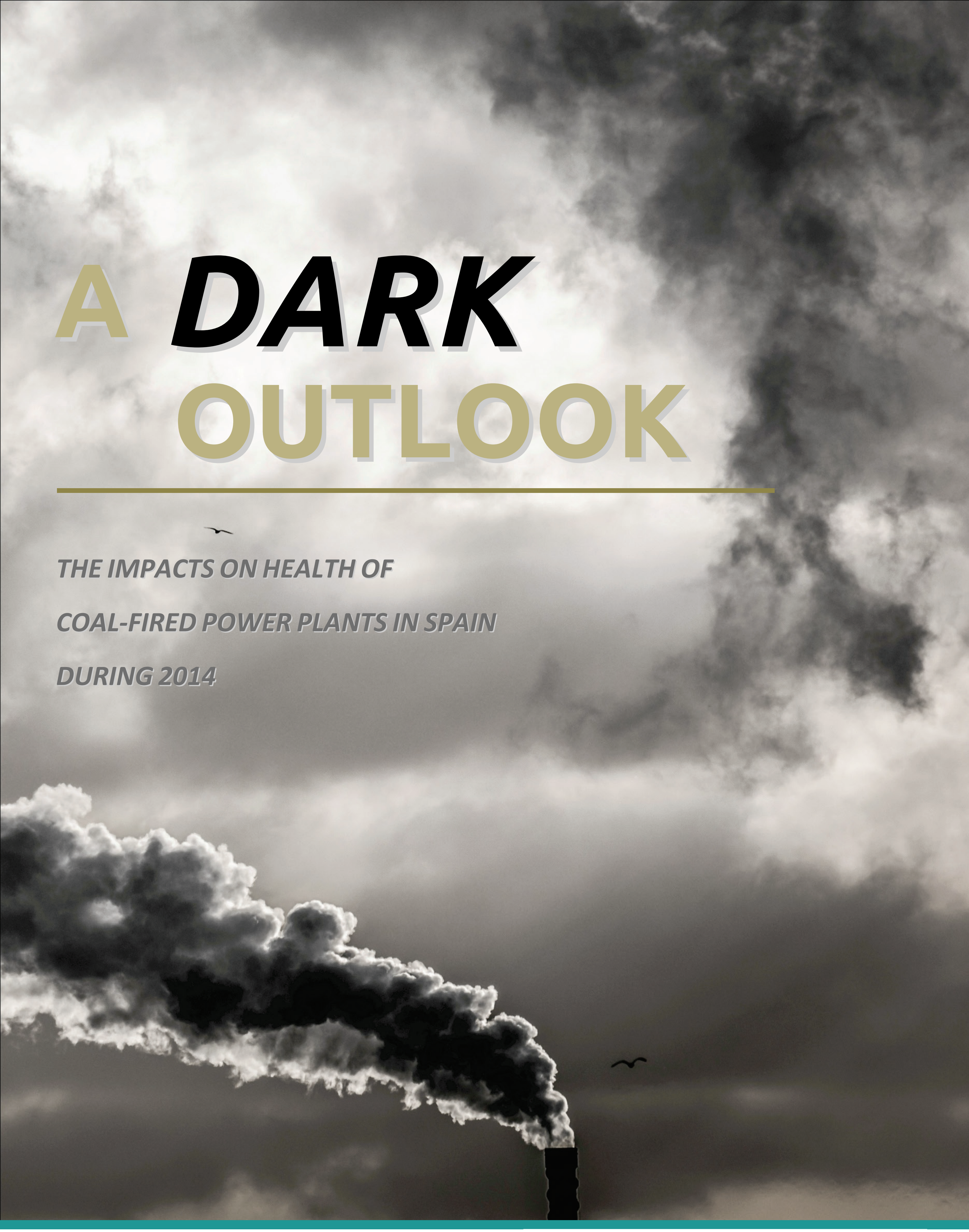

A DARK OUTLOOK

THE IMPACTS ON HEALTH OF COAL-FIRED POWER PLANTS IN SPAIN DURING 2014

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The **Instituto Internacional de Derecho y Medio Ambiente, IIDMA** (International Institute for Law and the Environment) is a non-profit organization registered in Spain and founded in 1996 with the aim of contributing to environmental protection and sustainable development through the study, development, implementation and enforcement of Law from an international and multidisciplinary approach. Since 1998, IIDMA is accredited as observer to the United Nations Environment Programme (UNEP) Governing Council, today the United Nations Environmental Assembly of UN Environment. In 2001 it was declared of public interest by the Spanish Ministry of Home Affairs.

This document contains the summary of the report entitled "*A Dark Outlook: The health impacts of coal-fired power plants in Spain during 2014*", which can be downloaded in the publications section of IIDMA's webpage.

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ACRONYMS

AC	*Autonomous Community*
AQG	*Air Quality Guidelines*
BAT	*Best Available Technique*
BOE	*Boletín Oficial del Estado* *(Spanish Official State Journal)*
CRF	*Concentration – response function*
CRP	*C-reactive protein*
ELV	*Emission Limit Value*
EU	*European Union*
EUTL	*European Union Transaction Log*
GHG	*Greenhouse Gas*
IARC	*International Agency for Research on Cancer*
IEA	*International Energy Agency*
IED	*Industrial Emissions Directive*
IPCC	*Intergovernmental Panel on Climate Change*
LCP	*Large Combustion Plant*
LCPD	*Large Combustion Plant Directive*
LLD	*Limited Lifetime Derogation*
MAPAMA	*Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente* *(Ministry of Agriculture and Fisheries, Food and Environment)*
NOx	*Nitrogen oxides*
PM	*Particulate matter*
PRTR	*Pollutant Release and Transfer Register*
REE	*Red Eléctrica Española*
SCR	*Selective Catalytic Reduction*
SNCR	*Selective Non-Catalytic Reduction*
SO_2	*Sulfur dioxide*
TNP	*Transitional National Plan*
UNECE	*United Nations Economic Commission for Europe*
US - EPA	*United States Environmental Protection Agency*
WHO	*World Health Organization*
WMO	*World Meteorological Organization*

EXECUTIVE SUMMARY

Climate change is a reality that threatens all living beings on the planet. For years, scientists around the world have provided sufficient evidence of this fact and the damage it produces, pointing to human activity as one of its major causes. Therefore, it is necessary and urgent to take measures to hold the increase in the global average temperature to well below 2 ° C with respect to pre-industrial levels, in accordance with the Paris Agreement objective. At the same time, it is essential to deal with air pollution produced by both greenhouse gases and other polluting gases such as particulate matter (PM_{10} and $PM_{2.5}$), nitrogen oxides (NOx) and sulfur dioxide (SO_2). These have serious impacts on health and the environment, and thus on the economy. The main sources of pollution include the transport sector, industrial activities and the energy sector. The pollution caused by the latter is mainly due to the burning of fossil fuels, such as coal. Despite being the most polluting source of generation, in Spain this fossil fuel plays a significant role in the production of electricity.

The objective of this report is to estimate the health impacts of emissions of pollutants into the air from Spanish coal-fired power plants[1] in 2014[2], as well as their associated health costs. To achieve this, the study has followed a two-phase approach. In the first one, the dispersion of pollutants (NO_2, SO_2 and particulate matter) was simulated using the CALPUFF mathematical model. This model has enabled to obtain the space-time variations of the concentration of these pollutants throughout 2014. At a later stage, the results of this simulation have been completed with demographic and epidemiological data in order to quantify the effects of these emissions on human health at provincial, regional and national levels. In order to do so, the respective *concentration-response functions* have been applied. These functions reflect the relationship between the concentration increase of a given pollutant and its impact on health.

In its first chapter, the report addresses the impacts of climate change as well as the effects on health produced by air pollution. It also analyzes the recommendations made by the World Health Organization to reduce these effects. Secondly, the report examines the situation of coal-fired power plants in Spain, with emphasis on their emissions. Finally, the third chapter presents the main results regarding the impacts on health related to the emissions of these plants.

The study shows the following results:

- In 2014, the emissions from coal power plants were responsible for **709 premature deaths, 459 hospital admissions due to cardiovascular and respiratory diseases, 10,521 cases of asthma symptoms in asthmatic children, 1,233 cases of bronchitis in children and 387 cases of chronic bronchitis in adults**. In addition, they were responsible for **747,686 restricted activity days and 163,326 work days lost**.

[1] There are 15 existing coal-fired power plants in Spain, with a total installed net capacity of 10,004 MW.
[2] The year 2014 has been chosen as it is the last one with complete available data of emissions.

- The total costs of the health impacts caused by coal during that year ranged between **880 and 1,667 million Euros**.

