion at high voltages, for example from North to South Germany, and at low voltages for decentralized generation, such as prosumers and small energy cooperatives. Reinforcing the grid and installing more interconnections is a costly solution to this problem.([22])

To increase the penetration of renewables then can be seen from the consumer side. That is, consumption adapting to generation, rather than having generation adapting to consumption. This is often referred to as demand response. The digitalisation of the energy system; development of cheaper and more efficient storage including in electric vehicles; the internet of things, automation and artificial intelligence; consumer behavioural changes; and cross-sector coupling are some of the most important changes in the market facilitating the adoption of demand response solutions.

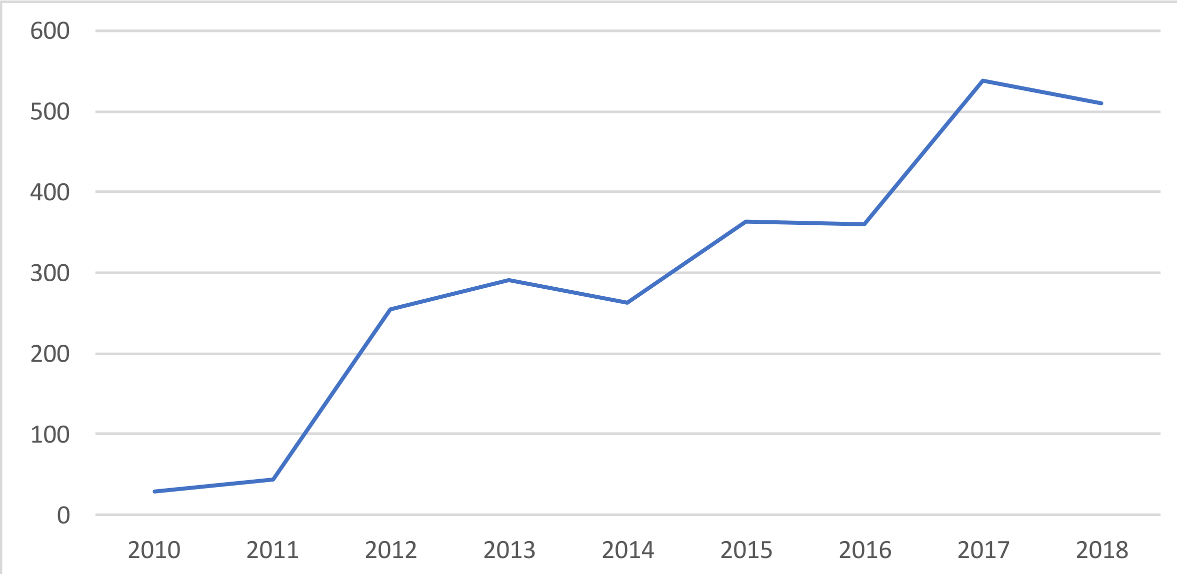
2.3.2 The need and costs of flexibility

The European Union Agency for the Cooperation of Energy Regulators (*ACER*) in its Market Monitoring Report report for 2018 concluded that "*the presence of negative prices emphasises the need for more flexible resources in the system, including demand response*" (ACER 2018). Negative electricity prices signal more generation than consumption. This occurs, amongst others, when there is significant inflexible generation such as wind, solar or nuclear, and little demand. The number of instances of negative prices can be correlated to the level of integration of renewables. Negative prices are signalling that it is cheaper to "pay to consume" rather than to stop the plant.([23]) This phenomenon ultimately demonstrate the need for flexibility and one of the ways to assess the costs associated with the lack thereof.

([22]) Generation from wind and solar can also cause other grid technical issues, such as frequency, voltage and rotor angle stability. The solution to these issues are provided by the so-called ancillary services, which can also be provided by some flexibility solutions such as batteries. We will not focus on these aspects in this report.

([23]) An early analysis of April to June 2020 of negative prices (due to lower consumption from Covid-19 and high renewable generation) in Germany and Belgium, a position paper from EnergyVille reaches similar conclusions in terms of the need of more flexibility into the system. https://www.energyville.be/en/press/position-paper-post-covid-recovery-challenges-and-opportunities-energy-system

Figure 18 **Instances of negative day ahead prices in selected bidding zones and in the EU.**

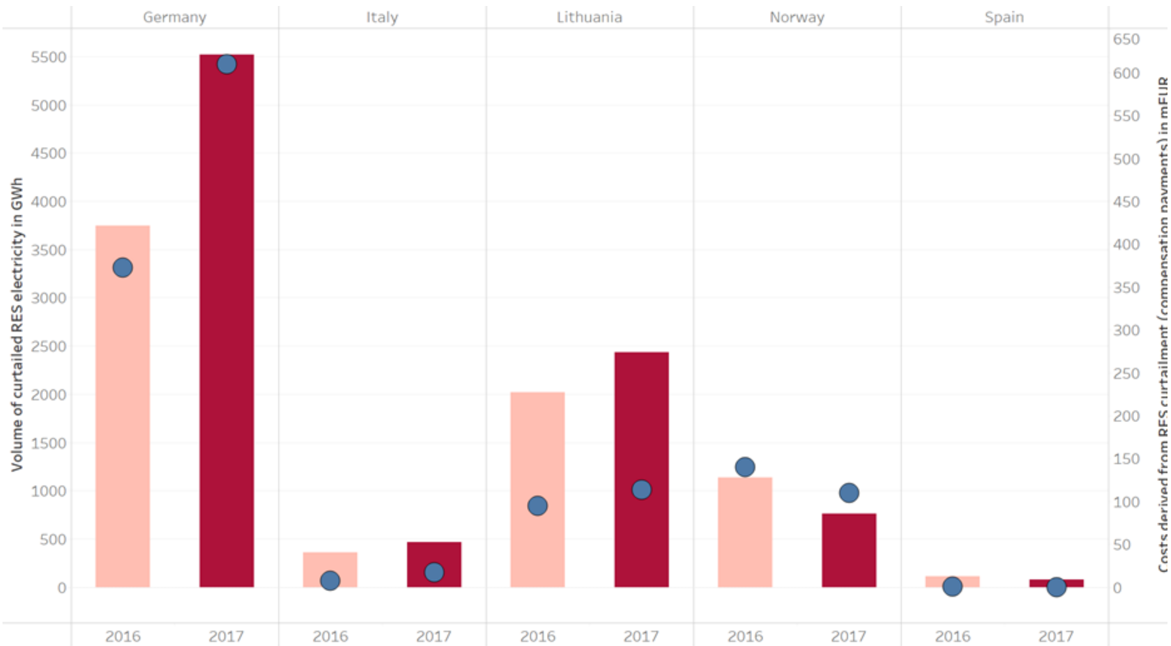


Source: (ACER 2018)

Another way to assess the costs of inflexibility is the curtailment of renewable energy generation. Curtailment can be put in place when balancing of supply and demand is not possible or when grid congestion occurs.

The costs of curtailment are particularly high in Germany. According to the Bundesnetzagentur (BNA), the German energy regulator, in 2017 wind supplied record levels of power and 10 200 GWh was curtailed. The cost of stabilising the grid reached €1.4 billion that year (BNA 2017). In 2018 the numbers were lower yet still important, with 7 919 GWh curtailed, with a total cost of stabilising the grid of €635 million (BNA 2018).

Figure 19 **Volumes of renewable Energy curtailments and their costs in selected countries and their costs.**



Notes: Bars represent volumes curtailed, on the left vertical axis, while circles represent costs from the curtailments, on the right axis.

Source: (CEER 2018).

2.3.3 Policy developments to foster flexibility

Demand response is not a new concept, and it has already been used in some form or another in several countries. Some examples:

- In the 80s, France was relying on inflexible nuclear generation. EDF offered a “peak days / step back” tariff. This had a maximum number of “red days” with high prices, known in advance, where people could react (RAP 2018, IEA 2012).
- Several countries set up day and night tariffs, which sometimes include weekends.
- Large industries have received discounts on grid charges in exchange of responding to system operators requests to lower their peak load.
- Aggregators have also large industries in their mix when proposing demand response through for example, capacity mechanisms seeking security of supply.

Policies at the EU level are facilitating the research and development, and the opening of markets for flexibility and demand response.

- The Clean Energy for all Europeans Package opens the door to different forms of demand response: changes in the markets to make them more accessible to demand response providers such as aggregators, inclusion of dynamic pricing to trigger demand response through price signals, incentives for the distribution system operators to consider demand response instead of investing in reinforcing the grid are amongst these measures. In particular, the clean energy package includes in the European Electricity Regulation (EU 2019b) that establishes network codes and guidelines to be adopted. The European Commission identified demand side flexibility as one of the two main areas to be developed as a priority through network codes and guidelines during the consultation for prioritization to the development of network codes (EC 2020b).

- The European Strategic Energy Technology Plan (SET Plan), a dedicated EU research and development programme, focuses on technologies to transition to a low-carbon economy. The plan covers three areas supporting the development of a flexible system that can integrate more renewables: Smart Energy System, Batteries, Energy Consumers.

However, the assessment by the European Commission of the NECPs highlights *"several shortcomings in the energy market (flexibility through smart grids, storage and limited demand-side response)".*

2.3.4 How to provide flexibility?

Behavioural changes. All type of consumers can potentially adapt the way they consume. They will do so depending on many factors, including: the reactivity and flexibility of the equipment in use (notably in industry), loss of comfort (households), and the level of incentives of the household.([24])

Digitalisation. The electricity sector is becoming more digitalised across Europe. Smart meters are rolled out, and appliances are becoming more connected. They provide almost instantaneous information on consumption to users, networks operators, and potentially to third parties. The remote control could be decided through algorithms, machine learning and eventually artificial intelligence taking into account information from a more digitalised and smarter grid. Moreover, the digitalisation and electrification of vehicles will allow for smarter charging. As JM. Glachant and N. Rossetto put it: "*artificial intelligence and the Internet of Things can become unavoidable and automated intermediaries, replacing direct human involvement in thousands of decisions concerning the management of vast sets of assets"* (Glachant and Rossetto 2018).

Storage. Centralised storage, notably hydro pumping storage, is one of the oldest systems of storage. It has the advantage to provide flexibility across seasons. Yet installing new pump storage needs an adequate topography, which is not available necessary near the variable generation, and has environmental impact.

Other storage technologies have become cheaper and with better features. For example, better reactivity, that is the speed of inputting and extracting electricity at short notice. Other important aspects are their capacity, their life expectancy, their ability to be located near the generation to avoid transmission losses and for how long it is efficient to store energy. ([25])

The deployment of electric batteries is increasing and they are becoming more affordable, with high levels of reactivity but small amounts of energy storage. Electric vehicles are a double edge solution. On the one hand, without optimisation, they can increase peak demand at the time when most people arrive at home or at work. On the other hand, with automation and connectivity, they can offer important flexibility.

Power to X. Hydrogen (H2) can be generated via electrolysis. This needs electricity, which can be powered by renewable electricity. When hydrogen is produced with renewables, it is often referred to as green hydrogen([26]). Hydrogen is being considered to add flexibility to the grid. Amongst others, it can be used as storage by being transformed back to electricity, as input in some industries or mixing it with natural gas in the grid, which is often called 'sector coupling'.

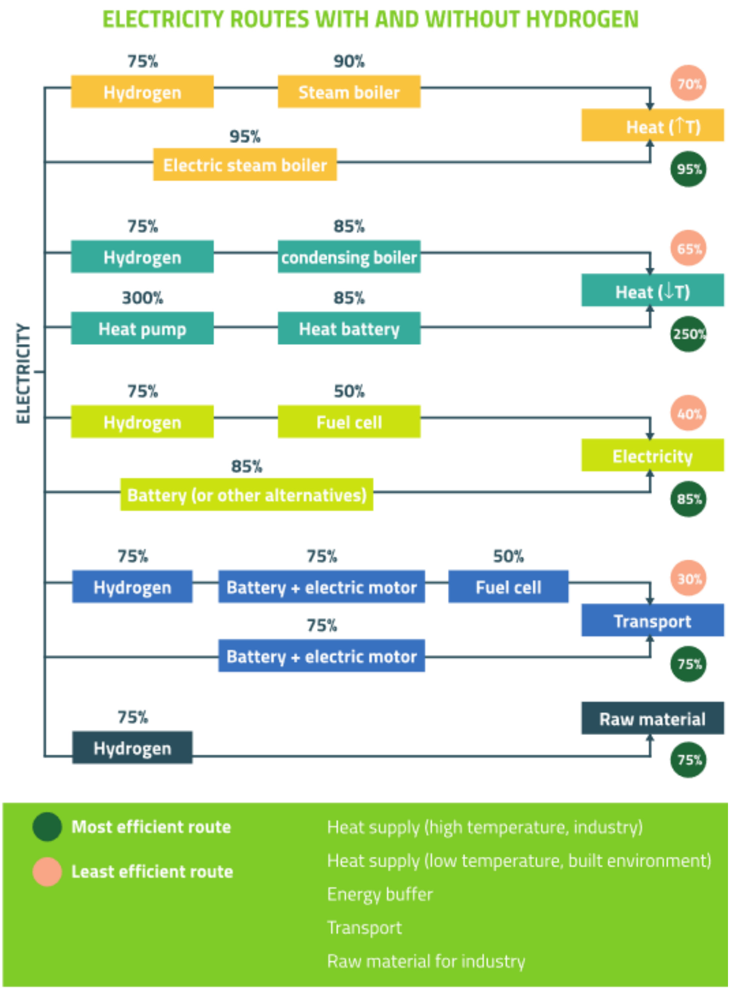
([24]) Later in this chapter, in the section *"Incentives for Flexibility"* we will explore the different ways in which economic incentives can be given to users to make them change their behaviour.

([25]) IRENA developed a framework in this line to valuate different technologies (IRENA 2020a).

([26]) Note that at the time of this paper no official taxonomy been yet established for hydrogen, making more difficult the task of understanding the actual reduction in carbon from this product.

A paper by R. Belmans and P. Vingerhoets concludes: "*The direct use of hydrogen as a supplier of energy services to the end user is limited. Due to the specific characteristics of the hydrogen molecule (very light, very low boiling temperature, very low energy density), mobile applications are doubtful. For stationary applications, the need for storage of energy is clearly present, but the required volume and the resulting pressure/temperature needs make hydrogen a poor choice. The same holds for strategic energy storage*"([27]) (Belmans and Vingerhoets 2020).

Figure 20 Electricity routes with and without hydrogen.



Source: (Belmans and Vingerhoets 2020)

2.3.5 Incentives for flexibility

For the uptake of flexibility, there needs to be enough return on investments. Moreover, for all investors, and households in particular as they are more risk adverse, price signals or incentives need to be sufficient and predictable lowering the risk to lose out from their investments.

([27]) The paper also concludes that "*[there is a] need for a clear taxonomy of hydrogen. The basis has to be the carbon content in order to ensure carbon neutrality in the most effective way*."

There are two main classifications on the ways to incentivise demand side response (IRENA 2019a):

- **Price-based (or implicit)** is when consumer electricity prices vary with the market prices. This gives incentives for consumption to adapt to the price signals. The Directive on Common Rules for the Internal Market for Electricity (EU 2019a) gives the option to consumers who have a smart meter to access this type of pricing, often called a dynamic tariff. CEER recommends that the reference price should be the day ahead price and that *"in order to access a dynamic price contract, the customer must have a smart meter that records consumption data at the same granularity as the relevant reference price*" (CEER 2018). A simplified version of this is the time of use tariffs, more commonly with a price for the day and one for the evening/weekend. For this to optimise the system, variations of prices should perfectly reflect the value and cost of electricity (including balancing) and/or transportation (congestion) in each time periods. Similarly, consumers should easily change their consumption, noting that consumers value significantly their comfort, so to get more buy-in these changes should not have an important impact on their lives.
- **Incentive-based (or explicit) demand response** is when there are organised markets, such as wholesale energy, reserves/balancing, and/or capacity markets proposing flexibility services. For example, a DSOs can organise an auction and pay consumers to change the time of consumption to avoid congestion on the grid. In this way the consumer receives directly a payment for the reduction rather than economise through lower consumption when prices are higher. The so-called (demand) aggregators are agents that act on behalf of consumers, and can pool together a number of consumers so to be able to provide services and avoid risks. Each aggregator will have a different business model to redistribute the benefits across consumers.

Note that, when well applied, these incentives should contribute to the integration of renewable energy in the system in a cost-efficient manner. The buy in from consumers do not depend only on the benefits they can make individually. They will depend on behavioural aspects: for example, in real life people do not relate equally to something presented as a "saving" than something presented as a "surplus" even when the final amount is the same. Business models and services, such as demand side aggregators, optimization systems in the household, the electric vehicle, apps, or others, that capture these aspects will be essential for its uptake. For this to be possible, there should be a sufficiently large market for new players to test different forms, e.g. not capturing the consumer through long term contracts, or having a de facto monopoly preventing from innovation. It is also important to consider that this innovation, digitalisation and potential forms of control need to ensure consumer's privacy and rights.

3 Impacts on fossil fuel consumption, greenhouse gas emissions and air pollutant emissions

Key messages:

The increased consumption of renewable energy in 2018 compared with 2005 levels allowed the EU to:

- reduce its total GHG emissions by 478 MtCO2, equivalent to 12 % of total EU GHG emissions;
- reduce energy dependence by cutting demand for fossil fuels by 145 Mtoe, or roughly 13 % of total EU fossil fuel consumption;
- contribute towards energy efficiency targets by statistically reducing the EU's primary energy consumption by 43 Mtoe, equivalent to a 3 % reduction in primary energy consumption across the EU;
- reduce the emissions for NOx and SO2 by 44 kt and 129 kt, respectively, but increase the emissions of PM10, PM2,5 and VOC by 122 kt, 120 kt and 247 kt respectively.

Along with energy efficiency, renewable energy is a key decarbonisation pillar of Europe's transition to a low-carbon economy and society. Delivering the commitments under the Paris Agreement will require the EU to cut its GHG emissions by 80 % to 95 % by 2050 (compared with 1990 levels) and to decarbonise the energy generation sector almost completely.

The EU's renewable energy targets are already one important part of the combined efforts to decarbonise the energy system. Progressing towards them will effectively displace fossil fuels and complement the other climate mitigation efforts. As improvements in energy efficiency gradually reduce our consumption of energy, the growing share of renewables results in a progressively larger displacement of non-renewable energy alternatives.

To date, the consumption of RES has steadily increased, both as a share of final energy consumption and in absolute numbers. The growth of renewable energy in the mix has already eroded market shares previously held by non-renewable sources, effectively reducing CO_2 emissions.

The following sections estimate the gross effect ([28]) of renewable energy on fossil fuel consumption and its associated GHG emissions and then — statistically — on primary energy consumption ([29]). The relative reductions in fossil fuel use and GHG emissions ([30]) are obtained by comparing actual growth in renewable energy since 2005 with a counterfactual scenario in which this growth would come from non-renewable energy sources. Effectively, this assumes that the growth in renewable energy since 2005 has substituted an equivalent amount of energy that would have been supplied by a country-specific mix of conventional sources. The approach considers neither life-cycle emissions nor carbon accounting. The

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([28]) The term 'gross' describes the theoretical character of the effects estimated in this way. The potential interactions between renewable energy deployment and the need to reduce GHG emissions under the EU-wide cap set by the Emissions Trading System (EU ETS), as well as wider interactions with the energy and economic system, were not modelled.

([29]) Primary energy consumption (Europe 2020-2030), compiled by Eurostat. See 1.2.2.

([30]) These concern the relative reduction in primary and gross inland consumption of fossil fuels, and the reduction in total GHG emissions including international aviation but excluding LULUCF. Definitions of primary and gross inland energy consumption are provided in the glossary. Note that, according to what has been written in 1.2.2, the primary and gross inland consumption of fossil fuels have been retrieved from Eurostat (codes PEC and GIC).

method is described in detail in the EEA report *Renewable energy in Europe — Approximated recent growth and knock-on effects* (EEA 2015).

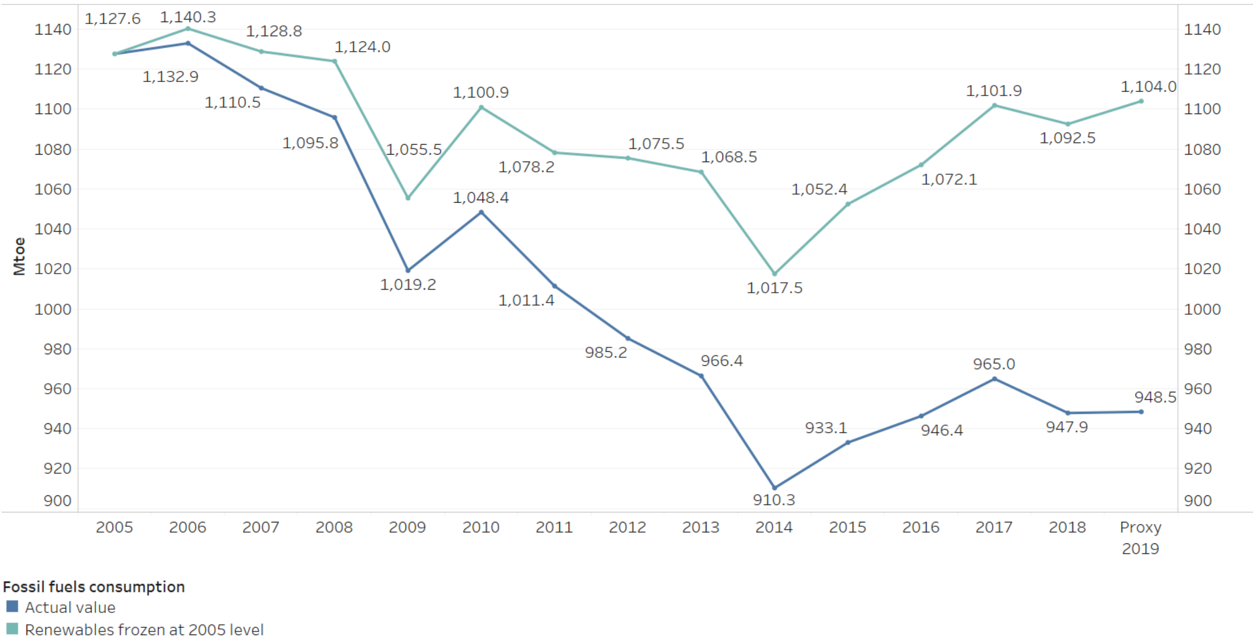
3.1 Avoided fossil fuel use

3.1.1 Effects at the EU level

The increase in the use of renewable energy compared with the level of RES consumption in 2005 allowed the EU to cut its demand for fossil fuels by 145 Mtoe in 2018 (more than 13 % of total primary fossil fuel consumption with renewables frozen at 2005 level) ([31]), as shown in Figure 21. This amount corresponds to almost the gross final energy consumption of France (151 Mtoe in 2018). The largest reductions were made in the consumption of solid fuels (57 Mtoe, representing 39 % of all avoided fossil fuels) and gaseous fuels (45 Mtoe, representing 31 % of all avoided fossil fuels).

Estimates by the EEA show that avoided fossil fuel consumption will further increase from 145 Mtoe in 2018 to 155 Mtoe in 2019, which is more than 12 % of total primary fossil fuel consumption ([32]) (see Table 5).

Figure 21 Estimated effect on fossil fuel consumption in the EU.



Notes: This figure shows the effect on primary energy consumption of fossil fuels due to the increase in renewable energy consumption since 2005 (excluding non-energy uses).

Sources: ETC/CME; (Eurostat 2020a); (Eurostat 2020e).

([31]) Eurostat's "Primary Energy Consumption" (coded PEC) indicator, because the data refer to a specific fuel group. This is equivalent to an 12 % reduction when the effects are calculated in proportion to the EU gross inland consumption of fossil fuels (retrieved from Eurostat's "Gross Inland Consumption" (coded GIC). Primary energy consumption is gross inland consumption, excluding all non-energy use of energy carriers. The RES effects were estimated with respect to primary energy consumption, given the availability of EEA early estimates for 2019 for primary energy consumption but not for gross inland consumption.

([32]) Eurostat's "Primary Energy Consumption". See 1.2.2.

Table 5 Estimated effect on fossil fuel consumption in the EU (Mtoe).

Fuel type	2005	2010	2015	2016	2017	2018	Proxy 2019
Solid fuels	0	-17	-52	-50	-52	-57	-61
Gaseous fuels	0	-23	-33	-39	-44	-45	-49
Petroleum products	0	-12	-21	-22	-25	-25	-28
Petrol	0	0	-2	-2	-2	-3	-3
Diesel	0	0	-10	-10	-12	-13	-13
Non-renewable waste	0	-0	-2	-2	-2	-2	-2
Total	0	-53	-119	-126	-137	-145	-155

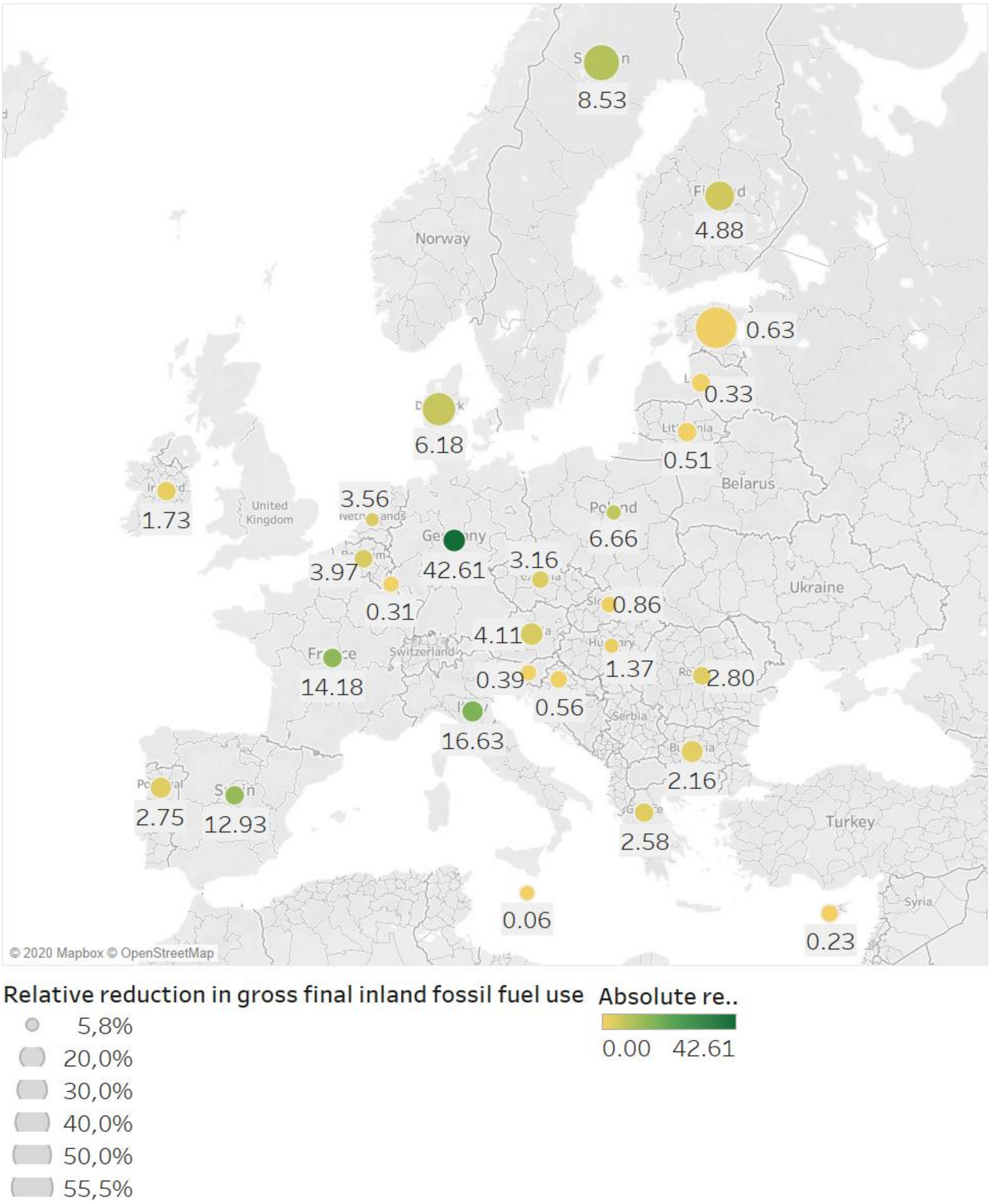
Notes: This table shows the estimated effect on primary energy consumption from fossil fuels (excluding non-energy uses) of the increase in renewable energy consumption since 2005.

Sources: ETC/CME; (Eurostat 2020a); (Eurostat 2020e).

3.1.2 Effects at the Member State level

The increase in renewable energy consumption in the Member States since 2005 has also had an impact on fossil fuel use and GHG emissions in the countries themselves. According to EEA calculations, in 2018, the largest relative reductions in the consumption of fossil fuels compared to 2005 were made by Estonia (56 %), Sweden (42 %), Denmark (35 %) and Finland (28 %), in proportion to their gross domestic fossil fuel use. In absolute terms, the greatest quantities of fossil fuels were avoided in Germany, Italy, France and Spain, where most renewable energy was consumed (Figure 22).

