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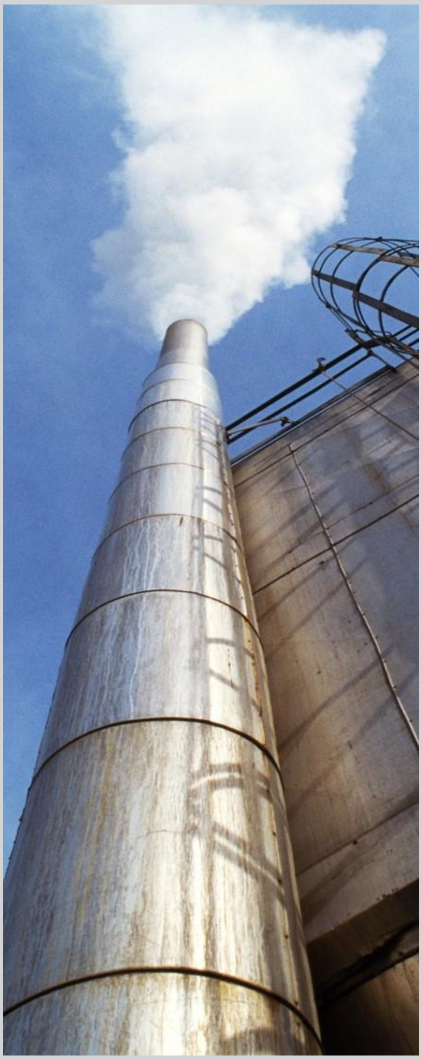
Impacts of renewable energy on air pollutant emissions

Calculation of implied emission factors based on GAINS data and estimated impacts for the EU-28





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Contents

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Summary

This report describes an approach to estimate the impact of gross final consumption of renewable energy sources (RES) on air pollutant emissions.

The introduction chapter presents the context for this exercise and more information on the considered air pollutants.

The chapter on the methodological framework contains the method implemented to estimate the RES effect on air pollutant emissions. The approach builds on the previously developed EEA method to estimate avoided GHG emissions due to RES consumption (see EEA, 2015). That chapter also gives an overview of available data sources and of the data source finally implemented to approximate the RES consumption effects on air pollutants, i.e. the GAINS database – specifically the set of 'underlying data' on activity and emissions that the European Commission (EC) consulted with the Member States and published on its website - http://ec.europa.eu/environment/air/reduction/assumptions.htm. Subsequently, the calculation of historic implied emission factors (IEF) and reference emission factors (REF) based on these data is described. The methodology chapter also contains the results of the IEF for the EU-28 as a whole. The detailed results of of IEF per Member State are included in the separate data annexes, 'Results of implied emission factors per Member State based on GAINS data', accompanying this report. Short discussions focusing on high/low values and on deviating trends are included.

The last chapter presents the overview of the RES consumption effect on emissions of air pollutants at the EU level.

1 Introduction

1.1 Background

The European energy sector is at the heart of an ongoing transition that aims to position the European economy on a low-carbon, resource-efficient path. The substitution of fossil fuels by a growing share of renewable energy sources is one of the most relevant climate mitigation options to date. Besides their mitigation role, renewable energy sources (RES) also have an impact on energy dependence and the emission of air pollutants. Therefore, insights into the growth of renewable energy consumption by technology, its co-benefits and potential trade-offs can usefully inform political choices in the EU Member States and the EEA countries in regard of short, medium and long-term RES development strategies and strategies to reduce air pollutant emissions and improve air quality.

The EEA publishes an annual renewable energy report, which includes, i.a., the estimated impact of renewable energy development since 2005 on energy consumption and emissions (EEA, 2017a). More specifically, it determines the effects on gross avoided greenhouse gas (GHG) emissions and fossil fuel substitution, and the resulting statistical effects on primary energy consumption.

The EEA intends to complement that report with estimates of RES effects on the emissions of key air pollutant emissions sulphur dioxide (SO_2), nitrogen oxide (NO_x), particulate matter ($PM_{2.5}$ – particulate matter 2.5 micrometres or less in diameter and PM_{10} – particulate matter having a diameter of less than 10 micrometres; see also Box 2) and volatile organic compounds (VOCs) (see Glossary).

1.2 Air pollution and renewable energy production

Air pollution results from the release into the atmosphere of various gases and particles (solids, liquid aerosols) at rates that exceed the natural capacity of the environment to dissipate and dilute or absorb them. These substances may reach concentrations in the air that cause undesirable health, environmental and economic impacts.

Air pollution related to oxidative processes can be categorized as outdoor (or ambient) air pollution that originates from anthropogenic sources. Fossil and renewable fuel combustion, for all kinds of end uses, is one of the major sources for ambient air pollution (EEA, 2017b). In its report on ambient air pollution of 2016, the WHO states that to date, air pollution – both ambient and household (indoor) – is the biggest environmental risk to health; ambient air pollution alone kills around 3 million people each year, mainly from chronic diseases (WHO 2016). For a detailed discussion of the effects of air pollutants, we refer to the Air Quality report 2017 (EEA, 2017b).

By being able to supply useful energy also through non-oxidative processes, many RES technologies can contribute substantially to the decrease of air pollution when they replace the combustion of fossil fuels. However, RES technologies relying on combustion processes do lead to air pollutant emissions and that is why for these technologies both avoided and induced air pollutant emissions have to be taken into account.

For estimating the effects of renewable energy consumption on the release of air pollutant emissions this report focuses on the major air pollutants SO_2, NO_x, $PM_{2.5}$, PM_{10} and VOCs. For these air pollutants, fuel combustion is one of the major sources. It was decided to exclude the effect on ammonia (NH_3) emissions, since (renewable) fuel combustion is a minor source of these emissions. NH_3 emissions arise primarily from the decomposition of animal manure and the application of fertiliser in the agricultural sector (EEA, 2018).

Box 1 – Sulphur dioxide (SO_2) and nitrogen oxide (NO_x) emissions and effects (EEA 2017, EPA 2018)

The largest sources of SO_2 in the atmosphere in the EU-28 are fuel combustion processes in the power generation sector, in industry, and in the commercial and residential sectors. Together, these sectors accounted for more than 90% of the SO_2 emissions in the EU-28 in 2015. Exposure to high concentrations of **SO_2** can harm the human respiratory system and make breathing difficult. Higher concentrations of SO_2 and SO_x can harm trees and plants by damaging foliage and decreasing growth. SO_2 and other SO_x can contribute to form acid rain, which harms sensitive ecosystems such as lakes and forests. Oxidation of SO_2 in the atmosphere lead to the formation of sulfuric acid (H_2SO_4) and the formation of particles that contribute to particulate matter (PM) pollution.

The major sources of **NO_x** are combustion processes. Nitric oxide (NO) accounts for the majority of NO_x emissions. NO is subsequently oxidised to form nitrogen dioxide (NO_2), although some NO_2 is emitted directly. In 2015, the EU-28 fuel combustion for road transport, power generation, industry, commercial and residential accounted for more than 80% of NO_x emissions. Exposure to high concentrations of **NO_2** can aggravate respiratory diseases such as asthma, while longer exposures may contribute to the development of asthma and possibly increase the susceptibility to respiratory infections.

H_2SO_4 formed by the oxidation of SO_2 is the main pollutant responsible of acid rains. It is followed by HNO_3 formed from the oxidation of NO_x. Similar as for SO_x, NO_x is a precursor for particulate matter (PM).

1.3 Purpose of this report

This technical report documents an approach to estimate the effects of renewable energy use (especially the growth in final energy consumption of RES since 2005) on the emission of air pollutants SO_2, NO_x, $PM_{2.5}$, PM_{10} and VOCs. It identifies data and information sources and proposes a method to carry out this estimation based on GAINS data. The ultimate aim is to enable a better understanding of benefits and trade-offs, in terms of air pollutant emissions, of renewable energy consumption in comparison to the non-renewable energy consumption it substitutes.

To facilitate understanding, this report summarises the methodological framework applied by EEA and its ETC/CME to estimate the effects of renewable energy on gross avoided greenhouse gas emissions, primary energy and fossil fuel consumption. That framework is used as starting base to estimate effects on air pollutant emissions. It was described in detail in an earlier report (see EEA, 2015).

1.4 Scope of the report

Due to limited availability of primary data, this assessment focuses on the 28 EU Member States. Although data for other EEA member countries may, in certain cases, be available publicly, collecting these data would require more resources than available for this exercise.

The method developed here is not suitable for assigning the effects to particular drivers, circumstances or policies, other than the deployment of RES itself. However, it is to be noted that other effects may be included because of the limitations of the method (see section 0). These other effects may play a more important role for air pollutant emissions than for GHG emissions, since the latter depend largely on the fuels combusted and their carbon content, while for air pollutant emissions other factors play an equally important role (see section 0).

It has to be noted that a precise quantification of the relative importance of the air pollutants is out of the scope of the current exercise. Assessing the impact of SOx and NOx emissions on concentrations of regulated air pollutants is not straightforward. The formation of secondary pollutants (like ozone or secondary inorganic aerosol) depends on complex chemical reactions that do not respond linearly to changes in emissions. It is therefore not easy to provide a simple answer to these questions without simulating the chemical reactions in the atmosphere that can influence the impact of these pollutants. However, given evidence that biomass burning is one of the main sources of primary particles (PM) emissions in winter (Denier van der Gon et al. (2015)) and has significant effects on PM concentrations, one can expect that that the observed significant increase of PM emissions equally leads to a significant increase in PM concentrations.

It is important to bear in mind that the assumptions are static, i.e. the same set of assumptions is applied invariably for all years in the period; the methods will thus become less accurate when the share of renewables in the energy mix becomes significant, as more complicated interactions in the energy system and the economy are not dynamically portrayed.

The results are best suited for analysis and conclusions on the aggregated EU level and care should be taken to interpret results on the national level. According to countries' information there are still discrepancies between some data in the GAINS model and national data, despite bilateral consultation on the data. However, in Section 0 results per country are included, since these can give a general indication of the influence of renewable energy consumption since 2005 on the evolution of air pollutant emissions for that country.

2 Methodological overview

2.1 Method for estimation of avoided GHG emissions forms the basis for estimating the effect on air pollutants

Since 2014, gross avoided GHG emissions due to the development of RES are calculated following a method developed by the EEA and its European Topic Centre on Air Pollution and Climate Change Mitigation (ETC/ACM). The approach can be used to assess the effects of increasing shares of renewable energy consumption on climate change mitigation efforts at national and EU level.

The method consists of three steps:

(1) The amount of renewable energy consumed in each country and year, by energy carrier and by technology is determined.
(2) The reference emission factors of the initial energy carriers are determined; this allows the calculation of the gross avoided GHG emissions per country and year.
(3) The results from step 2 are attributed to ETS and to non-ETS sectors respectively.

The method is based on official statistical data reported by countries to Eurostat. GHG effects can be calculated for individual EU Member States and for the EU as a whole, for each year starting with 2005, and until t-2, where t represents the current year. The calculation of RES effects takes into account the three energy market sectors introduced by the Renewable Energy Directive (Directive 2009/28/EC): electricity, heating and cooling, and transport.

For the calculation of country-specific reference emission factors in step 2, assumptions were made. For electricity production, the reference emission factor is a generation-weighted average emission factor for which nuclear generation, renewable electricity generation and blast furnace gas are excluded from the average because, in most cases, these sources will not be impacted by the deployment of RES. Via the calculated primary energy use per unit of electricity a reference emission factor of the initial energy carrier ‘electricity’ is determined. For heat production, country-specific emission factors are calculated similarly, so as to reflect the differences in the fuel mix between Member States. For transport fuels consumption, substitution rules are straightforward due to the dominance of gasoline and diesel in the sector and the comparable fuel efficiencies of vehicles using fossil fuels and biofuels (contrary to conditions for the other two energy carriers, electricity and heating).

The ‘2005-RES shares’ counterfactual scenario determines the GHG effects for the renewable energy that was added to the energy mix after the year 2005. The amounts of renewable energy consumed before and in 2005 are subtracted from later RES amounts, so that they do not count in the substitution.

The assumption is that each renewable energy carrier has substituted the same amount of energy of the initial energy carriers (electricity, heat and transport fuels) that would have otherwise been consumed in that country and year.

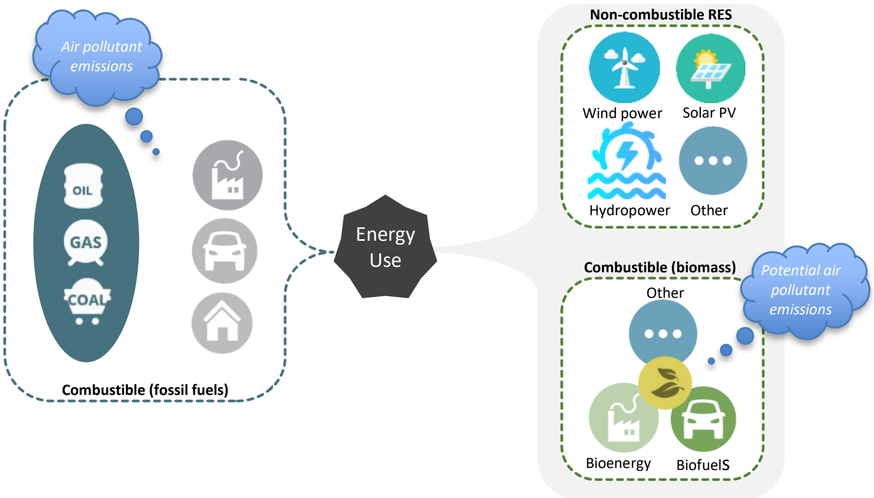
In step 3, emissions are attributed to ETS and non-ETS sectors, as follows:

- for renewable electricity (RES-E): 100 % of GHG effects are attributed to the ETS;
- for renewable heat (RES-H): technology- and country-specific attribution;
- for renewable transport (RES-T): 100 % of GHG effects attributed to non-ETS sectors.

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

This method is also applied here to determine the avoided air pollutant emissions due to the increased contribution made by RES. Besides avoided air pollutant emissions when fossil fuels are substituted, RES also cause surplus emissions when they deliver useful energy via technologies involving combustion. Essentially, this is because of four factors: the different composition of the renewable fuels, different operating parameters of the renewable energy technologies (RET), different abatement levels installed in RET and, at times, different operation of the RETs. Therefore, it is important to determine reference emission factors of different air pollutants for technologies relying on solid, gaseous and liquid fossil fuels which are substituted by the RET, as well as for the RET themselves. Ideally, these reference emission factors rely on the exact same assumptions as for GHG emissions. But in practice, due to the fact that emission factors for air pollutants strongly depend on the type of installation and its equipment with abatement technologies, and not solely on the type of fuel used (like for GHG emissions), the assumptions for the calculation of the reference emission factors for air pollutants will have to be more elaborate.

Figure 2.1 Substitution of fossil fuels by RES in the energy mix



Source: EEA

2.2 Estimation of effects on air pollutant emissions SO_2, NO_x, $PM_{2.5}$, PM_{10} and VOCs

The increasing share of renewables in the energy mix has also effects on air pollutant emissions. The EU impact assessment "A Roadmap for moving to a competitive low carbon economy in 2050" (EC, 2011) concludes that reducing emissions from fossil fuels tends to coincide with significant reductions in pollutants other than GHGs. Co-benefits include positive impacts on human health, the reduced pressures on ecosystems and a decrease in the costs of air pollution-related policies and measures. However, increased local air pollution can also result from additional PM and gaseous emissions associated with the combustion of certain RES, notably biomass (Karagulian et al., 2015).

Box 2 – Particulate matter ($PM_{2.5}$, PM_{10}) and volatile organic compound (VOC) emissions and effects (EEA 2017, EPA 2018)

Particulate matter (PM) means material suspended in the air in the form of solid particles or liquid droplets or a mixture of both, considered as an atmospheric pollutant. PM_{10} are inhalable particles, with aerodynamic diameters below 10 micrometers; $PM_{2.5}$ are inhalable particles with aerodynamic diameters below 2.5 micrometers (which is about 3% the diameter of a human hair).

The microscopic solids or droplets in PM are so small that they can be inhaled, thereby causing serious health problems. All particles less than 10 micrometers (both PM_{10} and $PM_{2.5}$) in diameter pose the greatest health problems compared with the other key air pollutants described in this report, because they can get deep into the lungs, some may even get into the bloodstream. In the environment, fine particles can cause reduced visibility (haze).

Some particles are emitted directly from an anthropogenic source such as fuel combustion for power generation, domestic heating, transport, industry, waste incineration and agriculture, as well as brakes, tyres and road wear and other types of anthropogenic dust. Others are emitted directly from natural sources such as sea salt and naturally disposed dust and pollen. Particles directly emitted as such in the atmosphere are called primary PM, while secondary PM is formed by chemical reactions in the atmosphere from precursor gases like SO_2, NO_x, NH_3 and VOCs.

In 2015, the EU-28 fuel combustion for road transport, power generation, industry, commercial and residential accounted for more than 60% of anthropogenic PM_{10} emissions and around 80% of anthropogenic $PM_{2.5}$ emissions.

VOCs are an important ambient air pollutant. VOCs are defined as any organic chemical compounds that under normal conditions are gaseous or can vaporize and enter the atmosphere. VOCs are numerous, varied, and ubiquitous. They include both human-made and naturally occurring chemical compounds. They are often divided into the separate categories of methane (CH_4) and non-methane (NMVOCs). Methane is an extremely efficient greenhouse gas, which contributes to enhanced global warming. VOCs have been found to be a major contributing factor to the production of ground level ozone (smog) and can be a precursor to secondary PM formation in the atmosphere.

Exposure to high concentrations of VOCs has also immediate health impacts. Environmental impacts caused by VOCs are production of ground level ozone , global warming and fauna and flora degradation.

Besides many other sources, fuel combustion produces VOCs either directly as products (e.g. gasoline) or indirectly as byproducts (e.g. automobile exhaust gas). In 2015 fuel combustion for power generation, industry, commercial and residential accounted for more than 30% of the NMVOC emissions in the EU-28. The largest source for NMVOC in the EU-28 in 2015 was industrial processes and product use which accounted for 50% of the emissions.

The EEA-study "Cobenefits of climate and air pollution regulations" (EEA, 2012) has also looked into air pollution effects of renewable energy. They conclude that the effect of climate policies on air pollution depends on the mix of climate measures taken. Reducing energy demand and increasing the share of carbon-free electricity lead to a decrease of air pollutant emissions. This is not necessarily the case of substituting fossil fuels by biomass.

In their 2012 report “Emissions from households and other small combustion sources and their reduction potential”, IIASA explains that air pollutant emissions from small combustion sources have grown in importance for three reasons (IIASA, 2012):

- Increased awareness about the threat to human health from the exposure to fine particulate matter. Combustion of solid fuels (wood and coal) in small stoves is a major source of primary emissions of $PM_{2.5}$.
- Establishment of stringent emission control legislation for other sources of air pollutant emissions, so that over time (uncontrolled) small combustion sources are gradually becoming the main sources of PM emissions.
- Enhanced overall focus on the use of wood and other biomass resources (including in small and less regulated combustion sources) as a result of greenhouse gas mitigation strategies and targets for renewable energy sources.