In light of the above, the Instituto Internacional de Derecho y Medio Ambiente makes the following recommendations:

- ✓ It is necessary to initiate the **decarbonization of the energy model** by elaborating a **coal phase-out plan which foresees the progressive closure of all coal-fired power plants by 2025.** It is not appropriate to allow the market itself to discourage the use of coal. In addition, governments and companies must put forward "**just transition" measures to ensure employment alternatives for the affected persons.**
- ✓ The Government of Spain and the regional and local authorities **must take urgent measures to reduce the air pollution levels in accordance with the World Health Organization guidelines**. In order to do so, they must ensure that those large combustion plants under the Transitional National Plan which continue operating beyond July 2020 comply with the emission limit values required by EU legislation. Currently, the environmental permits (Industrial Emissions Directive permits) of these plants allow them to emit above these limits.
- ✓ It is necessary for **energy companies to internalize the external costs associated with the generation of electricity produced through the burning of coal. These costs derive from the negative impact they generate on health and the environment.** In this way, the price of electricity from this fossil fuel could double or triple[3], making this source of energy economically unviable. Therefore, cleaner forms of energy would be more competitive.
- ✓ More **investments in renewable energy** should be made in order to increase electricity production from these sources. Technological and scientific developments make this type of generation increasingly competitive with respect to other conventional technologies.

Coal phase-out is a unique opportunity to reduce emissions and mitigate climate change. The resulting improvement in air quality will result in a higher level of protection of human health. Thus, it will prevent the premature death of hundreds of people each year, the occurrence of diseases and will favor the reduction of health costs. In Spain we all have the right to enjoy an environment suitable for personal development, in accordance with Article 45 of the Spanish Constitution. Therefore, it is necessary that short-term decisions are consistent with the commitment to fight against climate change and are aimed at achieving sustainable economic growth, while respecting the environment and without undermining the well-being of present and future generations.

[3] Epstein P. R. et al., Full cost accounting for the life cycle of coal, *Annals of the New York Academy of Sciences*, Volume 1219, Ecological Economics Reviews Pages 73-98 (2011).

THE ONLY THING WHICH CANNOT BE REUSED IS WASTED TIME.

WE MUST CHANGE NOW. TIME IS RUNNING OUT.

CHAPTER 1

THE ANTHROPOCENE: CLIMATE CHANGE AND AIR POLLUTION

The Earth System is the sum of the interaction of all processes - physical, chemical, biological and human - that occur in our planet. Throughout the different geological eras, this System has been subject to numerous changes induced by natural processes internal and external to the planet.

However, scientists have pointed out that human activity, namely the global economic system, is currently the first factor of change in the Earth System. They also indicate that the "great acceleration" of human activity since the beginning of the industrial revolution has led to a strong increase in greenhouse gas (GHG) emissions, ocean acidification, deforestation and deterioration of biodiversity. All this has generated significant changes in the functioning and structure of this System, giving rise to a new era of the Earth's geological history: the Anthropocene[4].

Connected to the so-called Anthropocene era, the concept of *planetary boundaries* has arisen. This concept identifies nine global priorities that must be addressed as a consequence of human-induced changes in the environment[5]. One of these priorities is climate change, called by scientists as one of the "core boundaries", meaning that its significant alteration would lead the Earth System to a new state, whose consequences are still unpredictable. The human species, due to the activities it carries out, has already surpassed this main planetary boundary.

During the 20th century, large amounts of GHGs, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFC) have been discharged into the atmosphere. These trap the heat of the sun -which would otherwise escape into space- in the lower layers of the atmosphere, thereby generating global warming. Most of these GHGs come from human activities such as burning fossil fuels to generate heat and energy, clearing forests - which are CO_2 sinks -, fertilizing crops, storing waste in landfills, raising livestock and some industrial production processes[6].

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[4] Cruzten, P.J. (2002). Geology of mankind: the Anthropocene. *Nature*, Vol. 415, pp. 23 (2002).
Steffen, W. et al.,The Anthropocene: are humans now overwhelming the great forces of Nature? *Ambio*, Vol. 36, Nº 8, pp. 614-621 (2007).
Hamilton, C. The Anthropocene as rupture. *The Anthropocene Review*, Vol.3, Issue 2, pp. 1–14 (2016).
[5] Rockström, J. et al., Planetary boundaries: exploring the safe operating space for humanity. *Ecology and Society*, Vol. 14, N 2, art. 32 (2009).
[6] United States Environmental Protection Agency (US EPA), *Overview of Climate Change Science.*

Climate change caused by these substances brings with it a series of phenomena such as the extinction of species of flora and fauna due to the affectation of habitats or melting of the ice caps which cannot only permanently alter the balance of the environment but also bring profound economic and social consequences.

1.1. The effects of climate change

One of the most evident manifestations of climate change is the rise in the average global temperature of the Earth's surface, which has increased by more than 0.8ºC over the last century[7]. The year 2016 experienced the highest registered temperatures, exceeding even the exceptionally high temperatures of 2015[8], which was marked by intense heat waves and devastating droughts.

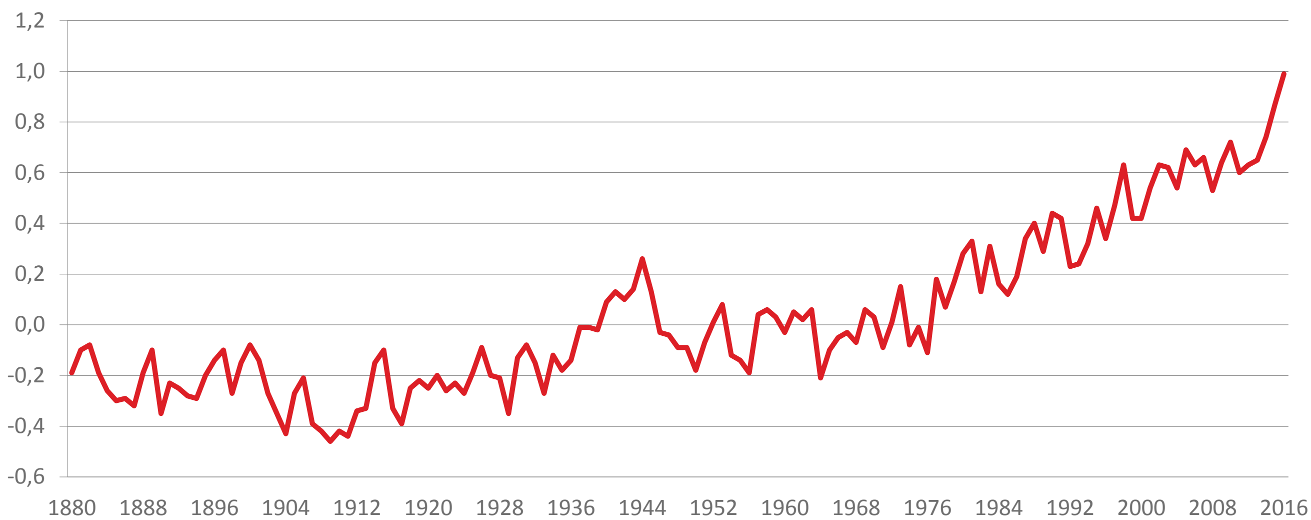


Figure 1 - Deviation of the mean annual global temperature [ºC] with respect to the average during the period 1951-1980. (Source: National Aeronautics and Space Administration, NASA)

While there are whole regions affected by high temperatures and droughts, there are others where extreme weather events like cyclones, storms and floods are becoming more frequent. High temperatures as well as the alteration of precipitation patterns have detrimental effects on crop yields, as these events largely determine the biosphere's ability to produce food for the consumption of humans and other animal species. Another consequence of global warming is the melting of polar ice caps that cause the sea level rise. This represents a serious threat to coastal communities and coastal ecosystems.

The development of less developed countries, with no resources to mitigate the effects of global warming is being seriously affected. Competition for resources generates migratory phenomena and increases conflicts. The Intergovernmental Panel on Climate Change (IPCC) estimates that by 2050 there will be 150 million environmental refugees, mainly due to events such as coastal flooding, erosion and agricultural disorders, among others. For developed countries this situation

[7] Ibid.

[8] World Meteorological Organization (WMO). More information available at: https://public.wmo.int/en/media/press-release/wmo-confirms-2016-hottest-year-record-about-11%C2%B0c-above-pre-industrial-era.

will be different. Specifically, at higher latitudes it is possible that climate change brings some benefits, since a 2 or 3°C increase would be positive for agriculture, it would lead to lower winter mortality and a possible increase in tourist activity. At the same time, this increase in temperature will cause countries located at lower latitudes to suffer due to water availability, which would most likely entail a decrease in agricultural performance[9].