Figure 22 **Total and relative reduction in gross inland fossil fuel use (per year, in 2018)**



Notes: The absolute reduction in gross inland fossil fuel use in 2018 compared to 2005, expressed in million tonnes of oil equivalent (Mtoe), is proportional with the increase of renewable energy consumption achieved between 2005 and 2018. It represents the annual estimate for 2018; the cumulative value over the period 2005 – 2018 is much larger. The relative reduction in gross inland fossil fuel use is expressed as the absolute reduction over a country's total gross inland consumption of fossil fuels.

Sources: ETC/CME; (Eurostat 2020a); (Eurostat 2020e).

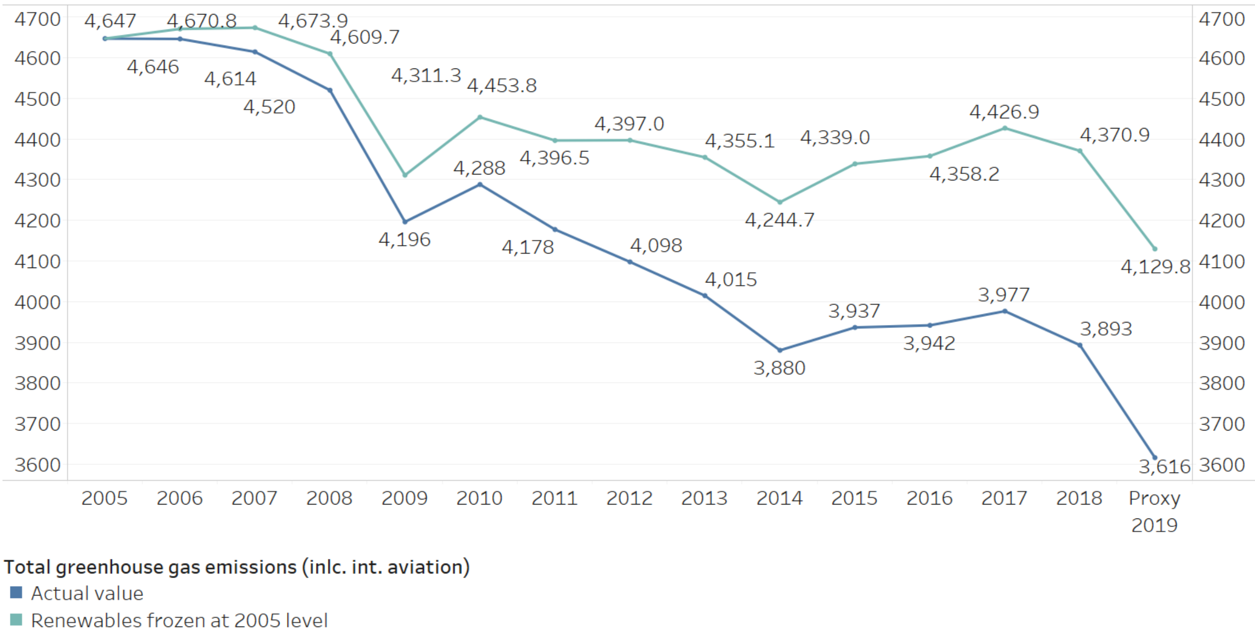
3.2 Gross avoided greenhouse gas emissions

3.2.1 Effects at the EU level

In 2018, total GHG emissions (including international aviation but excluding LULUCF) in the EU were 3 893 MtCO2. According to the EEA, the growth in the consumption of renewable energy after 2005 resulted in an estimated 478 Mt of gross avoided CO2 emissions at the EU level annually in 2018, delivering a gross reduction of 1 % of the EU's total GHG emissions in 2018 (frozen at 2005 level). Compared with 2017, this effect increased by 27.7 Mt (see Figure 23).

The estimated reduction in GHG emissions due to renewables in 2018 was similar to the total GHG emissions of France in 2018. The contribution from RES-E (349 MtCO2, or 73 % of all gross avoided emissions) was considerably larger than that of RES-H&C (81 MtCO2, or 17 % of all gross avoided emissions) and biofuels in transport (48 MtCO2, or around 10 % of total gross avoided emissions), as the increase in RES-E led to the strongest substitution of solid fuels — the most carbon-intensive fossil fuels — in the power sector. On the one hand, this testifies to the more rapid progress achieved since 2005 in decarbonising the EU power sector, compared with transport, heating and cooling, and industry. On the other hand, it hints at the increasing role that RES-E could play in decarbonising other end-use sectors. It also makes clear that a renewed focus on reducing GHG emissions in end-use sectors is necessary.

Figure 23 Estimated gross effect on GHG emissions in the EU.



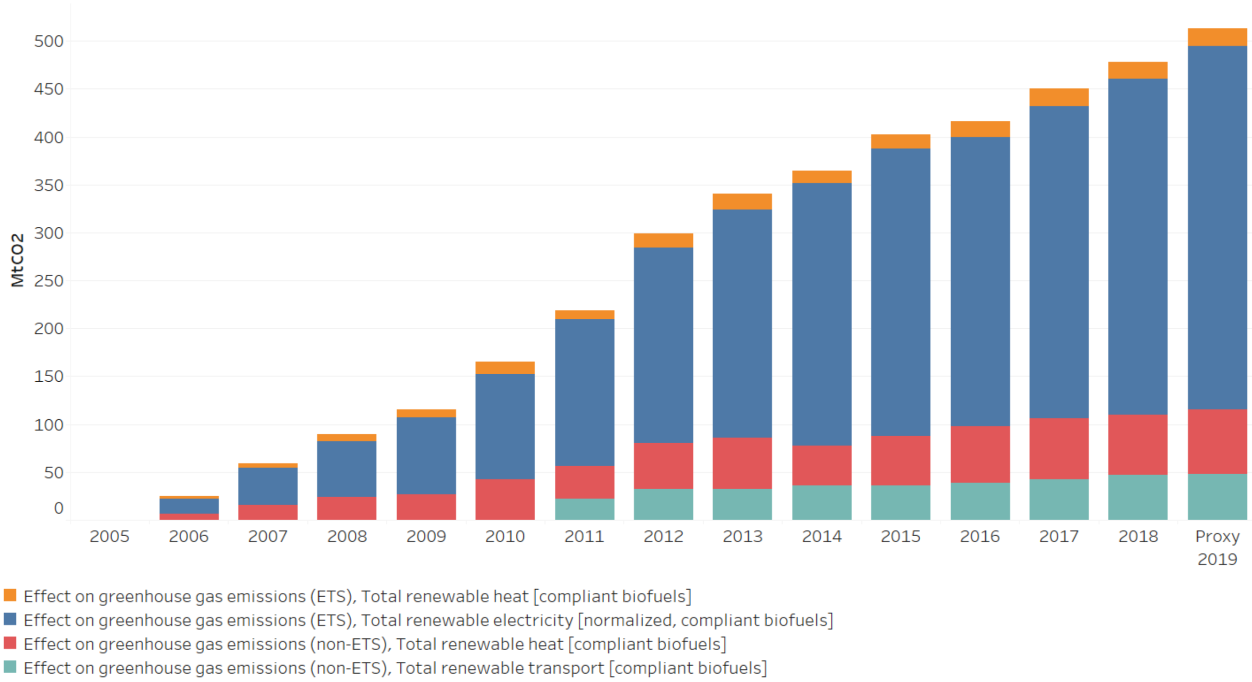
Notes: This figure shows the estimated gross reduction in total GHG emissions (including international aviation but excluding LULUCF) due to the increase in renewable energy consumption since 2005.

Sources: ETC/CME; (Eurostat 2020a); (Eurostat 2020e).

As shown in Figure 24 and Table 6, the gross avoided emissions within the Emissions Trading System (ETS) were estimated to be approximately 368 $MtCO_2$ in 2018. The gross avoided emissions in non-ETS sectors were estimated to be approximately 110 $MtCO_2$ ([33]).

Estimates by the EEA for 2019 show an increase in gross avoided GHG emissions of approximately 7.3 % from 2018 to 2019. The total avoided GHG emissions in Europe in 2019 are estimated to be 513 $MtCO_2$, roughly 12 % of the total GHG emissions (including international aviation).

Figure 24 Estimated gross reduction in GHG emissions in the EU, by energy market sector



Notes: This figure shows the estimated gross reduction in GHG emissions due to the increase in renewable energy consumption since 2005.

Source: ETC/CME; (Eurostat 2020a); (Eurostat 2020e).

([33]) These estimates are based on the assumption that RES-E generation always replaces a conventional mix of centralised electricity generation, which takes place within the EU ETS; transport emissions occur outside the ETS; renewable heat can replace heat that is produced in sectors falling either under the ETS or in non-ETS sectors. We assume that the share of ETS emissions in the industry sector is an indicator of the share of renewable heat production in the industry that takes place under the ETS.

Table 6 **Estimated gross reduction in GHG emissions in the EU (MtCO2).**

		2005	2010	2015	2016	2017	2018	Proxy 2019
ETS	Electricity	0	-110	-300	-302	-326	-351	-379
	Heating and cooling	0	-13	-15	-16	-18	-17	-18
	Transport	0	0	0	0	0	0	0
	All renewables	0	-123	-315	-318	-344	-368	-398
Non-ETS	Electricity	0	0	0	0	0	0	0
	Heating and cooling	0	-42	-51	-59	-63	-62	-67
	Transport	0	0	-36	-39	-43	-47	-48
	All renewables	0	-42	-88	-98	-106	-110	-116
Total	Electricity	0	-110	-300	-302	-326	-351	-379
	Heating and cooling	0	-55	-66	-76	-81	-80	-86
	Transport	0	0	-36	-39	-43	-47	-48
	All renewables	0	-166	-402	-416	-450	-478	-513

Notes: This table shows the estimated gross reduction in GHG emissions due to the increase in renewable energy consumption (normalised, certified biofuels) since 2005.

Source: ETC/CME; (Eurostat 2020a); (Eurostat 2020e).

3.2.2 Effects at Member State level

In terms of gross avoided GHG emissions in 2018, the countries with the largest estimated gross reductions were Germany (158 MtCO2), Italy (48 MtCO2), Spain and France (both 41 MtCO2) (Figure 26). In relative terms, significant GHG emission reductions (of 10 % or more of the total national GHG emissions, including international aviation and excluding LULUCF) were recorded in 10 countries in 2018 (Sweden, Denmark, Finland, Germany, Austria, Bulgaria, Latvia, Lithuania, Portugal and Spain), as illustrated in Figure 26. It should be noted again that these figures reflect the development of RES since 2005 — GHG emissions avoided through RES before this base year are excluded in this methodology.

Figure 25 Total and relative gross avoided GHG emissions (per country in 2018)

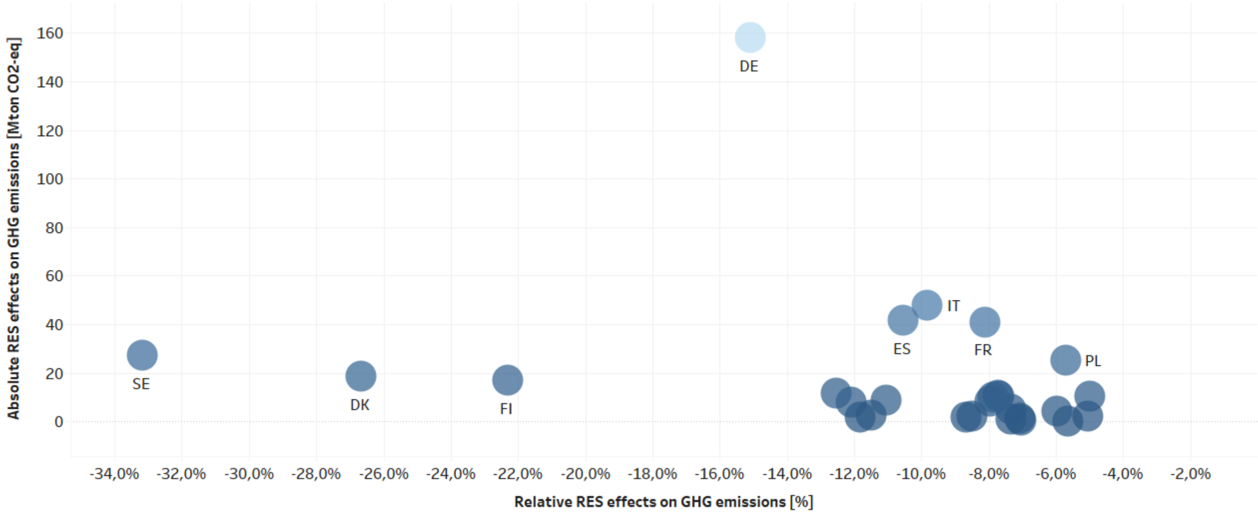
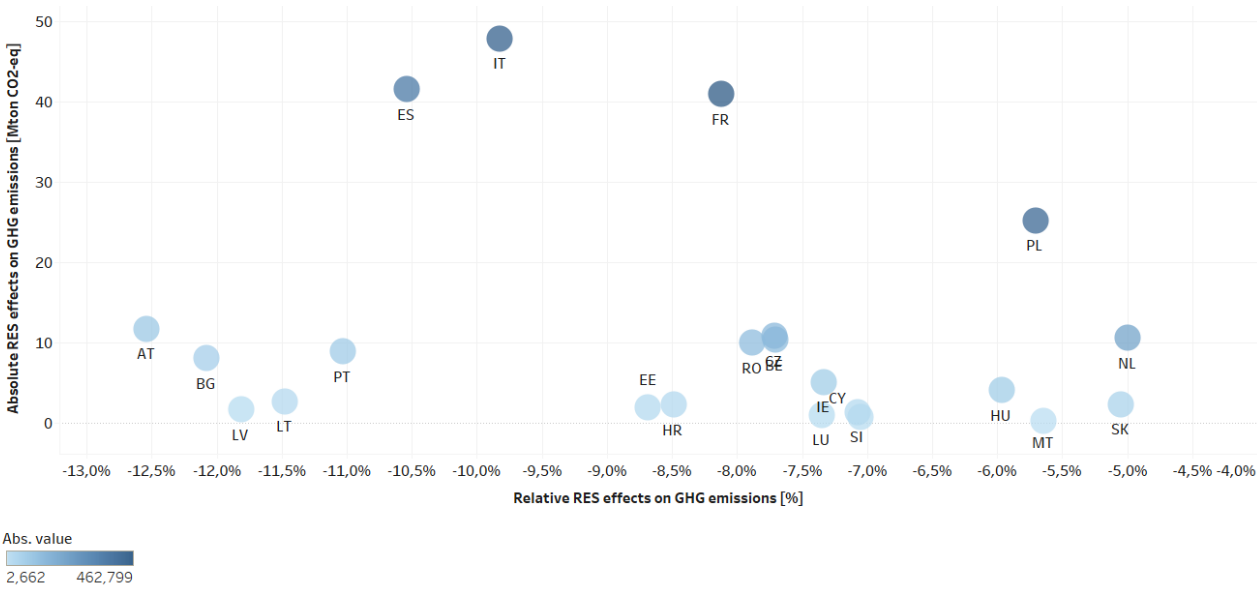


Figure 26 Total and relative gross avoided GHG emissions (per country in 2018) (zoom-in)



Notes: On both the figures, the vertical axis illustrates the absolute RES effects on GHG emissions in 2018 compared to 2005, expressed as million tonnes (Mt) of gross avoided CO2 emissions per country. The effect is proportional to the increase in national RES consumption between 2005 and 2018. The further up a country is situated, the higher its gross avoided GHG emissions (Mt CO2). The horizontal axis illustrates the (relative) impact of national RES growth since 2005 on national GHG emissions. The further to the right a country is, the more effective national RES consumption was to help reduce total national GHG emission (including international aviation and excluding LULUCF).

Source: ETC/CME; (Eurostat 2020a), (Eurostat 2020e).

3.3 Statistical impacts of renewable energy sources on primary energy consumption

3.3.1 Effects at EU level

The main energy efficiency policies at the EU level — the recast Energy Performance of Buildings Directive (EPBD) (EU 2010) and the recast Energy Efficiency Directive (EED) (EU 2012b) — set targets and objectives expressed in **primary** energy consumption (defined as gross inland energy consumption minus final non-energy consumption; see Glossary and Abbreviations). As energy efficiency and renewable energy are key drivers for achieving Europe's climate and energy targets by 2020 and 2030, synergies between RES technologies and their statistical impacts on primary energy ([34]) are presented below. The methodology underpinning these findings was described in a previous EEA report (EEA 2015) ([35]).

At the EU level, primary energy consumption followed an intermittent, yet decreasing, trend until 2014, after which it increased again up to 2017 and a marginal decrease of 0.7 % was observed between 2017 and 2018 (EEA 2020b). Next to the key driving factors that affect primary energy consumption, such as energy efficiency improvements, unusual weather conditions and economic activity, several other factors are of statistical importance for the overall trend, given their opposing effects:

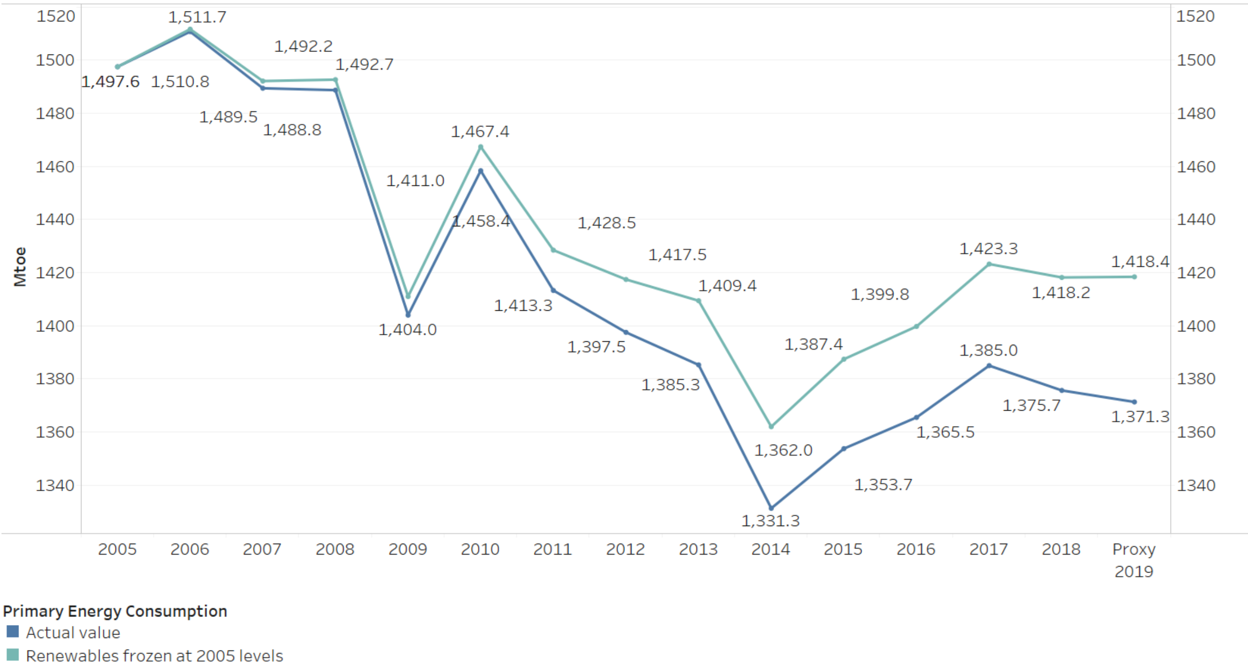
- Typically, a decreasing share of nuclear energy and thermal generation (excluding combined heat and power — CHP) in primary energy consumption is statistically diminishing the latter even if the final energy consumption is constant. Similarly, a growing share of certain renewable energy technologies, such as hydro- and wind power, statistically reduces the level of primary energy consumption, even where final energy use stays unchanged. This is because of the statistical methodologies in use: to estimate the primary energy of certain technologies or sources, energy statistics follow the common physical principle of the first measurable primary equivalent energy. For nuclear and geothermal energy, the first measurable primary equivalent energy is the heat that is being converted to electricity (at transformation efficiencies typically in the range of 40-60 %). In contrast, for solar PV and wind energy, the first measurable primary energy equivalent is the resulting electricity, which thus amounts to a 100 % transformation efficiency for these technologies, thereby improving the overall conversion efficiency of the energy system and statistically lowering the level of primary energy consumption.
- General factors driving the accounting of primary energy consumption upwards include an increasing share of specific renewable energy technologies, such as biomass-based electricity production. This is because the efficiency of electricity generation from biomass is, on average, lower than that from fossil fuels. Given these low efficiencies, converting the gross final electricity obtained from biomass into primary energy will, statistically, worsen the overall conversion efficiency of the energy system and thus increase total primary energy consumption.

The EEA estimates that deploying renewable energy since 2005 reduced primary energy consumption by 42.5 Mtoe in 2018 — more than the primary energy consumption of Czech Republic in 2018 (see Figure 27 and Table 7). Without the growth in renewable energy since 2005, primary energy consumption in the EU in 2018 could have been 3 % higher, while final energy use in end sectors could have remained unchanged.

([34]) Eurostat's "Primary energy consumption (Europe 2020-2030)". See 1.2.2.

([35]) Some changes have been made to the methodology for calculating the effects of renewable energy on primary energy consumption. It is assumed that the use of renewable biofuels does not have an impact on primary energy consumption, because the use of fossil fuels (such as petrol and diesel) is replaced by the same amount of biofuels. Heat extracted from the environment by heat pumps counts as renewable energy. To estimate the effect of heat pumps on fossil energy consumption and primary energy consumption, we assume a seasonal performance factor (SPF) for heat pumps of 3.0.

Figure 27 **Estimated effect on primary energy consumption in the EU.**



Notes: This figure shows the estimated effect on primary energy consumption due to the increase in renewable energy consumption since 2005.

Sources: ETC/CME; (Eurostat 2020a); (Eurostat 2020e).

Table 7 **Estimated effect on primary energy consumption in the EU (Mtoe).**

	2005	2010	2015	2016	2017	2018	Proxy 2019
Renewable electricity (normalised, certified biofuels)	0	-11,1	-34,3	-34,6	-38,8	-42,5	-47,0
Renewable heating and cooling (certified biofuels)	0	2,1	0,6	0,3	0,5	-0,1	-0,1
Renewable transport (certified biofuels)	0	0,0	0,0	0,0	0,0	0,0	0,0
All renewables (normalised, certified biofuels)	0	-9,0	-33,7	-34,3	-38,3	-42,5	-47,1

Notes: This table shows the estimated effect on primary energy consumption due to the increase in renewable energy consumption since 2005.

Sources: ETC/CME; (Eurostat 2020a); (Eurostat 2020e).

3.3.2 Effects at Member State level

The most important statistical effects of renewable energy on primary energy consumption were recorded for Denmark, Portugal, Greece and Sweden, where considerable reductions in primary energy consumption could be seen (-11 %, -7 %, -6 % and -6 %, respectively). In Estonia, Hungary, Latvia, Lithuania and Slovakia the statistical conventions in place resulted in slight increases in primary energy consumption due to the prevalence of biomass-based renewable energy in these countries. The effects of renewable energy on GHG emissions and energy consumption in 2018 are summarised by country in Annex 1.

3.4 Gross effect on air pollutant emissions

3.4.1 Effects at EU level

At the EU level, for 2018, the total estimated RES effect results in a decrease of air pollutant emissions of 44 kt for NOx and 129 kt for SO_2, compared with a counterfactual scenario in which RES consumption would have remained at the levels of 2005. However, for PM_{10}, $PM_{2.5}$ and VOC emissions, the result is an increase of respective 122, 120 and 247 kt in 2018 compared with 2005 (see tables below). On the relative level, comparing to total emissions frozen at 2005 level, the additional consumption of renewable energy sources across the EU since 2005 has led to a decrease of SO_2 and NO_x emissions in 2018, by 6 % and 1 %, respectively, than if RES use had remained at the same level of 2005. In contrast, an indicative increase of EU-wide emissions for PM and VOCs took place in 2018, following the increase in biomass use since 2005 (by 12 % for $PM_{2.5}$, 7 % for PM_{10} and 4 % for VOCs) (see second table of Annex 2).

In more detail, due to the increase in the gross final consumption of RES since 2005, all emissions from the RES-E market sector decreased, except for VOC emissions. The picture is different for the RES-H/C market sector, for which all the emissions increased, except for SO_2 emissions.

Example: *For heat non-ETS (essentially corresponding to the residential and services sectors), if it is assumed that 100 PJ of renewable solid fuels have replaced an equivalent amount of energy otherwise supplied with by average fossil fuel mix, this results in higher implied emission factors for all pollutants, except for* SO_2*. This is because, in most cases, less emitting fuels such as natural gas were part of the average fossil fuel mix.*

The larger the initial share of natural gas in the average fossil fuel mix, the higher the relative increase of the implied emission factors associated with the renewable solid fuels.

The assumption of using a weighted average emission factor for fossil fuels assumed to have been replaced by renewable energy means that, in the case of combustion-based renewables, emissions can increase for some pollutants. This is because some renewable fuels have higher emission factors than the weighted average fossil fuel emission factor of the fossil fuel they are assumed to substitute.

Table 8 Estimated effect on NOx emissions in the EU (kt)

	2005	2010	2015	2016	2017	2018	Proxy 2019
RES-E	0,0	-25,6	-49,4	-52,2	-57,2	-61,6	-67,9
RES-H/C	0,0	24,9	19,8	19,3	21,7	18,0	19,4
All RES	0,0	-0,8	-29,6	-32,9	-35,5	-43,7	-48,6
National Total (EEA, July 2020)	**10 504**	**8 409**	**7 037**	**6 828**	**6 707**	**6 444**	**N.A.**

Sources: ETC/CME, (IIASA 2017), (Eurostat 2020a), (Eurostat 2020e).

Table 9 **Estimated effect on PM10 emissions in the EU (kt)**

	2005	2010	2015	2016	2017	2018	Proxy 2019
RES-E	0,0	-1,2	-2,4	-2,4	-2,4	-2,4	-2,6
RES-H/C	0,0	127,7	116,7	125,6	134,5	124,2	128,8
All RES	0,0	126,5	114,3	123,2	132,0	121,8	126,3
National Total (EEA, July 2020)	**2 397**	**2 178**	**1 883**	**1 855**	**1 857**	**1 812**	**N.A.**

Sources: ETC/CME, (IIASA 2017), (Eurostat 2020a), (Eurostat 2020e).

Table 10 **Estimated effect on PM2.5 emissions in the EU (kt)**

	2005	2010	2015	2016	2017	2018	Proxy 2019
RES-E	0,0	-0,6	-1,7	-1,7	-1,8	-1,8	-1,9
RES-H/C	0,0	124,6	114,1	122,9	131,6	121,7	126,2
All RES	0,0	124,0	112,4	121,2	129,8	119,9	124,3
National Total (EEA, July 2020)	**1 551**	**1 440**	**1 214**	**1 197**	**1 199**	**1 147**	**N.A.**

Sources: ETC/CME, (IIASA 2017), (Eurostat 2020a), (Eurostat 2020e).

Table 11 **Estimated effect on SO2 emissions in the EU (kt)**

	2005	2010	2015	2016	2017	2018	Proxy 2019
RES-E	0,0	-41,8	-71,5	-69,9	-69,6	-69,0	-69,2
RES-H/C	0,0	-36,5	-46,3	-55,0	-57,9	-60,3	-64,0
All RES	0,0	-78,4	-117,8	-124,9	-127,5	-129,3	-133,3
National Total (EEA, July 2020)	**6 848**	**3 662**	**2 427**	**2 054**	**2 015**	**1 884**	**N.A.**

Sources: ETC/CME, (IIASA 2017), (Eurostat 2020a), (Eurostat 2020e).