To estimate the total effects of increased RES use on the emissions of air pollutants, assumptions need to be made regarding the emissions of all types of energy generation.
The emission factors for air pollutants depend strongly on the type and quality of the fuel used, the type of combustion installations and their efficiencies, the existence of abatement technologies in the installations and ultimately the operation of the installations.
The following two generic formulae can be used to estimate the effects of renewable energy on NO_x-emissions:

(1) For avoided NO_x-emissions:

$$\Delta \mathrm{NO}_x \text{ emissions}(yr, c) =$$

$$= \sum_{ret} \begin{array}{l} FE(ret, yr, c) \cdot \big[-e(ret) \cdot EF_{NO_x e}(yr, c) - h(ret) \cdot s(ret) \cdot EF_{NO_x, h, ETS}(yr, c) \\ \qquad -h(ret) \cdot \big(1 - s(ret)\big) \cdot EF_{NO_x, h, \mathrm{non-ETS}}(yr, c) \\ \qquad\qquad -g(ret) \cdot EF_{NO_x g}(yr, c) - d(ret) \cdot EF_{NO_x d}(yr, c)\big] \end{array}$$

Where:

ΔNO_x emissions(*yr c*)	=	Gross avoided NO_x emissions in a given year (*yr*) and country (*c*) [ton CO_2];
FE(*ret, yr, c*)	=	Gross final energy consumption of a renewable energy technology *ret* in a given year *(yr)* and country *(c)* [ktoe];
ret	∈	{hydropower, geothermal electricity, solar photovoltaic, ….};
e(*ret*)	=	Gross electricity production from renewable energy technology *ret* [ktoe /ktoe gross final energy];
h(*ret*)	=	Gross heat production from renewable energy technology *ret* [ktoe /ktoe gross final energy];
g(*ret*)	=	Gasoline replacement from renewable energy technology *ret* [ktoe/ktoe gross final energy];
d(*ret*)	=	Diesel replacement from renewable energy technology *ret* [ktoe/ktoe gross final energy];

$EF_{NOxe}(yr, c)$	=	Reference NO_x emission factor for electricity in a given year and country [kg CO_2/ktoe];
$EF_{NOxh,ETS}(yr, c)$	=	Reference NO_x emission factor for heat in a given year and country in the ETS sector [ton NO_x/ktoe];
$EF_{NOxh,ETS}(yr, c)$	=	Reference NO_x emission factor for heat in a given year and country in the non-ETS sector [ton NO_x/ktoe];
$EF_{NOxg}(yr, c)$	=	Reference NO_x emission factor for gasoline in a given year and country [ton NO_x /ktoe];
$EF_{NOxd}(yr, c)$	=	Reference NO_x emission factor for diesel in a given year and country [ton NO_x /ktoe];
s(*ret*)	=	Share of greenhouse gas effects in ETS for renewable energy technology *ret* [1=100%];

(2) For NO_x-emissions caused by the consumption of energy from renewable fuels:

$$\Delta \mathrm{NO}_x \text{ emissions}(yr, c) =$$

$$= \sum_{ret} FE(ret, yr, c) \cdot \Big[e(ret) \cdot EF_{NO_x e,BF}(yr, c) + h(ret) \cdot s(ret) \cdot EF_{NO_x,h,ETS,BF}(yr, c) + h(ret) \cdot \big(1 - s(ret)\big) \cdot EF_{NO_x,h,\text{non-ETS,BF}}(yr, c) + g(ret) \cdot EF_{NO_x bg}(yr, c) + d(ret) \cdot EF_{NO_x bd}(yr, c) \Big]$$

Where:

ΔNO_x emissions(yr c)	=	Gross NO_x emissions caused by renewable fuels in a given year (*yr*) and country (*c*) [ton CO_2];
FE(*ret, yr, c*)	=	Gross final energy consumption of a renewable energy technology *ret* in a given year *(yr)* and country *(c)* [ktoe];
ret	∈	{hydropower, geothermal electricity, solar photovoltaic, ….};
e(*ret*)	=	Gross electricity production from renewable energy technology *ret* [ktoe /ktoe gross final energy];
h(*ret*)	=	Gross heat production from renewable energy technology *ret* [ktoe /ktoe gross final energy];
g(*ret*)	=	Gasoline replacement from renewable energy technology *ret* [ktoe/ktoe gross final energy];
d(*ret*)	=	Diesel replacement from renewable energy technology *ret* [ktoe/ktoe gross final energy];
$EF_{NOxe, RF}(yr, c)$	=	Reference NO_x emission factor for electricity produced with renewable fuels (solid, liquid, gas) in a given year and country [kg CO_2/ktoe];
$EF_{NOxh,ETS, RF}(yr, c)$	=	Reference NO_x emission factor for heat produced with renewable fuels (solid, liquid, gas) in a given year and country in the ETS sector [ton NO_x/ktoe];

$EF_{NOxh,ETS,RF}(yr, c)$ = Reference NO_x emission factor for heat produced with renewable fuels (solid, liquid, gas) in a given year and country in the non-ETS sector [ton NO_x/ktoe];

$EF_{NOxbg}(yr, c)$ = Reference NO_x emission factor for biogasoline in a given year and country [ton NO_x /ktoe];

$EF_{NOxbd}(yr, c)$ = Reference NO_x emission factor for bio-diesel in a given year and country [ton NO_x /ktoe];

$EF_{NOx}(ret, yr, c)$ = Reference NO_x emission factor for renewable energy technology *ret* in a given year and country [ton NO_x /ktoe];

s(*ret*) = Share of greenhouse gas effects in ETS for renewable energy technology *ret* [1=100%];

A corresponding calculation method can be used to estimate effects on PM_{10}, $PM_{2.5}$, SO_2 and VOC emissions.

To be able to use this method, estimates for the average NO_x, SO_2 and PM_{10}, $PM_{2.5}$ emission factors for electricity from fossil fuels, diesel consumption and petrol consumption need to be determined. Separate emission factors are determined for the consumption of heat from fossil fuels, in the ETS and the non-ETS sectors respectively.

At the same time, emission factors also need to be determined for the consumption of renewable energy from specific RETs. Only direct emissions arising from the RETs are taken into account in this method (i.e. conversion of RES into useful energy). Accordingly, relevant contributions come from the following RETs:

- RETs using solid biomass, biogas and bioliquids to generate renewable electricity (RES-E);
- RETs using solid biomass, biogas and bioliquids to produce renewable heat (RES-H)
- RETs using biogasoline and biodiesel in transport (RES-T)

Effects of renewable electricity consumption in transport do not have to be calculated, as these are captured under renewable electricity generation (RES-E).

2.3 Identification and selection of data source for reference emission factors

As for the calculation of avoided GHG emissions, an appropriate data source needs to be identified, as key source from which to derive the activity data, per sector and fuel type, as input for the calculation of reference emission factors per air pollutant, technology and country. Ideally, we are aiming for the same detail and aggregation of sectors as used for the calculation of avoided GHG emissions (i.e. Eurostat based method, see section 2.1), so that assumptions and calculations could be made consistent and coherent for both co-benefits. However, air pollutant emissions are typically reported according to NFR classification of sectors ([1]) and not according to Eurostat energy balance classification of sectors ([2]), which is why these emissions do not correspond as such to the sectorial activity data (per fuel) from Eurostat.

Four sources were examined for this purpose:

([1]) Nomenclature for Reporting (NFR 14) under the LRTAP Convention,
([2]) Construction of the energy balances, https://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_balance#Construction_of_the_energy_balances

- air pollutant emission inventories reported by Parties in the context of the Long-range Transboundary Air Pollution Convention and its protocols (i.e. data submitted in accordance with the Nomenclature For Reporting (NFR) tables);
- the large combustion plants (LCP) emission inventories submitted by countries under the Large Combustion Plants Directive (2001/80/EC);
- historic datasets obtained from the GAINS model; and
- the EMEP/EEA Guidebook 2016 (EMEP/EEA, 2016).

All sources have specific drawbacks such as differing classification of sectors, limited scope in fuels, etc. None of them contains all necessary data at the required level of detail, as has been summarised in the next subsections.

2.3.1 The national air pollutant emissions inventories

With the available data and level of detail from the NFR tables it seemed possible to derive estimates for implied emission factors. However, deriving these estimates required numerous assumptions, such as air pollutant emission factors for biomass. These emission factors can vary considerably, according to the (abatement) technologies used.

The following sectors were looked at: Public electricity and heat production, Petroleum refining, Manufacture of solid fuels and other energy industries, Stationary combustion in manufacturing industries and construction, Stationary combustion in Commercial/institutional, Stationary combustion in Residential, and Stationary combustion in Agriculture/Forestry/Fishing. A main limitation is that only total emissions are reported and there are no emissions per type of fuel. An attempt was made to separate emissions from biomass from the total emissions, by assuming an emission factor (EF) for biomass (default factor from EMEP/EEA guidebook). Subsequently, emissions from biomass were subtracted from the total emissions in order to derive the non-biomass emissions. Both emissions (biomass, non-biomass) were then related to the respective activity data (biomass and non-biomass fuel consumption), in order to calculate an emission factor.

However, this attempt did not lead to plausible, robust values. Some of the most significant drawbacks were the lack of data, the lack of detail in the available data and the lack of consistency in the available data. In the light of these issues, this data source was disregarded.

2.3.2 The LCP emission inventory

The most important drawback with regard to data from the LCP ([3]) emission inventory is that only large combustion installations are captured, whilst medium and small combustion plants fall out of the scope of the inventory. Since the latter can be significant sources for air pollutant emissions, the LCP emission inventory was ruled out as main data source for this assessment.

2.3.3 Historic data from the GAINS model

The Gas and Air Pollution Interactions and Synergies (GAINS) ([4]) model and its historic data were considered the most suitable source for the calculation of country-specific emission factors for air pollutants. The results of the GAINS model are publicly available and give insights into the emissions of several substances related to activity data per technology (GAINS activities). Moreover, the results of the GAINS model were used for the negotiations of the adopted emission reduction commitments for 2030 as laid down in the NEC Directive (2016/2284/EU). For combustion technologies, the activity data are typically the amounts of fuel combusted. The results of the GAINS model are available in more detail than emission statistics. Another strength of this dataset is that IIASA consults with national experts on the input data. The bilateral consultations do not mean by default a full endorsement by all

([3]) Large Combustion Plants
([4]) GAINS is an integrated assessment model containing information on the sources and impacts of air pollutant and GHG emissions, and their interactions. For a more detailed description we refer to the website of IIAS (IIASA 2018).

Member States of all the information used in the GAINS model, but that they understand why there are sometimes discrepancies between the modelled data and national data. This was perceived as an important strength during the negotiations of the NEC Directive, even where GAINS-data and national data may differ quite a lot for some specific sectors.

2.3.4 The EMEP/EEA Guidebook 2016

The EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2016), formerly called the EMEP CORINAIR emission inventory guidebook, provides guidance on estimating emissions from both anthropogenic and natural emission sources. It is designed to facilitate reporting of emission inventories by countries to the UNECE Convention on Long-range Transboundary Air Pollution and the EU National Emission Ceilings Directive. Besides guidance on estimation methods for different sectors and technologies, it also provides default emission factors, typically referred to as Tier 1 emission factors. These can be used by countries, in certain cases when no country specific emission factors are available. In last instance, these default emission factors could be used for our exercise when totally no country-specific information could be retrieved. Another use of these default emission factors could be for comparison with values calculated based on data from other sources, such as from GAINS.

2.4 Method to calculate reference emission factors based on GAINS data

Two steps are followed for calculating the reference emission factors for key air pollutant emissions:

(1) First, for each individual pollutant the implied emission factors (IEF) are calculated per fuel type and country, based on GAINS activity and emissions data. These IEFs relate to the initial energy carriers ([5]).
(2) Second, the implied emission factors are multiplied with primary energy factors, in order to obtain the emission factors that relate to the final renewable energy consumption. The result of this multiplication is the reference emission factor (REF). This reference emission factor is then used to calculate the overall effect of renewable energy consumption – notably renewable electricity (RES-E), renewable heating and cooling (RES-H/C) and renewables used in transport (RES-T) – on air pollutant emissions.

The GAINS model contains emissions of ([6]):

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrogen oxides (NO_x)
- Nitrous oxide (N_2O)
- Particulate matter (total suspended particles (TSP), PM_{10}, $PM_{2.5}$ and PM_1)
- Sulphur dioxide (SO_2)
- Volatile organic compounds (VOCs)

Certain versions of the model also contain ammonia (NH_3), carbon monoxide (CO) and fluorinated greenhouse gases (F-Gases).

GAINS uses historic data on energy consumption from energy statistics. In addition, the model contains alternative pathways for energy use up to 2030, derived from national and international energy projections ([7]). Annex 2 gives an overview of the energy carriers that are available in the GAINS database.

([5]) In GAINS, the energy carriers are represented as specific ‘activities’.
([6]) Source: GAINS Europe online. http://gains.iiasa.ac.at/gains/EUN/index.login?logout=1. Accessed 10 February 2016.
([7]) Source: Aggregation of energy data in GAINS, document on the website http://gains.iiasa.ac.at/gains/.

In GAINS, the emissions from fuel combustion in a given year are calculated according to the following formula:

$$EM_p = \sum_{fc} (FC_{f,t} * EF_{f,t,p})$$

with:

- EM_p total national emission of pollutant *p*. [Unit: kt]
- FC_{ft} consumption of fuel *f* in combustion technology *t*. [Unit: PJ]
- $EF_{f,t,p}$ emission factor of pollutant *p* for combustion technology *t* using fuel *f*. [Unit: kt per PJ]

The GAINS historic data provides emissions and fuel consumption for a large number of technologies (GAINS activities). This makes it possible to calculate average national implied emission factors by fuel and technology.

> ***Example:*** *in 2010, 136 PJ of fuelwood was used in automatic single house boilers (<50W) in Germany. This caused an emission of 2.85 kton of PM. The implied emission factor (IEF) equals then to 2.85 kton PM/136 PJ = 0.021 kton/PJ. In the same way, implied emission factors can be calculated for a wide range of combinations of countries, technologies (GAINS activities) and fuels.*

2.4.1 Calculating reference emission factors for electricity from GAINS data

The following technologies (GAINS activities) are taken into account when calculating the IEF for electricity:

- Power & district heat plants – existing coal (> 50 MW th) [PP_EX_L]
- Power & district heat plants – existing (excl. coal) [PP_EX_OTH]
- Power & district heat plants – existing coal (< 50 MW th) [PP_EX_S]
- Power & district heat plants – IGCC [PP_IGCC]
- Power & district heat plants – IGCC with CCS [PP_IGCC_CCS]
- Power & district heat plants with internal combustion engines [PP_ENG]
- Power & district heat plants – new (excl coal) [PP_NEW]
- Power & district heat plants - new coal (> 50 MW th) [PP_NEW_L]
- Modern power plants – coal: ultra- and supercritical; gas: CCGT [PP_MOD]
- Modern power plants - coal: ultra- and supercritical; gas: CCGT with CCS [P_MOD_CCS]

The following fuels are taken into account when calculating the IEF of electricity from fossil fuels for country c ($EF_{NOx,e,ff}$(ff,*yr*,*c*)):

- Brown coal/lignite grade 1 [BC1]
- Brown coal/lignite grade 2 (also peat) [BC2]
- Derived coal (coke, briquettes) [DC]
- Natural gas (incl. other gases) [GAS]
- Gasoline and other light fractions of oil; includes biofuels [GSL]
- Hydrogen [H2]
- Hard coal, grade 1 [HC1]
- Hard coal, grade 2 [HC2]
- Hard coal, grade 3 [HC3]
- Heavy fuel oil [HF]
- Liquefied petroleum gas [LPG]
- Medium distillates (diesel, light fuel oil; includes biofuels) [MD]

- Black liquor [BLIQ]
- Waste fuels, non-renewable [WSFNR]

The following fuels are taken into account when calculating the IEF of electricity from renewable fuels ($EF_{NOx,e,rrf}$ (rf,*yr,c*)):

- Biogas [BIOG]
- Charcoal [CHCOA]
- Fuelwood direct [FWD]
- Waste fuel, renewable [WSFR]
- Remark: biofuels are included in MD and GSL (see previous)

With regard to air induced pollutant emissions, the relevant electricity-generating renewable energy technologies are those relying on solid biomass, biogas and bioliquids.

To calculate the IEF for country c of fossil fuels for electricity, the fossil fuel (ff) related NO_x emissions of the technologies t (GAINS activities) are divided by the fossil fuel consumption.

$$Implied\ EF_{NOx,e(ff,yr,c)} = \frac{\sum_{t,ff} NOx\ emissions\ (yr,c,t,ff)}{\sum_{t,ff} Fuel\ Consumption\ (yr,c,t,ff)}$$

To calculate the IEF for renewable fuels for electricity the renewable fuel related NO_x emissions of the technologies t (GAINS activities) are divided by the renewable fuel consumption. This is done for solid, liquid and gaseous renewable fuels.

$$Implied\ EF_{NOx,e(rf,yr,c)} = \frac{\sum_{act,rf} NOx\ emissions\ (yr,c,t,rf)}{\sum_{act,rf} Fuel\ Consumption\ (yr,c,t,rf)}$$

The avoided air pollutant emissions are calculated starting from the final renewable electricity consumption, analogous to the calculation of avoided GHG emissions (for a description refer to 2.1). However, the IEFs are calculated for initial energy carriers since these are available in the GAINS dataset. This explains why the IEF has to be multiplied by the primary energy factor in order to calculate the reference emission factor that relates to the final renewable electricity consumption.

The emission factor of electricity from fossil fuels in a given year (yr) and country (c) ($EF_{NOx,e,ff}$(ff, *yr, c*)) can then be calculated as follows:

$$\text{Reference EF}_{NOx,e,ff}(\text{ff}, yr, c) = \ Implied\ EF_{NOx,e(ff,yr,c)} \times PE_e(yr,c)$$

With PE_e(yr,c): primary energy use per unit of electricity in a given year (yr) and country (c) (see 2.2) the reference emission factor of electricity from renewable fuels is calculated in the same way as for fossil fuels.

In the GAINS data set, only data about solid renewable fuels are included separately, while for liquid and gaseous renewable fuels no separate data on emissions and activity data are included due to similarity in emission profiles. The latter are included in their corresponding fossil fuels categories: biogas is included in the category Natural Gas (incl. other gases) [GAS], and bioliquids are included in the categories Medium distillates [MD] and Gasoline [GSL] without specific emission factors existing for the renewable fuels. The EMEP/EEA guidebook too does not contain Tier 1 emission factors for liquid and gaseous biofuels (for further information on the EMEP/EEA guidebook see section 2.3.4).

According to expert feedback from IIASA, biogas emission factors are quite similar to those of natural gas, except for SO_2 emissions, which are higher. Therefore, natural gas combustion in engines [PP_ENG] is used as better estimate for this implied emission factor, since installations producing electricity from renewable gas are typically co-digesters combined with an engine where no purification takes place. While this leads to slightly higher implied emission factors, these are believed to be closer to reality regarding the emissions of SO_2 and of the other pollutants.