Spain is very vulnerable to climate change because of its geographical location and socio-economic characteristics[10]. The forecasts indicate that it will become an even hotter and drier country, and that the negative economic consequences would affect all sectors, from tourism to agriculture, as well as the electricity and water supply of large cities and coastal areas[11].

At present, almost the entire scientific community agrees on the need to take urgent measures to stop and reverse this process. Otherwise, we will face devastating natural disasters that will alter life as we know it on Earth[12]. Against this background, the international community adopted the Paris Agreement on December 2015, whose main objectives are to hold the increase in the global average temperature to well below 2 ° C with respect to pre-industrial levels and to promote low GHG emissions[13], among others.

[9] The impact of climate change in the economy, *The Economy Journal*, 23.01.2017.
[10] Ministry of Agriculture and Fisheries, Food and Environment (*Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente*-MAPAMA).
[11] The social impact of climate change is already a reality, *The Economy Journal*, 22.02.2016.
[12] United Nations, *Climate change*. URL: http://www.un.org/en/sections/issues-depth/climate-change/index.html.
[13] Art. 2, Paris Agreement.

1.2. Air pollution

In addition to GHGs, humans emit other substances that contribute to *air pollution*. This term was defined in 1979 by the United Nations Economic Commission for Europe (UNECE) as:

"the introduction by man, directly or indirectly, of substances or energy into the air resulting in deleterious effects of such nature as to endanger human health, harm living resources and ecosystems and material property and impair or interfere with amenities and other legitimate uses of the environment" [14].

Air pollution is a direct consequence of emissions into the air of gases, particulate matter and liquids from multiple sources, which concentrate in the atmosphere. The main sources of pollution include inefficient modes of transport, household fuels, waste burning, coal-fired power plants and industrial activities[15].

Despite the progress made in recent decades to improve air quality, air pollution still represents a global problem. At present, there are still risk situations that can adversely affect our health, depending on the concentrations to which we are subject and the duration of the exposure. Air pollution affects in many different ways. Nevertheless, it impacts the most on people who are already ill, as well as on the most vulnerable groups, such as children, the elderly and low-income families with limited access to medical care[16].

[14] Art. 1, Convention on long-range transboundary air pollution, done at Geneva on 13 November 1979. Ratification instrument of 7 June 1982 (Boletín Oficial del Estado (*Spanish Official Journal*) – BOE num. 59, of 10.03.1983).
[15] World Health Organization, *WHO releases country estimates on air pollution exposure and health impacts*. URL: http://www.who.int/mediacentre/news/releases/2016/air-pollution-estimates/en/.
[16] Source: WHO. More information at: http://www.who.int/phe/health_topics/outdoorair/databases/health_impacts/en/.

Another effect of air pollution is acidification[17], caused by *acid rain.* It is responsible for the destruction of forests, wildlife and the acidification of surface waters, which causes severe damage to fish and amphibians health.

The physical nature and composition of chemical air pollutants is very diverse. In addition to their natural or anthropogenic origin, they can be classified depending on the transformation they experience in the atmosphere. According to this classification, they can be distinguished between:

- **primary pollutants:** they are discharged directly into the atmosphere from sources, whether natural or anthropogenic, without having undergone any previous transformation.
- **secondary pollutants:** they originate as a consequence of the chemical and photochemical transformations and reactions experienced by the primary pollutants in the atmosphere.

The following table briefly describes the main air pollutants.

[17] Acidification can be defined as the loss of the neutralizing capacity of soil and water as a result of the return to the Earth surface– in acid form - of the sulfur oxides and nitrogen previously discharged into the atmosphere. Source: Regional Government of Valencia, Ministry of Agriculture, Environment, Climate Change and Rural Development.

Pollutant	Caractheristics and main anthropogenic sources	Impacts
Carbon monoxide (CO)	Odorless, colorless and tasteless gas. It is toxic and very flammable. It is produced by the incomplete combustion of organic fuels. The main anthropogenic sources are the transport sector, house-hold devices which burn fossil fuels, the metallurgical and paper-making industry and formaldehyde-producing plants.	Inhalation in small concentrations can cause mental confusion, vertigo, headache, nausea, weakness and loss of consciousness. On the other hand, with prolonged or continuous exposure, the nervous and cardiovascular systems can be affected, resulting in neurological and cardiac alterations.
Carbon dioxide (CO_2)	Colorless, odorless, slightly acid and non-flammable gas. Its main anthropogenic emissions come essentially from the burning of fossil fuels. Thus, the transport and the industrial sectors are its main sources.	Inhalation of high concentrations may lead to hyperventilation, loss of consciousness, tachycardia and headaches. If the exposure is prolonged or repetitive it can cause alterations in the metabolism of the person.
Nitrogen monoxide (NO)	Colorless gas, slightly soluble in water. It is formed as a by-product in all combustions carried out at high temperatures. The main sources of anthropogenic emissions are the exhaust pipes of motor vehicles and the burning of fossil fuels such as petroleum, coal or natural gas. Once emitted in the atmosphere, NO undergoes a rapid oxidation transforming into nitrogen dioxide. The latter is predominant in the atmosphere.	-
Nitrogen dioxide (NO_2)	Brown-reddish, non flammable and toxic gas which originates from the oxidation of NO.	It is irritant and corrosive to skin and the respiratory tract. Inhalation of high concentrations of this pollutant for a short period of time may lead to pulmonary edema. Prolonged exposure can affect the immune system and lungs, resulting in less resistance to infections and causing irreversible changes in the lung tissue.
Sulfur dioxide (SO_2)	Colorless, non-flammable and odorous gas. It is irritating and toxic. It is produced by burning fossil materials high in sulfur content, such as petroleum and coal, although it is also generated in many processes in the chemical industry.	It mainly affects the mucus and lungs causing coughing fits. Exposure to high concentrations for short periods of time can irritate the respiratory tract, cause bronchitis, asthmatic reactions, respiratory arrest, and congestion in the bronchial tubes of asthmatics.
PM_{10}	Particles with an aerodynamic diameter of ≤ 10 µm. They are commonly known as *coarse particles*. They are made up of inorganic compounds such as silicates, aluminates and heavy metals, among others, as well as organic material associated with carbon particles. In cities, traffic is the most important source deriving either from the emissions of vehicle engines or from the wear of pavement, tires and brakes. In the industrial field the burning of fossil fuels, especially the combustion of coal, is the main source of primary particulate matter.	Prolonged or repetitive exposure can cause harmful effects on the respiratory system.
$PM_{2.5}$	Particles with aerodynamic diameter of ≤2.5 µm. They are commonly known as *fine particles*. They are mainly made up of secondary particles formed in the atmosphere from precursor gases - particularly NOx, SO_2, VOC, NH_3 - through chemical processes or through liquid phase reactions	They penetrate the nose and the throat reaching the lungs. They may cause respiratory morbidity, deficiency of the lung function and lung cancer[18].

Table 1 – Main atmospheric pollutants (Own elaboration based on information obtained from PRTR-Spain)

[18] Source: United Nations Environment Programme.