Table 12 Estimated effect on VOC emissions in the EU (kt)

	2005	2010	2015	2016	2017	2018	Proxy 2019
RES-E	0,0	4,0	13,3	13,6	13,6	13,4	13,5
RES-H/C	0,0	232,8	223,9	242,0	255,1	233,4	242,3
All RES	0,0	236,8	237,1	255,5	268,7	246,8	255,9
National Total (EEA, July 2020)	**8 785**	**7 400**	**6 333**	**6 306**	**6 362**	**6 208**	**N.A.**

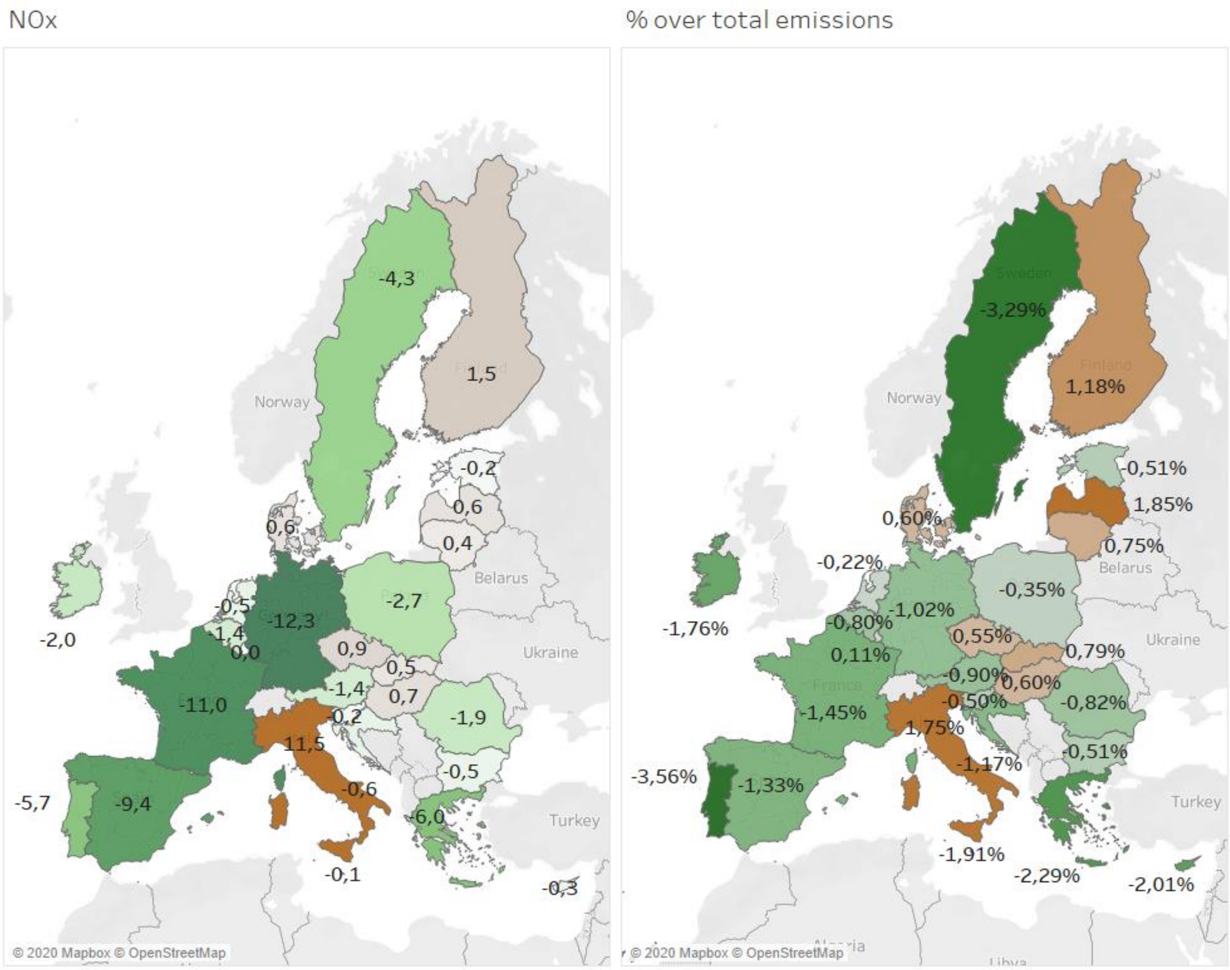
Sources: ETC/CME, (IIASA 2017), (Eurostat 2020a), (Eurostat 2020e).

3.4.2 *Effects at Member State level*

At the Member State level, absolute and relative impacts on key air pollutant emissions NO_x, SO_2, $PM_{2.5}$, PM_{10} and VOC in 2018 due to the increase of RES consumption since 2005 are illustrated in figures (Figure 28 to Figure 32 and in the tables in Annex 2). It can be observed that for countries that consume renewable fuels (solid, liquid, gaseous) some of the air pollutant emissions increase due to the different composition of the fuels and/or technologies (including abatement) used.

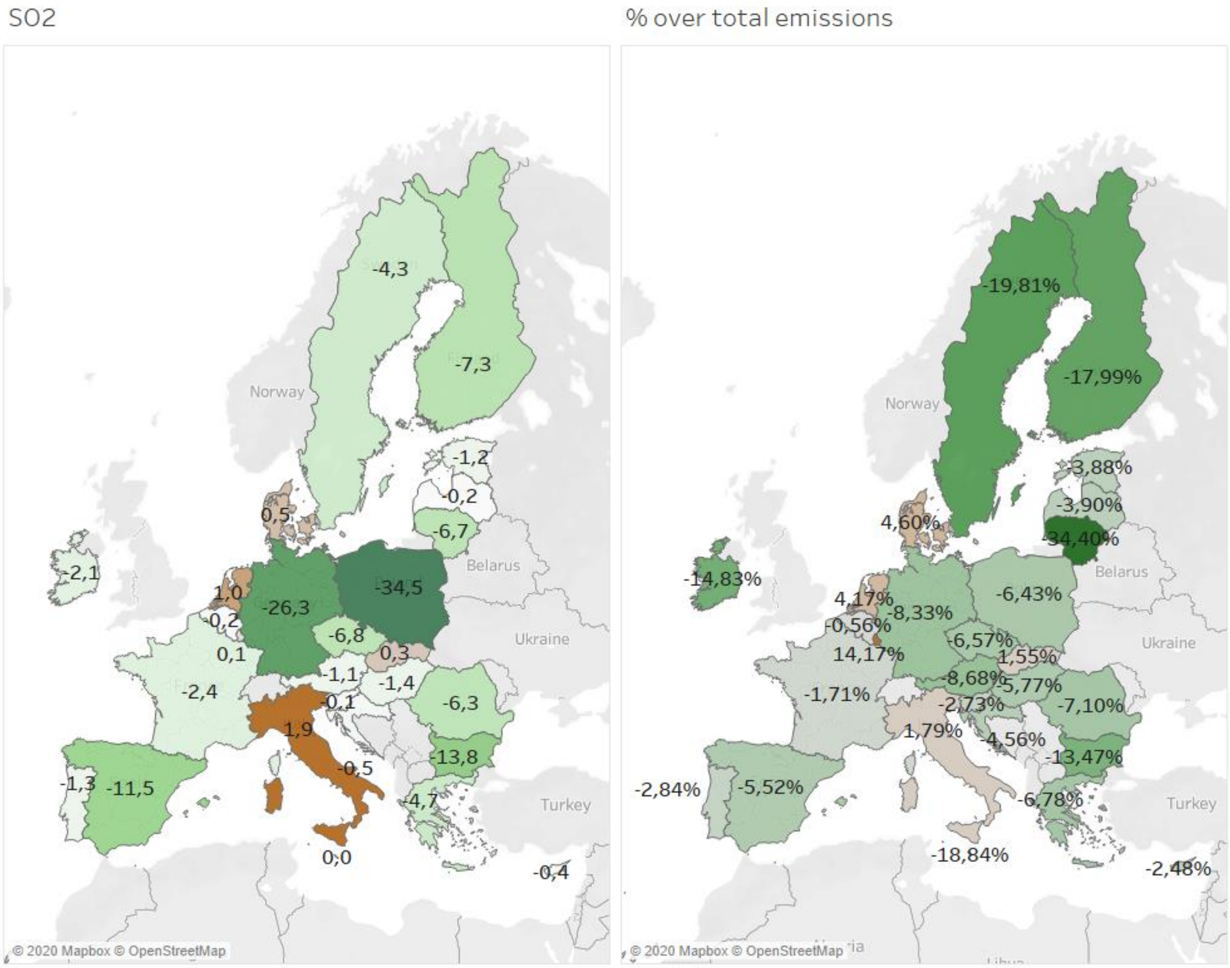
The results are best suited for analysis and conclusions on the aggregated EU level, where certainty is highest. Nevertheless, at the country level the results provide a useful general indication of the influence the increase in renewable energy consumption since 2005 had on air pollutant emissions. This follows from the likely interactions between the mix of renewable energy sources that supplied the energy, on the one hand, and the fossil fuel sources they substituted, on the other hand.

Figure 28 Estimated effects of RES consumption increase since 2005 on total NOx pollutant emissions in absolute values (kt, in 2018) and relative change over national total emissions (%, in 2018).



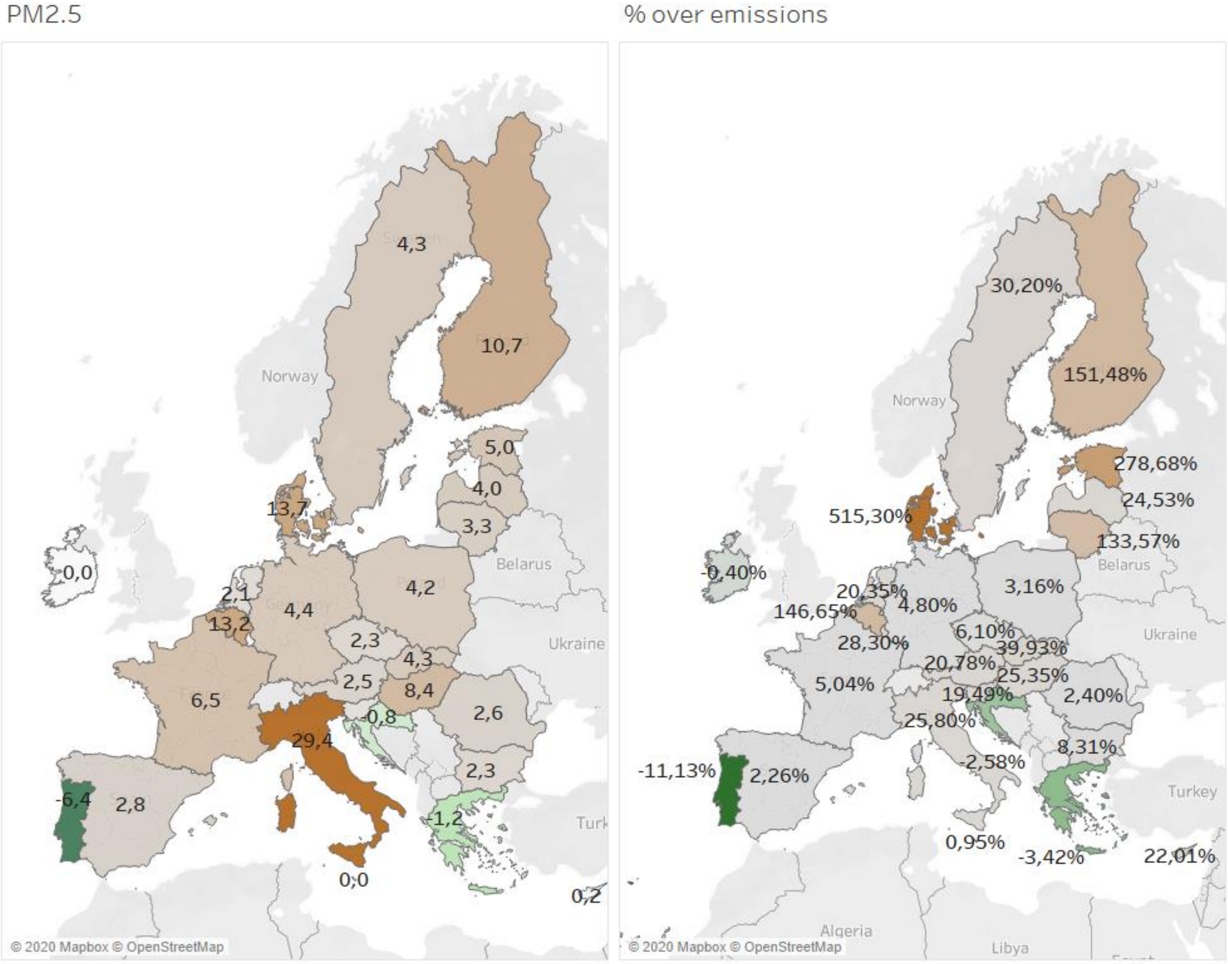
Sources: ETC/CME, ETC/CME, (IIASA 2017), (Eurostat 2020a), (Eurostat 2020e).

Figure 29	Estimated effects of RES consumption increase since 2005 on total SO2 pollutant emissions in absolute values (kt, in 2018) and relative change over national total emissions (%, in 2018).



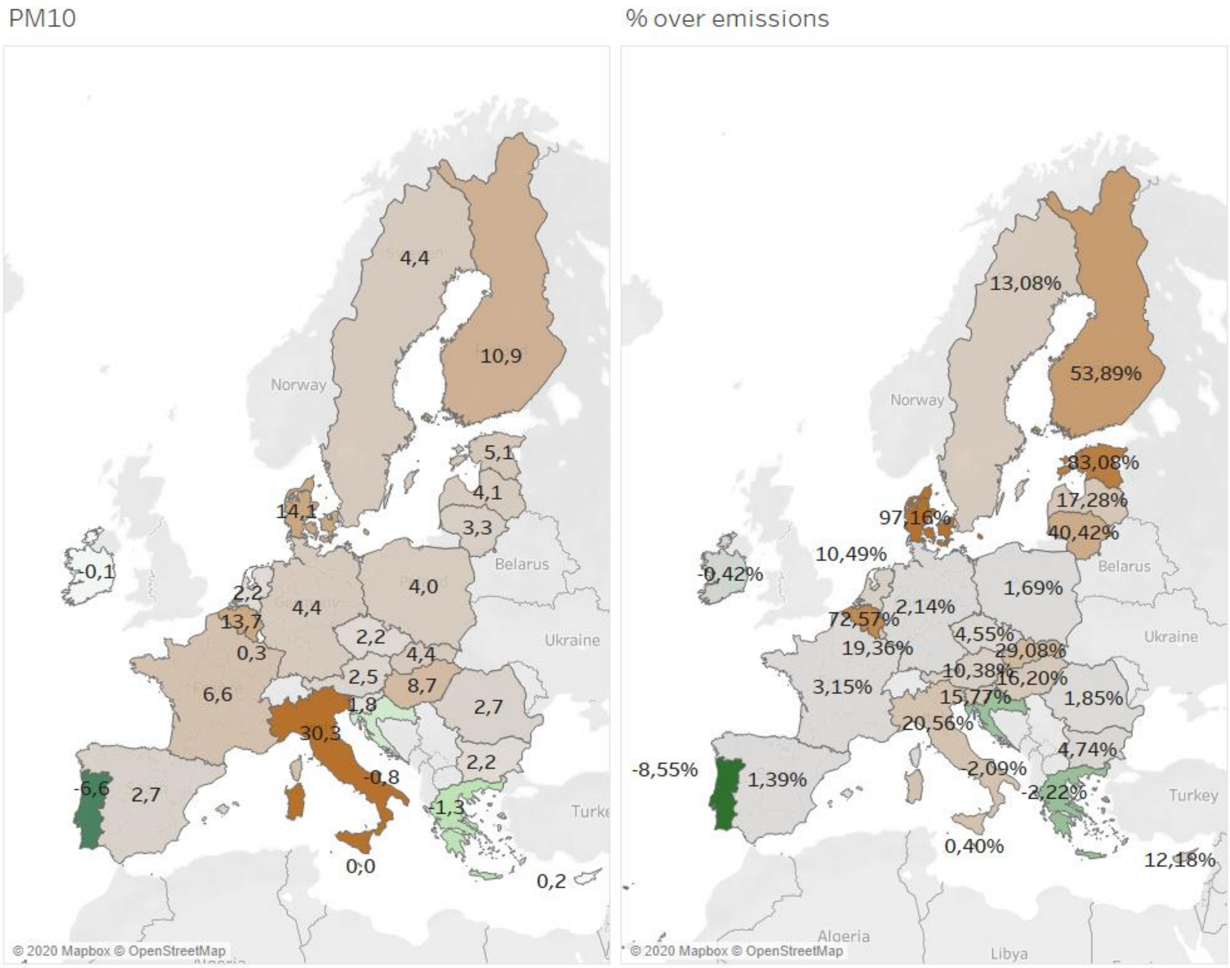
Sources: ETC/CME, (IIASA 2017), (Eurostat 2020a), (Eurostat 2020e).

Figure 30 **Estimated effects of RES consumption increase since 2005 on total $PM_{2.5}$ pollutant emissions in absolute values (kt, in 2018) and relative change over national total emissions (%, in 2018).**



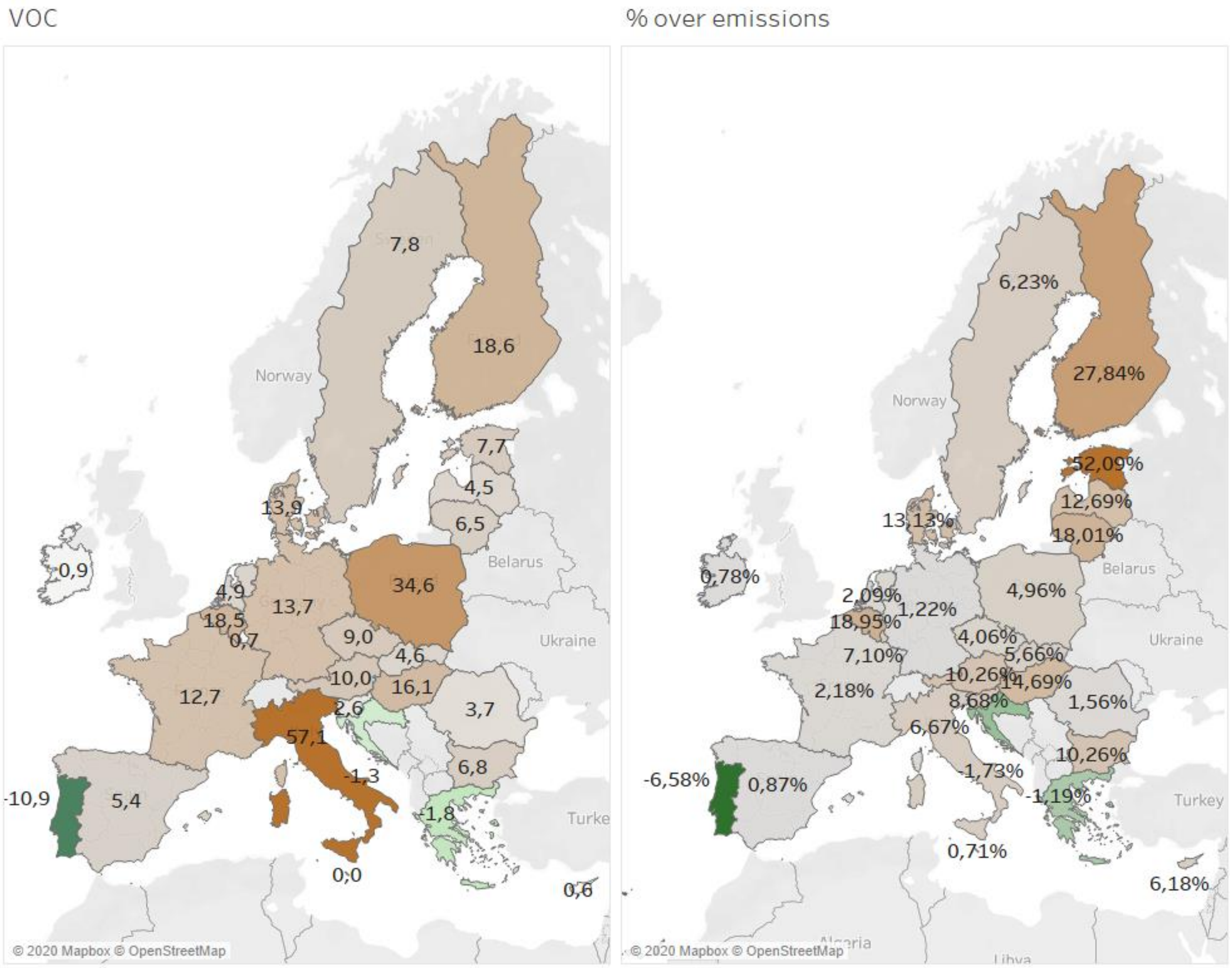
Sources: ETC/CME, (IIASA 2017), (Eurostat 2020a), (Eurostat 2020e).

Figure 31 Estimated effects of RES consumption increase since 2005 on total PM10 pollutant emissions in absolute values (kt, in 2018) and relative change over national total emissions (%, in 2018).



Sources: ETC/CME, ETC/CME, (IIASA 2017), (Eurostat 2020a), (Eurostat 2020e).

Figure 32	Estimated effects of RES consumption increase since 2005 on total VOC pollutant emissions in absolute values (kt, in 2018) and relative change over national total emissions (%, in 2018).



Sources: ETC/CME, (IIASA 2017), (Eurostat 2020a), (Eurostat 2020e).

Note that in the above figures (Figure 28 to Figure 32) the map at the right shows the relative change of emissions compared to 2005 due to RES deployment over the national total in 2018 while the second table of Annex 2 shows the relative effect of deploying renewable energy since 2005 on national total air pollutant emissions frozen at 2005 level in 2018.

In relative terms, for NO_x the results vary from a strong decrease to an increase in emissions (see Figure 28). The strongest decreases are caused by increasing shares of wind energy (both onshore and offshore) and, to a lesser extent, solar photovoltaic (Germany, Italy), which are not offset by an increase of emissions from biogas use in renewable electricity and biomass in renewable heat production.

For SO_2, all countries show a decreasing trend in emissions (Figure 29), because almost all the fossil fuels have higher implied emission factors than the renewable fuels, except for heat production by installations subject to the ETS.

For $PM_{2.5}$, PM_{10} and VOCs, all countries except for Portugal, Greece and Croatia, show a relative increase of emissions due to RES consumption, against the backdrop of biomass consumption increases in almost all countries over the period. The increase of RES-related particulate emissions is likely to have led to a strong increase of PM concentrations.

3.5 Indirect effects by renewable energy technology

Table 13 shows the estimated impact of each renewable energy technology on GHG emissions, fossil fuel consumption and primary energy consumption ([36]).

In 2017, the largest amounts of gross avoided GHG emissions were attributable to onshore wind energy (158 $MtCO_2$), solar PV energy (77 $MtCO_2$) and heat from solid biomass (71 $MtCO_2$) ([37]). Onshore wind and solar PV energy are also the most significant contributors to avoided primary energy consumption (27 and 13 Mtoe, respectively). For the avoided fossil fuel consumption, the first two most significant contributors are onshore wind (46 Mtoe) and heat from solid biomass (25 Mtoe).

The use of solid biomass for electricity and heating leads to a reduction in GHG emissions and fossil fuel consumption, but it drives up primary energy consumption.

Owing to the statistical conventions in place, consumption of concentrated solar power and geothermal energy can also increase primary energy consumption. These statistical interactions suggest that primary energy consumption trends alone do not present the full picture of the deeper energy consumption trends in end-use sectors.

For 2019, preliminary estimates by the EEA show that the amount of avoided GHG emissions will further increase to 155 $MtCO_2$. This is mainly driven by additional renewable energy consumption originating from onshore wind technologies, with estimated avoided GHG emissions of 32 $MtCO_2$ (an additional 10 $MtCO_2$ compared with 2018), followed by solid biomass, offshore wind and solar PV energy.

([36]) Eurostat's "Primary energy consumption (Europe 2020-2030)". See 1.2.2.

([37]) The impact of biomass consumption on actual GHG emissions is uncertain in the absence of accounting for LULUCF.

Table 13 Effect of renewable energy on GHG emissions and energy consumption by technology in the EU.

Source of renewable energy	Increase in renewable energy consumption since 2005 (ktoe)		Gross avoided GHG emissions ($MtCO_2$)		Avoided fossil fuel consumption (ktoe)		Effect on primary energy consumption (ktoe)	
	2018	Proxy 2019	2018	Proxy 2019	2018	Proxy 2019	2018	Proxy 2019
Renewable electricity								
Biogas	4 096	4 157	-37	-38	-9 807	-9 973	-54	-75
Bioliquids (certified)	409	409	-3	-3	-904	-905	21	21
Concentrated solar power	418	489	-4	-4	-1 078	-1 259	177	207
Geothermal	108	108	-1	-1	-244	-244	840	837
Hydropower excl. pumping (normalised)	320	333	-3	-3	-605	-653	-285	-321
Offshore wind (normalised)	3 346	3 971	-30	-36	-8 348	-9 995	-5 002	-6 024
Onshore wind (normalised)	18 429	20 305	-161	-177	-45 738	-50 331	-27 309	-30 026
Solar PV energy	9 343	10 005	-79	-84	-22 289	-23 838	-12 946	-13 832
Solid biomass	3 791	3 788	-33	-33	-9 381	-9 316	2 106	2 164
Tidal, wave and ocean energy	0	0	0	0	0	0	0	0
Renewable heat								
Biogas	2 782	2 922	-8	-9	-3 107	-3 263	-16	-17
Bioliquids (certified)	588	592	-2	-2	-656	-661	5	5
Geothermal	307	328	-1	-1	-343	-366	272	289
Renewable energy from heat pumps	9 063	9 705	-5	-5	-4 130	-4 447	-4.130	-4 447
Solar thermal	1 683	1 820	-5	-6	-1 880	-2 033	-197	-213
Solid biomass	18 516	20 059	-58	-63	-20 713	-22 438	3 975	4 306
Biofuels in transport								
Biodiesels (certified)	12 705	12 942	-39	-40	-12 705	-12 942	0	0
Bio gasoline (certified)	2 583	2 676	-7	-8	-2 583	-2 676	0	0
Other biofuels (certified)	154	158	0	0	-154	-158	0	0
Total renewables (normalised, certified biofuels)	**88 642**	**94 766**	**-478**	**-513**	**-144 665**	**-155 498**	**-42.543**	**-47 125**

Notes: This table shows the estimated effect on GHG emissions, fossil fuel consumption and primary energy consumption due to the increase in renewable energy consumption since 2005.

Source: ETC/CME. (Eurostat 2020a); (Eurostat 2020e).

Table 14 provides an overview of the estimated RES effects on air pollutant emissions per air pollutant, compared with the estimated RES effect on fossil fuel consumption, per renewable energy technology. The table illustrates that those technologies that do not combust renewable fuels (like wind power, solar PV, geothermal, heat pumps, solar thermal, etc.) have the largest reducing impact on air pollutant emissions.

For combustion-based renewable energy technologies (using solid, liquid and gaseous renewable fuels), an increase for some of the air pollutant emissions can be observed. This increase is due to the different composition of the renewable fuels and/or of the technology used, including the level of abatement installed compared with the fossil fuel/technology assumed to be substituted. These impacts are already reflected in the implied emissions factors that are used in the calculation of the effect.

Besides the fact that some combustible renewable fuels tend to have high emission factors for some key pollutants, also the characteristics of the fossil fuels assumed to be replaced (solid, liquid, gaseous) has an impact on the weighed implied emission factor for fossil fuels and, hence, on the resulting avoided emissions.

Example: *As illustrated in Table 14, in the RES-E and RES-H/C market sectors, combustible biomass-based technologies replace a relatively high share of fossil gaseous fuels, with relatively low emissions. This explains why the net effect on emissions is relatively large in such cases.*

Table 14	Estimated effects of RES consumption increase since 2005 on key air pollutant emissions (kt, per year, in 2018) and on fossil fuel consumption (ktoe, per year, in 2018) in the EU.

2018 (2005-RES shares counterfactual)	Effect on NOx emissions (kt)	Effect on PM_10 emissions (kt)	Effect on PM_2_5 emissions (kt)	Effect on SO2 emissions (kt)	Effect on VOC emissions (kt)	Effect on fossil fuel consumption; Gaseous fuels (ktoe)	Effect on fossil fuel consumption; Petroleum products (ktoe)	Effect on fossil fuel consumption; Solid Fuels (ktoe)	Effect on fossil fuel consumption; Total (ktoe) (1)
Renewable Electricity: Biogas	18,0	-0,1	0,0	-3,1	18,4	-1 805	-315,8	-7 444,5	-9 807
Renewable Electricity: Bioliquids [compliant]	0,6	0,0	0,0	-0,1	0,0	-432	-16,3	-431,3	-904
Renewable Electricity: Concentrated solar power	-1,0	0,0	0,0	-1,1	-0,1	-335	-153,5	-572,7	-1 078
Renewable Electricity: Geothermal	-0,2	0,0	0,0	-0,1	0,0	-103	-8,8	-124,9	-244
Renewable Electricity: Hydropower excl. pumping [normalized]	-1,1	-0,2	-0,1	-1,5	-0,1	-325	659,5	-925,7	-605
Renewable Electricity: Offshore wind [normalized]	-8,3	-0,2	-0,2	-4,5	-0,5	-1 442	-1 408,7	-5 296,9	-8 348
Renewable Electricity: Onshore wind [normalized]	-47,9	-2,0	-1,6	-37,6	-3,3	-10 687	-9 059,0	-24 814,5	-45 738
Renewable Electricity: Solar photovoltaic	-24,3	-1,0	-0,8	-16,6	-2,1	-6 199	-1 410,7	-14 035,8	-22 289
Renewable Electricity: Solid biomass	2,6	1,0	1,0	-4,5	1,2	-2 102	-2 471,2	-4 479,6	-9 381
Renewable Electricity: Tidal, wave and ocean energy	0,0	0,0	0,0	0,0	0,0	0	0,0	0,1	0
Total Renewable Electricity	**-61,6**	**-2,4**	**-1,8**	**-69,0**	**13,4**	**-23 429**	**-14 185**	**-58 126**	**-98 394**
Renewable Heat: Biogas	4,9	-1,7	-1,5	8,3	-0,8	-2 089	-821,3	-196,7	-3 107
Renewable Heat: Bioliquids [compliant]	0,7	0,0	0,0	0,0	0,0	-464	-173,2	-19,5	-656
Renewable Heat: Geothermal	-0,7	-0,2	-0,2	-0,7	-0,1	-230	-96,2	-16,8	-343
Renewable Heat: Renewable energy from heat pumps	-17,1	-4,4	-4,0	-14,2	-2,3	-5 652	-2 835,3	3 966,5	-4 130
Renewable Heat: Solar thermal	-3,3	-1,3	-1,2	-4,0	-0,7	-1 159	-616,3	-105,2	-1 880
Renewable Heat: Solid biomass	33,5	132,0	128,7	-49,8	237,3	-12 294	-6 334,7	-2 084,6	-20 713
Total Renewable Heat	**18,0**	**124,2**	**121,7**	**-60,3**	**233,4**	**-21 887**	**-10 877**	**1 544**	**-30 830**

Note: The effect on the total fossil fuel consumption is the sum of the effects on gaseous fuels, petroleum products, solid fuels and petrol, diesel and non-renewable waste. Solely the large fuel categories (gaseous fuels, petroleum products and solid fuels) are included in this table and that is why the total effect on fossil fuel consumption can be higher than the sum of the three individual effects in the previous three columns.