Liquid biofuels are mainly used as a mixture in engines. For this technology, the differences could be higher because of temperature, air/fuel concentration, operating conditions and different abatement technologies. Following expert feedback from IIASA, GAINS fuel categories Medium distillates [MD] and Gasoline [GSL] are used as best estimates for calculating the implied emission factors for liquid biofuels.

2.4.2 Calculating reference emission factors for heat in the ETS sector from GAINS data

The following technologies (GAINS activities) are taken into account when calculating the implied emission factors for heat from fossil fuels in the ETS sectors:

- Fuel conversion – combustion [CON_COMB]
- Fuel conversion (grate firing) [CON_COMB1]
- Fuel conversion (fluidized bed boiler) [CON_COMB2]
- Fuel conversion (pulverized bed boiler) [CON_COMB3]
- Medium boilers (<50MW) – automatic [DOM_COM_MB_A]
- Medium boilers (<50MW) - automatic (agr, forestry, other) [DOM_OTH_MB_A]
- Industry: chemical industry (combustion in boilers) [IN_BO_CHEM]
- Industry, transformation sector, combustion in boilers [IN_BO_CON]
- Industry: other sectors; combustion of fossil fuels other than brown coal/lignite and hard coal [IN_BO_OTH]
- Industry: other sectors; combustion of brown coal/lignite and hard coal in large boilers (> 50 MWth) [IN_BO_OTH_L]
- Industry: other sectors; combustion of brown coal/lignite and hard coal in small boilers (< 50 MWth) [IN_BO_OTH_S]
- Industry: paper and pulp production (combustion in boilers) [IN_BO_PAP]
- Industrial furnaces: chemical industry [IN_OC_CHEM]
- Industrial furnaces: iron and steel [IN_OC_ISTE]
- Industrial furnaces: non-ferrous metals [IN_OC_NFM]
- Industrial furnaces: non-metallic minerals [IN_OC_NMM]
- Industrial furnaces: other industry [IN_OC_OTH]
- Industrial furnaces: paper and pulp [IN_OC_PAP]

The following fuels are taken into account when calculating the implied emission factor of heat from fossil fuels in the ETS sector ($EF_{NOx,h\text{-}ETS,ff(ff,yr,c)}$):

- Brown coal/lignite grade 1 [BC1]
- Brown coal/lignite grade 2 (also peat) [BC2]
- Derived coal (coke, briquettes) [DC]
- Natural gas (incl. other gases) [GAS]
- Gasoline and other light fractions of oil; includes biofuels [GSL]
- Hydrogen [H2]
- Hard coal, grade 1 [HC1]
- Hard coal, grade 2 [HC2]

- Hard coal, grade 3 [HC3]
- Heavy fuel oil [HF]
- Liquefied petroleum gas [LPG]
- Medium distillates (diesel, light fuel oil; includes biofuels) [MD]
- Black liquor [BLIQ]
- Waste fuels, non-renewable [WSFNR]

The following fuels are taken into account when calculating the implied emission factor of heat from renewable fuels in the ETS sectors ($EF_{NOx,,h\text{-}ETS,rf}(rf,yr,c)$):

- Biogas [BIOG]
- Charcoal [CHCOA]
- Fuelwood direct [FWD]
- Waste fuel, renewable [WSFR]
- Remark: biofuels are included in medium distillates and gasoline (MD and GSL, see previous)

Concerning induced air pollutant emissions, the relevant heat-producing renewable energy technologies are those relying on solid biomass, biogas and bioliquids. The reference emission factors for fossil fuels and renewable fuels are calculated in the same manner as described above with regard to electricity. By multiplying the obtained reference emission factors with the primary factor for heat (see sections 2.2 and 2.4.1), emissions for fossil and renewable fuels are calculated starting from the final heat consumption.

Only for solid and gaseous renewable fuels, the GAINS data set presents separate activity data, not for liquid renewable fuels. Because of similarity in emission profiles, the latter are included in their corresponding fossil fuels categories: Medium distillates [MD] and Gasoline [GSL] without specific emission factors existing for the renewable fuels. The EMEP/EEA guidebook (see section 2.3.4) too does not contain Tier 1 emission factors for liquid biofuels. Following expert feedback from IIASA, GAINS fuels medium distillates and gasoline are used as best estimates for calculating the implied emission factors for liquid biofuels for these technologies.

For gaseous renewable fuels in GAINS, data are available for only two countries (Germany and Poland). In general, the implied emission factors calculated based on these data are higher than the implied emission factors for heat non-ETS (see section 2.4.3), which seemed implausible. Further investigations with IIASA experts led to the selection of the implied emission factor of heat, non-ETS, as best estimate for the implied emission factor for heat, ETS.

2.4.3 Calculating reference emission factors for heat in the non-ETS sector from GAINS data

The following technologies (GAINS activities) were taken into account when calculating the implied emission factors for heat in non-ETS sectors:

- Residential-commercial [DOM_COM]
- Medium boilers (<1MW) - manual (commercial) [DOM_COM_MB_M]
- Fireplaces (agr, forestry, other) [DOM_OTH_FPLACE]
- Medium boilers (<1MW) - manual (agr, forestry, other) [DOM_OTH_MB_M]
- Three-stone stove (agr, forestry, other) [DOM_OTH_PIT]
- Single house boilers (<50 kW) - automatic (agr, forestry, other) [DOM_OTH_SHB_A]
- Single house boilers (<50 kW) - manual (agr, forestry, other) [DOM_OTH_SHB_M]
- Cooking stoves (agr, forestry, other) [DOM_OTH_STOVE_C]
- Heating stoves (agr, forestry, other) [DOM_OTH_STOVE_H
- Fireplaces (households) [DOM_FPLACE]

- Three-stone stove (households) [DOM_RES_PIT]
- Single house boilers (<50 kW) automatic [DOM_SHB_A]
- Single house boilers (<50 kW) - manual [DOM_SHB_M]
- Heating stoves [DOM_STOVE_H]
- Cooking stoves [DOM_STOVE_C]

The same fossil and renewable fuels as for electricity and heat in the ETS sectors are taken into account to calculate the implied emission factors of heat from fossil fuels and from renewable energy, respectively, in the non-ETS sectors ($EF_{NOx,h\text{-}non\text{-}ETS,ff}(ff,yr,c)$; $EF_{NOx,h\text{-}non\text{-}ETS,rf}(rf,yr,c)$) (see 2.4.1 and 2.4.2).

Implied emission factors for fossil and renewable fuels are calculated in the same way as for electricity. By multiplying these reference emission factors with the primary factor for heat (see 2.2), the reference emission factor (REF) is determined. With this REF, emissions of fossil and renewable fuels are calculated, starting from the final heat consumption.

Except for solid and gaseous renewable fuels, the GAINS data sets present no separate activity data for liquid renewable fuels. As previously explained, because of similarity in emission profiles, liquid renewable fuels (bioliquids) are included in the corresponding fossil fuels categories Medium distillates [MD] and Gasoline [GSL] and no separate emission factors are used. The EMEP/EEA guidebook (2.3.4) also does not contain Tier 1 emission factors for liquid biofuels. Following expert feedback from IIASA, it was decided to use medium distillates [MD] and gasoline [GSL] as best estimates for calculating the implied emission factors for liquid biofuels for these technologies.

2.4.4 Calculating reference emission factors for transport fuels from GAINS data

The following technologies (GAINS activities) were taken into account when calculating the emission factors for transport fuels (EF_{NO_xd} and EF_{NO_xp}):

- Non-road: Construction machinery [TRA_OT_CNS]
- Non-road - other [TRA_OT_LB]
- Non-road - 2-stroke engines [TRA_OT_LD2]
- Non-road: Railways [TRA_OT_RAI]
- Buses [TRA_RD_HDB]
- Heavy duty vehicles [TRA_RD_HDT]
- Mopeds [TRA_RD_LD2]
- Cars [TRA_RD_LD4C]
- Light duty vehicles [TRA_RD_LD4T]
- Motorcycles [TRA_RD_M4]

The use of biofuels is limited to road and non-road transport, excluding therefore maritime transport, also inland shipping, and aviation.

The relevant fuels are:

- Gasoline [GSL]
- Diesel [MD]

The GAINS data sets present no information on separate emission factors of fossil fuels and renewable fuels in transport. Biofuels are included in medium distillates [MD] and gasoline [GSL]. The EMEP/EEA guidebook (EMEP/EEA, 2016) also does not contain Tier 1 emission factors for renewable fuels in transport.

In the context of this exercise, the first working assumption was that the SO_2 emissions of biofuels are equal to those of the corresponding fossil fuels. However, NO_x and $PM_{2.5}$ emissions could alter when blending fossil fuels and biofuels. Some studies conclude that ethanol blends and biodiesel blends would reduce PM emissions and produce higher levels of NO_x concentrations compared with fossil fuels (Marelli et al., 2015). However, there are also contradictory studies (Kousoulidou et al., 2008) of which some establish increases and other decreases. Emissions depend on many factors, such as the blend of the fuel, the type of vehicle, and testing conditions. Using specific emission factors related to specific blends, vehicles or conditions is thus not advisable. However, using a COPERT ([8]) modelled emission factor connected to the total vehicle park and its average properties would be acceptable. The study "Effect of biodiesel and bioethanol on exhaust emissions" (Kousoulidou et al., 2008) concludes that:

- The effect of biodiesel blends on NO_x emissions is highly dependent on engine technology. Available measurements have shown that B5-B10 blends show a marginal difference, i.e. in the order of 1%.
- For a complete current vehicle fleet, use of biodiesel is expected to lead to reductions of PM.
- With respect to the upcoming Euro 5 regulations on the control of the solid particle number, the effect of biofuel is expected either minimal or slightly positive.
- The effects of bioethanol on current spark-ignition vehicles are difficult to quantify. NO_x emissions are controlled by the stoichiometry and the catalyst condition rather than the fuel used.

In the report of the Danish projections of air pollutant emissions 2015-2030 (Nielsen et al., 2017) reference is made to a literature review carried out in the Danish research project REBECa. This review revealed that there are no significant changes in emission factors between neat gasoline and E5 gasoline-ethanol blends for the combustion related emission components: nitrogen oxides (NO_x) carbon monoxide (CO) and volatile organic compounds (VOCs) (Winther et al., 2012). Hence, due to the current low ethanol content in today's road transport gasoline, and given that the ethanol content is not expected to exceed 10% at any time in the near future, no modifications of the neat gasoline based COPERT emission factors are made in the inventory projections in order to account for ethanol usage. In the same report, for biodiesel, reference is made to REBECa results published by Winther (Winther, 2009), which show that the emission impact of using diesel-biodiesel blends is very small at low biodiesel blend ratios. Consequently, biofuel emission factor adjustments are not proposed for diesel vehicles either.

Bearing in mind (i) the different factors that influence emissions from transport fuels, (ii) the limited measurements carried out for some of these factors and their uncertainty, and (iii) several studies stating that the emission impact of renewable transport fuels is rather small at low blend ratios; for deriving the first estimate in the context of this exercise **the working hypothesis is that the substitution of fossil by renewable biofuels in transport does not lead to transparently "measurable" (positive or negative) change effects with regard to air pollutant emissions**.

2.4.5 Other methodological aspects

The implied emission factors thus calculated from GAINS data were compared with Tier 1 emission factors from the EMEP/EEA guidebook (EMEP/EEA, 2016) in order to check plausibility (see Table 2.1).

In the output of the GAINS model, results are only available at five-year intervals (2005, 2010, 2015, 2020). We use linear interpolation to calculate implied emission factors for intermediate years.

([8]) COPERT is a software tool used world-wide to calculate air pollutant and greenhouse gas emissions from road transport. The development of COPERT is coordinated by the European Environment Agency (EEA), in the framework of the activities of the European Topic Centre for Air Pollution and Climate Change Mitigation.

For example, when 20XX is a year in the period 2005-2010:

$$IEF(20XX, c) = \frac{(2010 - 20XX) \cdot IEF(2005, c) + (20XX - 2005) \cdot IEF(2010, c)}{(2010 - 2005)}$$

Where:

IEF(*yr,c*) = Implied Emission Factor in a given year (*yr*) and country (*c*) [kton/ktoe]

GAINS estimates historic emissions for each country based on data from international energy and industrial statistics, emission inventories and on data supplied by countries themselves. It assesses emissions on a medium-term time horizon, with projections being specified in five-year intervals through the year 2050. GAINS employs a uniform approach to all countries, which reflects the most important local factors. In 2014 IIASA held bilateral meetings with experts from all 28 Member States to review input data and results of the GAINS modelling exercise (Amman et al., 2014).

In February 2016, GAINS datasets were available for thirteen scenario groups (see Annex 1). The dataset from the WPE2014-CLE scenario is used for all the calculations. This is the updated 'current legislation' projection for 2030 of the PRIMES 2013 REFERENCE activity projection. This is a recent scenario that has been well-documented. All calculations are performed based on the dataset provided by IIASA on 28 March 2017.

For some countries, for some years, for RES-E and RES-H/C, no implied emission factor could be calculated for renewable solid and liquid fuels since no data were available in GAINS. It could be that there was in fact no renewable production based on solids or liquids or it could be that for some reason the data were not included in GAINS. The next variants could be distinguished, together with the applied adjustments:

- Implied emission factors are missing for the two first years (2005 and 2010) or for the two last years (2015 and 2020). The missing years were filled in by applying the trend of the EU-28 implied emission factor to the available implied emission factors for the country.
- Implied emission factors or one implied emission factor is missing for an intermediate year (2010 and/or 2015). The implied emission factors for these intermediate years are derived by interpolation.
- Implied emission factors are missing for the entire time series. The implied emission factor of the EU-28 was used as best estimate.
- Implied emission factors are missing for one year 2005 or 2020 and all the other implied emission factors show a constant value. The constant value is also applied to the missing implied emission factor.

It has to be noted that in this way an implied emission factor could, in principle, be added for years where no renewable production was taking place. However, if for those years no renewable energy consumption is reported, the calculation will result in a zero effect.

2.4.5 Discussion of the method

An advantage of using GAINS data is that the amount of fuel that corresponds to the emissions of a particular technology (GAINS activity) is known. The GAINS results are based on historical data and information inputs and assumptions of the modelers, including with regard to the application of abatement technologies, supplemented with information from bilateral consultations of (national) experts (IIASA, 2015).

The GAINS model is using data based on a variety of different statistical sources. The year 2005 is the calibration year and IIASA reproduced the modelled data for this year as closely as possible to the emission inventories. For future years, the emissions and activity data are results of the modelling according to the chosen scenario.

Ideally, the main data sources and the approach used in the calculation of gross avoided GHG emissions due to RES use would fully match the approach for estimating air pollution impacts due to RES consumption. There is, however, no exact correspondence of the activities in GAINS to the selection of Eurostat data used in calculating the primary energy factors. The GAINS activities include district heating and the use of blast furnace gas. Blast furnace gas is included in the GAINS fuel category "Natural gas (incl. other gases) [GAS]". District heating and blast furnace gas cannot be separated based on GAINS data, similar to the approach for estimating GHG effects. In GAINS, CHP is included under different activities and it is not reported separately. Thus, CHP cannot be separated based on GAINS data, while in the Eurostat approach for estimating GHG effects of RES consumption, CHP is excluded.

There are many factors that influence the emission of air pollutants, such as the replacement of old installations, increasing use of abatement technologies, operating conditions and fuel switching. When total emission effects are calculated, these factors may be more relevant than the increase of renewable energy consumption.

For particulate matter, some studies show that residential wood burning emissions are underestimated because current methodologies fail to include parts of the compounds that are semi-volatile. For example, Denier van der Gon et al. (2015) constructed a revised bottom-up emission inventory for residential wood combustion (RWC) accounting for the semivolatile components of the emissions. The authors conclude that the total European organic aerosol (OA) emission estimates increased by almost a factor of two but with substantial inter-country variation. This has important implications for $PM_{2.5}$ emissions, as OA is an important contributor to PM. The authors also observed that the EEA/EMEP emission inventory guidebook of 2013 was, at that time, recently updated for wood combustion PM emission factors. They analysed the new emission factors and concluded that they are in line with what was used in their study.

Despite the fact that the new emission factors are in line with the study's findings it is likely that these emissions are still underestimated in some country's emission inventories and in the GAINS emissions data.

Other insights into the effects of renewable energy could be obtained from Life Cycle Analysis using databases such as Ecoinvent and GaBi. We have chosen to limit this assessment to direct emission effects only, in line with the existing approach developed to estimate the effects of RES increase on GHG emissions in the energy system (EEA, 2015).

Finally, the amount of air pollutants that is emitted does not give complete insight into the environmental and health effects. These also depend on where and in which weather conditions the emissions take place. This may be especially important for small-scale biomass use. In addition, atmospheric processes can create new air pollutants.

2.5 Implied emission factors based on GAINS

Based on the GAINS data (dataset provided by IIASA on 28 March 2017, scenario WPE2014-CLE) implied emission factors are derived for:

- electricity from renewable fuels; solid, liquid, gas

- electricity from non-renewable fuels; total
- heat in ETS from renewable fuels; solid, liquid, gas
- heat in ETS from non-renewable fuels; total
- heat in non ETS from renewable fuels; solid, liquid, gas
- heat in non ETS from non-renewable fuels; total

for the air pollutants: NO_x, PM_{10}, $PM_{2.5}$, SO_2 and VOCs and for the years 2005, 2010, 2015 and 2020 with interpolations for all the intermediate years.

An overview of the selected technologies (GAINS activities) and fuels for each implied emission factor is included in Annex 4 of this report.

An overview of the detailed results per Member State is included in the background report 'Results of implied emission factors per Member State based on GAINS data' accompanying this report.

Implied emission factors for the EU-28

Table 2.1 provides an overview of the total EU-28 implied emission factors calculated with GAINS data as average IEFs (total emissions/total activity for all the EU-28 Member States) for the 5-year intervals between 2005 and 2020. For comparison the default Tier 1 emission factors from the EMEP/EEA guidebook (EMEP/EEA, 2016) are added. All the units are expressed in kt/PJ.

In general, the emission factors are decreasing over time and are below the default Tier 1 values. Except for SO_2 emission factors for biomass, where EU emission factors are higher than the default Tier 1 values.

For electricity production, except for the emission factors (for all pollutants) from gaseous renewable fuels, emission factors are decreasing. Emission factors for electricity production from liquid renewable fuels and non-renewable fuels show the strongest decreases. This means that air pollutant emissions will decrease in time even if a country would keep producing electricity from non-renewable fuels. However, if a country would increase electricity production from gaseous renewable fuels that replace gaseous non-renewable fuels, this would increase air pollutant emissions. For heat production in sectors under the EU ETS (see 'Heat ETS' in Table 2.1), the emission factor for SO_2 is decreasing stronger for non-renewable fuels than for solid and gaseous renewable fuels. For heat production occurring in sectors outside the EU ETS (see 'Heat non ETS' in Table 2.1) almost all emission factors are decreasing stronger for renewable fuels than for non-renewable fuels, except for NO_x from solid renewable fuels.