1.3. Air quality guidelines of the World Health Organization

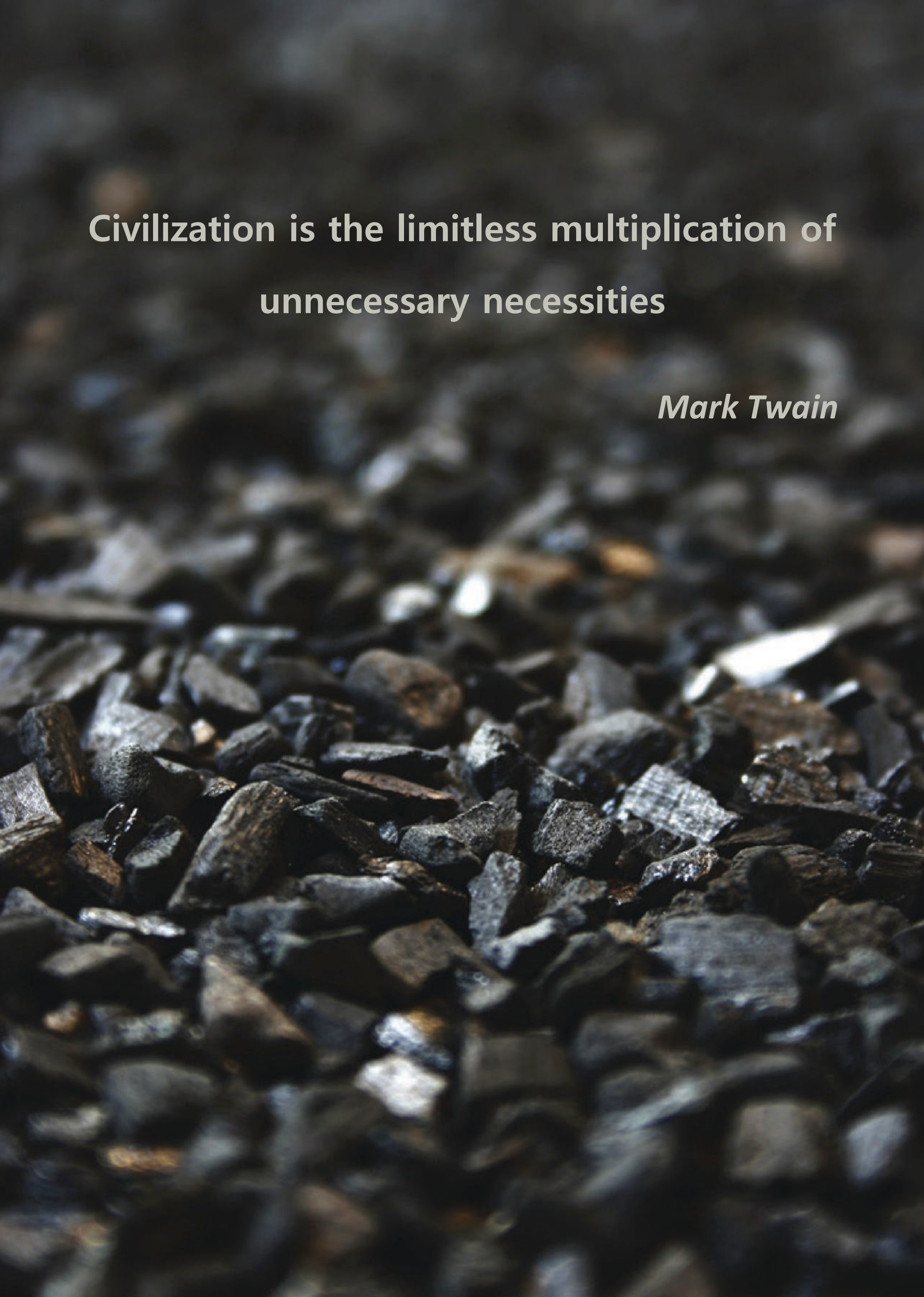
The World Health Organization (WHO) is the United Nations agency specialized in managing policies of prevention, promotion and intervention in health at world-wide level. Its experts develop health guidelines and standards, while helping countries address public health issues. Its air quality guidelines (AQG) are intended to support measures aimed at achieving air quality that protects the health of citizens in different situations. These guidelines are based on a comprehensive set of scientific evidence relating to air pollution and its health consequences[19].

The AQGs were published in 1987 and updated in 1997, based on the existing scientific evidence at that moment, which was evaluated by experts. In 2005, based on subsequent studies on air pollution effects on health, the information on particulate matter, ozone, NO_2 and SO_2 was updated, indicating, reviewed guideline values for each of them. These, however, cannot fully protect human health since, as the WHO itself states, epidemiological evidence indicates that the possibility of adverse health effects persists even when guideline values are reached. Thus, some countries may decide to adopt stricter national air quality standards setting lower concentration values[20]. Despite this, most of the air quality objectives established by the European Union (EU) and Spanish legislation -Directive 2008/50/ EC and Royal Decree 102/2011 respectively- are more permissive than the ones recommended by the WHO (Table 2). This shows a lack of will to protect the population from the health effects of air pollution. The result is that officially it may seem that our cities have better air quality than the one they really have.

Pollutant	Guideline Values WHO [µg/m^3]	Emission limits of Directive 2008/50/EC and Royal Decree 102/2011 [µg/m^3]		Average Period
$PM_{2.5}$	10	25	-	1 calendar year
PM_{10}	20	40	-	1 calendar year
	50	50	Not to be exceeded more than 35 times in any calendar year	24 hours
O_3	100	120	Maximum daily 8 hours mean from hourly running 8 hours. Not to be exceeded on more than 25 days per calendar year averaged over three years	8 hours
NO_2	40	40	-	1 calendar year
	200	200	Not to be exceeded more than 18 times in any calendar year	1 hour
SO_2	20	125	Not to be exceeded more than 18 times in any calendar year	24 hours

Table 2 – Comparative between the WHO guideline values and the limits established by EU and Spanish legislation

[19] WHO, *Air Quality Guidelines. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide*. Global Update 2005. Available at: http://www.euro.who.int/__data/assets/pdf_file/0005/78638/E90038.pdf.
[20] Ibid.


Civilization is the limitless multiplication of unnecessary necessities
Mark Twain

CHAPTER 2

COAL-FIRED POWER PLANTS IN SPAIN

Electricity is a good that we cannot do without. Year after year its demand increases. Therefore, it is essential to move towards an energy model which is sustainable and respectful with the environment. This implies encouraging the use of renewable energies instead of fossil fuels. However, today most of the activities related to the production of electricity are mainly based on the use of fossil fuels, essentially coal and natural gas, which are one of the main sources of air pollution.

2.1. The Spanish electricity system [21]

According to data of Red Eléctrica Española (REE), the transmission system operator in Spain, by 31 December 2016, the whole fleet of electricity generation facilities reached a total installed capacity of 105,308 MW of which 100,088 MW belonged to the so-called peninsular system and 5,220 MW corresponded to the so called non-peninsular one.

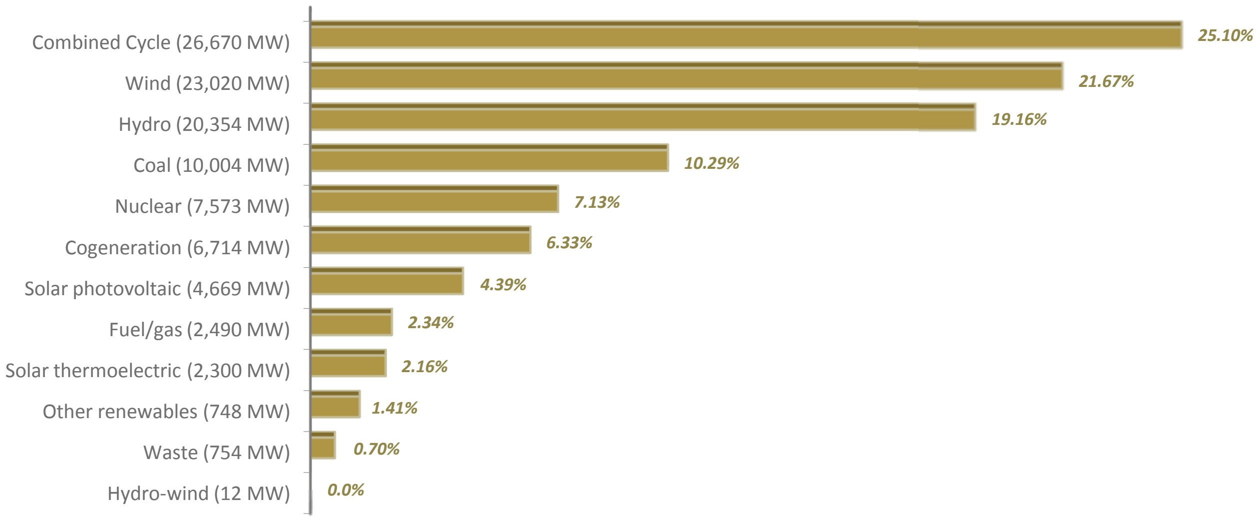


Figure 2 – Installed power capacity in Spain as of 31 December 2016 (Source: REE)

[21] The data of this section was obtained from the report of REE "The Spanish Electricity System – Preliminary Report 2016". Available at:
http://www.ree.es/sites/default/files/downloadable/avance_informe_sistema_electrico_2016_eng.pdf.

The demand for electrical energy reached 265,317 GWh in 2016, a 0.8% higher than in the previous year. On the other hand, generation registered a decrease of 1.9%, amounting to 262,850 GWh.

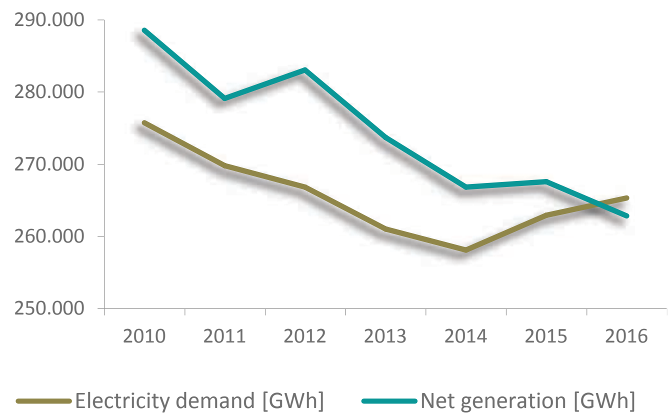


Figure 3 – Evolution of annual electricity demand and net generation in Spain (Source: REE)

As for the sources used in the peninsular system to cover electricity demand in 2016, it is worth mentioning the role of renewable ones. They increased their share to 41.1% while in the previous year they covered 36.9% of the demand.