Sources: ETC/CME, (IIASA 2017), (Eurostat 2020a), (Eurostat 2020e).

3.6 Country specific CO2 emission factors

To refine the methodology to calculate the RES-effect, country specific emission factors were constructed according to the methodology described in Annex 5.

The two tables on the next pages show the impact of using country specific emission factors on the effects on GHG emissions and energy consumption compared to using the default emission factors. Table 15 shows the effects calculated based on the country specific emission factors while Table 16 shows the effects calculated based on the default emission factors.

- Avoided GHG emissions are higher (-518 $MtCO_2$ for EU) with country specific emission factors than with default emissions factors (-478 $MtCO_2$ for EU); the difference corresponds to 1% of GHG emissions in 2018 in EU;
- A similar effect can be observed for the gross inland consumption where country specific emission factors lead to an effect of -149 Mtoe and default emission factors to an effect of -145 Mtoe; the difference corresponds to 1% of the gross inland consumption in 2018 in the EU;
- Similar for primary energy consumptions where country specific emission factors lead to an effect of -47 Mtoe and default emission factors to an effect of -43 Mtoe; the difference corresponds to 0,2% of the primary energy consumption.

Table 15 Effects of renewable energy on GHG emissions and energy consumption – method with country specific emission factors

Country	GHG emissions (incl. international aviation)	Effect of renewables		Gross inland consumption of fossil fuels	Effect of renewables		Primary energy consumption	Effect of renewables	
	$MtCO_2e$	$MtCO_2$	%	Mtoe	Mtoe	%	Mtoe	Mtoe	%
Austria	81,5	-14,1	-15	22,6	-4,2	-16	31,8	-0,8	-2
Belgium	123,6	-10,6	-8	40,9	-4,0	-9	46,8	-0,5	-1
Bulgaria	58,6	-7,5	-11	12,8	-2,2	-14	18,3	-0,6	-3
Croatia	24,4	-2,2	-8	6,0	-0,6	-8	8,2	-0,3	-3
Cyprus	9,9	-0,8	-7	2,4	-0,2	-9	2,5	-0,1	-3
Czech Republic	129,4	-14,2	-10	32,4	-3,3	-9	40,4	-0,4	-1
Denmark	51,3	-19,0	-27	11,5	-6,2	-35	17,8	-2,3	-11
Estonia	20,2	-2,1	-9	0,6	-0,6	-52	6,2	0,1	2
Germany	888,7	-165,8	-16	251,8	-43,0	-15	291,7	-15,5	-5
Greece	96,1	-7,9	-8	20,1	-2,7	-12	22,6	-1,6	-7
Finland	58,8	-18,5	-24	13,7	-4,9	-26	32,7	-0,5	-1
France	462,8	-47,9	-9	122,7	-14,9	-11	238,9	-5,1	-2
Hungary	64,1	-4,6	-7	18,5	-1,4	-7	24,5	0,0	0
Ireland	64,2	-6,9	-10	12,6	-1,9	-13	14,5	-0,8	-5
Italy	439,3	-58,0	-12	122,8	-17,9	-13	147,2	-4,8	-3
Latvia	12,2	-1,7	-12	2,8	-0,3	-11	4,7	0,3	6
Lithuania	20,6	-3,0	-13	5,0	-0,5	-9	6,3	0,3	5
Luxembourg	12,4	-1,0	-7	3,6	-0,3	-8	4,5	-0,1	-1
Malta	2,7	-0,2	-6	0,7	-0,1	-7	0,8	0,0	-3
Netherlands	200,5	-11,9	-6	70,8	-3,7	-5	64,7	-1,1	-2
Poland	415,9	-22,3	-5	96,2	-6,7	-7	101,1	-1,1	-1
Portugal	71,6	-10,2	-12	17,9	-2,9	-14	22,7	-1,9	-8
Romania	116,5	-8,3	-7	24,7	-2,9	-11	32,6	-1,4	-4
Slovakia	43,5	-2,4	-5	11,2	-0,9	-7	15,8	0,1	0
Slovenia	17,6	-1,4	-7	4,3	-0,4	-8	6,7	0,0	0
Spain	352,2	-46,9	-12	96,1	-13,8	-13	124,6	-5,7	-4
Sweden	54,6	-28,5	-34	14,1	-8,6	-38	47,0	-3,0	-6
EU-27	3893,2	-517,7	-12	1038,9	-149,0	-13	1375,7	-46,9	-3

Sources: ETC/CME, (Eurostat 2020a), (Eurostat 2020e).

Table 16 Effects of renewable energy on GHG emissions and energy consumption – method with default emission factors

Country	GHG emissions (incl. international aviation)	Effect of renewables		Gross inland consumption of fossil fuels	Effect of renewables		Primary energy consumption	Effect of renewables	
	$MtCO_2e$	$MtCO_2$	%	Mtoe	Mtoe	%	Mtoe	Mtoe	%
Austria	81,5	-11,7	-13	22,6	-4,1	-17	31,8	-0,7	-2
Belgium	123,6	-10,3	-8	40,9	-4,0	-11	46,8	-0,5	-1
Bulgaria	58,6	-8,0	-12	12,8	-2,2	-15	18,3	-0,6	-3
Croatia	24,4	-2,3	-8	6,0	-0,6	-9	8,2	-0,3	-3
Cyprus	9,9	-0,7	-7	2,4	-0,2	-9	2,5	-0,1	-3
Czech Republic	129,4	-10,8	-8	32,4	-3,2	-10	40,4	-0,3	-1
Denmark	51,3	-18,6	-27	11,5	-6,2	-35	17,8	-2,3	-11
Estonia	20,2	-1,9	-9	0,6	-0,6	-56	6,2	0,1	1
Germany	888,7	-158,1	-15	251,8	-42,6	-16	291,7	-15,1	-5
Greece	96,1	-8,3	-8	20,1	-2,6	-12	22,6	-1,5	-6
Finland	58,8	-16,9	-22	13,7	-4,9	-28	32,7	-0,4	-1
France	462,8	-40,9	-8	122,7	-14,2	-11	238,9	-4,4	-2
Hungary	64,1	-4,1	-6	18,5	-1,4	-8	24,5	0,0	0
Ireland	64,2	-5,1	-7	12,6	-1,7	-12	14,5	-0,6	-4
Italy	439,3	-47,8	-10	122,8	-16,6	-13	147,2	-3,6	-2
Latvia	12,2	-1,6	-12	2,8	-0,3	-11	4,7	0,3	6
Lithuania	20,6	-2,7	-11	5,0	-0,5	-12	6,3	0,3	5
Luxembourg	12,4	-1,0	-7	3,6	-0,3	-8	4,5	-0,1	-1
Malta	2,7	-0,2	-6	0,7	-0,1	-7	0,8	0,0	-3
Netherlands	200,5	-10,5	-5	70,8	-3,6	-6	64,7	-0,9	-1
Poland	415,9	-25,2	-6	96,2	-6,7	-7	101,1	-1,1	-1
Portugal	71,6	-8,9	-11	17,9	-2,8	-14	22,7	-1,9	-7
Romania	116,5	-10,0	-8	24,7	-2,8	-11	32,6	-1,3	-4
Slovakia	43,5	-2,3	-5	11,2	-0,9	-8	15,8	0,1	1
Slovenia	17,6	-1,3	-7	4,3	-0,4	-9	6,7	0,0	0
Spain	352,2	-41,5	-11	96,1	-12,9	-12	124,6	-4,8	-4
Sweden	54,6	-27,1	-33	14,1	-8,5	-42	47,0	-3,0	-6
EU-27	3893,2	-477,9	-11	1038,9	-144,7	-13	1375,7	-42,5	-3

Sources: ETC/CME, (Eurostat 2020a), (Eurostat 2020e).

4 EU developments in renewable energy sources in a global perspective

Key messages:

- During 2019, renewables represented slightly over one quarter of the total global electricity generation in 2019. There was 177 GW new renewable capacity installed globally, reaching 2 533 GW of global total installed capacity. This resulted in the slowest growth of the decade: 7.5 % in 2019.
- Hydro continues to dominate the total renewable installed capacity, with 1 187 GW installed capacity. Yet wind and solar PV continue to dominate its growth, with 622 GW and 578 GW of total installed capacity respectively. Wind installations picked up speed, with total installed capacity of 92 GW in 2019. Solar keeps its high growth with 98 GW new installed capacity in 2019, a similar rate than in 2018.
- Global investment in renewables in 2019 stood at EUR 252 billion, about 3 % annual increase. Investment levels are still below the peak of 2017 of almost EUR 288 billion, with the largest drop of 15 % in 2018. China receives the largest renewable investments.
- The worldwide employment in renewable energy increased in 2019, reaching an estimated 11.5 million, a 4 % annual growth.
- Renewable capacity per capita in the world stood at 0.33 kW per capita in 2019, Global renewable capacity per GDP stood at 28 kW per million EUR_{2017} PPP.

Worldwide, unequal access to affordable energy is significant. This inequality is even more pronounced when it comes to access to clean and sustainable energy. The world still relies largely on cheap and accessible energy sources, generally supplied by fossil fuels.

The UN adopted the 2030 Agenda for Sustainable Development, based on 17 Sustainable Development Goals (SDGs). SDG7 objective is to have “affordable, reliable, sustainable and modern energy for all” by 2030. Achieving this goal will have a knock-on effect on wellbeing, equality and development. For example, a World Bank study of rural India found reliable electricity increased the hours women spend in employment by 31 % and boosted household income by 17 % (World Bank 2016).

Yet, 840 million people in the world today have no access to electricity, and roughly 3 times that number use cooking fuels with environmental and health impacts. One of the three core foundation goals of the SDG7 is “to double the global share of renewable energy by 2030” (UN 2019b).

Similarly, the Paris Agreement within the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 2016, dealing with climate change mitigation, adaptation, and finance (UNFCCC 2015). The Paris Agreement's long-term temperature goal is to keep the increase in global average temperature to well below 2°C above pre-industrial levels; and to pursue efforts to limit the increase to 1.5°C. Under the Paris Agreement, each country determines its own plan on the policies it will undertake. Many of the national plans have the use of renewable electricity as a focal point to reduce greenhouse gas emissions. As of December 2020[38], 189 states or regional economic integration organizations (out of 194 that have signed the Agreement) have deposited their instrument of

([38]) UNTC, STATUS AS AT : 10-12-2020 09:15:44 EDT ratification, acceptance, approval or accession and as such became a Party to the Agreement. On 4 November 2020 took effect the withdrawal of the United States, but elections in the United States may lead to a new administration, and the United States may rejoin the Paris Agreement.([39])

This chapter focuses on global developments in RES-E only, such as installed RES-E capacities and investments. We will focus on contrasting European developments in this market sector with the changes occurring in other parts of the world. Other forms of renewable energy are used worldwide. Biomass and waste are widely used in some regions, for example for cooking and heating. But some of these are used in a manner that creates environmental and health harm. Though there is insufficient data to report on renewable energy consumption in a way that excludes these harmful sources from the set of clean and safe RES uses.

4.1 Renewable electricity capacities by region and main source

4.1.1 Renewable electricity development by region

The overall global renewable power capacity totalled to 2 533 GW by the end of 2019, about 7.5 % higher than in 2018. This increase is slightly lower than the 8 % increase in 2018, and the lowest growth since 2010, being just below the average growth since 2005 of 7.7 %. This rate of growth is equivalent to the capacity almost tripling since 2005 (IRENA 2020b).

Net additions of renewable capacity around the world were virtually the same in 2019 than in 2018, and equalled an estimated 177 GW(IRENA 2020b).

Overall, renewable electricity capacity account for 34 % of the total electricity capacity of 7 352 GW in 2019, compared to a 33 % in 2018. Since 2012, net additions of renewable power generation capacity outpaced net installations of non-renewable plants. In 2019, renewable electricity accounted for approximately 71 % of net additions in installed capacity, which stood at 250 GW (IRENA 2020b). The proportion of net renewable electricity installations has been steadily increasing since 2010, when it stood at 37 %.

By 2019, renewable energy targets had been adopted in 172 countries at the national or state/provincial level, which is a slight increase from 2018 with 169 countries, but still lower than 2017 when 179 countries had renewable energy targets in place. Around 10 000 cities are also implementing policies to reduce GHG emissions. With an increasingly urbanisation planned, the role of cities is key for lowering emissions.

The focus of policies and targets continued to be on the power sector, with policies for the heating and cooling and transport sectors advancing at a much slower pace. New and revised targets have become increasingly ambitious, particularly in the power sector. Of all the countries, 166 have power sector specific targets. Of these, 60 countries have targets to achieve 100 % of electricity generated by renewable sources, most of them with target year 2050 (REN21 2020).

The number of jurisdictions with Feed-in-Tariff (FiT) policies have remained stable, with 116 jurisdictions still having them in place. Yet, in 2019, there continues to be a shift towards market-based mechanisms such as auctions and tenders as policies to incentivise new renewable capacity investment. For example,

([39]) Besides the US, Turkey and Iran are the largest emitters based on greenhouse gas emissions for ratification () not having ratified the agreement. Turkey is the only candidate to the European Union and, with US, member of the G20 that has not ratified the Paris Agreement. Iraq, Libya, South Sudan, Yemen and Eritrea are the other signatories that have not ratified the agreement.

in the EU, the Renewable Energy Recast (EU 2018a), with similar principles as the ones laid down in the Guidelines on State aid for environmental protection and energy for the period 2014-2020 (EC 2014a) ([40]) encourages tenders with prices based on electricity market prices, and only allows FiT, in some exceptions, for small installations and technologies in early stages of market development.

Community and prosumers incentives are also gaining track in some countries. Although distributed renewable generation only accounts for 1 % of total generation, its uptake is accelerating (REN21 2020).

This ongoing growth in capacity and the geographical expansion in renewable power are driven by a number of factors: rising electricity demand, targeted renewable energy support mechanisms and continued improvements in the cost-competitiveness of solar PV and wind power (Frankfurt School-UNEP 2020).

This growth in capacity translated in an increased share of electricity produced, and consumed, from renewable sources. Renewable energy supplied an estimated 27 % of global electricity production in 2019. Hydropower accounted for some 58 % of that renewable electricity production, a slight decrease from the previous year, when it accounted for 60 %. Wind power and solar PV shares kept growing with a 21.6 % and 10.3 % each in 2019, compared to a 21 % and 9 % respectively in 2018. Bio-power shares of renewable electricity production remained stable at 8 % In Europe, a leading region in renewable generation, an estimated 35 % of total electricity was generated by renewable sources in 2019. In certain European countries, this increase was even more dramatic, such as in Denmark (77 %) or Germany (42 %). Large countries such as China had an estimated power generation of 26.4 % by renewables in 2019, while in the United States it was of 17.4 % (REN21 2020).([41])

In previous editions of this report, we clustered world countries and regions into **three categories** based on their RES-E capacity developments between 2005 and 2019, and the pace of their energy consumption. (expressed in total capacity, per capita capacity and capacity per unit GDP, as illustrated in Figure 33, Figure 34 and Figure 35).

1. **China, India, Brazil, ASOC (Asia, excluding China and India, and Oceania)** where electricity consumption is expanding rapidly, and both renewable energy and fossil fuel generation are being deployed to meet growing demand. ([42])
2. **EU, the UK and the United States** are experiencing slow or negative growth in electricity consumption. In these countries/regions, renewable energy is increasingly displacing existing generation and disrupting traditional energy markets and business models.([43])
3. **Africa, the Americas (excluding the United States and Brazil), the Middle East and OE-CIS (Other Europe and Commonwealth of Independent States)** where RES-E development has been relatively slow, despite growing electricity consumption.

This section will explore the evolution of each of these clusters during 2019.

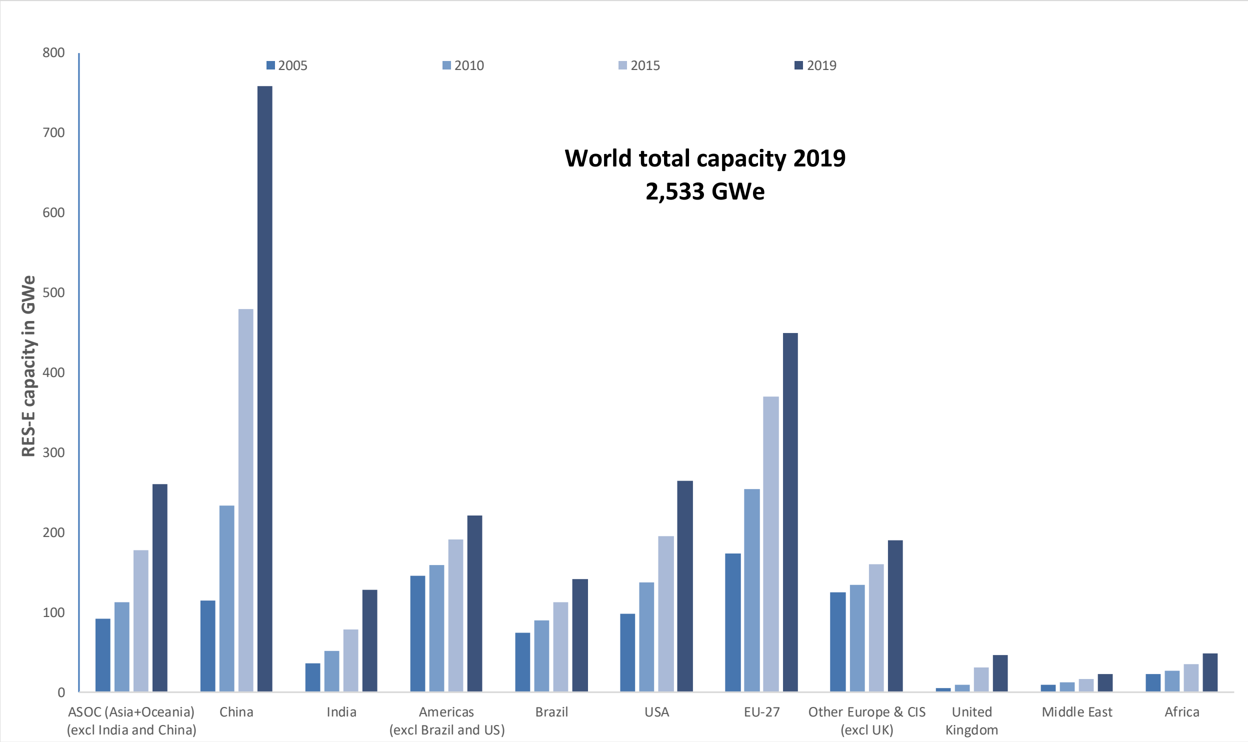
([40]) In January 2019, the European Commission announced its intention to prolong seven sets of State aid rules for a period of two years

([41]) REN 21 2020 uses estimates for generation in 2019, as data is not yet available in many countries for 2018. Figures for 2018 are based on reported national figures. For more details please consult the methodology in REN21 2020 report

([42]) This group also includes countries that are not aligned with the rest of countries, notably Japan, South Korea and Australia, where the levels of electrification are high and there is not the same level of available finance, skills, existing infrastructure, GDP and population growth than the rest of the ASOC region.

([43]) In previous years this cluster was composed of EU-28 and the United States.

Figure 33 RES-E capacities in selected world regions, 2005-2019.



Notes: ASOC refers to Asia and Oceania; OE-CIS refers to Other Europe and the Commonwealth of Independent States; full information about the geographical coverage and regional aggregations is provided in the glossary.

Source: (IRENA 2020a)

China, India, Brazil, ASOC (Asia, excluding China and India, and Oceania)

With 759 GW of RES-E capacity installed in 2019, China multiplied its capacity by a factor of 6.6 since 2005. It has a strong computed average annual growth (CAGR) of 114.4 %.([44]). China alone hosted 30 % of the world's renewable power capacity in 2019. Within the 38 % of installed capacity being RES-E, its major capacity base has been from hydropower plants (not including pumped storage), with 326 GW installed by 2019.

With a series of large-scale projects, hydropower in China increased sharply since the year 2000. The three- gorge project started production in 2003 and became fully functional in 2015, it totalled 22.5 GW. The second largest hydropower plant, Xiludou, finished construction in 2014 and has a capacity of almost 14 GW. China reached a peak of annual installations of around 30 GW in 2013. The growth in hydropower capacity has slowed down since then, with only 3 GW installed in 2019.

On the other hand, wind power capacity saw a large growth between 2010 and 2015, while solar PV was on the lead of new installations from 2015 until now. By the end of 2019, the total installed capacity was 210 GW for wind (+26 GW from the previous year) and 205 GW for solar PV (+30 GW from the previous year).

India has multiplied its RES-E capacity over the period 2005-2019 by a factor of 3.5 (from 36 GW to 128 GW). India has a strong hydropower base since the early 2000, which currently stands at 45 GW of

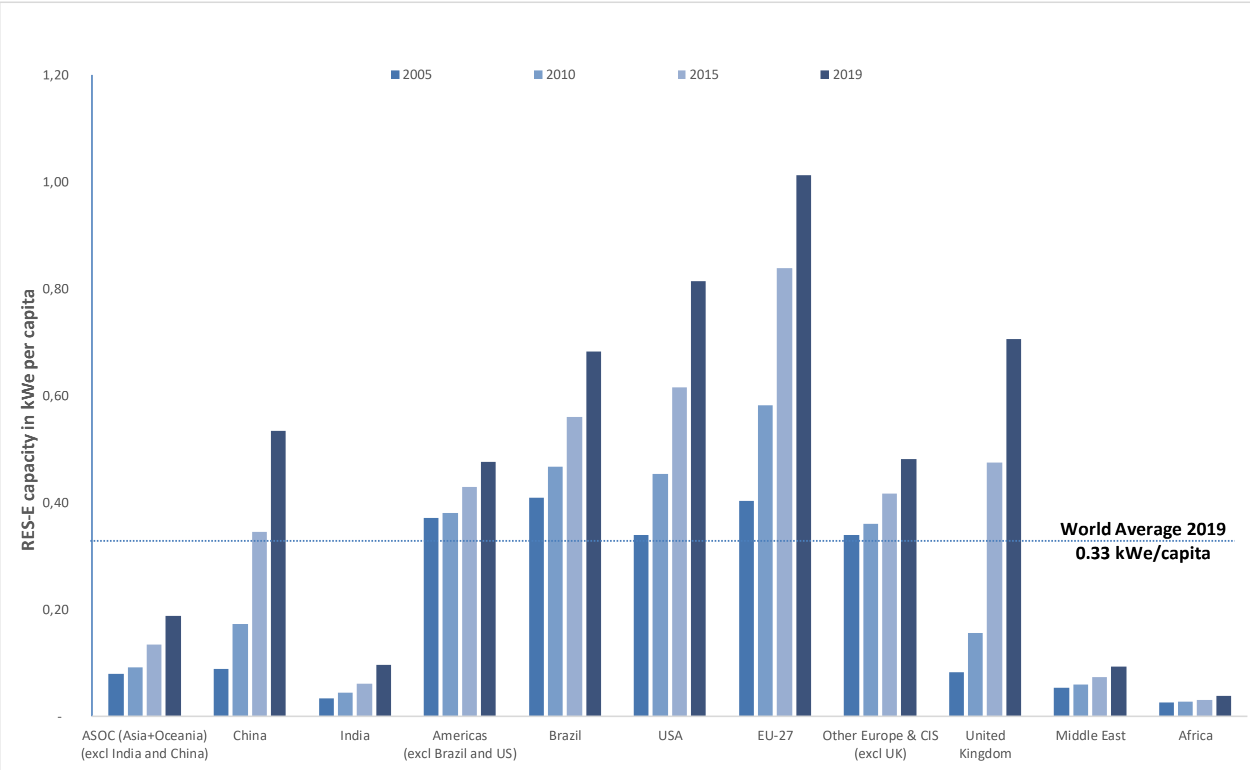
([44]) All average growths are calculated as CAGR in this chapter.

installed capacity. India has doubled the wind capacity in the last 5 years, and multiplied by 10 the solar PV capacity in the same period, reaching respectively 37 GW (only onshore wind) and 35 GW in 2019.

By the end of 2019, Brazil had an 83 % total installed capacity from RES-E and 76 % of this is coming from hydro, accounting for 109 GW installed capacity, from 62 GW in 2005. Wind had a strong and steady growth of around 2 GW installed capacity per year from 2015 to 2019. Solar PV saw a boom in installed capacity in 2017 and 2018 with 1 GW installed per year. However, net installed capacity of both sources of renewables slowed down in 2019, with around 0.5 GW installed capacity each that year (IRENA 2020a).

The rest of the ASOC currently has 260 GW installed renewable capacity. The region saw a year on year growth of 12 % for the region, one of the highest just after the Middle East at 14 % growth, and above the 7.7 % average growth since 2012. This meant a 28 GW net addition, under the 63 GW in China and just above the EU additions, which stand at 26 GW. The increases in 2019 were above 2018 levels, with 23 GW additions, an 11 % growth. This shows a sharp acceleration in these two years, when compared to 13 GW addition and 6 % growth in 2017.

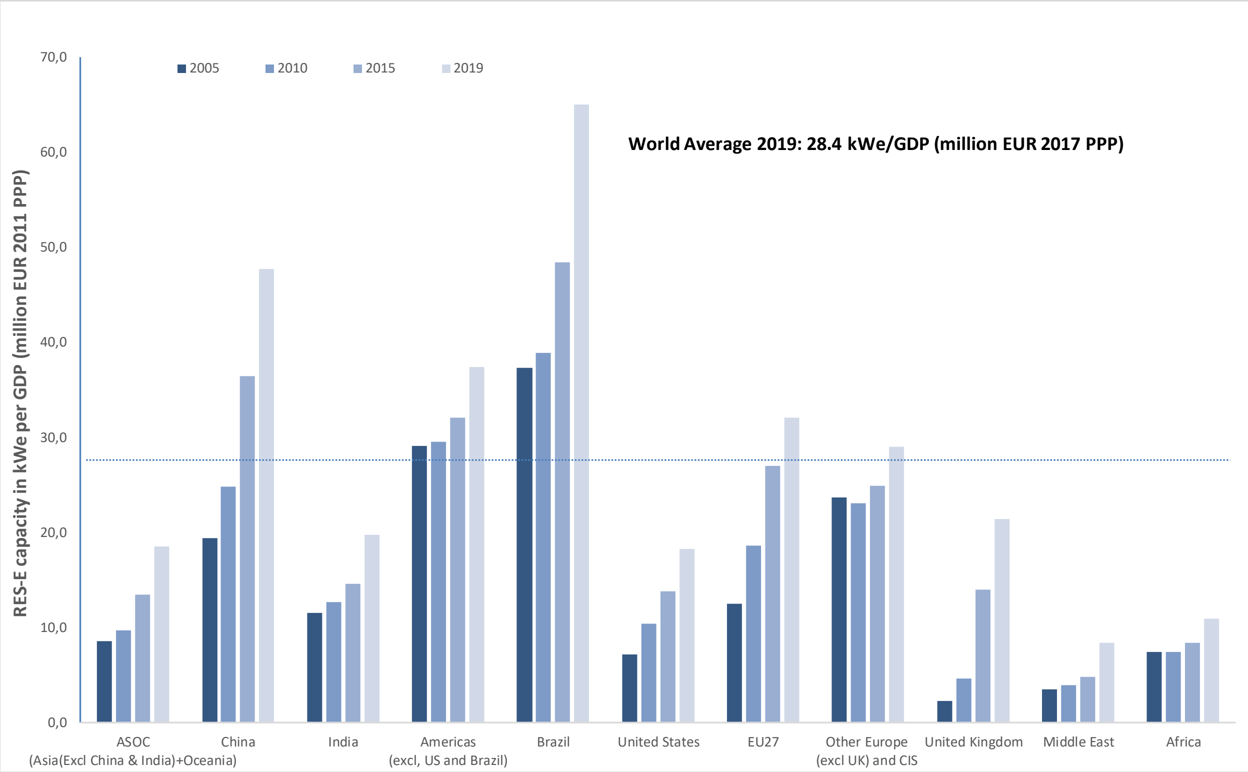
Figure 34 RES-E capacities per capita in selected world regions, 2005-2019.



Notes: ASOC refers to Asia (excluding China and India) and Oceania; OE-CIS refers to Other Europe and the Commonwealth of Independent States; full information about the geographical coverage and regional aggregations is provided in the glossary.

Sources: Population data are obtained from the UN/DESA/Population Division website (UN 2020); Renewable generation capacity is obtained from (IRENA 2020a).

Figure 35 RES-E capacities per GDP in selected world regions, 2005-2019.