Table 2.1 EU Implied emission factors (kt/PJ) for air pollutants (total EU emissions / total EU activity) and default Tier 1 values (kt/PJ) from the EMEP/EEA Guidebook 2016

[kt/PJ]	EMEP/EEA guidebook Tier1	2005	2010	2015	2020
Electricity from renewable fuels, solid, NO_x	0.081 (1)	0.094	0.078	0.074	0.072
Electricity from renewable fuels, solid, PM_{10}	0.155 (1)	0.011	0.012	0.010	0.011
Electricity from renewable fuels, solid, $PM_{2.5}$	0.133 (1)	0.010	0.010	0.009	0.010
Electricity from renewable fuels, solid, SO_2	0.011 (1)	0.023	0.025	0.024	0.025
Electricity from renewable fuels, solid, VOC	0.007 (1)	0.012	0.012	0.012	0.012
Electricity from renewable fuels, gas, NO_x	0.089 (2)	0.139	0.135	0.170	0.159
Electricity from renewable fuels, gas, PM_{10}	0.001 (2)	0.002	0.001	0.002	0.002
Electricity from renewable fuels, gas, $PM_{2.5}$	0.001 (2)	0.002	0.001	0.002	0.002

[kt/PJ]	EMEP/EEA guidebook Tier1	2005	2010	2015	2020
Electricity from renewable fuels, gas, SO_2	0.000 (2)	0.029	0.036	0.031	0.030
Electricity from renewable fuels, gas, VOC	0.003 (2)	0.058	0.039	0.068	0.060
Electricity from renewable fuels, liquid, NO_x	0.065-0.142 (3)	0.319	0.188	0.123	0.124
Electricity from renewable fuels, liquid, PM_{10}	0.003-0.025 (3)	0.014	0.003	0.001	0.001
Electricity from renewable fuels, liquid, $PM_{2.5}$	0.001-0.019 (3)	0.013	0.002	0.001	0.001
Electricity from renewable fuels, liquid, SO_2	0.047-0.495 (3)	0.040	0.038	0.016	0.014
Electricity from renewable fuels, liquid, VOC	0.001-0.002 (3)	0.027	0.017	0.010	0.007
Electricity from non-renewable fuels, total, NO_x	0.065-0.247 (4)	0.122	0.089	0.074	0.061
Electricity from non-renewable fuels, total, PM_{10}	0.001-0.025 (4)	0.009	0.005	0.004	0.003
Electricity from non-renewable fuels, total, $PM_{2.5}$	0.001-0.019 (4)	0.006	0.004	0.003	0.002
Electricity from non-renewable fuels, total, SO_2	0.000-1.680 (4)	0.264	0.134	0.071	0.048
Electricity from non-renewable fuels, total, VOC	0.001-0.003 (4)	0.004	0.004	0.005	0.005
Heat ETS from renewable fuels, solid, NO_x	0.091 (5)	0.094	0.087	0.082	0.079
Heat ETS from renewable fuels, solid, PM_{10}	0.143 (5)	0.022	0.017	0.022	0.020
Heat ETS from renewable fuels, solid, $PM_{2.5}$	0.140 (5)	0.020	0.015	0.019	0.018
Heat ETS from renewable fuels, solid, SO_2	0.011 (5)	0.025	0.023	0.021	0.022
Heat ETS from renewable fuels, solid, VOC	0.300 (5)	0.049	0.046	0.043	0.044
Heat ETS from renewable fuels, gas, NO_x	0.074 (6)	0.082	0.084	0.081	0.078
Heat ETS from renewable fuels, gas, PM_{10}	0.001 (6)	0.000	0.000	0.000	0.000
Heat ETS from renewable fuels, gas, $PM_{2.5}$	0.001 (6)	0.000	0.000	0.000	0.000
Heat ETS from renewable fuels, gas, SO_2	0.001 (6)	0.027	0.028	0.024	0.020
Heat ETS from renewable fuels, gas, VOC	0.023 (6)	0.002	0.002	0.002	0.002
Heat ETS from renewable fuels, liquid, NO_x	0.513 (7)	0.085	0.083	0.084	0.084
Heat ETS from renewable fuels, liquid, PM_{10}	0.020 (7)	0.001	0.001	0.001	0.001
Heat ETS from renewable fuels, liquid, $PM_{2.5}$	0.020 (7)	0.000	0.000	0.000	0.000
Heat ETS from renewable fuels, liquid, SO_2	0.047 (7)	0.043	0.021	0.024	0.023
Heat ETS from renewable fuels, liquid, VOC	0.025 (7)	0.003	0.003	0.003	0.003
Heat non ETS from renewable fuels, solid, NO_x	0.080 (8)	0.088	0.089	0.089	0.089
Heat non ETS from renewable fuels, solid, PM_{10}	0.760 (8)	0.378	0.330	0.281	0.260
Heat non ETS from renewable fuels, solid, $PM_{2.5}$	0.740 (8)	0.366	0.320	0.272	0.251
Heat non ETS from renewable fuels, solid, SO_2	0.011 (8)	0.028	0.027	0.027	0.027
Heat non ETS from renewable fuels, solid, VOC	0.600 (8)	0.681	0.549	0.458	0.407
Heat non ETS from renewable fuels, gas, NOx	0.051 (9)	0.082	0.084	0.081	0.078
Heat non ETS from renewable fuels, gas, PM_{10}	0.001 (9)	0.000	0.000	0.000	0.000
Heat non ETS from renewable fuels, gas, $PM_{2.5}$	0.001 (9)	0.000	0.000	0.000	0.000
Heat non ETS from renewable fuels, gas, SO_2	0.0003 (9)	0.027	0.028	0.024	0.020
Heat non ETS from renewable fuels, gas, VOC	0.002 (9)	0.002	0.002	0.002	0.002
Heat non ETS from renewable fuels, liquid, NO_x	0.051 (10)	0.046	0.044	0.043	0.044
Heat non ETS from renewable fuels, liquid, PM_{10}	0.002 (10)	0.001	0.001	0.001	0.001
Heat non ETS from renewable fuels, liquid, $PM_{2.5}$	0.002 (10)	0.001	0.001	0.001	0.001
Heat non ETS from renewable fuels, liquid, SO_2	0.070 (10)	0.057	0.048	0.035	0.033
Heat non ETS from renewable fuels, liquid, VOC	0.001 (10)	0.003	0.003	0.003	0.003
Heat ETS from non-renewable fuels, total, NO_x	0.074-0.173-0.513 (11)	0.026	0.023	0.023	0.023
Heat ETS from non-renewable fuels, total, PM_{10}	0.008-0.020-0.117 (11)	0.002	0.002	0.002	0.002
Heat ETS from non-renewable fuels, total, $PM_{2.5}$	0.008-0.020-0.108 (11)	0.001	0.001	0.001	0.001

[kt/PJ]	EMEP/EEA guidebook Tier1	2005	2010	2015	2020
Heat ETS from non-renewable fuels, total, SO_2	0.007-0.047-0.900 (11)	0.035	0.024	0.020	0.021
Heat ETS from non-renewable fuels, total, VOC	0.023-0.025-0.089 (11)	0.001	0.001	0.001	0.001
Heat non ETS from non-renewable fuels, total, NO_x	0.051-0.051-0.110 (12)	0.052	0.052	0.051	0.051
Heat non ETS from non-renewable fuels, total, PM_{10}	0.0012-0.0019-0.404 (12)	0.041	0.050	0.049	0.049
Heat non ETS from non-renewable fuels, total, $PM_{2.5}$	0.0012-0.0019-0.398 (12)	0.038	0.047	0.046	0.046
Heat non ETS from non-renewable fuels, total, SO_2	0.0003-0.070-0.900 (12)	0.114	0.127	0.116	0.118
Heat non ETS from non-renewable fuels, total, VOC	0.001-0.002-0.484 (12)	0.019	0.023	0.022	0.021

Sources: IIASA, 2017; EMEP/EEA, 2016.

Notes:

(1) Tier 1 emission factors for source category 1.A.1.a public electricity and heat production using biomass

(2) Tier 1 emission factors for source category 1.A.1.a public electricity and heat production using gaseous fuels

(3) Tier 1 emission factors for source category 1.A.1.a public electricity and heat production using gas oil (lower value) and heavy fuel oil (upper value)

(4) Minimum and maximum value of Tier 1 emission factors for source category 1.A.1.a public electricity and heat production using non renewable fuels (hard coal, brown coal, gaseous fuels, heavy fuel oil)

(5) Tier 1 emission factors for 1.A.4.b residential combustion using biomass, can be seen as the upper limit for non ETS heat production installations

(6) Tier 1 emission factors for 1.A.4.b residential combustion using gaseous fuels (no emission factors available for biogas), can be seen as the upper limit for non ETS heat production installations

(7) Tier 1 emission factors for 1.A.2 combustion in industry using liquid fuels

(8) Tier 1 emission factors for 1.A.2 combustion in industry using biomass, can be seen as the lower limit of the range for ETS heat production installations

(9) Tier 1 emission factors for 1.A.2 combustion in industry using gaseous fuels (no emission factors available for biogas), can be seen as the lower limit of the range for ETS heat production installations

(10) Tier 1 emission factors for 1.A.4.b residential combustion using liquid fuels

(11) Tier 1 emission factors for 1.A.2 combustion in industry using using non renewable fuels (solid fuels, gaseous fuels, liquid fuelsl), can be seen as the lower limit of the range for ETS heat production installations

(12) Tier 1 emission factors for 1.A.4.b residential combustion using non renewable fuels (hard coal and brown coal, gaseous fuels, liquid fuelsl), can be seen as the upper limit for non ETS heat production installations

3 RES effect on emissions of air pollutants

Based on the gross final energy consumption of renewable energy technologies (RETs), the attributes of individual RETs, primary energy use per unit of electricity or heat for the EU-28 and the Member States as included in the EEA database 2005-2015 (version July 2017, EEA 2017a), and the implied emission factors calculated with GAINS data for the EU-28 (EU average emission factors) and the Member States, an estimate is made of the gross effect ([9]) of renewable energy on air pollutant emissions for the EU-28 and per Member State. For the annual RES report and its chapter on avoided GHG emissions, calculations are based on the total RES consumptions that are normalised ([10]) and with compliant biofuels ([11]). The rationale for this choice is the aim for a clear visualisation of trends in line with the rules introduced by the Renewable Energy Directive (2009/28/EC, RED) for calculating the share of RES in gross final energy consumption. In the tables below, the impact on air pollutants is reported for normalised and compliant biofuels in order to be consistent with the RED.

3.1 RES effect on EU-28 level

3.1.1 RES effect by energy market sector

In addition to the total target for renewables for 2020 (to reach a 20% share in the gross final consumption of all fuels), the Renewable Energy Directive also mentions three energy market sectors in which renewables ought to increase: renewable electricity (RES-E), renewable heating and cooling (RES-H/C), and renewables in transport (RES-T).

At the EU level, for 2015, the total estimated RES effect results in a decrease of air pollutant emissions of 37 kt for NO_x and 143 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 respective 129, 127 and 263 kt in 2015 compared with 2005 (see Table 3.1, Table 3.2, Table 3.3, Table 3.4 and Table 3.5 below).

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.

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.

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 (Table 2.1). 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.

([9]) The term 'gross' describes the theoretical character of the effects estimated in this way. The potential interactions between renewable energy deployment, on the one hand, and the need to reduce GHG emissions under the EU policies, as well as wider interactions with the energy and economic system, were not modelled.

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

([11]) 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.

These results per market sector have to be combined with the results per technology to have a better understanding of driving factors for increasing/decreasing emissions (See 3.1.2).

Table 3.1 Estimated effect on NOx emissions in the EU-28 (kt)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
RES-E	0.0	-6.0	-12.0	-18.3	-24.2	-29.3	-35.0	-43.5	-49.8	-56.7	-66.0
RES-H/C	0.0	3.7	9.4	11.5	13.7	22.6	14.1	21.9	25.7	21.8	29.1
All RES	0.0	-2.3	-2.6	-6.8	-10.6	-6.7	-20.9	-21.6	-24.1	-34.9	-36.9
National Total (EEA, 15 August 2017)	11 986	11 696	11 295	10 471	9 565	9 377	9 024	8 669	8 281	7 913	7 751

Sources: IIASA, 2017; EEA, 2017a.

Table 3.2 Estimated effect on PM10 emissions in the EU-28 (kt)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
RES-E	0	-0.4	-0.7	-0.9	-1.0	-1.0	-1.3	-1.6	-1.6	-1.5	-1.3
RES-H/C	0	7.2	43.7	79.1	93.5	136.1	84.3	129.3	141.3	105.1	130.5
All RES	0	6.8	43.0	78.2	92.5	135.1	83.0	127.6	139.7	103.5	129.2
National Total (EEA, 15 August 2017)	No data available										

Sources: IIASA, 2017; EEA, 2017a.

Table 3.3 Estimated effect on PM2.5 emissions in the EU-28 (kt)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
RES-E	0	-0.2	-0.4	-0.5	-0.6	-0.5	-0.7	-0.9	-0.8	-0.8	-0.6
RES-H/C	0	7.2	42.5	76.9	91.0	132.5	82.3	126.0	137.7	102.5	127.1
All RES	0	7.0	42.1	76.5	90.5	132.0	81.6	125.2	136.8	101.7	126.5
National Total (EEA, 15 August 2017)	1 591	1 548	1 532	1 523	1 470	1 504	1 382	1 403	1 382	1 270	1 283

Sources: IIASA, 2017; EEA, 2017a.

Table 3.4 Estimated effect on SO2 emissions in the EU-28 (kt)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
RES-E	0	-18.2	-32.1	-43.0	-46.8	-46.3	-58.1	-71.5	-79.1	-84.6	-86.2
RES-H/C	0	-5.2	-6.2	-13.6	-18.7	-38.2	-42.7	-50.5	-56.6	-52.5	-56.4
All RES	0	-23.4	-38.2	-56.5	-65.5	-84.4	-100.7	-122.0	-135.7	-137.0	-142.6
National Total (EEA, 15 August 2017)	7 650	7 463	7 106	5 496	4 689	4 380	4 279	3 813	3 246	2 968	2 779

Sources: IIASA, 2017; EEA, 2017a.

Table 3.5 Estimated effect on VOC emissions in the EU-28 (kt)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
RES-E	0	0.5	1.4	2.0	2.6	4.1	6.1	8.2	12.1	13.6	13.9
RES-H/C	0	10.0	69.0	127.8	154.8	246.0	166.1	245.0	273.6	203.1	248.7
All RES	0	10.5	70.3	129.8	157.5	250.1	172.2	253.2	285.7	216.7	262.5
National Total (EEA, 15 August 2017)	9 055	8 853	8 483	8 108	7 537	7 555	7 149	6 990	6 837	6 552	6 581

Sources: IIASA, 2017; EEA, 2017a.

3.1.2 RES effect by technology

For the EU-28, Table 3.6 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. The implied emission factors for the EU as a whole are included in Table 2.1. Per Member State, the implied emission factors are included in the background report 'Results of implied emission factors per Member State based on GAINS data' accompanying this report.

Similar tables per Member State are provided in Annex 5 of this report.

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 3.6, 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 3.6 Estimated effects of RES consumption increase since 2005 on key air pollutant emissions (kt, per year, in 2015) and on fossil fuel consumption (ktoe, per year, in 2015) in EU-28

2015 (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	17.7	-0.1	0.0	-3.3	17.8	-1 461	-253	-8 180	-10 130
Renewable Electricity: Bioliquids [compliant]	0.6	0.0	0.0	0.0	0.0	-365	-45	-636	-1 075
Renewable Electricity: Concentrated solar power	-1.3	0.0	0.0	-1.3	-0.1	-310	-174	-700	-1 196
Renewable Electricity: Geothermal	-0.2	0.0	0.0	-0.1	0.0	-67	-9	-143	-225
Renewable Electricity: Hydropower excl. pumping [normalized]	-1.8	-0.2	-0.2	-2.6	-0.2	-270	402	-1 251	-1 096
Renewable Electricity: Offshore wind [normalized]	-11.8	-0.3	-0.2	-8.1	-0.5	-2 175	-1 472	-4 895	-8 726
Renewable Electricity: Onshore wind [normalized]	-44.2	-1.9	-1.5	-42.1	-2.7	-8 138	-6 330	-21 914	-37 401
Renewable Electricity: Solar photovoltaic	-25.1	-1.1	-0.9	-20.1	-2.1	-4 564	-1 124	-14 713	-20 984
Renewable Electricity: Solid biomass	0.1	2.4	2.2	-8.6	1.6	-3 328	-1 443	-6 667	-11 733
Renewable Electricity: Tidal, wave and ocean energy	0.0	0.0	0.0	0.0	0.0	-1	0	-1	-2
Total Renewable Electricity	**-66.0**	**-1.3**	**-0.6**	**-86.2**	**13.9**	**-20 679**	**-10 447**	**-59 099**	**-92 567**
Renewable Heat: Biogas	4.7	-1.6	-1.4	-2.5	-0.8	-1 703	-696	-361	-2 759
Renewable Heat: Bioliquids [compliant]	0.3	0.0	0.0	0.1	0.0	-197	-78	-36	-311
Renewable Heat: Geothermal	-0.3	-0.2	-0.2	-0.4	-0.1	-80	-46	-19	-145
Renewable Heat: Renewable energy from heat pumps	-10.5	-2.8	-2.6	-7.8	-1.5	-4 130	-1 884	2 902	-2 761
Renewable Heat: Solar thermal	-2.7	-1.2	-1.1	-3.4	-0.6	-846	-506	-161	-1 513
Renewable Heat: Solid biomass	37.6	136.3	132.4	-42.4	251.6	-12 695	-5 505	-3 196	-21 397
Total Renewable Heat	**29.1**	**130.5**	**127.1**	**-56.4**	**248.7**	**-19 651**	**-8 715**	**-871**	**-28 886**

Notes: 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: IIASA, 2017; EEA, 2017a.

3.2 RES effect at the MS level

3.2.1 RES effect by energy market sector

At the Member State level, impacts on key air pollutant emissions NO_x, SO_2, $PM_{2.5}$, PM_{10} and VOC in 2015 due to the increase of RES consumption since 2005 are illustrated in Table 3.7. For comparison, the total national emissions are also included in the table. Since there is no reporting of the total national PM10 emissions (EEA, 2017b), these are not shown in the table.

As already discussed in section 3.1.2, here too 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.