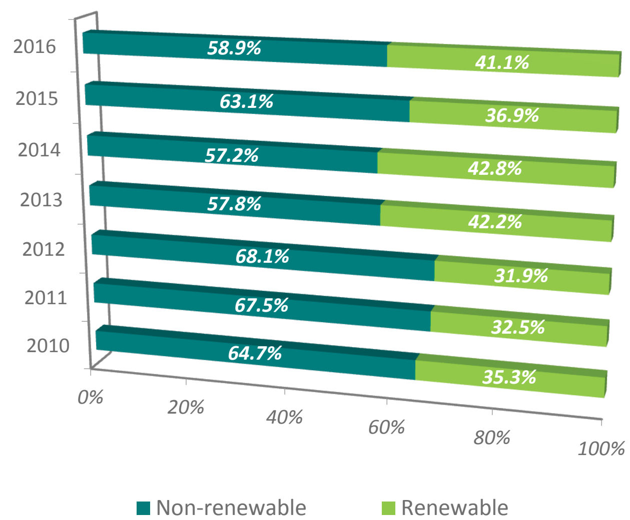


Figure 4 – Structure of the peninsular demand coverage (Source: REE)

Unfortunately, this increase was not due to a rise in their installed capacity. In fact, the latter amounted to around 49,900 MW, practically the same as in 2015. The main reason for this increase was because of the hydrological characteristics of the year, which caused a notable increase in hydro production (+25.1%) which lead to this source covering 14.1% of the demand.

As for the rest of renewable sources, wind was the first source of electricity among them, with a coverage of 19.2% of the demand. The participation of solar photovoltaic did not vary substantially, since it continued covering only 3%. This is mainly due to the low installed capacity - 4,425 MW - despite the high number of hours of sunshine in Spain, which, on average, throughout the year amount to 2,691[22]. In relation to this, it is worthwhile to highlight that Germany, despite receiving 40% less of sunshine hours per year[23], has an installed solar photovoltaic capacity of 38,235 MW[24]. This is by all means paradoxical. With regards to non-renewable energy sources, nuclear contributed the most to the demand in 2016 covering 22%, while coal came in second with 13.7%. The combined cycle and cogeneration share was 10.4% and 10.1%, respectively.

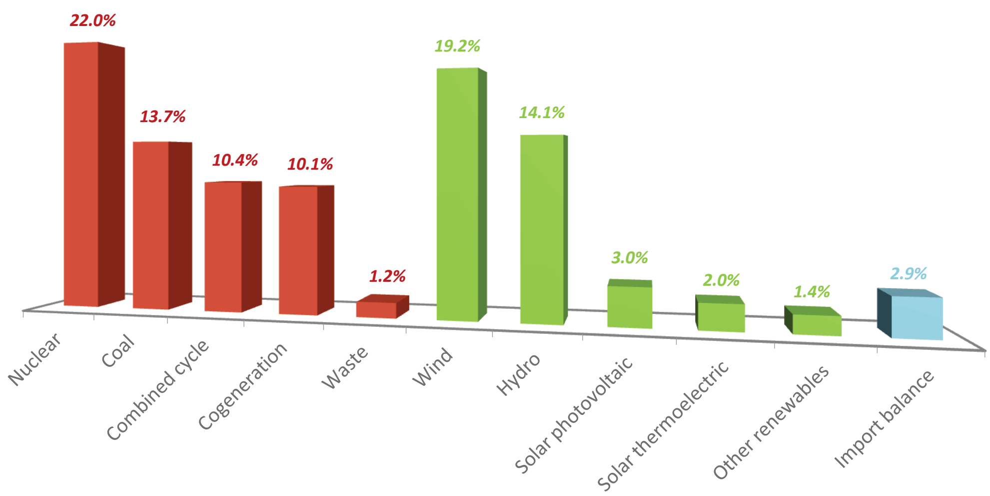


Figure 5 – Coverage of the electricity demand in the peninsular system, 2016. (Source: REE)

Energy sources

Energy sources can be grouped, according to the availability of their reserves, in:

<u>Non-renewable energy sources</u>: They can be found in nature in a limited amount and their speed of consumption is greater than their regeneration one. Thus, once they are totally consumed, they cannot be replaced. These sources can be divided into two groups: fossil fuels (petroleum, coal and natural gas) and nuclear energy. They produce emissions and waste that degrade the environment, apart from causing external dependency as they can only be found in certain areas of the planet.

<u>Renewable energy sources</u>: Renewable energy can be obtained from inexhaustible natural sources either because of the great amount of energy they contain or because of their natural regeneration capacity. The main renewable energy sources are: solar, wind, hydro, tidal and geothermal. Contrary to non-renewable sources, their use is not harmful to the environment. Furthermore, they are domestic energy sources. Therefore, their use decreases the external dependence with regards to energy supply.

[22] Source: http://www.climatedata.eu.
[23] Ibid.
[24] SolarPower Europe, *Solar Photovoltaic Jobs & Value Added in Europe*, November 2015.

2.2. The role of coal in electricity production

Despite being the most polluting source of generation, coal plays a significant role in the production of electricity in Spain. During the period from 2013 to 2015, this fuel has been the only source in the peninsular system that registered values of net generation and coverage of the annual energy demand in constant growth according to data from REE (Figure 6).

In 2013, coal was the third largest source of electricity, covering 14.6% of demand, behind nuclear and wind power, both covering 21.2%[25]. In addition, in 2014 - the year used as the reference for this report - coal was also the third source: it produced 44,064 GWh and covered 16.5% of the demand[26]. Once again, nuclear (22%) and wind (20.3%) were the two main sources. Finally, in 2015, coal was the second source of electricity (20.3%), only being surpassed by nuclear (21.7%)[27]. In 2016, coal registered a sharp decrease in generation and coverage capacity. This fall was not due to a specific energy plan, as it should have been, but to the increase in hydroelectric production and to a reduction of the coal fleet during that year.

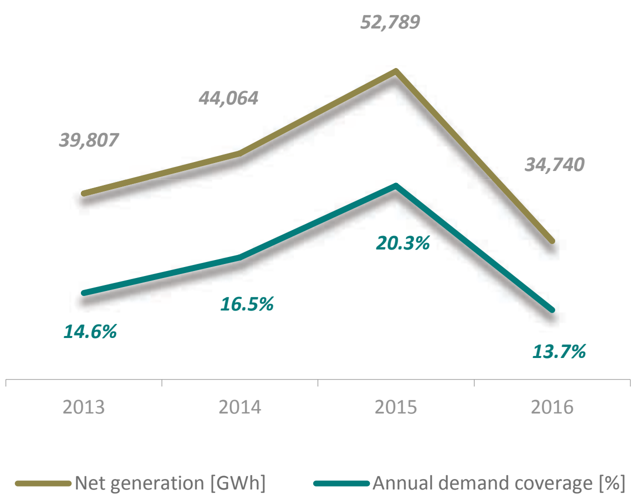


Figure 6 – Electricity generation with coal and its coverage of the annual demand in the peninsular system (Source: REE)

The increase in the use of coal during previous years was due to many different factors. One of them was the success of *fracking* in the United States, a technique of hydraulic fracturing in rocks that allows the extraction of gas and petroleum from the subsoil. These two fuels gradually replaced coal, as *fracking* favored their supply at very low prices. Therefore, surpluses of coal were dumped into world markets[28], causing its price to drop (Figure 7).

Another important factor was the low price of CO_2 emission allowances (Figure 7), which did not have and are not having the expected deterrent effect to force electricity companies to opt for cleaner production methods. On the contrary, they choose to continue emitting GHGs that cause global warming and to attend auctions to buy their emission allowances. One of the reasons for the low price of these allowances was due to the economic crisis of 2008, which caused a reduction of emissions and, consequently, a surplus of allowances. The result was a fall in the price of the CO_2 tonne to below 10 Euros, whereas when the EU Emissions Trading System was designed, it was calculated that in order to encourage the use of cleaner sources of energy[29] instead of coal the price of CO_2 would need to be around 25 Euros per tonne.