Notes: ASOC refers to Asia (excluding China and India) and Oceania; OE-CIS refers to Other Europe and the Commonwealth of Independent States; full information about the geographical coverage and regional aggregations is provided in the glossary. GDP is expressed as constant 2017 euro value (EUR2017) at purchasing power parity (PPP). (45)

Sources: (World Bank 2020b); (IMF 2020); (IRENA 2020a); (OECD 2020).

In terms of RES-E development per capita and per GDP, each of the countries and regions has very different trends and drivers, notably linked to existing electrification levels its growth of electrification, RES-E capacity installed, and GDP and population growth rates:

- Brazil remains the best performing country for both indexes. This is thanks to a legacy of high hydropower capacity. In per capita terms, RES-E has grown steadily over time, from 0.4 kW/capita in 2005 to 0.7 kW/capita in 2019. As the RES-E basis was already strong at the beginning of the period, growth in capacity per capita is small compared to countries in the same group, 3.7 % average since 2005, and 3.4 % in 2019. Brazil has a capacity of 65 kW/million constant EUR_{2017} (PPP) of GDP, with a year on year growth of 4.5 % from 2018 to 2019, compared to an average yearly growth of 4.5 % since 2005. However, China, India and other ASOC countries have grown at a significant faster rate in terms of per capita capacity.
- China increased its RES-E capacity per capita by a factor of more than 6, going from 0.09 kW per capita in 2005 to 0.5 kW per capita in 2019, an average growth of 13.8 %. This is partly due to high

(45) Processing GDP data for the period 2005-2019: GDP data expressed as constant 2017 international dollars at PPP for most countries for the period 2005-2019 are obtained from the World Bank database (World Bank 2020b). For the year 2019, GDP data for all countries where no 2019 data is provided but 2018 data are in the World Bank's database, are obtained from the World Economy Outlook database of the International Monetary Fund (IMF, 2020). For each country, a conversion factor is calculated dividing GDP data for 2018 expressed as constant 2017 international dollars at PPP by GDP data for 2018 expressed as current international dollars at PPP, and then it is multiplied by the 2019 GDP data of that country expressed as current prices in international dollars at PPP to transform it into GDP expressed as constant 2017 international dollars at PPP. The PPP conversion rate for the year 2017 between euros and dollars is obtained from the Organisation for Economic Co-operation and Development's database (OECD 2020).

increase of renewable capacity when compared to relatively low population growth as a legacy of population control policies in China. On the other hand, GDP growth in China has been strong, with slower growth of capacity per GDP when compared to per capita. China had 948 kW/million EUR_{2017} (PPP) of GDP in 2019, an increase of 4.3 % compared to 2018 lower to the average annual growth since 2005 of 6.6 %.

- India has a low capacity of RES-E per capita, at 0.1 kW/capita, well below the world average. This is partly due to low electrification per capita in the country. This figure is nevertheless increasing proportionally fast with an average growth of 8% since 2005 and a year on year increase of 7.4 % in 2019. India reached in 2019 19.7 kW per unit GDP in million EUR_{2017} (PPP), with an annual growth of 4.9 %, compared to an average growth of 3.9 % since 2005.

EU, the UK and the United States

EU more than doubled its installed renewable capacity over the period 2005-2019, from 174 GW to 449 GW. With 167 GW capacity, wind power was the EU's largest renewable power source in 2019, followed by hydropower at 129 GW (not including pumped storage). Solar PV capacity was 116 GW. The EU remains leader in CSP, with 2.3 GW of CSP in Spain, the largest capacity in the world. Wind power and solar PV accounted for 90 % of the annual increase in renewable power capacity, and offshore wind power represented around 25 % of the total European wind power market in 2019 (IRENA 2020a).

In the US, the renewable installed capacity amounted to 265 GW in 2019. With 104 GW of capacity in 2019, wind dominates RES-E total installed capacity. It is followed by hydro with a capacity of 84 GW, not including pumped storage, which has not seen much changes since 2010. Despite having less capacity installed, solar PV capacity has skyrocketed since 2005: from 0.5 GW to 60.5 GW in 2019. The US also has a CSP capacity of 1.8 GW, second after Spain, and way ahead of other countries.

The UK had 47 GW of renewable installed capacity in 2019. Wind is the dominating technology, with 24 GW total installed capacity in 2019, almost 60 % of which is onshore. Solar PV comes next, with 14 GW installed capacity, of which 3 GW of new capacity was installed in 2019, a 7 % annual growth. This is the lowest level of annual net installed capacity since 2011. More than half of this growth was offshore wind.

In terms of indicators relative to the size of the countries and groups of countries:

- By 2019 the EU had established itself as one of the world leaders in terms of installed capacity per capita. At 1 kW per capita in 2019, this measure has increased every year starting from 2005.[46] It had an average annual growth of 6.8 % since 2005, the year on year growth of 6.1 %, showing a slight deceleration. The United States has the second highest rate of capacity per capita at 0.8 kW per capita. The UK had a similar rate at 0.7 kW per capita
- With an average annual growth rate of 6.2 % in RES-E capacity per unit GDP over the period 2005-2019, the EU is also clearly outpacing other regions on the penetration of RES-E capacity in the market. (IRENA 2020a) the United States performance of installed capacity per unit GDP, 18 kW/million EUR_{2017} (PPP), was below the world average in 2019. The growth in this parameter for the United States stagnated after a growth period in 2005-2010.

([46]) The per capita capacity in Europe has grown due to the exclusion of the UK from the EU data. The UK has a lower than EU average rate of per capita installations at 0.7.

Africa, the Americas (excluding the United States and Brazil), the Middle East and OE-CIS (Other Europe and Commonwealth of Independent States)

The Americas (47) experienced a relatively limited growth in renewable capacity over the period 2005-2019 compared to other regions: from 146 GW to 221 GW, equivalent of an average annual growth of 3 %. The growth in 2019, of 4 %, is slightly above that average. The region had in 2019 a 0.5 kW per capita ratio, and 37 kW/million EUR_{2017} (PPP).

European and CIS countries outside the EU and UK, includes western and north European countries, as well as Eastern European and CIS countries. This is a very heterogeneous group of countries in terms of RES penetration, electricity generation, GDP and population. It is also very diverse in terms of the types of RES technologies that have been developed and their potential future net installations. Russia and Turkey are leaders in the region's total installed capacity with 53 GW and 45 GW respectively in 2019, representing 51 % of the regions' installed capacity. Norway and Switzerland follow with 35 GW and 17 GW installed respectively. Ukraine was the country with most net installations in the region in 2019 with 4.6 GW installed capacity, reaching 12.7 GW of total installed capacity. Turkey was the second country in terms of net installations in 2019 with 2.4 GW, and has been the country with largest growth in the last years, with 16.7 GW net installed between the end of 2014 and the end of 2019 (IRENA 2020a).

Turkey and the Russian Federation[48] have kept increasing their hydro capacity, with 4 GW and 0.5 GW installed in the last five years respectively, whereas Norway installed 1.4 GW. Turkey has been the fastest growing in terms of RES-E installation, with more than 16 GW installed in the last five years. Turkey have increased its solar PV capacity by over 6.2 GW in the last 5 years. Turkey also installed 3.8 GW of wind power in the last 5 years, whereas Norway installed 1.6 GW (IRENA 2020a).

The installed capacity per capita and GDP in the other European (except for the UK) and CIS countries region is relatively low per capita, at 0.5 kW per capita, and around the world average for GDP at 29 per unit of GDP in million constant EUR_{2017} (PPP).

The Middle East had 23 GW of RES-E total renewable installed capacity in 2019, with an annual increase of 14 %, almost 3 GW of capacity. Half of this increase happened in the United Arab Emirates. The Middle East has 0.09 kW of RES-E capacity per capita, one of the lowest in the world comparing the RES-E resource base with the size of the Middle East's economy reveals that it remains a region of weak performance on this parameter: 8.2 kW per unit of GDP in million constant EUR_{2017} (PPP). Furthermore, there are no signs yet that the speed of transforming the energy resource base of the Middle East's economy is picking up.

Africa had 48.4 GW of installed RES-E capacity in 2019, with a year on year increase of 2 GW. More than half of this newly installed capacity was in Egypt. The region had one of the lowest per capita ratio, with 0.04 kW/capita. This can be linked to low levels of electrification in the region, while having a relatively high population growth. Africa has 10.9 kW per unit of GDP in million constant EUR_{2017} (PPP).

4.1.2 Wind and solar photovoltaic capacity deployment

Wind, offshore and onshore, and solar PV, on-grid and off-grid, continue to be the renewable electricity generating technologies with fastest growth. This is due to substantial cost reductions in the last years, and there is still potential for innovation and economies of scale that points towards still an upwards trend. Wind power accounted for 622 GW of installed capacity, while solar PV accounted globally for 578 GW. The net added capacity in 2019 was 98 GW and 59 GW for solar PV and wind respectively, a

(47) Excluding the United States and Brazil, which are explored in earlier parts of this section
(48) IRENA adjusts the figures from the Russian federation for the Crimean peninsula, which are estimated.

growth of 20 % and 11 % respectively. Since 2016, there was more solar PV capacity net installations than wind.

Both onshore and offshore wind, and solar PV capacity have had rapidly falling costs per kWh, calculated in terms of Levelized Cost of Energy (calculated as LCOE). Onshore wind remains the least-cost option for new power generating capacity on average. But these costs depend on local drivers. This falling costs, combined with policy and financial support, have been drivers of the increase of capacity of these technologies (Frankfurt School-UNEP 2020) (for more details in this area see 4.2.3).

Despite a still strong growth and high net-installations, global PV growth is showing signs of deceleration, with 2019 growth being under the 5 years average of 28 % (IRENA 2020a). Leading countries slowed down their growth. Notably China, with 205 GW installed, equivalent of 35 % of the world PVs installations, had a growth of 17 %, when compared to a 49 % annual growth average in the last 5 years. Policy uncertainties were a main driver of this slow down (REN21 2020). Japan, with a 2019 growth of 11 % when compared to a 26 % 5-year average, and the United States, with an 18 % of growth when compared to a 31 % 5-year average.

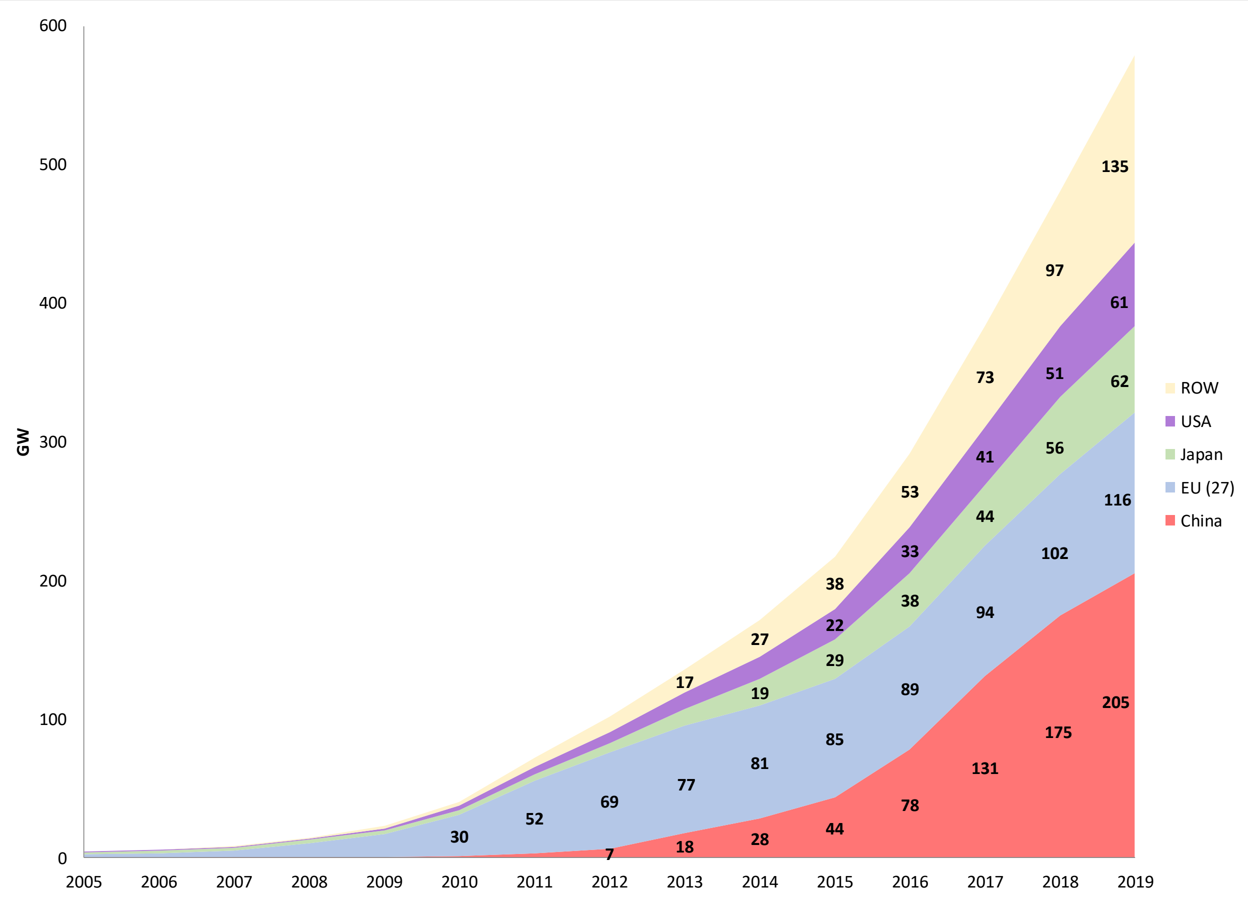
Wind growth picked up in 2019 when compared to 2018, with net additions of 59 GW when compared to 49 GW, or an 11 % growth when compared with a 9% growth respectively. With a 12 % average in the last 5 years, this latest quintenary has been much slower than previous periods, specially the one from 2005 to 2010 (IRENA 2020a). China is the largest country with installed capacity, with 205 GW, 34 % of the worlds installed capacity. Its growth has been slower in 2019 than in the previous 5 years average, with 14 % in 2019 (or 30 GW added) when compared to 17 %. It is nevertheless higher than in 2018, which saw a growth of 12 %. The EU with 116 GW maintains second position, with an added 14 GW from the previous years.

Solar PV and wind accounted for 23 % and 25% of the total installed renewable capacity. However, they represent the majority of the newly installed capacity, with over 55 % and 33 % of the renewables installed in 2019 respectively. In comparison, despite that hydro remains the largest source of renewable installed capacity at 1 187 GW, accounting for 47 % of total installed capacity, it only contributed to 7 % of newly renewable installed capacity in 2019, a total of 12 GW. (IRENA 2020a)

The EU has contributed significantly to the worldwide demonstration and commercialisation of solar PV and wind power (see Figure 36 and Figure 37). Following the implementation of significant policy support instruments, the EU has been one of the clear leaders worldwide since 2005. The growth of solar PV installations in EU has picked up in 2019 with a capacity increase of 14 % year-on-year, from an 8 % in 2018 and a 7 % for the last 5-year average.

The next countries and regions remain far behind China and the EU, with United States and Japan at 62 GW and 61 GW of installed capacity respectively, a growth of 11 % and 18% from the previous years. China, the EU, the United States and Japan together accounted for 77 % of global solar PV capacity in 2019, compared to 79 % in 2018. The rest of the world (ROW) accounted for 136 GW, with a 37 % growth in 2019, with new countries starting to grow quickly. Major contributions of added capacity beyond the 4 largest contributors come from India (7.7 GW), Vietnam (5.6 GW), Australia (4.6 GW), Ukraine (3.9 GW) and South Korea (3.4 GW).

Figure 36 **Growth in total solar PV capacity in the EU, the top three countries and the rest of the world, 2005-2019.**



Notes: The figure shows the maximum net generation capacity installed and connected. ROW: rest of the world.
Source: (IRENA 2020a).

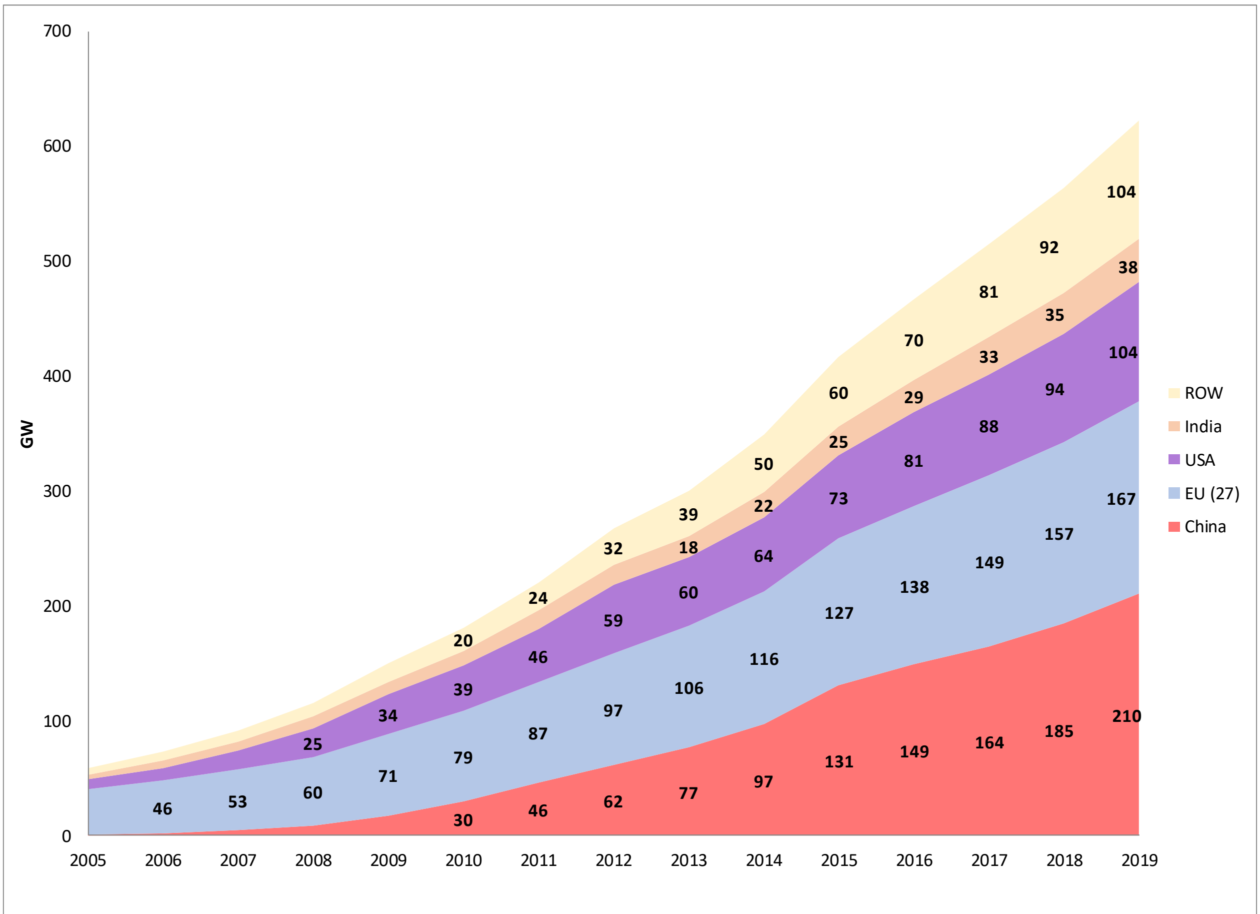
Global wind capacity in 2019 was 622 GW, with 594 GW onshore and 28 GW offshore. Offshore wind saw a growth of 20 % in new capacity installation in 2019, as compared to 25 % in the previous year and a 27% average in the last 5 years. China's offshore market had seen a particularly sharp increase, with a peak growth in 2016 of 165 %. Since then, the growth has slowed down, yet China remains a main contributor of worldwide offshore market in 2019, accounting for around 30 % of the new global capacity.

The EU was the leader in the wind market until 2015, when China took the lead in terms of installed capacity. China had an average growth of 17 % in the last 5 years, and overtaking the EU-27 ([49]). The United States has had a fast growth as well, as have some regions and countries around the world but remain far from EU and China. In 2019, China had 210 GW installed capacity, a growth of 14 % compared to 2018, asserting its position as global leader in this market. With 167 GW installed capacity in 2019, the EU is second in installed wind capacity, followed by the United States (104 GW, 10 % growth compared to 2018) and India (38 GW, 6 % growth compared to 2018) (see Figure 37). The EU, China, the United States and India together accounted for 83 % of the total installed wind power capacity worldwide in 2019. For the rest of the world, the UK lead the installed capacity with 24 GW net installed capacity. In

([49]) Note that the United Kingdom was the third major contributor to EU-28 capacity with 24 GW installed capacity in 2019, just below India in the country classification by installed capacity. This leads to very different results from last years' report.

Latin America, Mexico and Argentina were by large the largest contributors with an added 1.7 GW (+35 % year on year) and 0.9 GW (+115 % year on year). Also Australia, Norway and Ukraine all saw major increases with 1.5 GW (+25 %), 0.7 GW (+43 %) and 0.6 GW (+103 %) respectively. Senegal added for the first time wind capacity, with 50 MW installed.

Figure 37 **Growth in total wind power capacity in the EU, the top three countries and the rest of the world, 2005-2019.**



Notes: The figure shows the maximum net generation capacity installed and connected. ROW: rest of the world.
Source: (IRENA 2020a).

In 2019, electricity generated by wind and solar contributed to an estimated 8.7 % of global electricity production. This share is very heterogeneous across the world. Nine countries produced more than 20% of their electricity from wind and solar in 2019, with Denmark again a clear leader at 60 %. Many countries are making efforts to integrate more variable renewable generation in their systems, notably by expanding or modernising grid infrastructure to achieve higher levels of flexibility, or investing in new transmission lines. (REN21 2020) (see also section 2.3 on flexibility in the grid to integrate more variable renewable generation).

By the end of 2019, Solar PV and Solar CSP produced in 2019 close to 715 TWh and 16 TWh of electricity respectively. Solar PV represented around 2.8 % of annual global electricity generation and 22 % of renewable electricity generation. Solar PV continues to play a significant and growing role in electricity generation in several countries. Despite growth of capacity and decreased curtailment, grid connected solar PV generation accounted for only 3 % of total generation, compared to 2.7 % in 2018, with a total generation of 224 TWh (an increase of 27 % compared to the previous year). This low penetration despite growth in the PV market is due to skyrocketing demand increase in China. In some other countries there is a high penetration of solar PV on the energy mix: it accounted for around 10.7 % of total generation in Honduras and substantial shares also in Italy (8.6 %), Greece (8.3 %), Germany (8.2 %), and Chile (8.1 %) (REN21 2020).

In 2019, wind energy covered an estimated 5.9 % of global generation. Wind energy accounted for an estimated 57 % of Denmark's electricity generation in 2019, with high shares also in Ireland (32 %), Uruguay (29.5 %), and Portugal (26.4 %). In Germany, wind generation accounted for 21.8 % of total electricity generation, with a sharp increase of 12 % and 27 % of onshore and offshore generation respectively. In China, despite a rapid growth of wind capacity and generation (11 %), the also fast-growing electricity consumption meant that wind represented 5.5 % of total generation (up from 5.2 % in 2018).

4.2 Renewable energy investments

In this report we use the Frankfurt School-UNEP 2020 as main data source for investments, as a robust and complete source of data. However, it does not report on investments in large hydro plants as part of the renewable analysis. Yet, as reported in the previous section, the increase in hydro capacity was overall small. Global investment in renewable energy slightly grew in 2019, with EUR 252 billion, 3 % more than the previous year (EUR 244 billion). This is still below the 2015 all-time high of EUR 287 billion (Frankfurt School-UNEP 2020).

For the first time since 2009, capacity investment in wind outpaced capacity investments in solar, with EUR 123.4 billion and EUR 117.1 billion respectively. Wind investments increased year on year by 11%, while solar had a slight decrease of 2 %.

The investments in fossil and nuclear capacity decreased, with EUR 88 billion in 2019 compared to EUR 104 billion in 2018 – consisting of EUR 33 billion for coal plants, EUR 42 billion for gas-fired plants, and EUR 13.4 billion for new nuclear capacity. Investments in wind and solar were more than 3 times the investments in gas and coal-fired power plants.

Despite a decline in investments since 2017, China continues to invest in renewable energy significantly more than any other country: EUR 79 billion in 2019. This is the lowest level since 2015 and 6 % under the investments in 2018. India's investments, which are far lower than those of China, also dropped from EUR 9.7 billion in 2018 to EUR 8.3 billion in 2019. China remains the major lead in investments in renewable energy in developing countries.

Despite the drop in Chinese and Indian investments, the overall investments in renewables in developing countries increased by 5 %, from EUR 129 billion in 2018 to EUR 136 billion in 2019. There was also an increase in investments in developed countries from EUR 108 billion in 2018 to EUR 116 billion in 2019. The last time developed economies invested more than developing countries was back in 2014.

The United States saw a significant increase in investments, reaching a record EUR 49.6 billion in 2019, more than EUR 10 billion more than the previous year. On the other hand, Europe, with EUR 48.4 billion investments, saw a slight decline from 2018's level of EUR 52.7 billion. ([50])

([50]) The Frankfurt School-UNEP 2020 report states that the Covid-19 crisis has slowed down deal-making in renewables in recent months, similar as in other sectors, and predicts that this will affect, negatively, investment levels in 2020. It encourages governments to shape their economic recovery strategies towards more green jobs and investments, and to accelerate the phase-out of non-renewable sources.

4.2.1 Share in global renewable energy investments

Throughout the period 2005-2012, Europe (including CIS) ([51]) dominated global new investments in renewable energy (see Table 17). However, investment activity spread rapidly to new markets, highlighting Europe's pioneering role in developing renewables. In 2013, China outpaced Europe, with a share of 27 % in new investments, the largest proportion worldwide.

In 2018, China and Europe were the regions with most investments worldwide. In 2019, they lost a significant portion of the worldwide investments, with 29.6 % and 19.3 % respectively, compared to 32.3 % and 21.6 %, respectively in 2018. The Americas, including Brazil and the United States, took most of these lost shares, with respectively 4.5 %, 2.3 % and 19.7 %, totalling 26.5 % compared to a total 20.8 %.

Overall, there has been an increasing regional spread for renewable investments in the last year.

Table 17 Share of global new investments (%) in renewable energy per region, 2005-2019.

Region	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
ASOC	12.4	9.0	8.1	7.5	8.1	8.1	8.8	12.1	19.8	18.5	15.9	13.6	12.8	15.7	16.0
China	12.0	9.8	10.6	13.9	21.4	17.0	16.7	22.8	27.2	31.1	38.2	35.7	45.3	32.3	29.6
India	4.4	4.8	3.4	3.1	2.4	3.7	4.8	3.1	2.2	2.7	2.6	4.4	4.2	4.0	3.3
Brazil	3.7	4.5	6.2	6.3	4.4	3.0	3.5	3.2	1.7	2.7	2.0	1.9	1.9	1.2	2.3
Europe (incl. CIS)	45.5	41.6	42.6	44.8	46.3	46.8	44.6	34.8	24.5	24.0	19.3	24.2	13.7	21.6	19.3
USA	16.4	26.0	24.8	19.8	13.4	14.5	17.1	15.9	15.4	13.2	14.8	15.4	14.9	16.1	19.7
Americas	4.5	3.3	3.1	3.2	3.1	5.1	3.3	4.1	5.5	5.2	3.6	2.2	4.1	3.5	4.5
Middle East & Africa	1.1	1.1	1.2	1.3	1.0	1.7	1.1	4.0	3.8	2.8	3.6	2.5	3.1	5.6	5.4

Notes: (1) ASOC refers to Asia and Oceania; CIS refers to the Commonwealth of Independent States; full information about geographical coverage and regional aggregations is provided in the glossary. Dark green indicates the band with the highest shares; red denotes the band with the lowest; yellow denotes the midpoint percentile.
(2) Graded colour scale from red (lowest share) to green (highest share) in one year

Source: (Frankfurt School-UNEP 2020).

4.2.2 Growth in renewable energy investments

Between 2005 and 2007, renewable energy investments saw an increase in most regions. In 2008 and 2009, the economic crisis affected liquidity and slowed down the growth in renewable energy investments. Investment growth recovered quickly in 2010, when most industries were still recovering from or still affected by the crisis. But in 2011 the growth in investments started to slow down again. The period from 2005 to 2011, was dominated by low policy uncertainty but strongly affected by the crisis. Europe was dominating the market from the beginning of the period and had an average annual growth of 23 %. Yet the most significant growth was in China, the United States and India (despite the two latter having negative growth during the economic crisis), with average annual growth of 31 %, 24 % and 25 % respectively.

([51]) CIS refers to the Commonwealth of Independent States. For full details, please see geographical notations in the glossary.

Overall, during the period 2005-2011, global investments showed a growing trend although there were increases and decreases in different countries. Yet, in 2012, for the first time, total investments declined. The following year saw an even sharper decline. In Europe and the United States, where most of the investments were taking place until that year, policy uncertainties and retroactive policy changes took place, shaking investors' confidence. Moreover low natural gas prices, due to the rapidly increasing shale gas extractions in the United States, attracted the interest of investors in the gas supply chain and power plants. India and Brazil also saw a decline in investments. Since during that period they represented a small fraction of the global investments, these reductions have less impact than those of the EU and the United States. In the meantime, investments in ASOC, China, and the Americas (except Brazil and Unites States) grew during that period.