Table 3.7 Estimated effects of RES consumption increase since 2005 on key air pollutant emissions and national total emissions (kt, per year, in 2015)

	NO_x				PM_{10}			$PM_{2.5}$				SO_2				VOCs			
	RES All	RES E	RES H&C	National Total	RES All	RES E	RES H&C	RES All	RES E	RES H&C	National Total	RES All	RES E	RES H&C	National Total	RES All	RES E	RES H&C	National Total
AT	-0.8	-0.7	-0.1	149	2.3	0.1	2.3	2.3	0.1	2.3	17	-1.3	-0.4	-0.8	15	9.9	0.3	9.6	113
BE	-0.6	-1.0	0.3	197	12.0	0.1	11.9	11.6	0.1	11.5	27	0.4	0.2	0.2	43	16.5	-0.1	16.6	120
BG	-0.7	-0.6	-0.1	132	1.2	-0.1	1.2	1.3	-0.1	1.4	29	-9.6	-2.1	-7.5	142	4.4	0.1	4.3	93
CY	-0.2	-0.1	-0.1	15	0.1	0.0	0.1	0.1	0.0	0.1	1	-0.6	-0.4	-0.1	13	0.2	0.1	0.2	7
CZ	0.7	-0.8	1.5	165	1.9	0.0	2.0	2.0	0.0	2.0	23	-8.3	-3.6	-4.7	123	8.5	2.7	5.8	139
DE	-1.9	-13.7	11.8	1 187	5.9	-0.7	6.6	5.8	-0.6	6.5	99	-16.7	-13.9	-2.8	352	16.7	0.6	16.1	1 020
DK	-0.1	-1.2	1.2	114	9.8	0.0	9.9	9.6	0.0	9.6	20	0.6	-0.2	0.8	11	9.8	-0.1	9.9	109
EE	-0.1	-0.2	0.1	31	2.6	-0.2	2.8	2.6	-0.2	2.7	9	-0.9	-0.7	-0.2	32	4.1	0.0	4.1	23
EL	-4.9	-5.0	0.1	241	0.5	-0.6	1.1	0.6	-0.4	1.0		-4.3	-4.5	0.2	120	2.1	-0.2	2.3	122
ES	-10.5	-10.4	-0.1	905	2.5	-0.2	2.7	2.5	-0.1	2.7	125	-12.4	-10.9	-1.4	273	5.2	0.0	5.2	584
FI	1.2	-0.6	1.8	140	7.1	0.0	7.1	7.0	0.0	7.0	22	-5.0	-0.8	-4.2	42	12.2	0.3	11.9	88
FR	-8.1	-4.6	-3.5	835	4.1	-0.1	4.1	4.0	-0.1	4.1	165	-5.0	-5.1	0.1	153	8.9	1.2	7.7	623
HR	-0.6	-0.6	-0.1	53	-0.3	0.0	-0.3	-0.3	0.0	-0.2	20	-0.6	-0.6	0.0	15	-0.4	0.0	-0.4	61
HU	2.3	-0.3	2.6	123	21.7	0.0	21.7	20.9	0.0	20.9	54	-2.6	-0.3	-2.4	24	40.6	0.1	40.5	139
IE	-1.2	-1.2	0.0	80	-0.1	-0.1	0.0	0.0	-0.1	0.0	14	-1.7	-1.2	-0.5	18	0.7	0.0	0.6	101
IT	11.9	4.3	7.6	763	33.2	0.0	33.1	32.2	0.1	32.1	160	-0.1	-1.9	1.8	123	61.0	5.4	55.6	842
LT	0.4	0.0	0.4	55	2.3	0.0	2.3	2.4	0.0	2.4	18	-6.1	0.0	-6.1	18	5.2	0.1	5.1	59
LU	0.0	0.0	0.0	22	0.2	0.0	0.2	0.2	0.0	0.2	2	0.0	0.0	0.0	1	0.4	0.0	0.3	10
LV	0.2	0.1	0.0	37	-0.1	0.0	-0.2	-0.1	0.0	-0.1	18	0.0	0.0	-0.1	4	0.3	0.4	-0.1	41
MT	-0.1	-0.1	0.0	3	0.0	0.0	0.0	0.0	0.0	0.0	0	-0.1	-0.1	0.0	3	0.0	0.0	0.0	2
NL	0.2	-0.7	0.8	228	2.2	0.0	2.2	2.1	0.0	2.1	13	0.3	-0.2	0.6	30	5.4	0.7	4.7	139
PL	-2.9	-3.5	0.6	714	3.1	0.0	3.1	3.2	0.0	3.2	125	-25.6	-7.5	-18.1	690	23.9	0.9	22.9	531
PT	-4.4	-3.2	-1.2	180	-8.0	0.0	-8.0	-7.8	0.0	-7.8	46	-0.7	-0.9	0.2	50	-12.9	0.2	-13.1	180
RO	-2.9	-3.2	0.3	214	2.0	-0.4	2.4	2.0	-0.4	2.4	112	-12.6	-12.5	-0.1	152	2.9	-0.1	3.0	313
SE	-2.9	-2.1	-0.8	130	5.1	0.1	5.0	5.0	0.1	4.9	19	-4.0	-1.9	-2.1	19	9.4	-0.1	9.5	164
SI	-0.1	-0.2	0.1	35	2.1	0.0	2.1	2.0	0.0	2.1	12	-0.1	-0.1	0.1	5	3.0	0.1	2.9	32
SK	0.5	0.1	0.4	86	3.9	0.0	3.9	3.9	0.0	3.9	30	-0.1	-0.2	0.1	71	4.3	0.6	3.6	89
UK	-11.2	-16.7	5.5	918	12.1	1.1	11.0	11.5	1.1	10.4	105	-25.6	-16.3	-9.3	236	20.3	0.7	19.7	835
EU-28	**-36.9**	**-66.0**	**29.1**	**7 751**	**129.2**	**-1.3**	**130.5**	**126.5**	**-0.6**	**127.1**	**1 283**	**-142.6**	**-86.2**	**-56.4**	**2 779**	**262.5**	**13.9**	**248.7**	**6 581**

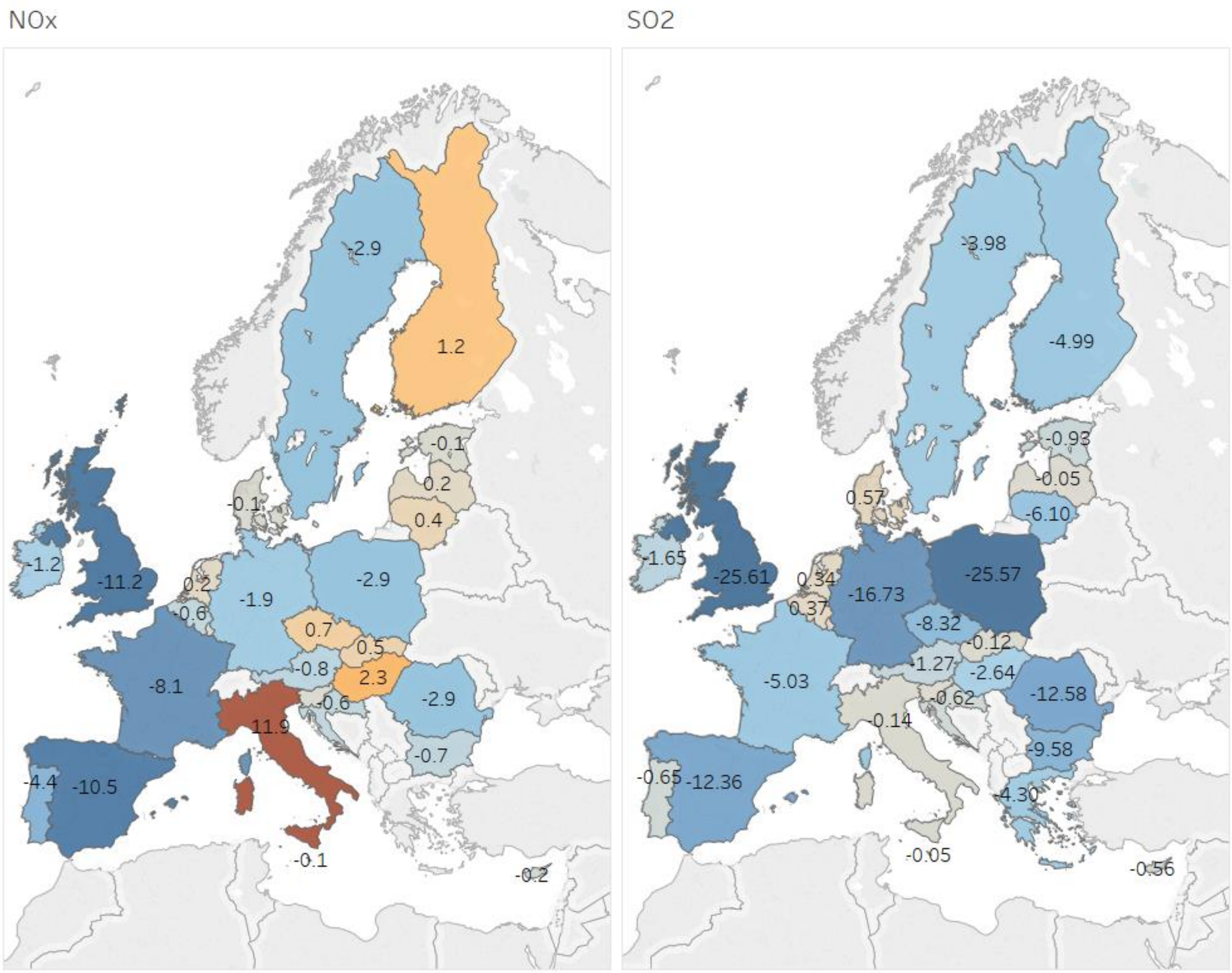
Sources: IIASA, 2017; EEA, 2017a

3.2.2 Total RES effect and total RES effect as percentage of national emissions – maps

As explained in the scoping section (see Section 1.3) 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.

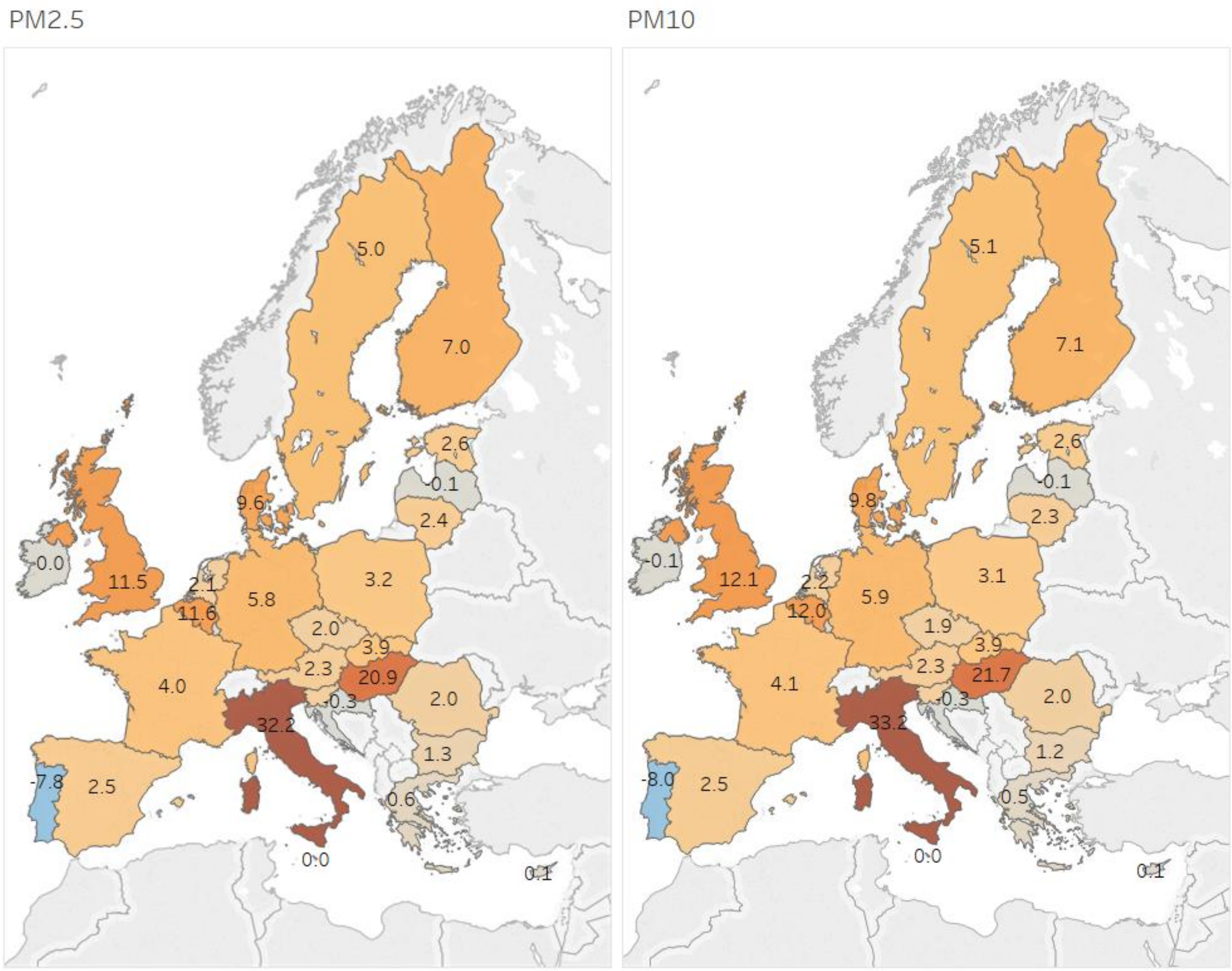
The following three figures provide a geographic overview of the total estimated effect on key air pollutant emission, due to the increase in gross final energy consumption from renewables since 2005. The effect, expressed as percentage of total national air pollutant emissions, is illustrated in the last two figures. Since there is no reporting of the total national PM_{10} emissions (EEA, 2017b), the percentage is not shown geographically for this pollutant.

Figure 3.1 Estimated effects of RES consumption increase since 2005 on total NOx and SO2 pollutant emissions (kt, per year, in 2015)



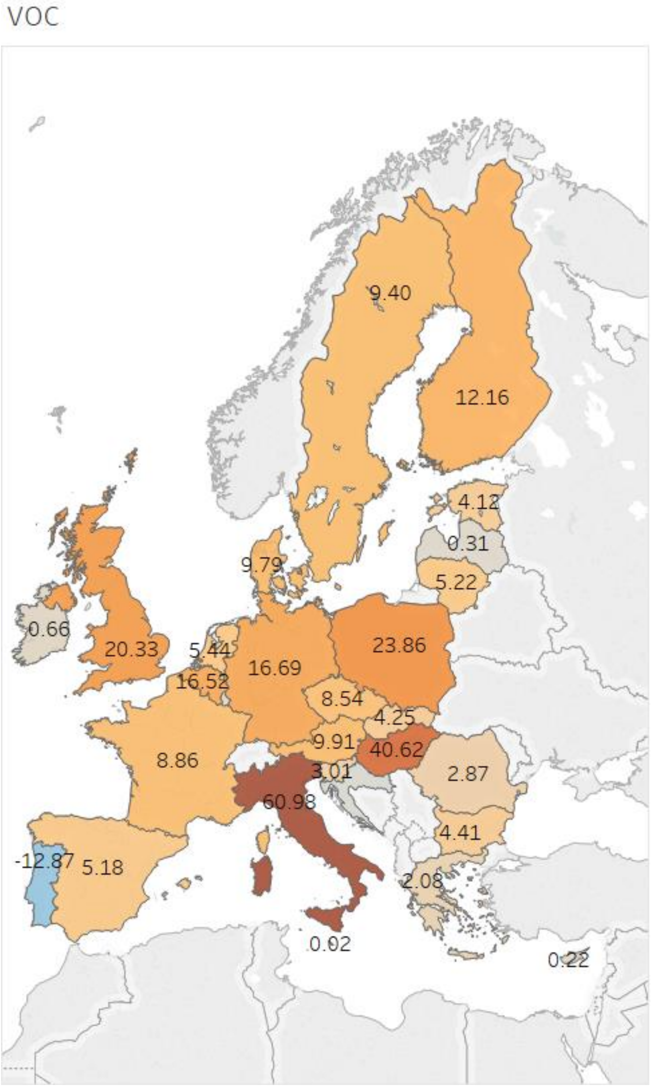
Sources: IIASA, 2017; EEA, 2017a.

Figure 3.2 Estimated effects of RES consumption increase since 2005 on total PM emissions (kt, per year, in 2015)



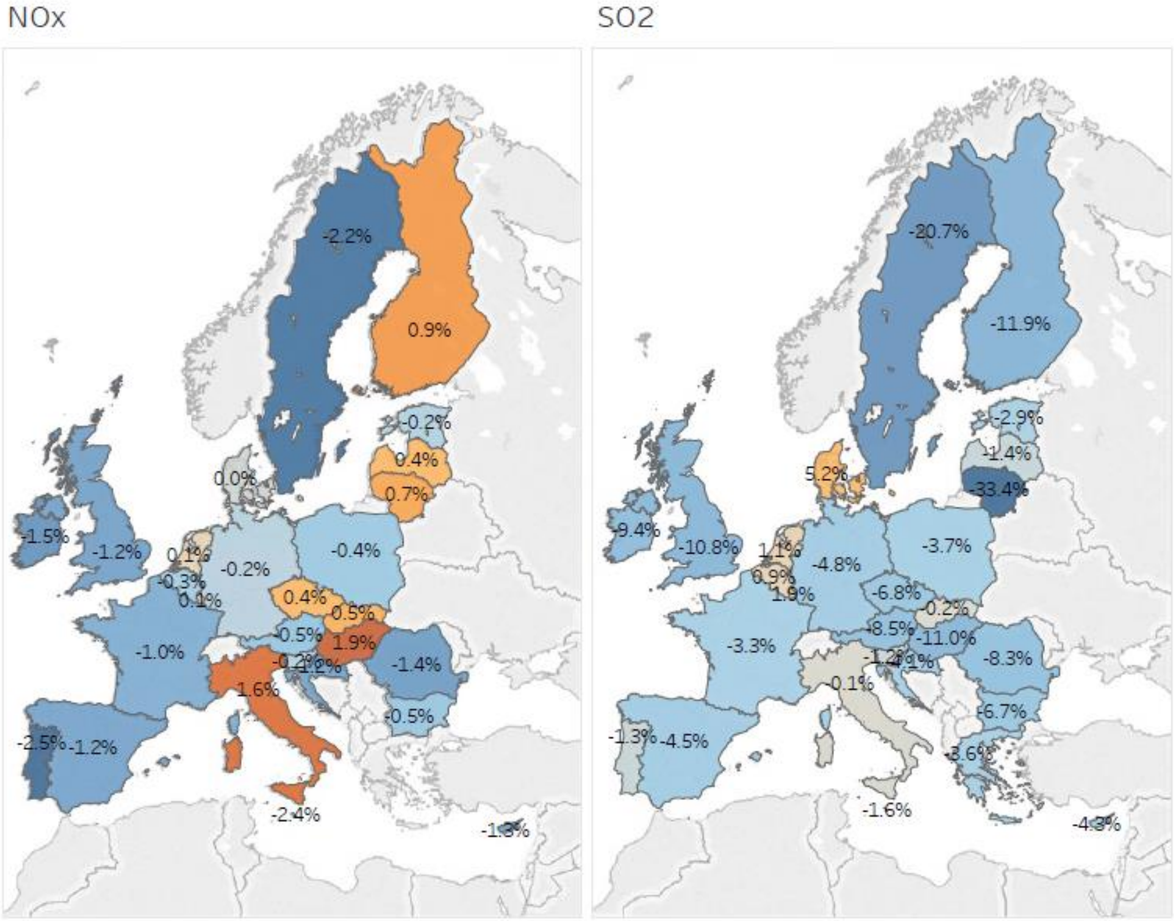
Sources: IIASA, 2017; EEA, 2017a.