[25] REE, *The Spanish electricity system,* 2013.
Available at: http://www.ree.es/sites/default/files/downloadable/inf_sis_elec_ree_2013_v1.pdf.
[26] REE, *The Spanish electricity system,* 2014.
Available at: http://www.ree.es/sites/default/files/downloadable/inf_sis_elec_ree_2014_v2.pdf.
[27] REE, *The Spanish electricity system,* 2015.
Available at: http://www.ree.es/sites/default/files/downloadable/inf_sis_elec_ree_2015.pdf.
[28] The low prices of coal catapults its use in coal plants in Spain, *La Vanguardia*, January 2016.
URL: http://www.lavanguardia.com/natural/20160111/301318198522/precio-carbon-termicas-espana.html.
[29] Ibid.

Furthermore, the use of coal has also been stimulated by the numerous amounts of aid which the Spanish Government has granted both to its extraction and burning. This aid has mainly consisted on subsidies for mining companies and *capacity payments* granted to electricity companies. In addition, during the period from 2011 until 2014, ten coal plants which burnt indigenous coal benefited from the so-called *preferential dispatch mechanism*[30].

These factors, among others, have hindered a greater commitment towards other sources of electricity which are cleaner and safer for the climate and for our health.

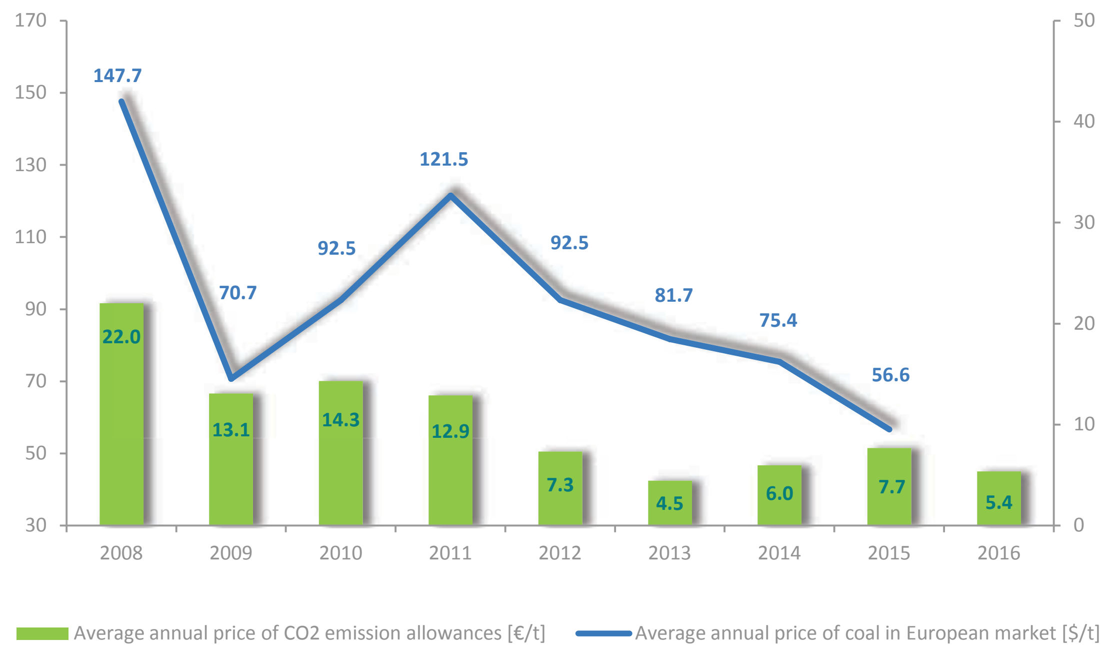


Figure 7 – Evolution of average annual price of coal in the European market[31] and of CO_2 emission allowances[32]

[30] This mechanism was intended to encourage the use of indigenous coal in electricity generation. For that purpose, a financial compensation and priority of dispatch in the electricity market were given to the owners of ten combustion plants running on indigenous coal in exchange of producing certain volumes of electricity out of that coal. For more information please see, *Information Box 3* in the complete report in Spanish.

[31] Source: British Petroleum Database.

[32] Source: SENDECO2.

2.3. Coal - fired power plants in Spain

A coal power plant is an installation that produces energy from the combustion of this fossil fuel. Spain has 15 coal-fired power plants with an installed net capacity of around 10,004 MW. In addition, there is another coal plant -La Pereda- of 50 MW of capacity which is not included in the group of electricity generation facilities according to data of REE. Most of these plants are located in the north of the Iberian peninsula, in the Autonomous Communities (AA.CC) of Asturias, Castilla y León and Galicia. The others are in Andalucía, Aragón and Balearic Islands. The main operators are the largest electricity companies in the country. Endesa Generación is the operator which owns most of the coal plants (5,167.8 MW), ahead of Gas Natural Fenosa with 1,909.3 MW of installed capacity and Hidroeléctrica del Cantábrico (EDP Spain) owner of 1,224 MW. Further back are Viesgo (869.9 MW), Iberdrola Generación (833.5 MW) and Hulleras del Norte S.A. (50 MW).