Investments in renewables took a positive turn again in 2014-2015. Since then, investments have been fluctuating significantly between growth and degrowth with multiple factors affecting regional and global investments (Frankfurt School-UNEP 2020).

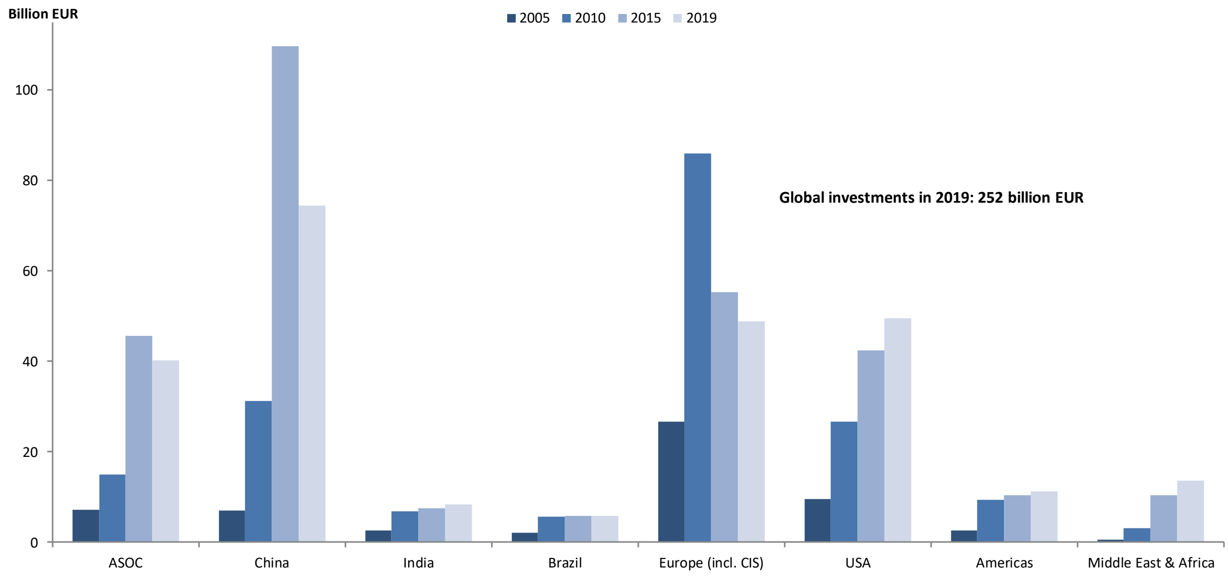
In 2019, the global investments increased by 3%, after a decrease of 15 % in 2018, with levels still below the peaks in 2017 and 2015 (EUR 287.7 billion and EUR 287 billion respectively) ([52]). Despite a significant increase of investments in the United States, and increases in India and Brazil, these were counterbalanced by the decreases of investments in China and Europe.

China, the country with the highest investments in 2019, shrunk its investments by 6 %, reaching its lowest level of investment since 2013. This is driven by cutbacks of the government support in solar PV by limiting access to the feed-in-tariff. This despite the lower costs of this technology. The decline in solar PV was moderated by investments in wind energy, amongst others due to the feed-in-tariff for off-shore wind that finished at the end of 2019 (Frankfurt School-UNEP 2020).

Europe also saw a reduction of 7% in investments. This is due to less capacity in off-shore wind. However, this trend might be reverted as many large investments of off-shore wind projects are on the pipeline for the upcoming years. The United States growth in investments, of 26 %, was mostly driven by investors wanting to take advantage of a tax credit in onshore wind before its ending. Investments in the United States were in 2019 slightly above European investments, for the second time (the first time was in 2017).

([52]) To note that the source data is in USD. Year on year growth in EUR will thus be different than year on year growth in USD depending on the average yearly exchange rate USD/EUR.

Figure 38 Total new investments in renewable energy by region, 2005-2019.



Notes: Figures converted to euros using annual exchange rates from the Eurostat database. ASOC refers to Asia (excluding India and China) and Oceania; CIS refers to the Commonwealth of Independent States; full information about the geographical coverage and regional aggregations is provided in the glossary.

Sources: Investments (Frankfurt School-UNEP 2020); Exchange rates (Eurostat 2020b).

4.2.3 *Total new investments by technology*

New investments in renewable energy in 2019 saw a shift towards more investments in wind power than in solar energy. They respectively accounted for 49 % and 46 % of total investment in renewables. Wind investments increased from EUR 111 billion to EUR 123 billion, a 10 % increase, while solar decreased by 2 % from EUR 119 billion to EUR 117 billion.([53]) Onshore wind saw the largest increase, with 11 % increase from EUR 30 billion to EUR 33.5 billion.

Solar energy (including behind the meter PV) and wind power received strong policy support — to varying extents around the world. They experienced rapid technological learning and decreasing Levelized Cost of Energy (LCOE). Historically, onshore wind has lower LCOE than solar PV. However, LCOE of solar PV has dropped sharply since 2010, with a slower decrease in onshore wind during the same period. Offshore wind also saw a rapid decline of LCOE since 2012. By the end of 2019, LCOEs for solar PV and onshore wind were roughly at the same level, while offshore wind remained higher. (Frankfurt School-UNEP 2020).

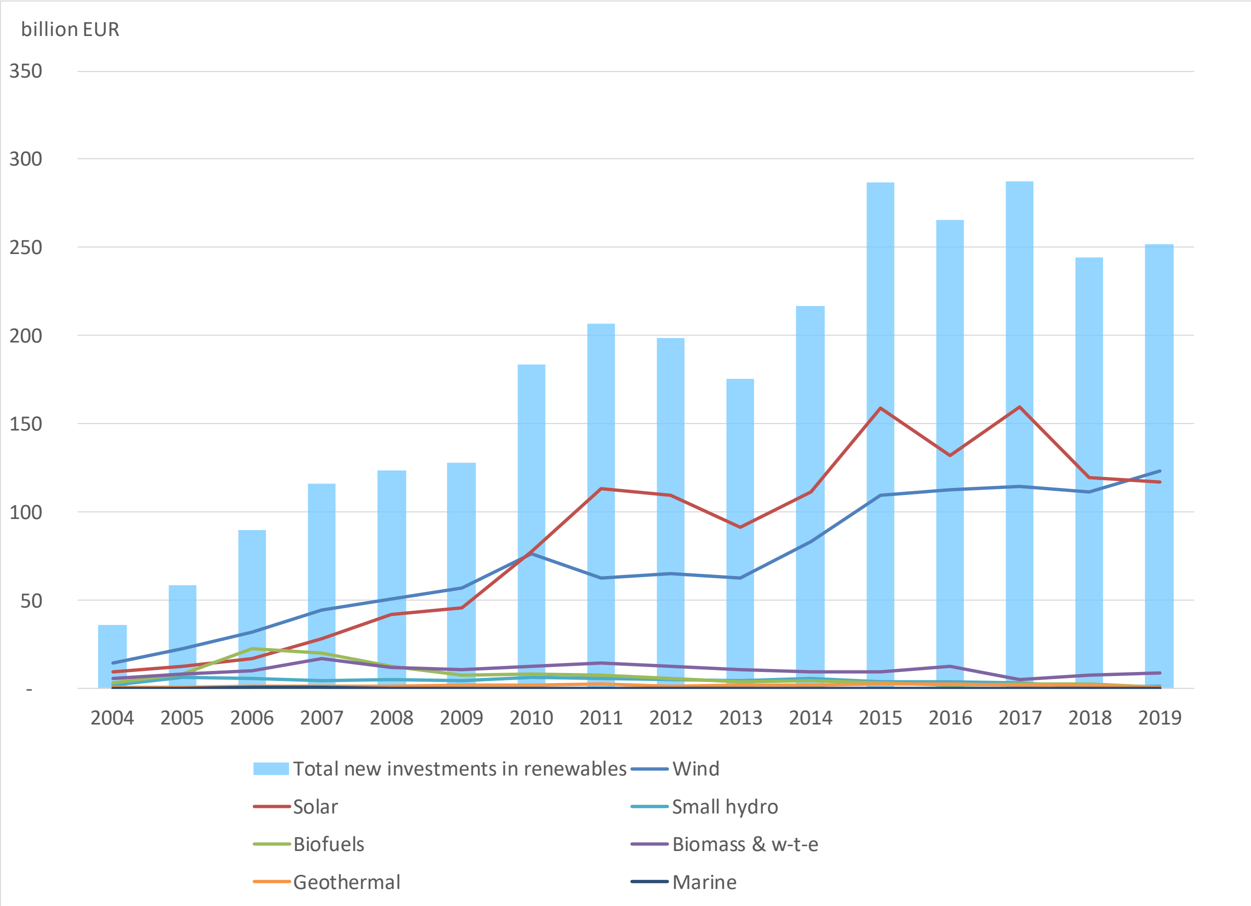
From 2005 to 2009, investments in wind power grew rapidly and made up the largest share of total investments. In 2010, solar energy became slightly above wind investments. Since then, solar has received larger investments than wind, although it also suffered more year on year volatility. Since 2017, solar investments have been declining, while wind saw a sharp increase in 2019.

China cut down its support to solar PV. As the largest country for renewable investments, this has a significant impact at the global scale. This led to an interesting shift in this market. While utility-scale project investments dropped by 19 %, investments in small-scale solar systems, jumped 30 % to EUR 58.3 billion. This is due to sharp decreases in the costs of small installations.

Investment in other renewable technologies, such as biomass, waste-to-energy, small-scale hydropower and geothermal power, remained relatively small over the period 2005-2019. Biofuels experienced a steady growth in new investment from 2005 to 2007, with first-generation biofuels. After 2008, investments in biofuels started to decline with some minor fluctuations. In 2019 the investment was of EUR 0.4 billion, from EUR 2.5 billion in 2018. Geothermal energy also declined, with EUR 0.9 billion investments in 2019, one billion less than in 2018. However, biomass and small hydro saw an increase in investments in 2019, with EUR 1.5 billion, doubling last year’s investment. Investments in biomass and waste plants increased by 10 %, to EUR 8.7 billion. There were no investments in marine technology in 2019.

([53]) Frankfurt School-UNEP publishes their figures in USD. We used Eurostat USD to EUR exchange rates.

Figure 39 **Total global new investment by technology, 2005-2019.**



Source: Frankfurt School-UNEP 2020; Eurostat

4.3 Renewable energy employment

Renewables accounted for an estimated 11.5 million jobs worldwide in 2019, up from 11 million the previous year, or a 4 % increase (IRENA 2020c). Except for hydro, the estimates include direct and indirect jobs, and traditional biomass is not included as a source of renewable energy([54]). Figure 40 shows the countries with larger absolute number of jobs in the sector. Like the previous years, China, the EU and Brazil were the largest employers, accounting together more than half of the global renewable energy workforce. China accounted for 4.4 million jobs (37 %), the EU for 1.15 million jobs (10 %) and Brazil for 1.15 million jobs (10 %) respectively (solid blue bars in Figure 40). Adding the 5 largest employers, that is including India and the United States, shows further concentration with almost three quarters of the global renewable energy jobs. Most of the leading countries being based in Asia, these regions accounted for 63% of total jobs in renewables.

In the EU([55]), it is estimated that there are 1.3 million jobs in renewable energy, with 0.15 million based in the UK. Within the EU, Germany was the larger country, with 309 thousand jobs. The largest employer is the bioenergy sector, with a total of 0.7 million jobs (including UK). Wind followed with 292 thousand jobs, 44 thousand of which in the UK. Germany tops the ranking in Europe, with 309 thousand jobs, but the employment in the sector has been declining since 2011 when it reached the peak of 417 thousand jobs. France was another large employer, with roughly 90 thousand jobs. Other countries like Spain have seen an increase in jobs for renewables, and new European directives lowering barriers for solar PV installations could help further increase the employment in the sector.

Some of the main countries kept establishing themselves as world leaders, China, Brazil and India saw an increase of jobs in 2019, with 7 %, 3 % and 15 % respectively. In the meantime, other large countries lost jobs in the sector in 2019. For example, EU, United States and Japan respectively by 3 %, 13 % and 11 %. The ROW saw an increase of 2 % of jobs, showing a slight redistribution towards traditionally less dominant countries.

Figure 40 also presents renewable jobs in relative terms for the selected countries and the rest of the world, i.e. renewable energy related jobs as the percentage share of the total labour force in the country — the blue-dotted bars in Figure 40. Malaysia and Brazil are the top two countries with respect to renewable energy-related jobs as percentages of the labour force in 2019, with 1.19 % and 1.09 %. They are far ahead to the third ranked, the EU at 0.66 %. At the global level, on average 0.33 % of the labour force is engaged in the renewable energy sector.

Solar PV, with 3.8 million jobs, accounted for 33 % of the world's renewable energy workforce in 2019, while bioenergy is now at 3.5 million jobs, accounting for 31 % of renewables jobs.([56]) China hosted more than half of the PV employment, some 2.2 million jobs.([57]) Bioenergy jobs have been growing fast, with a 9 % growth in 2019 and 13 % in 2018, with the main employment being in biofuels. Solar growth in the last two years have been 7 % and 2 % respectively.

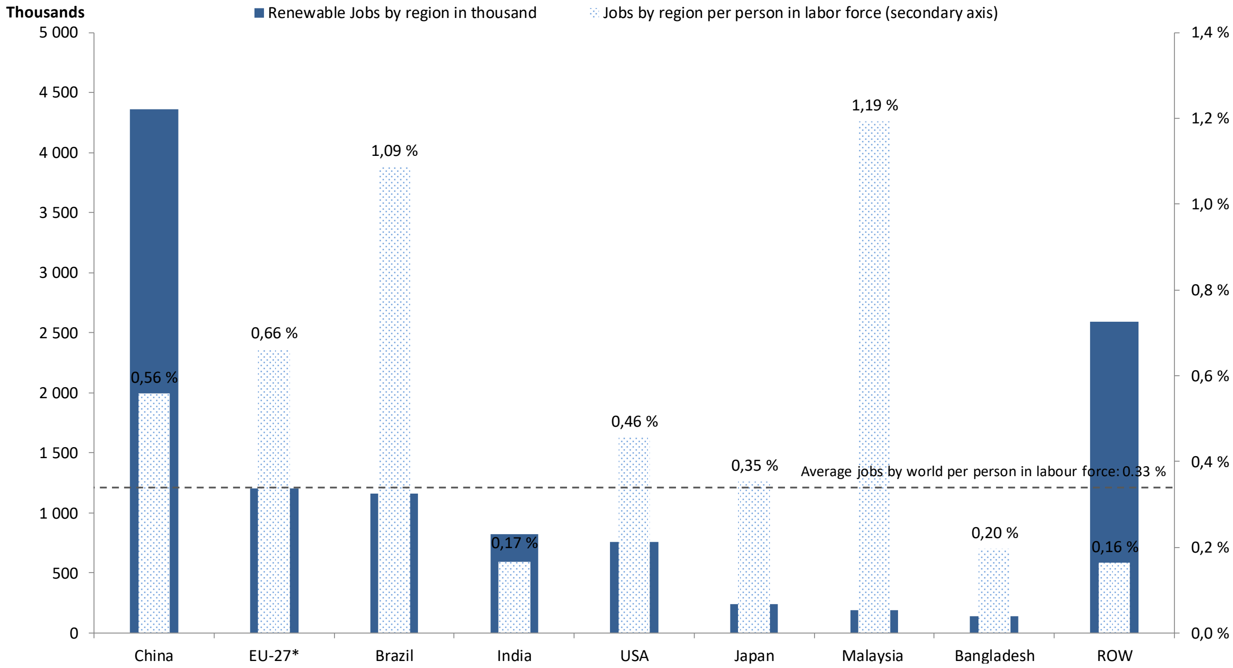
([54]) For more information on the methodology used by IRENA, please consult IRENA's "Renewable Energy and Jobs Annual Review 2020" (IRENA 2020c)

([55]) IRENA reports that the latest available data is for 2019. The figures provided by IRENA are based on EurObserv'ER and some national data. For more information see footnote 19 in the IRENA report (IRENA 2020c).

([56]) The global jobs estimates from IRENA, the indirect jobs from hydro-power are not accounted for, which might overestimate these percentages. Nevertheless, the trend remains when compared to other renewables beyond hydro.

([57]) Figures as presented in (IRENA 2020c) report, based on CNREC (China National Renewable Energy Centre) (2020), Communication with experts, May 2020.

Figure 40 Direct and indirect jobs related to renewable energy in 2019 by region.



Notes: The primary *y*-axis displays absolute numbers (thousands of jobs) in 2019 as estimated by IRENA (IRENA 2020b). The secondary *y*-axis relates the absolute number of jobs to the total labour force of each region, thus displaying jobs in the renewable energy sector as percentages of the total labour force. The jobs displayed include both direct and indirect jobs along the value chain, except for hydro. For more information on the estimates, assumptions and sources for renewable jobs data, consult (IRENA 2020b).

Sources: Absolute jobs (IRENA 2020c); data on labour force (World Bank 2020).

5 Glossary and abbreviations

Abbreviations	Name
CHP	Combined heat and power
CSP	Concentrated solar power
EEA	European Environment Agency
EED	Energy Efficiency Directive (Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC) (see also EU, 2012)
EJ	Exajoule (one quintillion joules)
ENTSO-E	European Network of Transmission System Operators for Electricity
EPBD	Energy Performance of Buildings Directive (Directive 2010/31/EU on the energy performance of buildings) (see also EU, 2010)
ETC/ACM	European Topic Centre for Air Pollution and Climate Change Mitigation. The ETC/ACM is a consortium of European institutes contracted by the EEA to carry out specific tasks in the field of air pollution and climate change.
ETS	Emissions Trading System
EU	European Union
EU-28	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovenia, Slovakia, Spain, Sweden, United Kingdom
EU-27	EU-28 without United Kingdom
Final Non-Energy Consumption	Non-energy use (or consumption) covers those fuels that are used as raw materials in the different sectors and are not consumed as a fuel or transformed into another fuel
Heating degree days	Heating degree day (HDD) index is a weather-based technical index designed to describe the need for the heating energy requirements of buildings.
GDP	Gross domestic product
GFEC	Gross final energy consumption means the energy commodities delivered for energy purposes to industry, transport, households, services — including public services, agriculture, forestry and fisheries — as well as the consumption of electricity and heat by the energy branch for electricity and heat production, and including losses of electricity and heat in distribution and transmission (see Article 2(f) of Directive 2009/28/EC, the Renewable Energy Directive). It excludes transformation losses, which are included in gross inland energy consumption (GIEC). In calculating a Member State's GFEC for the purpose of measuring its compliance with the targets and interim Renewable Energy Directive (RED) and national renewable energy action plan (NREAP) trajectories, the amount of energy consumed in aviation shall, as a proportion of that Member State's GFEC, be considered to be no more than 6.18 % (4.12 % for Cyprus and Malta)
GHG	Greenhouse gas
GIC	Gross Inland Consumption; see GIEC
GIEC	Gross Inland Energy Consumption, sometimes shortened to Gross Inland Consumption, is the total energy demand of a country or region. It represents the quantity of energy necessary to satisfy inland consumption of the geographical entity under consideration
GW	Gigawatt
GWe	Gigawatt electrical (referring to capacity)
IEA	International Energy Agency
ILUC	Indirect land use change, in the context of Directive (EU) 2015/1513 of the European Parliament and of the Council, of 9 September 2015, amending Directive 98/70/EC relating

	to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources (see also EU, 2015)
IRENA	International Renewable Energy Agency
ktoe	Kilotonnes of oil equivalent
kW	Kilowatt electrical (capacity)
LULUCF	Land use, land use change and forestry — a term used in relation to the forestry and agricultural sector in the international climate negotiations under the United Framework Convention on Climate Change (UNFCCC)
Mt	Million tonnes (megatonnes)
Mtoe	Million tonnes of oil equivalent
MW	Megawatt
NREAP	National renewable energy action plan
OECD	Organisation for Economic Co-operation and Development
PEC	Primary energy consumption. In the context of the EED, this represents GIEC minus Final Non-Energy Consumption
PPA	Power Purchase Agreement. A Power Purchase Agreement (PPA) secures the payment stream for a Build-Own Transfer (BOT) or concession project for an independent power plant (IPP). It is between the purchaser "offtaker" (often a state-owned electricity utility) and a privately owned power producer (World Bank)
PPP	Purchasing power parity PPP are the rates of currency conversion that try to equalise the purchasing power of different currencies, by eliminating the differences in price levels between countries. The basket of goods and services priced is a sample of all those that are part of final expenditures: final consumption of households and government, fixed capital formation, and net exports (OECD).
PV	(Solar) photovoltaic (energy)
RED	Renewable Energy Directive (Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC) (see also EU, 2009)
RED II	As part of the Clean Energy for all Europeans initiative (November 2016), the Commission adopted a legislative proposal for a recast of the RED. The European Parliament and the EU Council proposed amendments and a final compromise was agreed among the EU institutions on 14 June 2018. The RED II is expected to be officially adopted by the end of 2018.
Renewable waste	The biodegradable fraction of industrial and municipal waste
RES	Renewable energy sources
RES-E	Renewable electricity
RES-H&C	Renewable heating and cooling
RES-T	Renewable energy consumed in transport
RET	Renewable energy technology
SHARES	Short Assessment of Renewable Energy Sources. A tool developed by Eurostat with the aim of facilitating the calculation of the RES share according to the RED
SPF	Seasonal performance factor
UNFCCC	United Nations Framework Convention on Climate Change

Geographical coverage in Chapter 4

The presentation of the global picture in Chapter 4 follows, as far as possible, the geographic coverage and regional aggregation used by the International Energy Agency (IEA). For investments, the aggregation used by Frankfurt School-UNEP (Frankfurt School-UNEP, 2018) was used, given that a finer corresponding aggregation was not available.

Africa	Includes Algeria; Angola; Benin; Botswana (from 1981); Cameroon; Congo; Côte d'Ivoire; Democratic Republic of the Congo; Egypt; Eritrea; Ethiopia; Gabon; Ghana; Kenya; Libya; Mauritius; Morocco; Mozambique; Namibia (from 1991); Niger (from 2000); Nigeria; Senegal; South Africa; South Sudan; Sudan*; United Republic of Tanzania; Togo; Tunisia; Zambia; Zimbabwe and Other Africa. Other Africa includes Botswana (until 1980); Burkina Faso; Burundi; Cape Verde; Central African Republic; Chad; Comoros; Djibouti; Equatorial Guinea; The Gambia; Guinea; Guinea-Bissau; Lesotho; Liberia; Madagascar; Malawi; Mali; Mauritania; Namibia (until 1990); Niger (until 1999); Réunion; Rwanda; São Tomé and Príncipe; Seychelles; Sierra Leone; Somalia; Swaziland; and Uganda. *South Sudan became an independent country on 9 July 2011. From 2012 onwards, data for South Sudan have been reported separately.
Americas	OECD countries: Canada, Chile, Mexico and the United States. Non-OECD: Argentina; Plurinational State of Bolivia; Brazil; Colombia; Costa Rica; Cuba; Curaçao*; Dominican Republic; Ecuador; El Salvador; Guatemala; Haiti; Honduras; Jamaica; Nicaragua; Panama; Paraguay; Peru; Trinidad and Tobago; Uruguay; Bolivarian Rep. of Venezuela Other Non-OECD Americas: Antigua and Barbuda; Aruba; Bahamas; Barbados; Belize; Bermuda; British Virgin Islands; Cayman Islands; Dominica; Falkland Islands (Malvinas); French Guiana; Grenada; Guadeloupe; Guyana; Martinique; Montserrat; Puerto Rico (for natural gas and electricity); St. Kitts and Nevis; Saint Lucia; Saint Pierre et Miquelon; St. Vincent and the Grenadines; Suriname; Turks and Caicos Islands; Bonaire (from 2012); Saba (from 2012); Saint Eustratius (from 2012); and Sint Maarten (from 2012).
ASOC	OECD countries: Australia, Israel, Japan, Korea and New Zealand Non-OECD countries: Bangladesh; Brunei Darussalam; Cambodia (from 1995); India; Indonesia; DPR of Korea; Malaysia; Mongolia (from 1985); Myanmar; Nepal; Pakistan; Philippines; Singapore; Sri Lanka; Chinese Taipei; Thailand; Viet Nam and Other Asia. Other Asia includes Afghanistan; Bhutan; Cambodia (until 1994); Cook Islands; Fiji; French Polynesia; Kiribati; Lao People's Democratic Republic; Macau, China; Maldives; Mongolia (until 1984); New Caledonia; Palau (from 1994); Papua New Guinea; Samoa; Solomon Islands; Timor-Leste; Tonga and Vanuatu.
Other Europe and CIS (Commonwealth of Independent States) (OE-CIS)	Albania, Andorra, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Channel Islands, Georgia, Iceland, Isle of Man, Kazakhstan, Kosovo, Kyrgyz Republic, Liechtenstein, Macedonia, FYR, Moldova, Monaco, Montenegro, Norway, Russian Federation, San Marino, Serbia, Switzerland, Tajikistan, Turkey, Turkmenistan, Ukraine, Uzbekistan.
Middle East	Bahrain; Islamic Republic of Iran; Iraq; Jordan; Israel; West Bank Gaza; Kuwait; Lebanon; Oman; Qatar; Saudi Arabia; Syrian Arab Republic; United Arab Emirates and Yemen.

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Annex 1 Effects of renewable energy on GHG emissions and energy consumption

The table below summarises the effect of deploying renewable energy since 2005 on GHG emissions and energy consumption by country in 2018, as discussed in Sections 3.1-3.3 of this report.

Country	GHG emissions (incl. international aviation)	Effect of renewables		Gross inland consumption of fossil fuels	Effect of renewables		Primary energy consumption	Effect of renewables	
	$MtCO_2e$	$MtCO_2$	%	Mtoe	Mtoe	%	Mtoe	Mtoe	%
Austria	81,5	-11,7	-13	22,6	-4,1	-17	31,8	-0,7	-2
Belgium	123,6	-10,3	-8	40,9	-4,0	-11	46,8	-0,5	-1
Bulgaria	58,6	-8,0	-12	12,8	-2,2	-15	18,3	-0,6	-3
Croatia	24,4	-2,3	-8	6,0	-0,6	-9	8,2	-0,3	-3
Cyprus	9,9	-0,7	-7	2,4	-0,2	-9	2,5	-0,1	-3
Czech Republic	129,4	-10,8	-8	32,4	-3,2	-10	40,4	-0,3	-1
Denmark	51,3	-18,6	-27	11,5	-6,2	-35	17,8	-2,3	-11
Estonia	20,2	-1,9	-9	0,6	-0,6	-56	6,2	0,1	1
Germany	888,7	-158,1	-15	251,8	-42,6	-16	291,7	-15,1	-5
Greece	96,1	-8,3	-8	20,1	-2,6	-12	22,6	-1,5	-6
Finland	58,8	-16,9	-22	13,7	-4,9	-28	32,7	-0,4	-1
France	462,8	-40,9	-8	122,7	-14,2	-11	238,9	-4,4	-2
Hungary	64,1	-4,1	-6	18,5	-1,4	-8	24,5	0,0	0
Ireland	64,2	-5,1	-7	12,6	-1,7	-12	14,5	-0,6	-4
Italy	439,3	-47,8	-10	122,8	-16,6	-13	147,2	-3,6	-2
Latvia	12,2	-1,6	-12	2,8	-0,3	-11	4,7	0,3	6
Lithuania	20,6	-2,7	-11	5,0	-0,5	-12	6,3	0,3	5
Luxembourg	12,4	-1,0	-7	3,6	-0,3	-8	4,5	-0,1	-1
Malta	2,7	-0,2	-6	0,7	-0,1	-7	0,8	0,0	-3
Netherlands	200,5	-10,5	-5	70,8	-3,6	-6	64,7	-0,9	-1
Poland	415,9	-25,2	-6	96,2	-6,7	-7	101,1	-1,1	-1
Portugal	71,6	-8,9	-11	17,9	-2,8	-14	22,7	-1,9	-7
Romania	116,5	-10,0	-8	24,7	-2,8	-11	32,6	-1,3	-4
Slovakia	43,5	-2,3	-5	11,2	-0,9	-8	15,8	0,1	1
Slovenia	17,6	-1,3	-7	4,3	-0,4	-9	6,7	0,0	0
Spain	352,2	-41,5	-11	96,1	-12,9	-12	124,6	-4,8	-4
Sweden	54,6	-27,1	-33	14,1	-8,5	-42	47,0	-3,0	-6
EU-27	3893,2	-477,9	-11	1038,9	-144,7	-13	1375,7	-42,5	-3

Notes: This table shows the estimated effect of the increase in renewable energy consumption since 2005 on GHG emissions (total emissions, including international aviation and excluding LULUCF), gross inland consumption of fossil fuels and primary energy consumption.

Source: EEA; (Eurostat 2020a); (Eurostat 2020e).

Annex 2 Effects of renewable energy on air pollutant emissions

The table below summarises the absolute effect (in kt) of deploying renewable energy since 2005 on air pollutant emissions and the national total emission (in kt) by pollutant and by country in 2018, as discussed in Section 3.4 of this report.