Figure 3.3 Estimated effects of RES consumption increase since 2005 on total VOC emissions (kt, per year, in 2015)



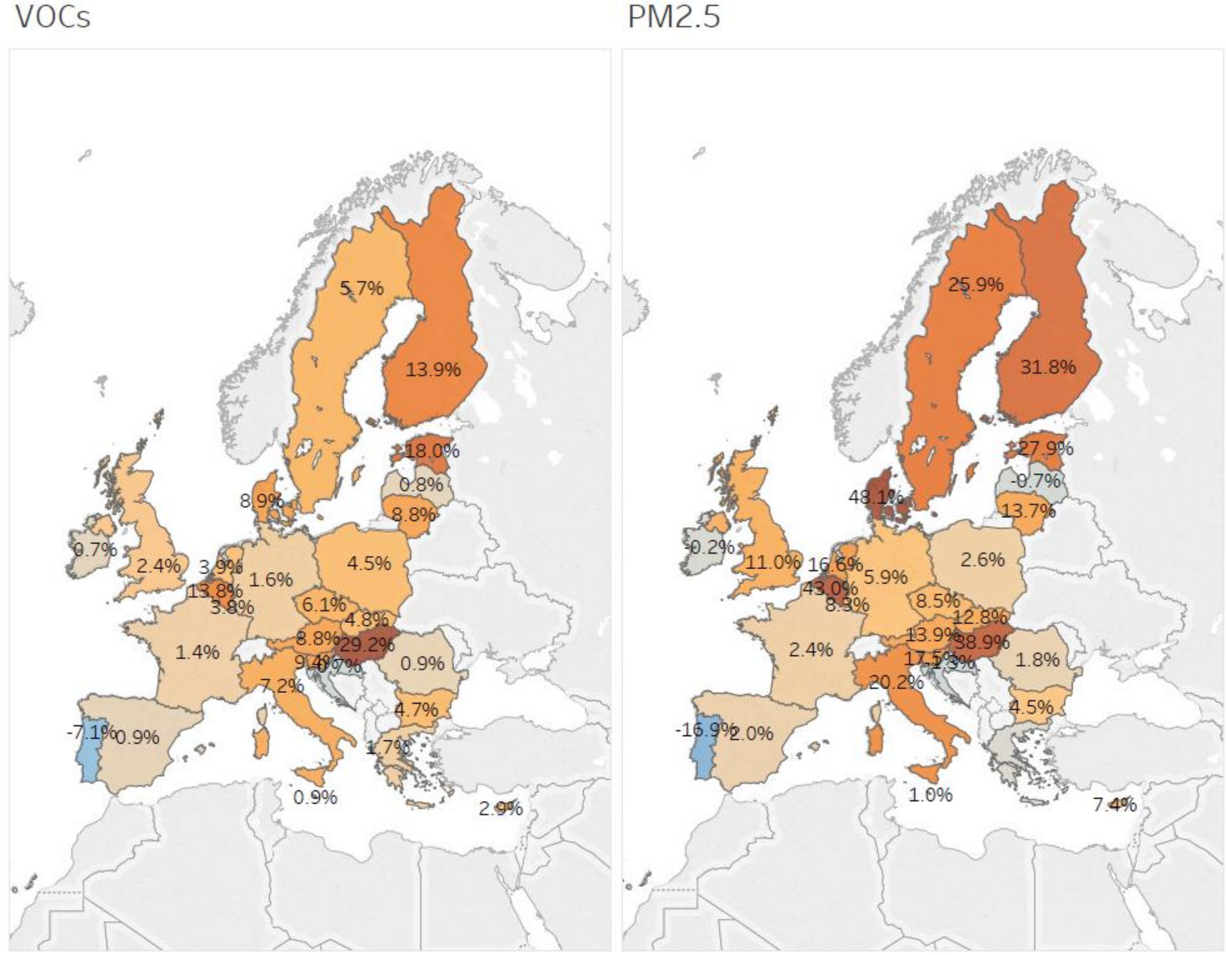
Sources: IIASA, 2017; EEA, 2017a.

Figure 3.4 Estimated effects of RES consumption increase since 2005 on total NOx and SO2 pollutant emissions as percentage of national total emissions (%, in 2015)



Sources: IIASA, 2017; EEA, 2017a.

Figure 3.5 Estimated effects of RES consumption increase since 2005 on total VOCs and PM2.5 pollutant emissions as percentage of national total emissions (%, in 2015)12



Sources: IIASA, 2017; EEA, 2017a.

In relative terms, for NO_x the results vary from a strong decrease to an increase in emissions (see Figure 3.4). The strongest decreases are caused by increasing shares of wind energy (both onshore and offshore) and, to a lesser extent, heat pumps (Portugal, Sweden, Ireland, Hungary), which are not off-set by an increase of emissions from biomass use in renewable electricity and in renewable heat production.

For SO_2, all countries show a decreasing trend in emissions (Figure 3.4), because almost all of the fossil fuels have higher implied emission factors than the renewable fuels, except for heat ETS (see table 2.1 for EU implied emission factors).

For $PM_{2.5}$ and VOCs, except for Portugal, which has decreased its consumption of biomass considerably since 2005, all countries 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 in $PM_{2.5}$ emissions is likely to have led to a strong increase of PM concentrations.

[12] There is no map for PM10 since national total emissions for PM10 are not available.

4 Conclusion

To estimate the impact of gross final consumption of renewable energy sources (RES) on air pollutant emissions, the ETC/ACM in collaboration with EEA has developed an approach based on the previously developed EEA method to estimate avoided GHG emissions due to RES consumption. It starts from the amount of renewable energy consumed in each country and year, by energy carrier and by technology, and combines these parameters with reference emission factors of the initial energy carriers. This allows the calculation of the gross avoided air pollutant emissions per country and year.

For several reasons explained in this report, GAINS data were considered to be the most suitable starting point for calculating the implied emission factors and reference emission factors underpinning the assessment. The results of these calculations are included in this report for the EU-28 and in the separate data annexes, ‘Results of implied emission factors per Member State based on GAINS data’, accompanying this report for the detailed results of IEF per Member State.

The resulting impact on air pollutant emissions is presented in Section 0 of this report. Whilst the results and conclusions have the highest level of confidence at the aggregated EU level, the country-level findings provide a useful general indication of the impacts on air pollutant emissions due to the interplay between the evolution of the renewable energy mix and the fossil fuel sources they substituted. One of the general conclusions that can be drawn from the assessment is that the larger the initial share of natural gas in the average fossil fuel mix, the higher the relative increase will be of the implied emission factors associated with the increased use of renewable solid fuels.

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Glossary

BF	Biofuel
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CHP	Combined heat and power
CLRTAP	Convention on Long-range Transboundary Air Pollution
COPERT	COPERT is a software tool used world-wide to calculate air pollutant and greenhouse gas emissions from road transport. The development of COPERT is coordinated by the European Environment Agency (EEA), in the framework of the activities of the European Topic Centre for Air Pollution and Climate Change Mitigation.
CRF	The Common Reporting Format sector classification and standardised tables containing mainly numerical information submitted electronically by Annex I Parties under the United Nations Framework Convention on Climate Change
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)
EF	Emission Factor. Measure of the average amount of a specific pollutant discharged into the atmosphere by a specific process, fuel, equipment, or source. It is expressed as the number of kilograms or tonnes of pollutant emitted per ton fuel or material. To estimate emissions of air pollutants typically process, technology (including abatement technology), fuel specific emission factors are multiplied with activity data (fuel consumption, production amounts).In this paper the term reference emission factor (REF) is also used. See under REF for more explanation.
EMEP	The European Monitoring and Evaluation Programme is a scientifically based and policy driven programme under the Convention on Long-range Transboundary Air Pollution (CLRTAP) for international co-operation to solve transboundary air pollution problems
ETC/CME	European Topic Centre on Climate Change Mitigation and Energy. The ETC/CME is a consortium of European institutes contracted by the EEA to carry out specific tasks in the field of air pollution and climate change
(EU) ETS	European Union Emissions Trading Scheme Directive (Directive 2009/29/EC amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community)
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, the United Kingdom
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 (cf. Art. 2f of Directive 2009/28/EC). With this, it excludes transformation losses, which are included in GIEC. In calculating a Member State's gross final energy consumption for the purpose of measuring its compliance with the targets and interim RED and NREAP trajectories, the amount of energy consumed in aviation shall, as a proportion of that Member State's gross final consumption of energy, be considered to be no more than 6.18% (4.12% for Cyprus and Malta).
GHG	Greenhouse gas

GIEC	Gross inland energy consumption, sometimes abbreviated as 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.
IEA	International Energy Agency
IEF	Implied Emission Factor. In this paper implied emission factor means that based on the GAINS data emissions are divided by fuels consumed for (mostly) several technologies (or GAINS categories) in order to obtain emission factors for RES-E, RES-H/C (ETS and non ETS) and RES-T. It differs from the emission factor since it may comprise different activities with different technologies and their related EF. The implied emission factor is calculated by dividing the sum of the emissions caused by all the technologies by the sum of the fuel consumptions of those technologies.
IGCC	Integrated Gasification Combined Cycle
ILUC	Indirect land-use change
kt	Kilotonnes
ktoe	Kilotonne of oil equivalent
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
MMD	Monitoring Mechanism Decision (Decision 28/2004/EC of 11 February 2004 concerning a mechanism for monitoring Community greenhouse gas emissions and for implementing the Kyoto Protocol)
MMR	Monitoring Mechanism Regulation (Regulation (EU) No 525/2013 of the European Parliament and of the Council of 21 May 2013 on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at national and Union level relevant to climate change and repealing Decision No 280/2004/EC)
Mtoe	Million tonne of oil equivalent
MW	Megawatt
MWh	Megawatt-hour (1 million W-h)
NFR	Nomenclature For Reporting, NFR tables are standard excel tables containing air pollutant emission and activity data. The tables are filled in by a country and form together with the Informative Inventory Report (IIR) the national air pollutant emission inventory.
NH3	Ammonia (a compound of nitrogen and hydrogen)
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
NREAP	National Renewable Energy Action Plan
PE	Primary energy: in the context of the EED, this represents GIEC minus n on-energy use
PJ	Petajoule (10^{15} Joules)
$PM_{2.5}$	the fraction of particles with an aerodynamic diameter smaller than 2,5 µm
PM_{10}	the fraction of particles with an aerodynamic diameter smaller than 10 µm
PR	Progress Report
PRIMES	Price-driven and agent-based energy market equilibrium model
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)
REF	Reference Emission Factor. In this paper, reference emission factor means the emission factor for each country that is used in order to calculate the effect of renewable energy consumption on air pollutant emissions. Reference emission factors are calculated for RES-E, RES-H/C (ETS and non-ETS) and RES-T. The implied emission factors (see under IEF in this Annex) are calculated for initial energy carriers since these are available in the

	GAINS dataset. That is why the implied emission factor is multiplied by the primary energy factor in order to calculate the reference emission factor that relates to the final renewable electricity consumption of a country in a certain year.
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
RF	Renewable Fuel
SHARES	Short Assessment of Renewable Energy Sources. Tool developed by Eurostat and aimed at facilitating the calculation of the share of energy from renewable sources according to the RED
SO_2	Sulphur dioxide
SOx	Sulphur oxides
SPF	Seasonal performance factor
UNFCCC	United Framework Convention on Climate Change – an international environmental treaty concerning climate change
VOCs	Volatile organic compounds

Annexes

Annex 1 OVERVIEW OF AVAILABLE GAINS SCENARIO'S

Table A1.1 Overview of scenario groups in GAINS Europe online (13)

Scenario	Description
EC4MACS_FINAL	Scenarios for final assessment within EC4MACS - December 2011
ECLIPSE	Scenario for ECLIPSE project
EnerGEO_FINAL	Scenarios for the EnerGEO project, final version. This group contains updates of CLE scenarios form January 2013 plus scenarios with 2005 emission factors and MTFR controls.
Gothenburg Protocol Revision	Scenarios for the revision of the Gothenburg Protocol
IEA_WEO2011	IEA_WEO2011 scenarios
TSAP Report #1	Scenarios prepared for the Revision of the EU Thematic Strategy on Air Pollution (TSAP). Scenarios usually take the PRIMES 2010 Reference Scenario (and associated control strategies) as starting point, but include comments from Member States.
TSAP Report #10	Scenarios for TSAP review, used in TSAP report #10
TSAP Report #11	The scenarios in this group pertain to the final analysis prior to the Proposal for a Directive of the European Parliament and of the Council on the reduction of national emissions of certain atmospheric pollutants and amending Directive 2003/35/EC as of 18 December 2013.
TSAP Report #16	TSAP Report #16
TSAP Report #6-8	These are the scenarios described in the report for the TSAP meeting in Dec 2012
TSAP_Consultations_2014	Contains scenarios created to support the country consultations in 2014 under TSAP
TSAP_Euro6_RDE	Covers scenarios for EURO 6 NO_x sensitivity study, Sept 2016.
UNEP	Copy of the WEO 2009 REF but with Asia09 emission vector TO be used for the UNEP assessment as a baseline

Under the Scenario group 'TSAP Report #16', the following scenarios are available ([14]):

- WPE2014-CLE: The updated 'current legislation' projection for 2030 of the PRIMES 2013 REFERENCE activity projection
- WPE2014-MTFR: The updated 'maximum technically feasible emission reduction' projection for 2030 of the PRIMES 2013 REFERENCE activity projection
- WPE2014-OPT: The re-optimized 67% gap closure scenario of the PRIMES 2013 REFERENCE activity projection for 2030
- NAT2014-CLE: The updated 'current legislation' scenario for 2030 for the national activity projections
- NAT2014-MTFR: The updated 'maximum technically feasible emission reduction' scenario for 2030 for the national activity projections

([13]) Source: GAINS Europe online. http://gains.iiasa.ac.at/gains/EUN/index.login?logout=1. Accessed 10 February 2016.
([14]) Adjusted historic emission data, projections, and optimized emission reduction targets for 2030 –A comparison with COM data 2013, Part A: Results for EU-28, TSAP Report #16A, Version 1.1, Editor: Markus Amann, International Institute for Applied Systems Analysis IIASA, January 2015.

Table A2.2 Energy carriers in the GAINS database (15)

Energy carriers in the GAINS database	**Description**
BC1	Brown coal/lignite, grade 1
BC2	Brown coal/lignite, grade 2 (includes peat)
DC	Derived coal (coke, briquettes)
ELE	Electricity
GAS	Natural gas (incl. CNG and derived gases)
GSL	Gasoline and other light fractions of oil; includes biofuels
H2	Hydrogen
HC1	Hard coal, grade 1
HC2	Hard coal, grade 2
HC3	Hard coal, grade 3
HF	Heavy fuel oil
HT	Heat (steam, hot water)
HYD	Hydro
LPG	Liquefied petroleum gas
MD	Medium distillates (diesel, light fuel oil; includes biofuels)
NUC	Nuclear
OS1	Biomass fuels
ARD	*Agricultural residuals - direct use*
BGS	*Bagasse*
BIO	*Biogas*
BMG	*Biomass gasification*
CHCOA	*Charcoal*
DNG	*Dung*
FWD	*Fuelwood direct*
OS2	Other biomass and waste fuels
BLIQ	*Black liquor*
WSFR	*Waste fuel, renewable*
WSFNR	*Waste fuels, non-renewable*
REN	Renewable energy other than biomass
GTH	*Geothermal*
SHP	*Small hydro power*
SPV	*Solar photovoltaic*
STH	*Solar thermal*
WND	*Wind*

(15) Source: Aggregation of energy data in GAINS, document on the website http://gains.iiasa.ac.at/gains/.

Annex 3 SUSPENDED PARTICULATES (TSP/SPM)

"Suspended particulate matter" is measured and characterised in various ways ([16]):
Total Suspended Particles is the fraction sampled with high-volume samplers, approximately particle diameters <50-100 µm.
PM_{10}: Inhalable particles, diameter <10 µm. Penetrates through the nose, by nose breathing.
Thoracic particles: approx. equal PM_{10}.
$PM_{2.5}$: "Fine fraction", diameter <2.5 µm. Penetrates to the lungs.
Black smoke: a measure of the blackness of a particle sample, sampled on a white filter paper, transformed to a mass value (µg/m3) for the particle sample by means of a standard curve. Gives a relative value for the soot content of the sample.

([16]) Source: European Environment Agency, 2008, European Environment Agency, 2008, This report is available as a website at http://www.eea.europa.eu/publications/2-9167-057-X/page021.html.

Annex 4 GAINS ACTIVITIES AND FUELS USED FOR CALCULATING IMPLIED EMISSION FACTORS

Implied emission factor	Fuel category	GAINS activities	Fuels
Electricity renewable fuels	solid	PP_EX_OTH, PP_EX_S PP_EX_L PP_NEW PP_NEW_L PP_MOD PP_MOD_CCS PP_IGCC PP_IGCC_CCS PP_ENG	CHCOA, FWD, WSFR
Electricity renewable fuels	gas (1)		GAS
Electricity renewable fuels	liquid		MD, GSL
Electricity non-renewable fuels	total excl. renewables		BC1, BC2, DC, GAS, GSL, H2, HC1, HC2, HC3, HF, LPG,MD
Heat ETS renewable fuels	solid	CON_COMB CON_COMB1 CON_COMB2 CON_COMB3 DOM_COM_MB_A DOM_OTH_MB_A IN_BO_CHEM IN_BO_CON IN_BO_OTH IN_BO_OTH_L IN_BO_OTH_S IN_BO_PAP IN_OC_CHEM IN_OC_ISTE IN_OC_NFME IN_OC_NMMI IN_OC_OTH IN_OC_PAP	CHCOA, FWD, WSFR
Heat ETS renewable fuels	gas (2)		BIOG
Heat ETS renewable fuels	liquid		MD, GSL
Heat ETS non-renewable fuels	total excl. renewables		BC1, BC2, DC, GAS, GSL, H2, HC1, HC2, HC3, HF, LPG,MD
Heat non ETS renewable fuels	solid	DOM_COM DOM_COM_MB_M DOM_OTH_FPLACE DOM_OTH_MB_M DOM_OTH_PIT DOM_OTH_SHB_A DOM_OTH_SHB_M DOM_OTH_STOVE_C DOM_OTH_STOVE_H DOM_RES_FPLACE DOM_RES_PIT DOM_RES_SHB_A DOM_RES_SHB_M DOM_RES_STOVE_C DOM_RES_STOVE_H	CHCOA, FWD, WSFR
Heat non ETS renewable fuels	gas		BIOG
Heat non ETS renewable fuels	liquid		MD, GSL
Heat non ETS non-renewable fuels	total excl. renewables		BC1, BC2, DC, GAS, GSL, H2, HC1, HC2, HC3, HF, LPG,MD

Notes: (1) For gas, only the technology PP_ENG was taken into account for natural gas
(2) For gas, the implied emission factor of heat non-ETS was taken.