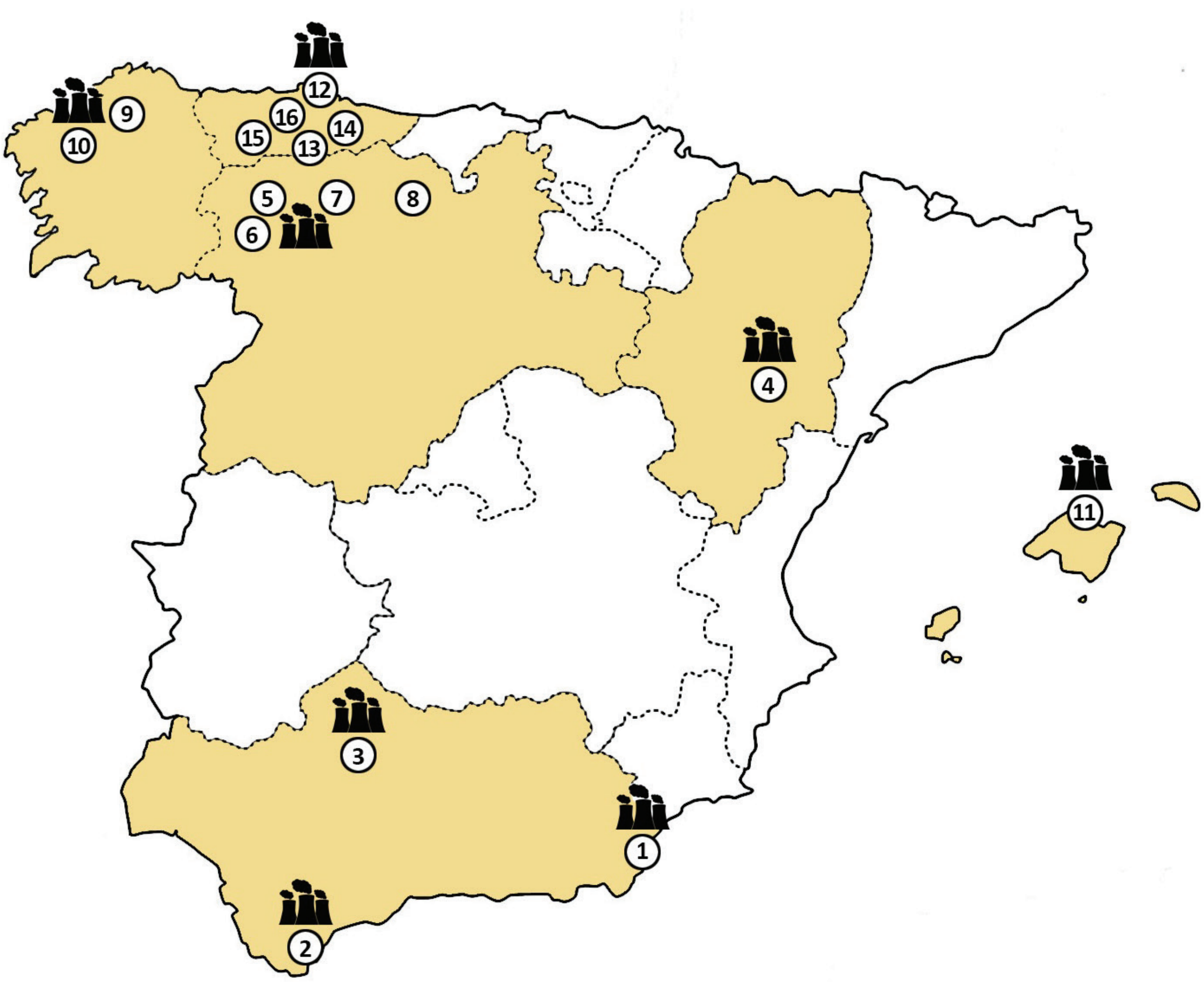


Illustration 1 –Location of existing coal plants in Spain

	Coal plant	Municipality	AA. CC	Year of commissioning	Net installed capacity[33] (MW)	Owner
1	LITORAL (G1) LITORAL (G2)	Carboneras (Almería)	Andalucía	1985 1997	557.5 562.1	Endesa Generación
2	LOS BARRIOS	Los Barrios (Cádiz)	Andalucía	1985	570.1	Viesgo
3	PUENTE NUEVO	Espiel (Córdoba)	Andalucía	1981	299.8	Viesgo
4	ANDORRA (G1) ANDORRA (G2) ANDORRA (G3)	Andorra (Teruel)	Aragón	1981	352.2 352.1 351.4	Endesa Generación
5	ANLLARES	Páramo del Sil (León)	Castilla y León	1982	346.8	Gas Natural Fenosa[34]
6	COMPOSTILLA (G3) COMPOSTILLA (G4) COMPOSTILLA (G5)	Cubillos del Sil (León)	Castilla y León	1972 1981 1985	323.3 341.2 340.7	Endesa Generación
7	LA ROBLA (G1) LA ROBLA (G2)	La Robla (León)	Castilla y León	1971 1984	264 355.1	Gas Natural Fenosa
8	VELILLA (G1) VELILLA (G2)	Velilla del Río Carrión (Palencia)	Castilla y León	1964 1986	143.4 342.4	Iberdrola Generación
9	AS PONTES (G1) AS PONTES (G2) AS PONTES (G3) AS PONTES (G4)	As Pontes de García Rodríguez (A Coruña)	Galicia	1976	351 351.1 350.3 350.9	Endesa Generación
10	MEIRAMA	Ordes (A Coruña)	Galicia	1980	557,2	Gas Natural Fenosa
11	ALCÚDIA (G1) ALCÚDIA (G2) ALCÚDIA (G3) ALCÚDIA (G4)	Alcudia	Islas Baleares	1981 1982 1997 1997	113.6 113.6 120.6 120.6	Endesa Generación
12	ABOÑO (G1) ABOÑO (G2)	Gijón	Principado de Asturias	1974 1985	341.8 535.9	HC-EDP
13	LA PEREDA	Mieres	Principado de Asturias	1995	50[35]	Hulleras del Norte
14	LADA (G4)	Langreo	Principado de Asturias	1981	347.7	Iberdrola Generación
15	NARCEA (G2) NARCEA (G3)	Tineo	Principado de Asturias	1969 1984	154.3 347.5	Gas Natural Fenosa
16	SOTO DE RIBERA (G3)	Ribera de Arriba	Principado de Asturias	1984	346.3	HC-EDP

Table 3 – Characteristics of the existing coal-fired power plants in Spain

[33] Source: Ministry of Energy, Tourism and Digital Agenda. *Administrative Register of Energy Production Installations.*
[34] Gas Natural Fenosa is the owner of 66.66% of this plant. The remaining 33.33% is owned by Endesa Generación.
[35] Source: Hunosa group.

2.3.1. Emission limit values

Currently, the main EU legal instrument which regulates power plants is Directive 2010/75/EU on industrial emissions (IED)[36]. Large combustion plants (LCPs)[37], which include coal power plants, contribute significantly to the emission of pollutants into the air, having a considerable impact on human health and the environment[38]. In order to reduce the pollution caused by these emissions, it is necessary to limit them through the establishment of emission limit values (ELVs) which are foreseen in the IED permit granted to each installation[39].

These permits must include conditions ensuring that emissions into the air from these power plants do not exceed the values set out in Annex V, part 1 of the IED[40], which contains ELVs for SO_2, NOx and PM, among other pollutants. These ELVs came into effect on January 1 2016 replacing the ones established by the previous Directive (Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plants - LCPD). However, today almost all of the ELVs set in the permits of coal power plants in Spain are above the ones established in the IED. Many are even higher than the ELVs provided in the derogated LCPD, what is contrary to the IED itself (Table 4)[41]. This is because, over the years, all these installations have been subject to different derogations allowing them to pollute above the ELVs established in these two EU Directives.

The IED foresees the following derogations:

- the **Transitional National Plan** (**TNP**)[42], in force from 1 January 2016 until 30 June 2020. Combustion plants covered by the plan may be exempted from compliance with the ELVs set out in Annex V, part 1 of the IED. It establishes maximum total annual emissions of SO_2, NOx and particulate matter for all of the plants covered by the TNP. After this period, those plants which want to continue functioning must comply with the ELVs provided in Annex V, part 1 of the IED.

- the **Limited Lifetime Derogation (LLD)**[43], which allows plants to be exempted from complying with the ELVs set out in Annex V part 1 of the IED with the condition that they operate no more than 17,500 hours from 1 January 2016, until 31 December 2023, at the latest. After this date, the plant must shut down or be able to meet the ELVs set out in Annex V, part 2 of the IED, which are applicable to new combustion plants.

In addition, the IED allows for another derogation for those installations which are part of a **small isolated system**[44]. These, are exempted from compliance with the IED ELVs until 31 December 2019,

[36] OJ L 334, 17.12.2010.
[37] LCPs are combustion plants whose total rated termal input is equal or greater than 50 MW (Art. 28, IED). According to Art. 3(25) of the IED a “combustion plant” is any technical apparatus in which fuels are oxidised in order to use the heat thus generated.
[38] Paragraph 29, Preamble, IED.
[39] Art. 14(1)(a), Ibid.
[40] Art. 30(2), ibid.
[41] Art. 32(2), Ibid.
[42] Art. 32, ibid.
[43] Art. 33, ibid.
[44] Art. 34, ibid.

Combustion plant[45]	Directive 2001/80/EC (LCPD)			Directive 2010/75/EU (IED)			IED permit			IED derogation
-	NOx	SO_2	PM	NOx	SO_2	PM	NOx	SO_2	PM	-
ABOÑO (G1)	500	400	50	200	200	20	650	1,600	100	*TNP*
ABOÑO (G2)	500	400	50	200	200	20	650	484	50	*TNP*
ALCUDIA (G1 & G2)	500	400	50	200	200	20	500	400	20	*Small isolated system*
ALCUDIA (G3 & G4)	500	400	50	200	200	20	500	800	20	*Small isolated system*
ANDORRA	500	92% (a)	50	200	96% (a)	20	1,200	2,500	130	*TNP*
ANLLARES	1.200	400	50	200	200	20	1,750	2,750	350	*LLD*
AS PONTES	500	400	50	200	200	20	650	1,200	100	*TNP*
COMPOSTILLA (G3)	1.200	400	50	200	200	20	1,300	1,200	200	*TNP*
COMPOSTILLA (G4 & G5)	1.200	400	50	200	200	20	1,300	1,100	100	*TNP*
LA ROBLA (G1)	500	400	50	200	200	20	1,500	2,000	400	*TNP*
LA ROBLA (G2)	500	400	50	200	200	20	1,200	400	50	*TNP*
LADA	500	400	50	200	200	20	1,000	400	50	*TNP*
LITORAL	500	400	50	200	200	20	500	400	50	*TNP*
LOS BARRIOS	500	400	50	200	200	20	500	200	50	*TNP*
MEIRAMA	500	400	50	200	200	20	650	2,400	150	*TNP*
NARCEA (G2)	600	562	100	200	200	20	1,200	1,200	100	*TNP*
NARCEA (G3)	1.200	400	50	200	200	20	1,200	400	75	*TNP*
PUENTE NUEVO	500	400	50	200	200	20	850	200	50	*TNP*
SOTO DE RIBERA (G3)	500	400	50	200	200	20	650	400	50	*TNP*
VELILLA (G1)	600	679	100	200	200	20	1,750	3,000	280	*TNP*
VELILLA (G2)	500	400	50	200	200	20	1,200	400	100	*TNP*

(a) = minimum desulphurisation index.

Table 4 – Comparative between ELVs (mg/Nm^3) set out in EU Directives and in IEDpermits of coal plants

[45] La Pereda is a multi-fuel firing combustion plant. Thus, its ELVs must be set out through the procedure established in Art. 8(1) of the LCPD and 40(1) of the IED.

2.3.2. The PRTR Protocol and emissions into the air

On 25 June 1998, the European Community signed the UNECE Convention on Access to Information, Decision-Making and Access to Justice in Environmental Matters, also known as the Aarhus Convention[46]. The Convention acknowledges that a wider public access to environmental information and a greater dissemination of this information contribute to raising awareness on these issues and, as a consequence, to an improvement of the environment[47].

Afterwards, in May 2003, a total of 36 countries and the European Community signed the Protocol on Pollutant Release and Transfer Register (PRTR Protocol)[48] in Kyiv. The objective of this Protocol is:

"to enhance public access to information through the establishment of coherent, integrated, nationwide pollutant release and transfer registers (…) which could facilitate public participation in environmental decision-making as well as contribute to the prevention and reduction of pollution of the environment"[49].