	NO_x				PM_{10}				$PM_{2.5}$				SO_2				VOCs			
	RES All	**RES-E**	**RES H&C**	**Total**	**RES All**	**RES-E**	**RES H&C**	**Total**	**RES All**	**RES-E**	**RES H&C**	**Total**	**RES All**	**RES-E**	**RES H&C**	**Total**	**RES All**	**RES-E**	**RES H&C**	**Total**
AT	-1,4	-0,8	-0,5	151	2,5	0,1	2,4	26	2,5	0,1	2,4	14	-1,1	-0,6	-0,6	12	10,0	0,3	9,7	107
BE	-1,4	-1,8	0,4	169	13,7	0,1	13,6	32	13,2	0,1	13,1	22	-0,2	0,0	-0,2	38	18,5	-0,3	18,8	116
BG	-0,5	-0,4	-0,1	97	2,2	-0,1	2,2	48	2,3	-0,1	2,4	30	-13,8	-2,6	-11,2	89	6,8	0,2	6,6	73
CY	-0,3	-0,1	-0,2	15	0,2	0,0	0,3	2	0,2	0,0	0,2	1	-0,4	-0,2	-0,2	17	0,6	0,1	0,5	10
CZ	0,9	-0,6	1,5	162	2,2	0,0	2,2	51	2,3	0,0	2,3	39	-6,8	-2,4	-4,4	97	9,0	2,7	6,3	231
DE	-12,3	-22,8	10,5	1 202	4,4	-1,0	5,4	211	4,4	-0,9	5,3	97	-26,3	-22,0	-4,3	289	13,7	0,2	13,5	1 140
DK	0,6	-1,4	2,1	106	14,1	-0,1	14,1	29	13,7	0,0	13,8	16	0,5	-0,2	0,6	11	13,9	-0,1	14,0	120
EE	-0,2	-0,2	0,0	32	5,1	-0,2	5,3	11	5,0	-0,1	5,1	7	-1,2	-1,0	-0,2	31	7,7	0,0	7,6	22
EL	-6,0	-5,6	-0,4	255	-1,3	-0,5	-0,8	57	-1,2	-0,3	-0,8	33	-4,7	-5,1	0,4	65	-1,8	-0,1	-1,7	150
ES	-9,4	-8,7	-0,8	698	2,7	-0,1	2,9	198	2,8	-0,1	2,9	125	-11,5	-9,3	-2,2	197	5,4	-0,2	5,5	624
FI	1,5	-1,8	3,2	127	10,9	-0,1	11,0	31	10,7	0,0	10,7	18	-7,3	-1,8	-5,4	33	18,6	0,3	18,2	85
FR	-11,0	-6,3	-4,7	749	6,6	-0,1	6,6	216	6,5	0,0	6,5	134	-2,4	-3,6	1,2	136	12,7	1,8	10,9	595
HR	-0,6	-0,5	-0,1	51	-0,8	0,0	-0,8	38	-0,8	0,0	-0,7	29	-0,5	-0,6	0,1	10	-1,3	0,1	-1,3	72
HU	0,7	-0,2	1,0	120	8,7	0,0	8,7	62	8,4	0,0	8,4	42	-1,4	-0,2	-1,2	23	16,1	0,0	16,0	125
IE	-2,0	-2,0	0,0	110	-0,1	-0,2	0,1	28	0,0	-0,1	0,1	12	-2,1	-1,5	-0,6	12	0,9	0,0	0,9	110
IT	11,5	4,3	7,2	669	30,3	0,0	30,3	177	29,4	0,1	29,3	143	1,9	-2,0	4,0	110	57,1	5,4	51,7	913
LT	0,4	-0,1	0,5	58	3,3	0,0	3,3	11	3,3	0,0	3,3	6	-6,7	0,1	-6,8	13	6,5	0,2	6,3	43
LU	0,0	0,0	0,0	20	0,3	0,0	0,3	2	0,3	0,0	0,3	1	0,1	0,0	0,1	1	0,7	0,1	0,6	10
LV	0,6	0,1	0,5	34	4,1	0,0	4,1	28	4,0	0,0	4,0	20	-0,2	0,0	-0,2	4	4,5	0,4	4,1	40
MT	-0,1	-0,1	0,0	6	0,0	0,0	0,0	1	0,0	0,0	0,0	0	0,0	-0,1	0,0	0	0,0	0,0	0,0	3
NL	-0,5	-1,4	0,9	244	2,2	0,0	2,2	23	2,1	0,0	2,1	12	1,0	-0,4	1,3	25	4,9	0,6	4,3	240
PL	-2,7	-3,6	0,9	762	4,0	-0,1	4,2	243	4,2	-0,1	4,3	137	-34,5	-6,2	-28,2	502	34,6	1,0	33,6	733
PT	-5,7	-2,7	-3,0	155	-6,6	0,0	-6,6	71	-6,4	0,0	-6,4	51	-1,3	-0,7	-0,6	45	-10,9	0,2	-11,1	155
RO	-1,9	-2,2	0,4	225	2,7	-0,3	3,0	146	2,6	-0,3	2,9	111	-6,3	-6,2	-0,1	82	3,7	-0,1	3,7	237
SE	-4,3	-2,7	-1,6	126	4,4	0,1	4,2	38	4,3	0,1	4,2	18	-4,3	-1,9	-2,4	17	7,8	-0,1	7,9	134
SI	-0,2	-0,2	0,0	34	1,8	0,0	1,8	13	1,8	0,0	1,8	11	-0,1	-0,1	0,0	5	2,6	0,1	2,5	32
SK	0,5	0,1	0,4	67	4,4	0,0	4,4	20	4,3	0,0	4,3	15	0,3	-0,2	0,5	20	4,6	0,6	4,0	86
EU-27	**-43,7**	**-61,6**	**18,0**	**6 444**	**121,8**	**-2,4**	**124,2**	**1 812**	**119,9**	**-1,8**	**121,7**	**1 147**	**-129,3**	**-69,0**	**-60,3**	**1 884**	**246,8**	**13,4**	**233,4**	**6 208**

Source: ETC/CME, (IIASA 2017), (Eurostat 2020a), (Eurostat 2020e).

The table below summarises the relative effect of deploying renewable energy since 2005 on total air pollutant emissions frozen at 2005 level (%) and the national total emissions (in kt) by pollutant and by country in 2018, as discussed in Section 3.4 of this report.

	NO_x				PM_{10}				$PM_{2.5}$				SO_2				VOCs			
	RES All	**RES-E**	**RES H&C**	**Total**	**RES All**	**RES-E**	**RES H&C**	**Total**	**RES All**	**RES-E**	**RES H&C**	**Total**	**RES All**	**RES-E**	**RES H&C**	**Total**	**RES All**	**RES-E**	**RES H&C**	**Total**
AT	-0,90%	-0,55%	-0,36%	151	10,38%	0,31%	10,01%	26	20,78%	0,59%	19,93%	14	-8,68%	-4,58%	-4,50%	12	10,26%	0,26%	9,94%	107
BE	-0,80%	-1,04%	0,24%	169	72,57%	0,25%	71,81%	32	146,65%	0,36%	144,49%	22	-0,56%	-0,01%	-0,55%	38	18,95%	-0,24%	19,30%	116
BG	-0,51%	-0,44%	-0,07%	97	4,74%	-0,17%	4,93%	48	8,31%	-0,24%	8,60%	30	-13,47%	-2,89%	-11,18%	89	10,26%	0,28%	9,92%	73
CY	-2,01%	-0,61%	-1,42%	15	12,18%	-0,11%	12,32%	2	22,01%	-0,12%	22,20%	1	-2,48%	-1,26%	-1,26%	17	6,18%	0,64%	5,47%	10
CZ	0,55%	-0,38%	0,93%	162	4,55%	-0,07%	4,62%	51	6,10%	-0,07%	6,19%	39	-6,57%	-2,47%	-4,31%	97	4,06%	1,19%	2,80%	231
DE	-1,02%	-1,86%	0,88%	1 202	2,14%	-0,46%	2,62%	211	4,80%	-0,90%	5,80%	97	-8,33%	-7,07%	-1,46%	289	1,22%	0,02%	1,20%	1 140
DK	0,60%	-1,32%	1,98%	106	97,16%	-0,18%	97,88%	29	515,30%	-0,24%	524,61%	16	4,60%	-1,54%	6,35%	11	13,13%	-0,05%	13,20%	120
EE	-0,51%	-0,47%	-0,04%	32	83,08%	-1,43%	88,08%	11	278,68%	-1,54%	302,57%	7	-3,88%	-3,26%	-0,66%	31	52,09%	0,19%	51,67%	22
EL	-2,29%	-2,16%	-0,14%	255	-2,22%	-0,79%	-1,46%	57	-3,42%	-0,99%	-2,48%	33	-6,78%	-7,35%	0,66%	65	-1,19%	-0,08%	-1,10%	150
ES	-1,33%	-1,22%	-0,11%	698	1,39%	-0,06%	1,46%	198	2,26%	-0,08%	2,35%	125	-5,52%	-4,53%	-1,10%	197	0,87%	-0,03%	0,89%	624
FI	1,18%	-1,38%	2,63%	127	53,89%	-0,21%	54,39%	31	151,48%	-0,11%	152,20%	18	-17,99%	-5,25%	-14,09%	33	27,84%	0,39%	27,21%	85
FR	-1,45%	-0,83%	-0,63%	749	3,15%	-0,03%	3,18%	216	5,04%	-0,03%	5,08%	134	-1,71%	-2,59%	0,92%	136	2,18%	0,30%	1,87%	595
HR	-1,17%	-0,97%	-0,21%	51	-2,09%	-0,12%	-1,98%	38	-2,58%	-0,08%	-2,51%	29	-4,56%	-5,15%	0,66%	10	-1,73%	0,09%	-1,82%	72
HU	0,60%	-0,20%	0,81%	120	16,20%	-0,03%	16,24%	62	25,35%	-0,03%	25,39%	42	-5,77%	-1,01%	-4,85%	23	14,69%	0,04%	14,64%	125
IE	-1,76%	-1,76%	0,00%	110	-0,42%	-0,71%	0,29%	28	-0,40%	-1,08%	0,69%	12	-14,83%	-11,06%	-4,74%	12	0,78%	-0,01%	0,79%	110
IT	1,75%	0,65%	1,09%	669	20,56%	0,00%	20,56%	177	25,80%	0,08%	25,68%	143	1,79%	-1,81%	3,74%	110	6,67%	0,60%	6,00%	913
LT	0,75%	-0,14%	0,89%	58	40,42%	0,10%	40,23%	11	133,57%	0,18%	132,59%	6	-34,40%	0,68%	-34,69%	13	18,01%	0,37%	17,50%	43
LU	0,11%	-0,09%	0,21%	20	19,36%	0,09%	19,23%	2	28,30%	0,12%	28,11%	1	14,17%	0,98%	12,93%	1	7,10%	0,56%	6,47%	10
LV	1,85%	0,40%	1,44%	34	17,28%	0,05%	17,20%	28	24,53%	0,07%	24,41%	20	-3,90%	0,80%	-4,63%	4	12,69%	1,01%	11,44%	40
MT	-1,91%	-1,58%	-0,34%	6	0,40%	-0,31%	0,72%	1	0,95%	-0,35%	1,30%	0	-18,84%	-25,23%	11,77%	0	0,71%	0,27%	0,44%	3
NL	-0,22%	-0,57%	0,35%	244	10,49%	-0,08%	10,58%	23	20,35%	-0,12%	20,53%	12	4,17%	-1,41%	5,74%	25	2,09%	0,25%	1,83%	240
PL	-0,35%	-0,48%	0,12%	762	1,69%	-0,05%	1,74%	243	3,16%	-0,07%	3,24%	137	-6,43%	-1,23%	-5,33%	502	4,96%	0,14%	4,81%	733
PT	-3,56%	-1,72%	-1,91%	155	-8,55%	-0,02%	-8,53%	71	-11,13%	-0,02%	-11,12%	51	-2,84%	-1,57%	-1,31%	45	-6,58%	0,10%	-6,67%	155
RO	-0,82%	-0,98%	0,16%	225	1,85%	-0,23%	2,09%	146	2,40%	-0,27%	2,69%	111	-7,10%	-7,04%	-0,07%	82	1,56%	-0,04%	1,60%	237
SE	-3,29%	-2,09%	-1,25%	126	13,08%	0,36%	12,62%	38	30,20%	0,71%	29,02%	18	-19,81%	-9,86%	-12,10%	17	6,23%	-0,05%	6,29%	134
SI	-0,50%	-0,47%	-0,03%	34	15,77%	-0,12%	15,93%	13	19,49%	-0,13%	19,68%	11	-2,73%	-2,92%	0,21%	5	8,68%	0,29%	8,34%	32
SK	0,79%	0,19%	0,60%	67	29,08%	0,00%	29,08%	20	39,93%	0,01%	39,92%	15	1,55%	-0,74%	2,33%	20	5,66%	0,73%	4,86%	86
EU-27	**-0,67%**	**-0,95%**	**0,28%**	**6 444**	**7,20%**	**-0,13%**	**7,36%**	**1 812**	**11,68%**	**-0,16%**	**11,87%**	**1 147**	**-6,43%**	**-3,53%**	**-3,10%**	**1 884**	**4,14%**	**0,22%**	**3,91%**	**6 208**

Source: ETC/CME, (IIASA 2017), (Eurostat 2020a), (Eurostat 2020e).

Annex 3 Methodology and data sources for calculating approximated RES shares

The general methodology to calculate the approximated RES shares is laid out in the EEA report *Renewable energy in Europe — Approximated recent growth and knock-on effects* (EEA 2015). The data have been updated to reflect the most up-to-date values available at the end of July 2020, when no officially reported RES data for 2019 were available.

Some improvements in the methodology were made for the estimation of 2016 RES shares:

- The calculation is made in Eurostat's Short Assessment of Renewable Energy Sources (SHARES) tool. This improves consistency with the methodology laid out in the RED and RES shares data published by Eurostat.

An exponential trend extrapolation, instead of a linear extrapolation, is used as the standard fall-back option. Variables, data sources and methods used in the RES proxy calculation:

Electricity sector

- Hydro; Trend change on Eurostat Supply, transformation and consumption of electricity (nrg_cb_e), Eurostat.
- Mixed hydro without pumping; Trend change on Hydro provisional, Eurostat. Discontinued in Eurostat Early estimate and not in nrg_cb_e.
- Wind; Trend change on Eurostat Supply, transformation and consumption of electricity (nrg_cb_e), Eurostat.
- Offshore wind capacity; Trend change on WindEurope.
- Photovoltaic; Trend change on Eurostat Supply, transformation and consumption of electricity (nrg_cb_e), Eurostat.
- Photovoltaic capacity; Trend change on photovoltaic cumulative capacity installed from EurobservER Photovoltaic Barometer.
- Solid biofuels; Trend change on Eurostat Supply, transformation and consumption of electricity (nrg_cb_e), Eurostat.
- Other renewable; Trend change on Eurostat Supply, transformation and consumption of electricity (nrg_cb_e), Eurostat.
- Other liquid biofuels; Trend change on Eurostat Supply, transformation and consumption of electricity (nrg_cb_e), Eurostat.
- Transmission and distribution losses; Trend change on Eurostat Supply, transformation and consumption of electricity (nrg_cb_e), Eurostat.
- Imports; Trend change on Eurostat Supply, transformation and consumption of electricity (nrg_cb_e), Eurostat.
- Exports; Trend change on Eurostat Supply, transformation and consumption of electricity (nrg_cb_e), Eurostat.
- Gross electricity consumption; Trend change on Eurostat Supply, transformation and consumption of electricity (nrg_cb_e), Eurostat.
- Electricity production from Natural Gas; Trend change on Eurostat Supply, transformation and consumption of electricity (nrg_cb_e), Eurostat.

Transport sector

- Electricity in road transport; Exponential trend extrapolation if $R^2 \geq 0.8$ else previous year values
- Electricity in other transport; Exponential trend extrapolation if $R^2 \geq 0.8$ else previous year values

- Biogases; Trend change on Supply, transformation and consumption of renewables and wastes (nrg_cb_rw), Eurostat.
- Natural Gas on road; Exponential trend extrapolation if $R^2 \geq 0.8$ else previous year values.
- Bio gasoline; Trend change on Supply, transformation and consumption of oil and petroleum products (nrg_cb_oil), Eurostat.
- Biodiesel; Trend change on Supply, transformation and consumption of oil and petroleum products (nrg_cb_oil), Eurostat.
- Other liquid biofuels; Exponential trend extrapolation if $R^2 \geq 0.8$ else previous year values.
- Share of compliant biofuels; Share derived from RES SHARES 2018 data i.e. previous year share applied.
- Fossils in transport (RES Oil); Trend change on FEC transport fossils from ENEF proxy.
- Biofuels from waste; Exponential trend extrapolation if $R^2 \geq 0.8$ else previous year values.

Heating and cooling sector

- Geothermal energy; Trend change on Supply, transformation and consumption of derived heat (nrg_cb_h), Eurostat.
- Solar thermal; Trend change on Supply, transformation and consumption of derived heat (nrg_cb_h), Eurostat.
- Municipal Waste – Renewable; Trend change on Supply, transformation and consumption of derived heat (nrg_cb_h), Eurostat.
- Solid biofuels; Trend change on Supply, transformation and consumption of derived heat (nrg_cb_h), Eurostat.
- Biogases; Trend change on Supply, transformation and consumption of derived heat (nrg_cb_h), Eurostat.
- Biodiesels; Trend change on Supply, transformation and consumption of derived heat (nrg_cb_h), Eurostat.
- Other liquid biofuels; Trend change on Supply, transformation and consumption of derived heat (nrg_cb_h), Eurostat.
- Transmission and distribution losses; Trend change on Supply, transformation and consumption of derived heat (nrg_cb_h), Eurostat.
  RES OIL, COAL and GAS

Industry sector; Trend change on FEC Industry from ENEF proxy.

- Other sector; Trend change on FEC Industry from ENEF proxy.
- RES REN
- RES REN sectors; Exponential trend extrapolation if $R^2 \geq 0.8$ else previous year values
- Charcoal; Exponential trend extrapolation if $R^2 \geq 0.8$ else previous year values
- Solid biofuels excluding charcoal; Exponential trend extrapolation if $R^2 \geq 0.8$ else previous year values
- Otherwise in RES REN; Trend change on Supply, transformation and consumption of renewables and wastes (nrg_cb_rw), Eurostat.

Member State data (not included by default, but received during Eionet consultation):

- Belgium submitted detailed and complete RES shares data for 2019, which replaced the EEA's proxy calculations.
- Ireland submitted detailed and complete RES shares data for 2019, which replaced the EEA's proxy calculation.
- Germany submitted RES SUMMARY results, which were distributed into the detailed RES SHARES improving the EEA's proxy calculation. Data was applied as drivers.
- Lithuania submitted basic energy consumption data, which improved the EEA's proxy calculation. Data was applied as drivers.

- Portugal submitted basic energy consumption data, which improved the EEA's proxy calculation. Data was applied as drivers.
- Latvia provided a corrected value, which replaced the EEA's proxy value.

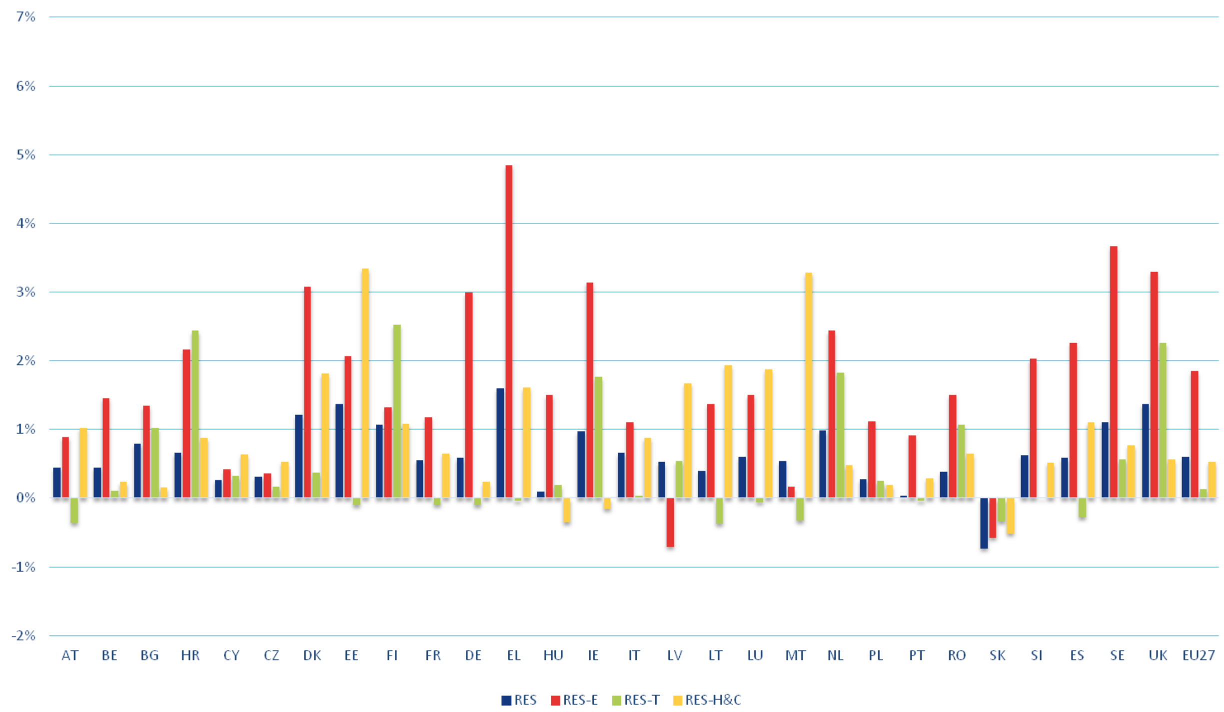
Annex 4 Discussion of main 2018/2019 changes by sector and country

Changes in calculated RES shares proxies for the years 2018/2019 are compared with historically (2005-2018) observed changes in RES shares by way of descriptive statistics to determine statistically significant deviations from the historical changes.

If, in 2018/2019, changes in RES shares were significantly different but within the historically observed minima and maxima, the results were considered plausible without further analysis. If the 2018/2019 changes in RES shares were higher or lower than historically observed changes, further in-depth analysis was performed. The reasons for these strong decreases or increases were found and are described below.

Figure 41 shows the changes between approximated 2019 RES shares and 2018 RES shares, while Table 18 provides detailed insights.

Figure 41 Changes in approximated RES shares in 2019 compared with 2018 in percentage points



Source: EEA.

Table 18 Shares of renewable energy (%) in 2018 and 2019.

	RES			RES-E			RES-T			RES-H&C		
	2017	2018	Change	2017	2018	Change	2017	2018	Delta	2017	2018	Change
Austria	33.4	33.9	0.4	73.1	73.9	0.9	9.8	9.4	-0.4	34.0	35.0	1.0
Belgium	9.4	9.9	0.5	18.9	20.4	1.5	6.6	6.8	0.1	8.2	8.4	0.2
Bulgaria	20.5	21.3	0.8	22.1	23.5	1.3	8.1	9.1	1.0	33.3	33.5	0.2
Croatia	28.0	28.7	0.7	48.1	50.3	2.2	3.9	6.3	2.4	36.5	37.4	0.9
Cyprus	13.9	14.2	0.3	9.4	9.8	0.4	2.7	3.0	0.3	36.8	37.4	0.6
Czech Republic	15.1	15.5	0.3	13.7	14.1	0.4	6.5	6.7	0.2	20.6	21.2	0.5
Denmark	35.7	36.9	1.2	62.4	65.5	3.1	6.6	6.9	0.4	46.7	48.5	1.8
Estonia	30.0	31.4	1.4	19.7	21.8	2.1	3.3	3.2	-0.1	53.7	57.0	3.3
Finland	41.2	42.2	1.1	36.8	38.1	1.3	14.9	17.4	2.5	54.6	55.7	1.1
France	16.6	17.2	0.6	21.2	22.4	1.2	9.0	9.0	-0.1	21.8	22.4	0.7
Germany	16.5	17.1	0.6	38.0	41.0	3.0	7.9	7.8	-0.1	13.6	13.9	0.2
Greece	18.0	19.6	1.6	26.0	30.9	4.9	3.8	3.8	0.0	30.2	31.8	1.6
Hungary	12.5	12.6	0.1	8.3	9.8	1.5	7.7	7.9	0.2	18.1	17.8	-0.4
Ireland	11.1	12.0	1.0	33.2	36.4	3.1	7.2	8.9	1.8	6.5	6.3	-0.2
Italy	17.8	18.4	0.7	33.9	35.0	1.1	7.7	7.7	0.0	19.2	20.1	0.9
Latvia	40.3	40.8	0.5	53.5	52.8	-0.7	4.7	5.3	0.5	55.9	57.6	1.7
Lithuania	24.4	24.8	0.4	18.4	19.8	1.4	4.3	4.0	-0.4	45.6	47.6	1.9
Luxembourg	9.1	9.7	0.6	9.1	10.6	1.5	6.5	6.5	-0.1	8.8	10.7	1.9
Malta	8.0	8.5	0.5	7.7	7.9	0.2	8.0	7.6	-0.3	23.4	26.7	3.3
Netherlands	7.4	8.4	1.0	15.1	17.6	2.4	9.6	11.4	1.8	6.1	6.6	0.5
Poland	11.3	11.6	0.3	13.0	14.1	1.1	5.6	5.9	0.2	14.8	15.0	0.2
Portugal	30.3	30.4	0.0	52.2	53.1	0.9	9.0	9.0	0.0	41.2	41.5	0.3
Romania	23.9	24.3	0.4	41.8	43.3	1.5	6.3	7.4	1.1	25.4	26.1	0.6
Slovakia	11.9	11.2	-0.7	21.5	20.9	-0.6	7.0	6.6	-0.3	10.6	10.1	-0.5
Slovenia	21.1	21.8	0.6	32.3	34.4	2.0	5.5	5.5	0.0	31.6	32.1	0.5
Spain	17.5	18.0	0.6	35.2	37.4	2.3	6.9	6.7	-0.3	17.5	18.6	1.1
Sweden	54.6	55.8	1.1	66.2	69.9	3.7	29.7	30.3	0.6	65.4	66.2	0.8
United Kingdom	11.0	12.4	1.4	30.9	34.2	3.3	6.5	8.7	2.3	7.5	8.1	0.6
European Union	18.9	19.5	0.6	32.2	34.1	1.9	8.3	8.4	0.1	21.1	21.7	0.5

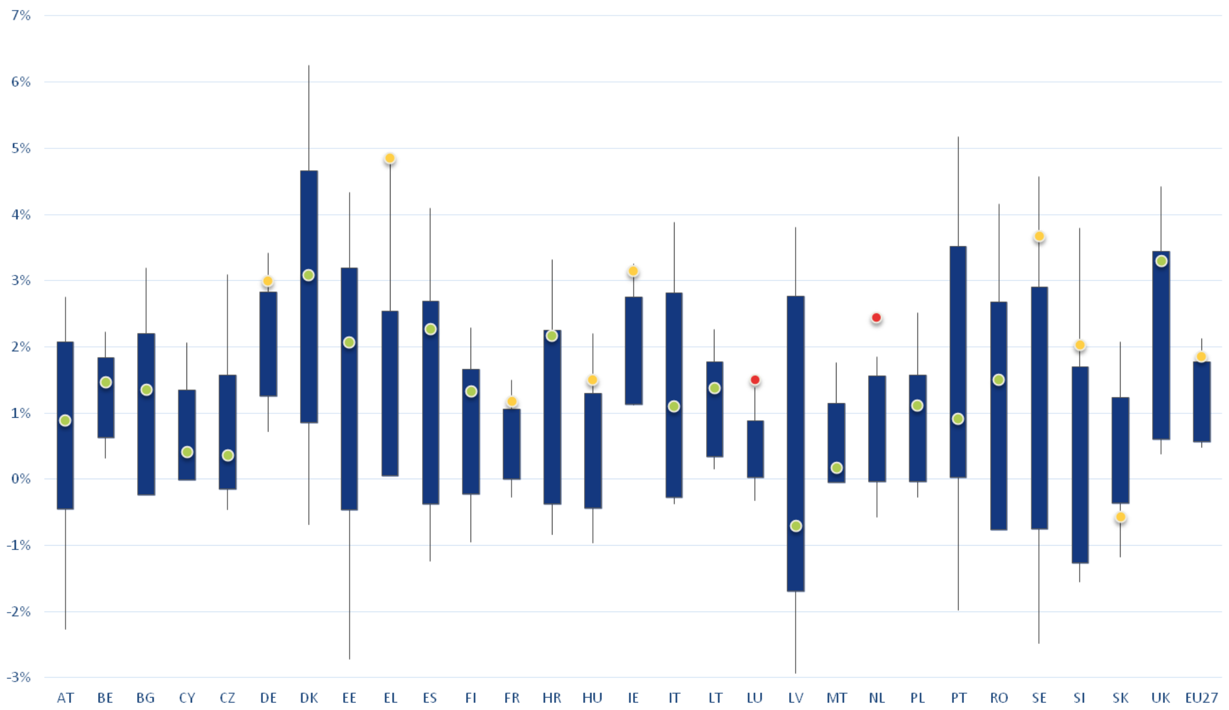
Sources: EEA; (Eurostat 2019b).

Renewable electricity

The change in the RES-E shares proxy for 2019 compared with 2018 (+1.9 %) for the whole EU is larger by 0.1 standard deviations than the average annual change in RES-E shares in the period from 2005 to 2018 (+1.17%).