Annex 5 MEMBER STATES' ESTIMATED RES EFFECT ON AIR POLLUTANT EMISSIONS PER AIR POLLUTANT COMPARED TO THE ESTIMATED RES EFFECT ON FOSSIL FUEL CONSUMPTION, PER RENEWABLE ENERGY TECHNOLOGY

Austria									
2015 (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)**
Renewable Electricity: Biogas	0.1	0.0	0.0	0.0	0.3	-25	-2	-23	-58
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	-0.3	0.0	0.0	-0.1	0.0	-209	-16	-191	-494
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	-0.4	0.0	0.0	-0.2	0.0	-267	-20	-244	-630
Renewable Electricity: Solar photovoltaic	-0.1	0.0	0.0	0.0	0.0	-72	-5	-65	-169
Renewable Electricity: Solid biomass	0.2	0.1	0.1	0.0	0.0	-123	-9	-112	-289
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-0.7**	**0.1**	**0.1**	**-0.4**	**0.3**	**-696**	**-52**	**-635**	**-1 639**
Renewable Heat: Biogas	0.0	0.0	0.0	0.0	0.0	-15	-7	-5	-27
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	-23	-11	-8	-42
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	-2	-1	-1	-4
Renewable Heat: Renewable energy from heat pumps	-0.3	0.0	0.0	-0.1	0.0	-50	-43	10	-65
Renewable Heat: Solar thermal	-0.2	0.0	0.0	-0.1	0.0	-58	-28	-20	-105
Renewable Heat: Solid biomass	0.4	2.4	2.3	-0.6	9.7	-558	-266	-192	-1 017
Total Renewable Heat	**-0.1**	**2.3**	**2.3**	**-0.8**	**9.6**	**-706**	**-357**	**-215**	**-1 260**

Belgium									
2015 (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)**
Renewable Electricity: Biogas	0.1	0.0	0.0	0.0	0.1	-89	0	-22	-122
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	-16	0	-4	-22
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	0.0	0.0	0.0	0.0	0.0	1	0	0	1
Renewable Electricity: Offshore wind [normalized]	-0.5	0.0	0.0	-0.1	-0.1	-346	-1	-87	-475
Renewable Electricity: Onshore wind [normalized]	-0.3	0.0	0.0	0.0	-0.1	-240	0	-61	-330
Renewable Electricity: Solar photovoltaic	-0.5	0.0	0.0	-0.1	-0.1	-372	-1	-94	-511
Renewable Electricity: Solid biomass	0.1	0.1	0.1	0.4	0.0	-381	-1	-96	-524
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-1.0**	**0.1**	**0.1**	**0.2**	**-0.1**	**-1 443**	**-2**	**-364**	**-1 982**
Renewable Heat: Biogas	0.0	0.0	0.0	0.0	0.0	-45	-29	-8	-82
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	-4	-3	-1	-8
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Renewable energy from heat pumps	-0.1	0.0	0.0	-0.1	0.0	-8	-20	0	-24
Renewable Heat: Solar thermal	0.0	0.0	0.0	0.0	0.0	-12	-8	-2	-22
Renewable Heat: Solid biomass	0.4	12.0	11.6	0.2	16.7	-361	-229	-64	-654
Total Renewable Heat	**0.3**	**11.9**	**11.5**	**0.2**	**16.6**	**-430**	**-288**	**-75**	**-790**

Bulgaria									
2015 (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	-0.1	0.1	0	0	-30	-31
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	-0.2	0.0	0.0	-0.5	0.0	0	0	-231	-232
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	-0.2	0.0	0.0	-0.7	0.0	0	-1	-348	-349
Renewable Electricity: Solar photovoltaic	-0.2	0.0	0.0	-0.7	0.0	0	-1	-354	-354
Renewable Electricity: Solid biomass	0.0	0.0	0.0	-0.1	0.0	0	0	-39	-39
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-0.6**	**-0.1**	**-0.1**	**-2.1**	**0.1**	**0**	**-2**	**-1 002**	**-1 004**
Renewable Heat: Biogas	0.0	0.0	0.0	-0.1	0.0	-3	-1	-1	-5
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	-1	0	0	-1
Renewable Heat: Renewable energy from heat pumps	-0.2	-0.7	-0.6	-1.8	-0.3	-59	-21	68	-11
Renewable Heat: Solar thermal	-0.1	-0.2	-0.2	-0.5	-0.1	-15	-5	-5	-24
Renewable Heat: Solid biomass	0.2	2.2	2.2	-5.1	4.7	-216	-77	-67	-360
Total Renewable Heat	**-0.1**	**1.2**	**1.4**	**-7.5**	**4.3**	**-292**	**-104**	**-4**	**-401**

Croatia									
2015 (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	0.0	0.0	-3	-1	-33	-37
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	-0.3	0.0	0.0	-0.3	0.0	-14	-4	-167	-185
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	-0.3	0.0	0.0	-0.3	0.0	-14	-4	-169	-187
Renewable Electricity: Solar photovoltaic	0.0	0.0	0.0	0.0	0.0	-1	0	-12	-13
Renewable Electricity: Solid biomass	0.0	0.0	0.0	0.0	0.0	-1	0	-17	-19
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-0.6**	**0.0**	**0.0**	**-0.6**	**0.0**	**-33**	**-10**	**-399**	**-442**
Renewable Heat: Biogas	0.0	0.0	0.0	0.0	0.0	-3	-2	0	-6
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	-7	-5	-1	-12
Renewable Heat: Renewable energy from heat pumps	0.0	0.0	0.0	0.0	0.0	-8	-6	11	-4
Renewable Heat: Solar thermal	0.0	0.0	0.0	0.0	0.0	-5	-4	0	-9
Renewable Heat: Solid biomass	0.0	-0.2	-0.2	0.0	-0.4	20	14	2	35
Total Renewable Heat	**-0.1**	**-0.3**	**-0.2**	**0.0**	**-0.4**	**-4**	**-3**	**11**	**4**

Cyprus									
2015 (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	-0.1	0.1	0	-11	0	-11
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	-0.1	0.0	0.0	-0.2	0.0	0	-45	0	-45
Renewable Electricity: Solar photovoltaic	0.0	0.0	0.0	-0.1	0.0	0	-28	0	-28
Renewable Electricity: Solid biomass	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-0.1**	**0.0**	**0.0**	**-0.4**	**0.1**	**0**	**-84**	**0**	**-84**
Renewable Heat: Biogas	0.0	0.0	0.0	0.0	0.0	0	-6	0	-6
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	0	-2	0	-2
Renewable Heat: Renewable energy from heat pumps	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Solar thermal	-0.1	0.0	0.0	-0.1	0.0	0	-30	0	-30
Renewable Heat: Solid biomass	0.0	0.1	0.1	0.0	0.2	0	-17	0	-17
Total Renewable Heat	**-0.1**	**0.1**	**0.1**	**-0.1**	**0.2**	**0**	**-54**	**-1**	**-54**

Czech Republic									
2015 (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)**
Renewable Electricity: Biogas	0.1	0.0	0.0	-1.3	2.7	-30	-1	-589	-620
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	-0.1	0.0	0.0	-0.3	0.0	-6	0	-116	-122
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	-0.1	0.0	0.0	-0.3	0.0	-6	0	-121	-128
Renewable Electricity: Solar photovoltaic	-0.7	0.0	0.0	-1.2	0.0	-27	-1	-544	-573
Renewable Electricity: Solid biomass	0.0	0.0	0.0	-0.6	0.0	-20	-1	-386	-407
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-0.8**	**0.0**	**0.0**	**-3.6**	**2.7**	**-89**	**-4**	**-1 758**	**-1 850**
Renewable Heat: Biogas	0.3	-0.3	-0.3	-0.7	-0.2	-93	-13	-42	-148
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Renewable energy from heat pumps	-0.2	-0.3	-0.2	-0.6	-0.2	-75	-11	70	-16
Renewable Heat: Solar thermal	0.0	0.0	0.0	-0.1	0.0	-11	-2	-5	-17
Renewable Heat: Solid biomass	1.4	2.6	2.6	-3.3	6.2	-538	-76	-243	-857
Total Renewable Heat	**1.5**	**2.0**	**2.0**	**-4.7**	**5.8**	**-716**	**-102**	**-220**	**-1 038**

Denmark									
2015 (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	0.0	0.0	0	-74	0	-74
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	0.0	0.0	0.0	0.0	0.0	0	5	0	5
Renewable Electricity: Offshore wind [normalized]	-0.6	0.0	0.0	-0.1	-0.1	0	-1 239	0	-1 239
Renewable Electricity: Onshore wind [normalized]	-0.7	0.0	0.0	-0.1	-0.1	0	-1 317	0	-1 317
Renewable Electricity: Solar photovoltaic	-0.1	0.0	0.0	0.0	0.0	0	-220	0	-220
Renewable Electricity: Solid biomass	0.1	0.0	0.0	0.1	0.0	0	-303	0	-303
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-1.2**	**0.0**	**0.0**	**-0.2**	**-0.1**	**0**	**-3 149**	**0**	**-3 149**
Renewable Heat: Biogas	0.1	0.0	0.0	0.0	0.0	-20	-16	-2	-37
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	-2	-2	0	-5
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Renewable energy from heat pumps	-0.2	-0.1	-0.1	-0.1	0.0	-93	147	-7	46
Renewable Heat: Solar thermal	-0.1	0.0	0.0	0.0	0.0	-14	-11	-1	-27
Renewable Heat: Solid biomass	1.4	10.0	9.7	0.8	9.9	-517	-408	-42	-966
Total Renewable Heat	**1.2**	**9.9**	**9.6**	**0.8**	**9.9**	**-647**	**-290**	**-52**	**-989**

Estonia									
2015 (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	0.0	0.0	0	0	-10	-10
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	-3	-3
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	-0.2	-0.1	-0.1	-0.4	0.0	-5	-1	-163	-169
Renewable Electricity: Solar photovoltaic	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Solid biomass	0.0	-0.1	-0.1	-0.3	0.0	-6	-1	-187	-194
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-0.2**	**-0.2**	**-0.2**	**-0.7**	**0.0**	**-11**	**-2**	**-364**	**-377**
Renewable Heat: Biogas	0.0	0.0	0.0	0.0	0.0	-3	-3	0	-6
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Renewable energy from heat pumps	-0.1	0.0	0.0	0.0	0.0	-41	-42	81	-2
Renewable Heat: Solar thermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Solid biomass	0.2	2.8	2.7	-0.2	4.1	-80	-79	-13	-172
Total Renewable Heat	**0.1**	**2.8**	**2.7**	**-0.2**	**4.1**	**-124**	**-123**	**67**	**-180**

Finland									
2015 (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	-0.1	0.3	-3	-3	-66	-73
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	-0.1	0.0	0.0	0.0	0.0	-2	-2	-46	-51
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	-1	-1	-22	-24
Renewable Electricity: Onshore wind [normalized]	-0.5	0.0	0.0	-0.4	0.0	-13	-14	-335	-370
Renewable Electricity: Solar photovoltaic	0.0	0.0	0.0	0.0	0.0	0	0	-1	-1
Renewable Electricity: Solid biomass	-0.1	0.0	0.0	-0.3	0.0	-12	-13	-308	-340
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-0.6**	**0.0**	**0.0**	**-0.8**	**0.3**	**-31**	**-33**	**-778**	**-860**
Renewable Heat: Biogas	0.0	0.0	0.0	0.0	0.0	0	-2	0	-3
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Renewable energy from heat pumps	-0.9	-0.1	-0.1	-1.2	-0.1	-101	-373	309	-156
Renewable Heat: Solar thermal	0.0	0.0	0.0	0.0	0.0	0	-1	0	-1
Renewable Heat: Solid biomass	2.8	7.2	7.0	-3.0	11.9	-271	-902	-218	-1 391
Total Renewable Heat	**1.8**	**7.1**	**7.0**	**-4.2**	**11.9**	**-372**	**-1 277**	**91**	**-1 550**

France									
2015 (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)**
Renewable Electricity: Biogas	0.1	0.0	0.0	-0.3	1.5	-99	-18	-120	-267
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	1.2	0.0	0.0	1.1	0.1	383	68	464	1 035
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	-4.4	-0.1	-0.1	-4.2	-0.3	-1 422	-253	-1 723	-3 848
Renewable Electricity: Solar photovoltaic	-1.7	0.0	0.0	-1.6	-0.1	-548	-97	-664	-1 483
Renewable Electricity: Solid biomass	0.2	0.0	0.0	-0.2	0.0	-93	-16	-112	-251
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	-1	-1
Total Renewable Electricity	**-4.6**	**-0.1**	**-0.1**	**-5.1**	**1.2**	**-1 780**	**-316**	**-2 156**	**-4 815**
Renewable Heat: Biogas	0.0	0.0	0.0	0.1	0.0	-76	-41	-11	-129
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	-10	-6	-2	-18
Renewable Heat: Renewable energy from heat pumps	-3.8	-0.3	-0.3	-0.1	-0.2	-990	-821	690	-873
Renewable Heat: Solar thermal	-0.2	0.0	0.0	-0.1	0.0	-49	-27	-7	-83
Renewable Heat: Solid biomass	0.5	4.5	4.4	0.2	8.0	-385	-208	-57	-651
Total Renewable Heat	**-3.5**	**4.1**	**4.1**	**0.1**	**7.7**	**-1 512**	**-1 103**	**613**	**-1 753**

Germany									
2015 (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)**
Renewable Electricity: Biogas	5.8	-0.1	-0.1	0.1	1.1	-203	-46	-5 795	-6 173
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	-0.1	0.0	-3	-1	-87	-92
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	-1	0	-27	-28
Renewable Electricity: Hydropower excl. pumping [normalized]	-0.1	0.0	0.0	-0.1	0.0	-2	-1	-66	-71
Renewable Electricity: Offshore wind [normalized]	-3.2	-0.1	-0.1	-2.2	-0.1	-92	-21	-2 615	-2 785
Renewable Electricity: Onshore wind [normalized]	-7.5	-0.3	-0.2	-5.1	-0.3	-216	-49	-6 173	-6 575
Renewable Electricity: Solar photovoltaic	-9.0	-0.3	-0.3	-6.2	-0.3	-261	-59	-7 428	-7 912
Renewable Electricity: Solid biomass	0.3	0.1	0.1	-0.4	0.3	-45	-10	-1 274	-1 357
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-13.7**	**-0.7**	**-0.6**	**-13.9**	**0.6**	**-823**	**-187**	**-23 465**	**-24 993**
Renewable Heat: Biogas	3.1	-0.4	-0.3	-0.4	-0.2	-945	-415	-197	-1 558
Renewable Heat: Bioliquids [compliant]	0.2	0.0	0.0	0.1	0.0	-113	-50	-24	-186
Renewable Heat: Geothermal	0.0	0.0	0.0	-0.1	0.0	-27	-12	-6	-45
Renewable Heat: Renewable energy from heat pumps	-0.3	-0.3	-0.2	-0.8	-0.2	-680	-305	655	-313
Renewable Heat: Solar thermal	-0.5	-0.1	-0.1	-0.6	-0.1	-279	-123	-58	-460
Renewable Heat: Solid biomass	9.4	7.4	7.2	-1.0	16.7	-2 313	-1 017	-483	-3 812
Total Renewable Heat	**11.8**	**6.6**	**6.5**	**-2.8**	**16.1**	**-4 357**	**-1 922**	**-112**	**-6 373**

Greece									
2015 (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	-0.1	0.1	-4	-4	-14	-23
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	-0.7	-0.1	-0.1	-0.6	0.0	-49	-48	-152	-249
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	-1.9	-0.2	-0.2	-1.7	-0.1	-130	-128	-407	-665
Renewable Electricity: Solar photovoltaic	-2.4	-0.3	-0.2	-2.1	-0.2	-160	-157	-499	-816
Renewable Electricity: Solid biomass	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-5.0**	**-0.6**	**-0.4**	**-4.5**	**-0.2**	**-343**	**-337**	**-1 073**	**-1 753**
Renewable Heat: Biogas	0.0	0.0	0.0	0.0	0.0	-3	-8	-1	-12
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	1	2	0	3
Renewable Heat: Renewable energy from heat pumps	0.1	0.0	0.0	0.3	0.0	-30	-202	135	-96
Renewable Heat: Solar thermal	-0.2	0.0	0.0	-0.1	0.0	-24	-77	-6	-107
Renewable Heat: Solid biomass	0.3	1.1	1.1	0.0	2.3	-25	-80	-6	-111
Total Renewable Heat	**0.1**	**1.1**	**1.0**	**0.2**	**2.3**	**-82**	**-365**	**123**	**-324**

Hungary									
2015 (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	-0.1	0.1	-10	0	-50	-61
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	0.0	0.0	0.0	0.0	0.0	-2	0	-9	-10
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	-0.2	0.0	0.0	-0.2	0.0	-25	-1	-129	-156
Renewable Electricity: Solar photovoltaic	0.0	0.0	0.0	0.0	0.0	-4	0	-23	-28
Renewable Electricity: Solid biomass	0.0	0.0	0.0	0.0	0.0	-8	0	-44	-54
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-0.3**	**0.0**	**0.0**	**-0.3**	**0.1**	**-49**	**-2**	**-255**	**-309**
Renewable Heat: Biogas	0.0	0.0	0.0	0.0	0.0	-13	-3	-1	-16
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	-8	-2	-1	-11
Renewable Heat: Renewable energy from heat pumps	0.0	0.0	0.0	0.0	0.0	-6	-1	5	-2
Renewable Heat: Solar thermal	0.0	0.0	0.0	0.0	0.0	-8	-2	-1	-10
Renewable Heat: Solid biomass	2.6	21.7	21.0	-2.2	40.6	-1 261	-254	-100	-1 615
Total Renewable Heat	**2.6**	**21.7**	**20.9**	**-2.4**	**40.5**	**-1 296**	**-261**	**-97**	**-1 654**

Ireland									
2015 (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)**
Renewable Electricity: Biogas	0.1	0.0	0.0	0.0	0.1	-7	0	-7	-15
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	0.0	0.0	0.0	0.0	0.0	3	0	3	7
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	-1.3	-0.1	-0.1	-1.1	-0.1	-440	-21	-455	-922
Renewable Electricity: Solar photovoltaic	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Solid biomass	0.0	0.0	0.0	0.0	0.0	-24	-1	-24	-50
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-1.2**	**-0.1**	**-0.1**	**-1.2**	**0.0**	**-467**	**-22**	**-484**	**-980**
Renewable Heat: Biogas	0.0	0.0	0.0	0.0	0.0	-1	-1	0	-2
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Renewable energy from heat pumps	-0.1	-0.1	-0.1	-0.3	0.0	-7	-29	13	-23
Renewable Heat: Solar thermal	0.0	0.0	0.0	-0.1	0.0	-6	-7	-2	-14
Renewable Heat: Solid biomass	0.1	0.2	0.2	-0.1	0.7	-21	-23	-6	-50
Total Renewable Heat	**0.0**	**0.0**	**0.0**	**-0.5**	**0.6**	**-34**	**-59**	**5**	**-89**