The calculated changes in the RES-E shares proxies 18 Member States are within 1 standard deviation of the average changes for the period 2005-2017. In 10 Member States, the 2018/2019 change is significantly different from the 2005-2018 average at the 5 % level (Greece, France, Germany, Hungary, Ireland, Netherlands, Sweden, Luxembourg, Slovenia and Slovakia), as shown in Figure 42. Of those, two Member States showed changes in RES-E shares that were larger than the historically observed average ±1 standard deviation.

Figure 42 **Changes in RES-E shares between 2018 and 2019 compared with historically observed annual changes in RES-E shares (2005-2018) in percentage points.**



Notes: Blue bars show the range of average annual changes in RES shares between 2005 and 2018, plus or minus one standard deviation. Thin lines represent minimum and maximum year-to-year changes in this period. Dots show the change in proxy RES share for 2019 compared with 2018. Green: change between 2018 and 2019 within 1 standard deviation of changes from 2005 to 2018. Yellow: change between 2018 and 2019 within minimum and maximum change from 2005 to 2018. Red: change between 2018 and 2019 larger than changes from 2005 to 2018.

Source: EEA.

The following Member State show larger changes in RES-E shares than have been historically observed.

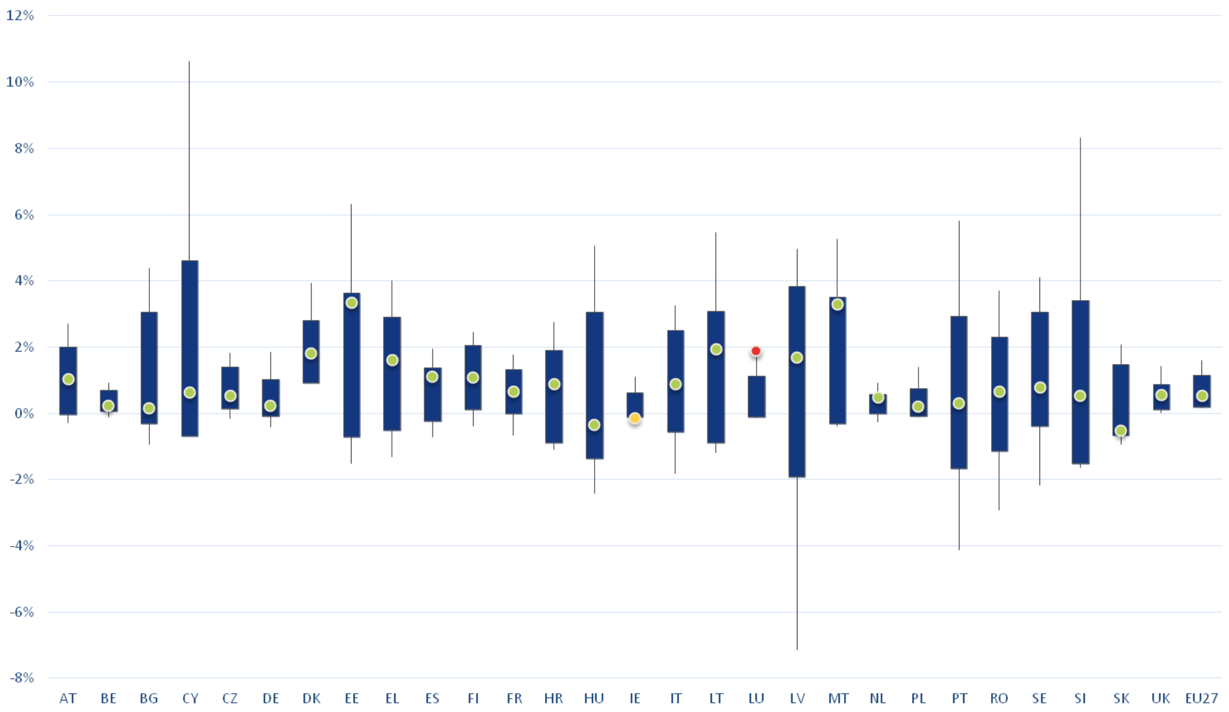
Luxembourg: RES-E reached 10.6% due to 15.7% increase in electricity generation from wind increased and 67.0% from solid biofuels.

Renewable heating and cooling

The change in the RES-H&C shares proxy for 2019 compared with 2018 (+0.5 %) for the whole EU is smaller by 1. standard deviations than the average annual change in RES-H&C shares in the period from 2005 to 2018 (+0.7%). This deviation is significant at the 5 % level (p = 0.002).

The calculated changes in the RES-H&C shares proxies for 22 Member States are within 1 standard deviation of the average changes for the period 2005-2018. In two Member States, the 2018/2019 change is significantly different from the 2005-2018 average at the 5 % level (Ireland and Luxembourg), as shown in Figure 43. Of those, one Member State showed changes in RES-H&C shares that are larger than the historically observed average ±1 standard deviation.

Figure 43	Change in RES-H&C shares between 2018 and 2019 compared with historically observed annual changes in RES-H&C shares (2005-2018) in percentage points



Notes: Blue bars show the range of average annual changes in RES shares between 2005 and 2018, plus or minus one standard deviation. Thin lines represent minimum and maximum year-to-year changes in this period. Dots show the change in proxy RES share for 2019 compared with 2018. Green: change between 2018 and 2019 within 1 standard deviation of changes from 2005 to 2018. Yellow: change between 2018 and 2019 within minimum and maximum change from 2005 to 2018. Red: change between 2018 and 2019 larger than changes from 2005 to 2018.

Source: EEA.

The following Member State shows larger changes in RES-H&C shares than have been historically observed. The changes detailed below may be calculation artefacts due to the lack of timely data available on bioenergy consumption in heating and cooling.

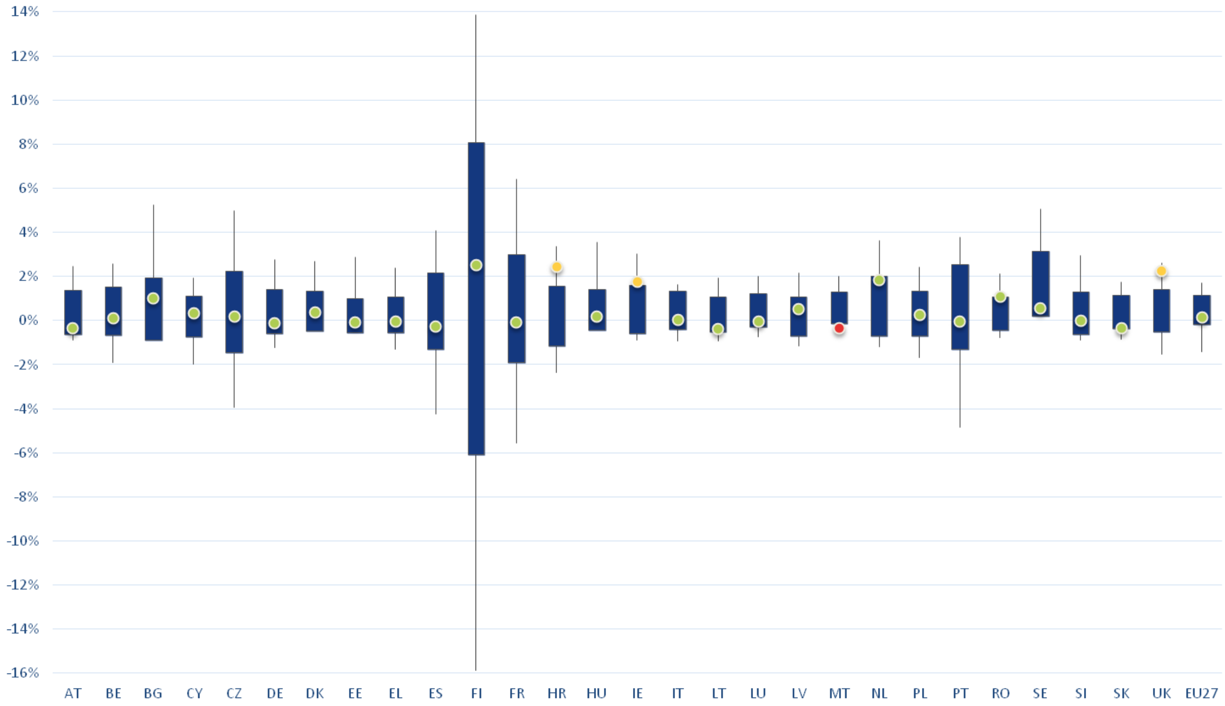
Luxembourg: RES H&C reached 10.7%, when derived heat increased by 56.6% compared to 2018.

Renewable transport fuels

At the EU level, the RES-T shares proxy for 2019 increased only slightly compared with 2018 (+0.1 %). This small increase is lower by 0.05 standard deviations than the average annual change in RES-T shares over the period from 2005 to 2018 (+0.5 %), and it is only at the threshold of being significantly different at the 5 % level (p = 0.05) because the change between 2010 and 2011 (-1.3 %) showed a decrease in the RES-T share.

The calculated changes in the RES-T shares proxies for 24 Member States are within one standard deviation of the average changes for the period 2005-2018. In three Member States, the change between 2018 and 2019 was significantly different from the 2005-2018 average at the 5 % level (Croatia, Ireland and Malta), as illustrated in Figure 44. Of those, one Member State showed changes in RES-T shares that are larger than the historically observed average ±1 standard deviation.

Figure 44 **Changes in RES-T shares between 2018 and 2019, compared with historically observed annual changes in RES-T shares (2005 -2018) in percentage points**



Notes: Blue bars show the range of average annual changes in RES shares between 2005 and 2018, plus or minus one standard deviation. Thin lines represent minimum and maximum year-to-year changes in this period. Dots show the change in proxy RES share for 2019 compared with 2018. Green: change between 2018 and 2019 within 1 standard deviation of changes from 2005 to 2018. Yellow: change between 2018 and 2019 within minimum and maximum change from 2005 to 2018. Red: change between 2018 and 2019 larger than changes from 2005 to 2018.

Source: EEA.

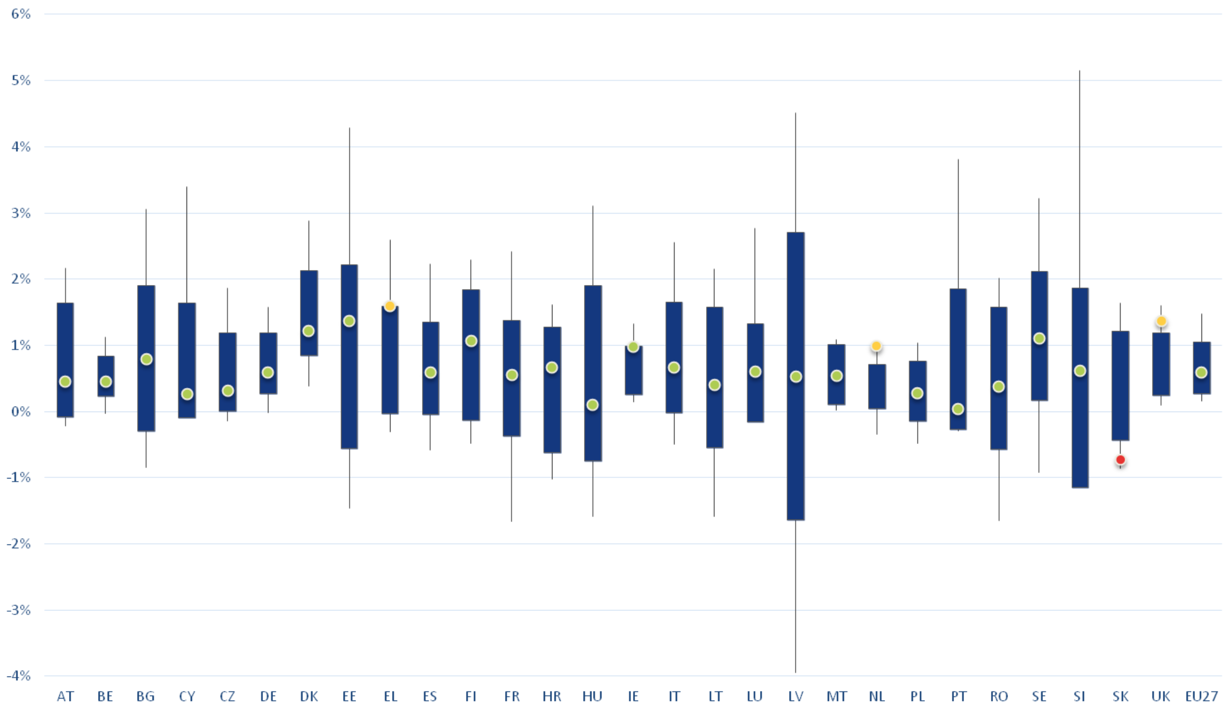
The following Member State show larger changes in RES-T shares than have been historically observed.

Malta: Consumption of compliant biofuels decreased by -0.2 while consumption of all transport fuels increased. This led to -0.3% decrease in the RES-T.

Total renewable energy sources

The change in the RES shares proxy for 2019 compared with 2018 (+0.6 %) for the whole EU was lower than the observed average annual change in RES shares in the period from 2005 to 2018(+0.7 %). This is significantly different at the 5 % level (p = 0.002).

Figure 45 **Change in RES shares between 2018 and 2019, compared with historically observed annual changes in RES shares (2005-2017) in percentage points**



Notes: Blue bars show the range of average annual changes in RES shares between 2005 and 2018, plus or minus one standard deviation. Thin lines represent minimum and maximum year-to-year changes in this period. Dots show the change in proxy RES share for 2019 compared with 2018. Green: change between 2018 and 2019 within 1 standard deviation of changes from 2005 to 2018. Yellow: change between 2018 and 2019 within minimum and maximum change from 2005 to 2018. Red: change between 2018 and 2019 larger than changes from 2005 to 2018.

Source: EEA.

The calculated changes in the RES shares proxies for 24 Member States are within one standard deviation of the average changes in the period from 2005 to 2018. In two Member States, the change between 2018 and 2019 was significantly different from the 2005-2018 average at the 5 % level (Greece, Netherland and Slovakia). Of those, one Member State showed changes in RES shares that are larger than the historically observed average ±1 standard deviation.

In Slovakia, consumption of solid biofuels in electricity decreased by 25.1%, and consumption of compliant biofuels in transport decreased slightly more than gross final consumption of energy in transport. RES decreased -0.7% compared to 2018.

However, it should be stressed that the RES proxy calculations tend to underestimate RES shares. One reason is the lack of timely data available on bioenergy consumption in heating and cooling.

Proxy 2018 versus RES shares 2018

Table 19 provides insights into the difference between approximated 2018 RES shares (calculated in 2019) and actual 2018 RES shares (available for the first time in 2020). For some countries, these differences can be larger, especially when looking at the amount of RES-T. These differences can stem from different methodologies used by countries following the adoption of the ILUC Directive (EU, 2015a), as well as from the difficulty of replicating the specific accounting rules in the RED concerning very specific shares of RES-T (see also Section 1.2.2).

Table 19 **2018 RES shares by sector compared with approximated RES shares by sector (all %).**

	RES			RES-E			RES-T			RES-H&C		
	Final	Proxy	Change	Final	Proxy	Change	Final	Proxy	Change	Final	Proxy	Change
Austria	33.4%	32.9%	-0.6%	73.1%	77.3%	4.3%	9.8%	10.1%	0.3%	34.0%	31.9%	-2.1%
Belgium	9.4%	9.3%	-0.1%	18.9%	18.2%	-0.7%	6.6%	6.8%	0.2%	8.2%	8.1%	-0.1%
Bulgaria	20.5%	18.7%	-1.8%	22.1%	20.0%	-2.1%	8.1%	8.0%	-0.1%	33.3%	30.0%	-3.3%
Cyprus	13.9%	9.9%	-3.9%	9.4%	9.2%	-0.2%	2.7%	2.5%	-0.2%	36.8%	24.6%	-12.2%
Czech Republic	15.1%	14.9%	-0.2%	13.7%	13.9%	0.2%	6.5%	6.8%	0.2%	20.6%	20.0%	-0.7%
Germany	16.5%	16.6%	0.1%	38.0%	37.8%	-0.2%	7.9%	7.9%	0.0%	13.6%	13.9%	0.2%
Denmark	35.7%	36.4%	0.7%	62.4%	63.0%	0.6%	6.6%	5.2%	-1.3%	46.7%	48.0%	1.4%
Estonia	30.0%	28.1%	-1.9%	19.7%	17.6%	-2.1%	3.3%	0.4%	-2.9%	53.7%	51.8%	-1.9%
Greece	18.0%	17.0%	-1.0%	26.0%	26.2%	0.2%	3.8%	4.1%	0.2%	30.2%	27.2%	-3.0%
Spain	17.5%	17.8%	0.3%	35.2%	35.6%	0.4%	6.9%	7.1%	0.1%	17.5%	18.3%	0.9%
Finland	41.2%	41.7%	0.6%	36.8%	36.1%	-0.7%	14.9%	17.3%	2.4%	54.6%	55.3%	0.7%
France	16.6%	16.8%	0.2%	21.2%	21.0%	-0.1%	9.0%	9.2%	0.2%	21.8%	22.0%	0.2%
Croatia	28.0%	27.7%	-0.3%	48.1%	48.2%	0.0%	3.9%	1.1%	-2.7%	36.5%	36.9%	0.4%
Hungary	12.5%	13.7%	1.2%	8.3%	8.3%	0.0%	7.7%	8.4%	0.7%	18.1%	19.8%	1.7%
Ireland	11.1%	11.0%	0.0%	33.2%	33.2%	-0.1%	7.2%	7.2%	0.0%	6.5%	6.5%	0.0%
Italy	17.8%	17.6%	-0.2%	33.9%	32.4%	-1.5%	7.7%	6.7%	-1.0%	19.2%	19.4%	0.2%
Lithuania	24.4%	24.3%	-0.2%	18.4%	18.4%	0.0%	4.3%	4.3%	0.0%	45.6%	45.2%	-0.5%
Luxembourg	9.1%	8.9%	-0.2%	9.1%	7.9%	-1.3%	6.5%	6.3%	-0.2%	8.8%	8.6%	-0.1%
Latvia	40.3%	40.2%	-0.1%	53.5%	53.9%	0.4%	4.7%	5.1%	0.4%	55.9%	56.2%	0.3%
Malta	8.0%	7.5%	-0.5%	7.7%	7.7%	0.0%	8.0%	6.1%	-1.9%	23.4%	19.9%	-3.4%
Netherlands	7.4%	7.0%	-0.4%	15.1%	14.9%	-0.2%	9.6%	6.8%	-2.8%	6.1%	6.0%	-0.1%
Poland	11.3%	10.9%	-0.3%	13.0%	13.9%	0.9%	5.6%	3.6%	-2.1%	14.8%	14.6%	-0.2%
Portugal	30.3%	27.9%	-2.4%	52.2%	53.0%	0.8%	9.0%	7.5%	-1.5%	41.2%	34.8%	-6.4%
Romania	23.9%	24.8%	0.9%	41.8%	42.4%	0.6%	6.3%	7.6%	1.3%	25.4%	26.6%	1.1%
Sweden	54.6%	57.0%	2.3%	66.2%	68.7%	2.5%	29.7%	45.1%	15.4%	65.4%	69.5%	4.1%
Slovenia	21.1%	21.9%	0.7%	32.3%	32.9%	0.6%	5.5%	3.1%	-2.4%	31.6%	33.4%	1.8%
Slovakia	11.9%	11.7%	-0.2%	21.5%	24.5%	3.0%	7.0%	7.9%	1.0%	10.6%	9.8%	-0.8%
United Kingdom	11.0%	11.1%	0.1%	30.9%	31.2%	0.4%	6.5%	4.9%	-1.5%	7.5%	8.1%	0.6%
European Union	18.9%	18.9%	0.1%	32.2%	32.2%	0.0%	8.3%	8.6%	0.3%	21.1%	21.2%	0.1%

Sources: EEA; (Eurostat 2020b).

At the EU level, approximated RES share was estimated to be 0.1 percentage points higher than the final RES share published by Eurostat. Sectoral RES shares were overestimated in transport by 0.3 percentage points, RES-E by 0.0 percentage points and for heating and cooling by 0.1 percentage points.

Deviations in RES shares are less than 4.0 percentage point for all Member States, and deviations are larger than 1 percentage point in six Member States. At sectoral level, deviations are larger than 1 percentage point in seven Member States for RES-E shares, in eleven Member States for RES-T shares and in twelve Member States for RES-H&C shares. Short-term proxy estimates are most difficult in the heating and cooling sector. This is mainly the result of two effects: (1) on the one hand, bioenergy is the predominant renewable energy source in this sector, but useful data sources are unavailable there; (2) on the other hand, gross final energy consumption in the heating and cooling sector is hard to estimate due to the strong influence of climatic conditions.

For some Member States, the deviation between proxy and final data for 2018 is considerable. The largest deviation occurred for Sweden in the transport sector. For Sweden, high annual fluctuations in transport data caused overestimation. In RES-H&C, Portugal was overestimated, and Cyprus underestimated by the 5-year linear function.

In general, the approximated 2018 RES proxy shares overestimated rather than underestimated actual RES shares in 2018.

Annex 5 Methodology for the construction of country specific CO2 emission factors

Method

In this Annex we describe for each of the emission factors:

1. The **current/default method** (ETC/CME 2019c) to calculate the CO2 emission factors with default CO2 emission factors according to Annex VI of Commission Regulation 601/2012. This method has been described in the first report (EEA 2015) according to the old Eurostat methodology for energy balances. In 2019 Eurostat adapted its methodology for the energy balances with an impact on energy products – fuels and on energy flows. The description of the current method in this paper takes into account the flows and fuels from the new methodology.
   Countries report the energy content of their fuel consumed to Eurostat [in ktoe or in TJ] and this is the basis for the calculation of the implied emission factors (see 1.1-1.3).
2. The **proposed country specific method** for using country specific CO2 emission factors based on the proportion of country specific net calorific values to the calorific values of Annex VI of Commission Regulation 601/2012 (EU 2012a) applied to the default emission factors of that same annex.
   The **country specific method** starts from the energy content of the fuel consumed similar as the current/default method but seeks to use a country specific NCV to estimate a country specific CO2 emissions factor.
   The emission factors from Commission Regulation 601/2012 (Annex VI) (EU 2012a) are related to net calorific values per fuel type. We assume that the net calorific value of a certain fuel type is directly proportional with the CO2 emission factor for that fuel type. It can be that a country uses a fuel type with small deviation in characteristics from the default from Annex VI but it is then assumed that the related CO2 emission factor deviates proportional. That is why we use this relationship to calculate the country specific CO2 emission factor by using the country specific NCV.

Sources for the data are:

- Eurostat, Complete energy balances, nrg_bal_c: for input and output data for electricity and heat.
- Eurostat, Calorific values, nrg_bal_cv: for country specific calorific values per year.
- Annex VI of Commission Regulation 601/2012 (EU 2012a): for default calorific values and the related default CO2 emission factors.

The energy balance guide (Eurostat 2019c) describes the methodology for the construction of the energy balance and includes detailed descriptions of all fields. Eurostat has set up a cascade system for the choice of calorific values for constructing countries' energy balances (Eurostat, 2019, p. 9). If countries report on calorific values according to the obligations then Eurostat uses these values and makes own calculations based on these values if necessary (for coal and oil products). If countries do not report then Eurostat uses the calorific values from Commission Regulation 601/2012 (EU 2012a). For products not covered by this regulation, the net calorific values used are Eurostat's estimates. These estimates take into account the Commission Decision 2007/589/EC (EU 2007).

Emission factors for electricity

The formula for calculation of the emission factors for electricity in the **current/default method** goes as follows:

$$EFe(yr,c) = \frac{\sum_{f_i} \text{Input\_e}(yr,c,f_i) \times EF(f_i)}{\text{Output\_e}(yr,c,f_o)}$$

With:

Input_e(*yr,c,f*$_i$)	=	Transformation input - electricity and heat generation - main activity producer electricity only - energy use [TI_EHG_MAPE_E] + Transformation input - electricity and heat generation - autoproducer electricity only - energy use [TI_EHG_APE_E].
f_i Input	=	All fuels from list in Table 20
Output_e(*yr,c,f*$_i$)	=	Gross electricity production [58] - main activity producer electricity only [GEP_MAPE] + Gross electricity production - autoproducer electricity only [GEP_APE]
f_o Output	=	Electricity [E7000] for all fuels from list in table 5.1
EF(f_i)	=	CO_2 emission factors per fuel type (t CO_2/TJ; see Annex VI of Commission Regulation 601/2012).

To use **country specific CO2 emission factors**, the EF(f_i) is replaced by EF($f_{i,}$y,c), country specific emission factor per fuel, per year according to:

$$EF\ (f_i, yr, c) = \frac{NCV(fi,c,y)}{NCVr(fi)} \times EFr(fi)$$

With:

EFr(f_i)	=	CO_2 emission factors per fuel type (t CO_2/TJ; see Annex VI of Commission Regulation 601/2012).
NCVr(f_i)	=	NCV per fuel type from Commission Regulation 601/2012 (Annex VI)
NCV($f_{i,}$y,c)	=	NCV per fuel type, per year, per country from nrg_bal_cv (Calorific values)

(58) GEP = Gross Electricity Production. Complementing indicator that allows showing electricity and heat production from each fuel. The blocks of the energy balance matrix do not allow seeing electricity and heat generation from each specific fuel. Source: Energy balance guide, Methodology guide for the construction of energy balances & Operational guide for the energy balance builder tool, 31 January 2019, Eurostat

Table 20 **Fuels used for the calculation of CO2 emission factors.**

C0110	Anthracite	**O4300**	Refinery feedstocks
C0121	Coking coal	**O4610**	Refinery gas
C0129	Other bituminous coal	**O4620**	Ethane
C0210	Sub-bituminous coal	**O4630**	Liquefied petroleum gases
C0220	Lignite	**O4640**	Naphtha
C0311	Coke oven coke	**O4652XR5210B**	Motor gasoline (excluding biofuel portion)
C0320	Patent fuel	**O4661XR5230B**	Kerosene-type jet fuel (excluding biofuel portion)
C0330	Brown coal briquettes	**O4671XR5220B**	Gas oil and diesel oil (excluding biofuel portion)
C0340	Coal tar	**O4680**	Fuel oil
P1100	Peat	**O4694**	Petroleum coke
P1200	Peat products	**O4695**	Bitumen
G3000	Natural gas	**W6100**	Industrial waste (non-renewable)
O4100_TOT	Crude oil	**W6220**	Non-renewable municipal waste
O4200	Natural gas liquids		

Source: (ETC/CME 2019c).

Emission factors for heat

The formula for calculation of the emission factors for heat in the current method goes as follows:
By using CO_2-emission factors per type of fuel (EF(f_i)), **fuel use is converted to an amount of GHG emission.**
The reference emission factor for the initial energy carrier heat EFh(yr,c) is calculated as follows:

$$EFh(yr,c) = \frac{\sum_{f_i} \text{Input\_h}(yr,c,f_i) \times \text{EF}(f_i)}{\sum_{f_i} \text{Input\_h}(yr,c,f_i) \times \text{h}(f_i)}$$

With:

EF(f_i)	=	CO_2 emission factors per type of fuel (t CO_2/TJ; see Annex VI of Commission Regulation 601/2012).
Input_h(*yr,c,fi*)	=	Final consumption - industry sector - energy use [FC_IND_E] + Final consumption - other sectors - energy use [FC_OTH_E].
f_i	=	All fuels from list in table 5.1

h(fi) = Fuel-dependent efficiency of heat production. It is assumed to be 87% for coal/solid fuels; 89% for oil/liquid fuels; and 90% for gas/gaseous fuels (based on Vatopoulos, et al.).

To use country specific CO2 emission factors, the EF(f_i) is replaced by EF(f_i,y,c), country specific emission factor per fuel, per year according to:

$$EF\ (f_i, yr, c) = \frac{NCV(fi, c, y)}{NCVr(fi)} \times EFr(fi)$$

With:

EFr(f_i) = CO_2 emission factors per fuel type (t CO_2/TJ; see Annex VI of Commission Regulation 601/2012).

NCVr(f_i) = NCV per fuel type from Commission Regulation 601/2012 (Annex VI)

NCV(f_i,y,c) = NCV per fuel type, per year, per country from nrg_bal_cv (Calorific values)

Emission factors for transport fuels

Substitution rules are straightforward in the transport sector, due to the dominance of petrol and diesel in the sector and the comparable fuel efficiencies of vehicles (contrary to conditions for the other two energy carriers, electricity and heating). The assumption for this sector is therefore that renewable transport fuels (essentially biodiesel and bioethanol) replace the conventional transport fuels petrol and diesel on a one-to-one basis, according to their specific energy content.

In the current method, the fuel-specific emission factors for the conventional energy carriers petrol and diesel (EF(fi)) are taken from Annex VI of the Commission Regulation 601/2012/EU (EU 2012a). On this basis, primary energy use per unit of transport (PEt) and reference emission factors of the initial energy carriers petrol and diesel can be calculated.

To use country specific CO2 emission factors, the EF(f_i) is replaced by EF(f_i,y,c), country specific emission factor per fuel, per year according to the same formula as for electricity and heat.

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