Italy									
2015 (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)**
Renewable Electricity: Biogas	10.4	0.1	0.1	-0.3	7.1	-499	-64	-786	-1 385
Renewable Electricity: Bioliquids [compliant]	0.6	0.0	0.0	0.1	0.0	-346	-44	-545	-961
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	-0.2	0.0	0.0	0.0	0.0	-61	-8	-96	-170
Renewable Electricity: Hydropower excl. pumping [normalized]	-0.4	0.0	0.0	-0.1	-0.1	-153	-20	-241	-424
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	-2.3	-0.1	-0.1	-0.6	-0.6	-906	-117	-1 428	-2 516
Renewable Electricity: Solar photovoltaic	-4.2	-0.2	-0.1	-1.1	-1.0	-1 630	-210	-2 568	-4 524
Renewable Electricity: Solid biomass	0.4	0.2	0.2	0.2	0.0	-200	-26	-315	-555
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**4.3**	**0.0**	**0.1**	**-1.9**	**5.4**	**-3 796**	**-488**	**-5 980**	**-10 534**
Renewable Heat: Biogas	0.5	0.0	0.0	0.2	0.0	-192	-48	-10	-250
Renewable Heat: Bioliquids [compliant]	0.1	0.0	0.0	0.0	0.0	-36	-9	-2	-47
Renewable Heat: Geothermal	0.1	0.0	0.0	0.0	0.0	69	17	4	89
Renewable Heat: Renewable energy from heat pumps	-1.7	0.1	0.0	0.3	0.2	-1 318	-403	883	-794
Renewable Heat: Solar thermal	-0.2	0.0	0.0	0.0	0.0	-139	-35	-7	-181
Renewable Heat: Solid biomass	8.8	33.1	32.0	1.2	55.4	-2 737	-681	-147	-3 565
Total Renewable Heat	**7.6**	**33.1**	**32.1**	**1.8**	**55.6**	**-4 354**	**-1 159**	**720**	**-4 747**

Latvia									
2015 (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)**
Renewable Electricity: Biogas	0.1	0.0	0.0	0.0	0.4	-16	-3	-53	-73
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	0.0	0.0	0.0	0.0	0.0	1	0	3	4
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	-5	-1	-15	-21
Renewable Electricity: Solar photovoltaic	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Solid biomass	0.1	0.0	0.0	0.0	0.0	-17	-3	-55	-77
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**0.1**	**0.0**	**0.0**	**0.0**	**0.4**	**-37**	**-7**	**-119**	**-167**
Renewable Heat: Biogas	0.0	-0.1	-0.1	-0.1	0.0	-16	-13	-2	-30
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Renewable energy from heat pumps	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Solar thermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Solid biomass	0.0	-0.1	-0.1	0.0	-0.1	2	2	0	4
Total Renewable Heat	**0.0**	**-0.2**	**-0.1**	**-0.1**	**-0.1**	**-13**	**-11**	**-2**	**-26**

Lithuania									
2015 (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	0.0	0.1	-4	-1	-12	-17
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	-0.1	0.0	0.0	0.0	0.0	-38	-7	-123	-172
Renewable Electricity: Solar photovoltaic	0.0	0.0	0.0	0.0	0.0	-3	-1	-11	-15
Renewable Electricity: Solid biomass	0.1	0.0	0.0	0.0	0.0	-16	-3	-53	-74
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**-62**	**-11**	**-199**	**-278**
Renewable Heat: Biogas	0.0	-0.1	0.0	-0.2	0.0	-6	-2	-2	-9
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	1
Renewable Heat: Renewable energy from heat pumps	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Solar thermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Solid biomass	0.4	2.4	2.5	-5.9	5.1	-181	-51	-68	-300
Total Renewable Heat	**0.4**	**2.3**	**2.4**	**-6.1**	**5.1**	**-186**	**-53**	**-70**	**-309**

Luxemburg									
2015 (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	0.0	0.0	-5	0	0	-7
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	0.0	0.0	0.0	0.0	0.0	-2	0	0	-2
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	-5	0	0	-6
Renewable Electricity: Solar photovoltaic	0.0	0.0	0.0	0.0	0.0	-12	0	0	-14
Renewable Electricity: Solid biomass	0.0	0.0	0.0	0.0	0.0	-6	0	0	-7
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-30**	**0**	**0**	**-36**
Renewable Heat: Biogas	0.0	0.0	0.0	0.0	0.0	-4	-2	0	-7
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Renewable energy from heat pumps	0.0	0.0	0.0	0.0	0.0	-1	-2	0	-2
Renewable Heat: Solar thermal	0.0	0.0	0.0	0.0	0.0	-1	-1	0	-2
Renewable Heat: Solid biomass	0.0	0.2	0.2	0.0	0.3	-14	-6	-1	-21
Total Renewable Heat	**0.0**	**0.2**	**0.2**	**0.0**	**0.3**	**-20**	**-11**	**-2**	**-32**

Malta									
2015 (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	0.0	0.0	0	-1	0	-1
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Solar photovoltaic	-0.1	0.0	0.0	-0.1	0.0	0	-20	0	-20
Renewable Electricity: Solid biomass	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-0.1**	**0.0**	**0.0**	**-0.1**	**0.0**	**0**	**-22**	**0**	**-22**
Renewable Heat: Biogas	0.0	0.0	0.0	0.0	0.0	0	-1	0	-1
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Renewable energy from heat pumps	0.0	0.0	0.0	0.0	0.0	0	-2	0	-2
Renewable Heat: Solar thermal	0.0	0.0	0.0	0.0	0.0	0	-4	0	-4
Renewable Heat: Solid biomass	0.0	0.0	0.0	0.0	0.0	0	-1	0	-1
Total Renewable Heat	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0**	**-9**	**0**	**-9**

Netherlands									
2015 (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)**
Renewable Electricity: Biogas	0.2	0.0	0.0	0.0	0.8	-48	0	-103	-151
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Offshore wind [normalized]	-0.1	0.0	0.0	0.0	0.0	-58	0	-125	-183
Renewable Electricity: Onshore wind [normalized]	-0.5	0.0	0.0	-0.1	0.0	-228	0	-488	-716
Renewable Electricity: Solar photovoltaic	-0.2	0.0	0.0	0.0	0.0	-64	0	-136	-200
Renewable Electricity: Solid biomass	0.0	0.0	0.0	0.0	0.0	-22	0	-48	-70
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-0.7**	**0.0**	**0.0**	**-0.2**	**0.7**	**-420**	**0**	**-901**	**-1 321**
Renewable Heat: Biogas	0.2	0.0	0.0	0.1	0.0	-85	-17	-8	-110
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	-19	-4	-2	-25
Renewable Heat: Geothermal	-0.1	0.0	0.0	0.0	0.0	-50	-10	-5	-65
Renewable Heat: Renewable energy from heat pumps	-0.2	0.0	0.0	0.0	0.0	-113	-31	72	-71
Renewable Heat: Solar thermal	0.0	0.0	0.0	0.0	0.0	-9	-2	-1	-11
Renewable Heat: Solid biomass	0.9	2.2	2.1	0.4	4.7	-336	-68	-30	-434
Total Renewable Heat	**0.8**	**2.2**	**2.1**	**0.6**	**4.7**	**-612**	**-132**	**27**	**-716**

Poland									
2015 (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	-0.4	0.9	-37	-7	-117	-164
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	-0.1	0.0	0.0	-0.1	0.0	-10	-2	-31	-43
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	-3.2	-0.1	-0.1	-4.5	-0.2	-437	-81	-1 401	-1 960
Renewable Electricity: Solar photovoltaic	0.0	0.0	0.0	0.0	0.0	-3	0	-8	-12
Renewable Electricity: Solid biomass	-0.1	0.1	0.1	-2.6	0.2	-352	-65	-1 127	-1 576
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-3.5**	**0.0**	**0.0**	**-7.5**	**0.9**	**-838**	**-155**	**-2 684**	**-3 756**
Renewable Heat: Biogas	0.0	-0.5	-0.5	-0.9	-0.2	-19	-8	-27	-54
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	-0.1	-0.1	-0.2	0.0	-4	-2	-6	-12
Renewable Heat: Renewable energy from heat pumps	-0.1	-0.4	-0.4	-0.8	-0.2	-9	-5	0	-13
Renewable Heat: Solar thermal	-0.2	-0.5	-0.5	-1.0	-0.2	-18	-7	-25	-51
Renewable Heat: Solid biomass	0.8	4.6	4.7	-15.2	23.5	-409	-164	-571	-1 144
Total Renewable Heat	**0.6**	**3.1**	**3.2**	**-18.1**	**22.9**	**-459**	**-186**	**-628**	**-1 273**

Portugal									
2015 (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	0.0	0.3	-11	-2	-39	-53
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	-5	-1	-20	-27
Renewable Electricity: Hydropower excl. pumping [normalized]	-0.2	0.0	0.0	-0.1	0.0	-37	-7	-135	-183
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	-1	-2
Renewable Electricity: Onshore wind [normalized]	-2.7	0.0	0.0	-0.7	-0.1	-422	-82	-1 528	-2 078
Renewable Electricity: Solar photovoltaic	-0.2	0.0	0.0	-0.1	0.0	-33	-6	-118	-161
Renewable Electricity: Solid biomass	0.0	0.0	0.0	0.0	0.0	-48	-9	-174	-236
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-3.2**	**0.0**	**0.0**	**-0.9**	**0.2**	**-556**	**-108**	**-2 014**	**-2 739**
Renewable Heat: Biogas	0.0	0.0	0.0	0.0	0.0	-4	-5	0	-9
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	-1
Renewable Heat: Renewable energy from heat pumps	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Solar thermal	-0.2	0.0	0.0	-0.1	0.0	-31	-33	0	-65
Renewable Heat: Solid biomass	-1.1	-8.0	-7.8	0.3	-13.0	410	431	3	845
Total Renewable Heat	**-1.2**	**-8.0**	**-7.8**	**0.2**	**-13.1**	**374**	**394**	**3**	**771**

Romania									
2015 (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	-0.1	0.1	-3	0	-11	-14
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	-0.4	-0.1	0.0	-1.6	0.0	-66	0	-241	-307
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	-2.1	-0.3	-0.2	-7.9	-0.1	-333	-1	-1 220	-1 554
Renewable Electricity: Solar photovoltaic	-0.6	-0.1	-0.1	-2.4	0.0	-101	0	-368	-469
Renewable Electricity: Solid biomass	0.0	0.0	0.0	-0.5	0.0	-23	0	-85	-108
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-3.2**	**-0.4**	**-0.4**	**-12.5**	**-0.1**	**-526**	**-2**	**-1 925**	**-2 453**
Renewable Heat: Biogas	0.0	0.0	0.0	0.0	0.0	-5	-2	-1	-8
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	-6	-2	-1	-9
Renewable Heat: Renewable energy from heat pumps	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Solar thermal	0.0	0.0	0.0	0.0	0.0	0	0	0	-1
Renewable Heat: Solid biomass	0.3	2.4	2.4	-0.1	3.0	-145	-47	-23	-215
Total Renewable Heat	**0.3**	**2.4**	**2.4**	**-0.1**	**3.0**	**-157**	**-51**	**-25**	**-233**

Slovak Republic									
2015 (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)**
Renewable Electricity: Biogas	0.1	0.0	0.0	-0.1	0.6	-115	0	0	-115
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	0.0	0.0	0.0	0.0	0.0	-4	0	0	-4
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Solar photovoltaic	-0.1	0.0	0.0	-0.1	0.0	-109	0	0	-109
Renewable Electricity: Solid biomass	0.1	0.0	0.0	0.0	0.0	-235	0	0	-235
Renewable Electricity: Tidal. wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**0.1**	**0.0**	**0.0**	**-0.2**	**0.6**	**-464**	**0**	**0**	**-464**
Renewable Heat: Biogas	0.1	0.0	0.0	0.0	0.0	-33	-2	-16	-52
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	1
Renewable Heat: Renewable energy from heat pumps	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Solar thermal	0.0	0.0	0.0	0.0	0.0	-4	0	-2	-6
Renewable Heat: Solid biomass	0.3	4.0	3.9	0.1	3.6	-148	-11	-73	-232
Total Renewable Heat	**0.4**	**3.9**	**3.9**	**0.1**	**3.6**	**-185**	**-14**	**-91**	**-290**

Slovenia									
2015 (2005-RES shares counterfactual)	**Effect on NOx emission s (kt)**	**Effect on PM_10 emission s (kt)**	**Effect on PM_2_5 emission s (kt)**	**Effect on SO2 emission s (kt)**	**Effect on VOC emission s (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	0.0	0.1	-23	-10	0	-33
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	-0.1	0.0	0.0	0.0	0.0	-38	-16	0	-54
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Onshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	-1	-1	0	-2
Renewable Electricity: Solar photovoltaic	-0.1	0.0	0.0	-0.1	0.0	-63	-26	0	-89
Renewable Electricity: Solid biomass	0.0	0.0	0.0	0.0	0.0	-11	-5	0	-16
Renewable Electricity: Tidal, wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-0.2**	**0.0**	**0.0**	**-0.1**	**0.1**	**-136**	**-57**	**0**	**-193**
Renewable Heat: Biogas	0.0	0.0	0.0	0.0	0.0	-5	-4	0	-9
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	-0.1	0.0	0.0	0.0	0.0	-26	-19	-2	-47
Renewable Heat: Renewable energy from heat pumps	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Solar thermal	0.0	0.0	0.0	0.0	0.0	-7	-5	0	-12
Renewable Heat: Solid biomass	0.2	2.1	2.1	0.1	2.9	-72	-54	-5	-131
Total Renewable Heat	**0.1**	**2.1**	**2.1**	**0.1**	**2.9**	**-110**	**-82**	**-8**	**-199**

Spain									
2015 (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	-0.1	0.4	-20	-11	-45	-77
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	-1.3	0.0	0.0	-1.3	-0.1	-310	-174	-700	-1 196
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	0.0	0.0	0.0	0.0	0.0	-11	-6	-26	-44
Renewable Electricity: Offshore wind [normalized]	0.0	0.0	0.0	0.0	0.0	-1	-1	-3	-4
Renewable Electricity: Onshore wind [normalized]	-7.2	-0.2	-0.1	-7.2	-0.4	-1 677	-941	-3 793	-6 480
Renewable Electricity: Solar photovoltaic	-1.9	0.0	0.0	-2.0	-0.1	-455	-255	-1 030	-1 759
Renewable Electricity: Solid biomass	0.1	0.1	0.1	-0.3	0.1	-152	-85	-345	-589
Renewable Electricity: Tidal, wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-10.4**	**-0.2**	**-0.1**	**-10.9**	**0.0**	**-2 627**	**-1 474**	**-5 941**	**-10 149**
Renewable Heat: Biogas	0.1	0.0	0.0	0.0	0.0	-23	-15	-2	-41
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	-7	-5	-1	-13
Renewable Heat: Renewable energy from heat pumps	-0.8	-0.4	-0.3	-0.7	-0.2	-221	-160	223	-153
Renewable Heat: Solar thermal	-0.5	-0.2	-0.1	-0.5	-0.1	-136	-91	-14	-241
Renewable Heat: Solid biomass	1.1	3.3	3.2	-0.2	5.5	-325	-217	-33	-575
Total Renewable Heat	**-0.1**	**2.7**	**2.7**	**-1.4**	**5.2**	**-713**	**-488**	**174**	**-1 023**

Sweden									
2015 (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)**
Renewable Electricity: Biogas	0.0	0.0	0.0	0.0	0.0	0	11	0	11
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	0.3	0.0	0.0	0.3	0.0	0	452	0	452
Renewable Electricity: Offshore wind [normalized]	-0.1	0.0	0.0	-0.1	0.0	0	-184	0	-184
Renewable Electricity: Onshore wind [normalized]	-2.1	-0.1	-0.1	-1.8	-0.2	0	-3 224	0	-3 224
Renewable Electricity: Solar photovoltaic	0.0	0.0	0.0	0.0	0.0	0	-24	0	-24
Renewable Electricity: Solid biomass	-0.1	0.1	0.1	-0.3	0.1	0	-865	0	-865
Renewable Electricity: Tidal, wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-2.1**	**0.1**	**0.1**	**-1.9**	**-0.1**	**0**	**-3 834**	**0**	**-3 834**
Renewable Heat: Biogas	0.0	0.0	0.0	0.0	0.0	-7	-15	-13	-35
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Renewable energy from heat pumps	-1.5	-0.1	0.0	-1.1	-0.1	-223	479	-375	-119
Renewable Heat: Solar thermal	0.0	0.0	0.0	0.0	0.0	-1	-3	-2	-6
Renewable Heat: Solid biomass	0.7	5.1	4.9	-0.9	9.5	-324	-634	-545	-1 502
Total Renewable Heat	**-0.8**	**5.0**	**4.9**	**-2.1**	**9.5**	**-555**	**-173**	**-934**	**-1 662**

United Kingdom									
2015 (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)**
Renewable Electricity: Biogas	0.6	0.0	0.0	-0.4	0.6	-208	-3	-253	-474
Renewable Electricity: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Concentrated solar power	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Electricity: Hydropower excl. pumping [normalized]	-0.2	0.0	0.0	-0.2	0.0	-53	-1	-65	-122
Renewable Electricity: Offshore wind [normalized]	-7.3	-0.2	-0.1	-5.5	-0.2	-1 677	-26	-2 042	-3 829
Renewable Electricity: Onshore wind [normalized]	-5.7	-0.1	-0.1	-4.3	-0.2	-1 305	-20	-1 590	-2 981
Renewable Electricity: Solar photovoltaic	-2.8	-0.1	0.0	-2.1	-0.1	-647	-10	-789	-1 478
Renewable Electricity: Solid biomass	-1.3	1.5	1.4	-3.7	0.6	-1 531	-24	-1 865	-3 496
Renewable Electricity: Tidal, wave and ocean energy	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Total Renewable Electricity	**-16.7**	**1.1**	**1.1**	**-16.3**	**0.7**	**-5 423**	**-84**	**-6 604**	**-12 380**
Renewable Heat: Biogas	0.1	-0.1	-0.1	-0.4	0.0	-82	-17	-9	-108
Renewable Heat: Bioliquids [compliant]	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Geothermal	0.0	0.0	0.0	0.0	0.0	0	0	0	0
Renewable Heat: Renewable energy from heat pumps	0.0	-0.2	-0.2	-0.7	-0.1	-98	-32	59	-68
Renewable Heat: Solar thermal	0.0	0.0	0.0	-0.1	0.0	-18	-4	-2	-24
Renewable Heat: Solid biomass	5.4	11.2	10.6	-8.1	19.8	-1 891	-381	-215	-2 487
Total Renewable Heat	**5.5**	**11.0**	**10.4**	**-9.3**	**19.7**	**-2 090**	**-433**	**-167**	**-2 686**

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