[46] This Convention has also been signed and ratified by Spain. Instrument of ratification of the Convention in Access to Information, Decision-Making and Access to Justie in Environmental Matters, done at Aarhus (Denmark) on 25 June 1998 (BOE N. 40, 16.02.2005).
[47] Source: United Nations Economic Commission for Europe.
[48] Available at:
https://www.unece.org/fileadmin/DAM/PRTR_Protocol_e.pdf.
[49] Art. 1, PRTR Protocol.

In order to bring Community legislation into line with the PRTR Protocol, Regulation (EC) No 166/2006[50] was adopted. It requires Member States to report annually to the European Commission on pollutant emissions and off-site transfer data notified by certain industrial facilities. Spain, in compliance with this European Regulation and as part of the PRTR Protocol, implemented the Spanish Pollutant Release and Transfer Register (PRTR-Spain)[51] currently managed by the Ministry of Agriculture and Fisheries, Food and Environment (MAPAMA).

The PRTR-Spain is a register in the form of an accessible electronic database which became operational on January 1 2008. It contains annual information on the amounts of pollutant releases to air, water and land as well as off-site transfers of waste and of pollutants in wastewater from facilities which carry out the activities listed in Annex I of Royal Decree 508/2007[52]. Coal power plants are included in this register. Thus, they must report, among others, their emissions into air of the pollutants included in Annex II of that Royal Decree if these emissions exceed a certain threshold, also specified in Annex II. These pollutants include CO_2, NOx, SO_2 and PM_{10}, which are emitted in large quantities by these plants.

The total annual emissions of these pollutants from coal-fired power plants in Spain during the period 2007-2015 are indicated below. The figures also include the emissions of those plants which are no longer in operation[53]. In addition, a series of graphics comparing these emissions with the ones from other thermal power stations and combustion installations in Spain are also shown down below.

[50] Regulation (EC) No 166/2006 of the European Parliament and of the Council of 18 January 2006 concerning the establishment of a European Pollutant Release and Transfer Register and amending Council Directives 91/689/EEC and 96/61/EC (OJ L 33, of 4.2.2006).
[51] Available at: http://www.prtr-es.es/.
[52] Royal Decree 508/2007 of 20 April regulating the provision of information on the E-PRTR emissions Regulation and the IPPC permits (BOE num. 96, of 21.04.2007).
[53] This information has been obtained from the PRTR-Spain.

CO_2 emissions

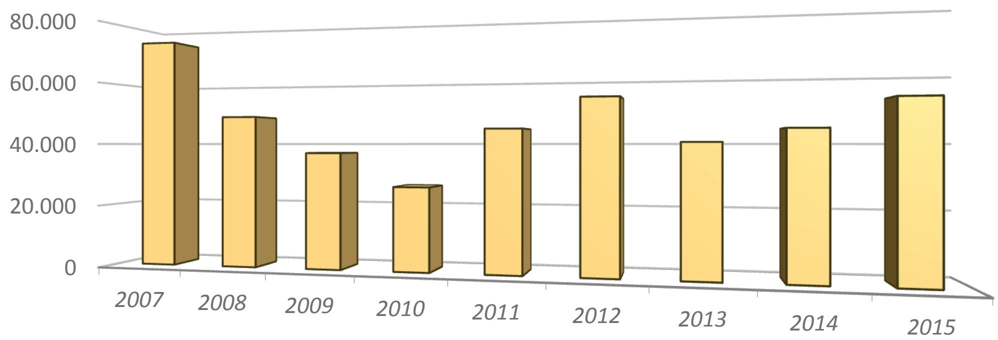


Figure 8 – Annual evolution of CO_2 emissions from coal power plants [kilotonnes/year]

In the electricity sector, the variation of CO_2 emissions is related to the technologies used to generate electricity. All combustion installations, including coal power plants are responsible for emitting high quantities of this GHG. If we compare CO_2 emissions from coal and from the remaining combustion installations, it can be seen that in 2008, the year in which the economic crisis began, both coal and the rest of combustion installations were responsible for very similar amounts of CO_2 emissions (Figure 9). In the following two years, the emissions caused by the rest of the combustion plants surpassed those of the coal plants. However, during the period from 2011 to 2014, when coal burning was being subsidized through the *preferential dispatch mechanism*, coal plants were, again, the largest emitters of CO_2. This trend continued to increase in 2015 as electricity generation from coal increased as well. In this year, coal plants were responsible for more than 53,000 kilotonnes of CO_2, equivalent to 60.3% of emissions from all of Spain's combustion installations.

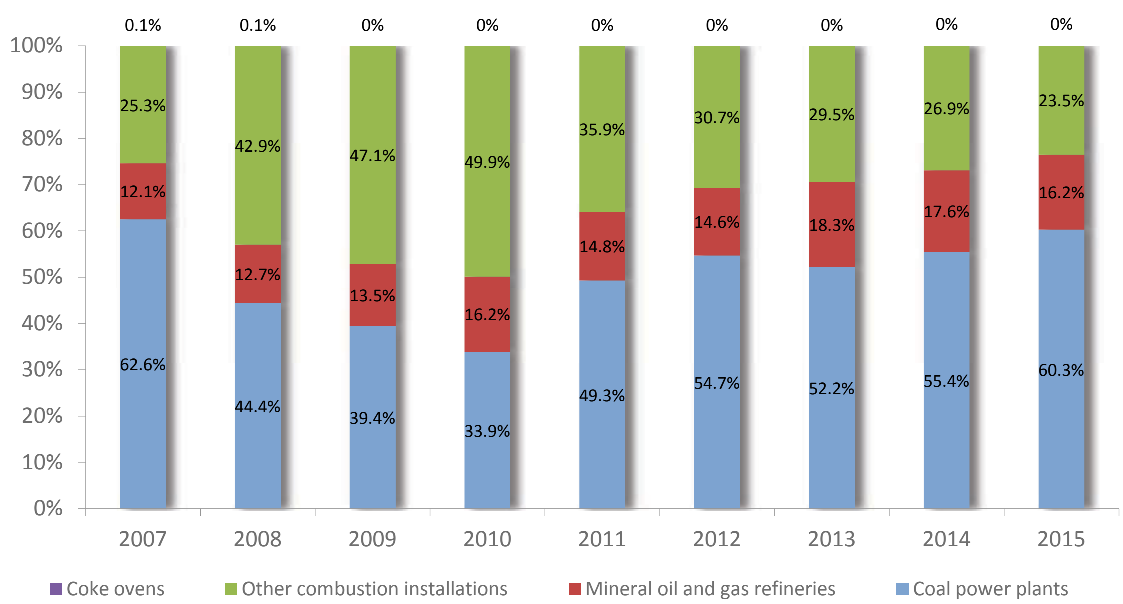


Figure 9 – Annual CO_2 emissions of thermal power stations and combustion installations in Spain (Source: Own elaboration with data from PRTR-Spain and European Union Transaction Log, EUTL)

NOx emissions

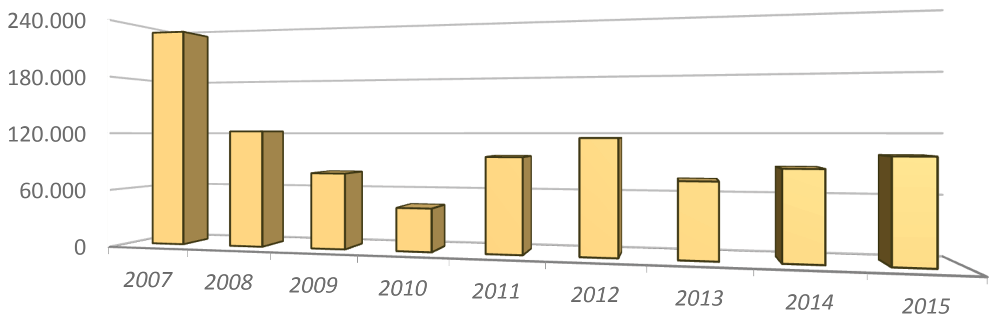


Figure 10 – Annual evolution of NOx emissions from coal power plants [tonnes/year]

NOx emissions from coal power plants have represented around 40-50% of the total emissions from combustion installations in Spain during the last years (Figure 11). This is because although the majority of coal plants have installed primary reduction techniques for NOx emissions, they do not have the secondary techniques which would allow them to reduce these emissions significantly[54]. The formation of NOx during the combustion of coal is produced both by the oxidation of nitrogen contained in this fuel (NOx of the fuel) and by the nitrogen contained in the combustion air (thermal NOx). The former is produced in greater quantity.

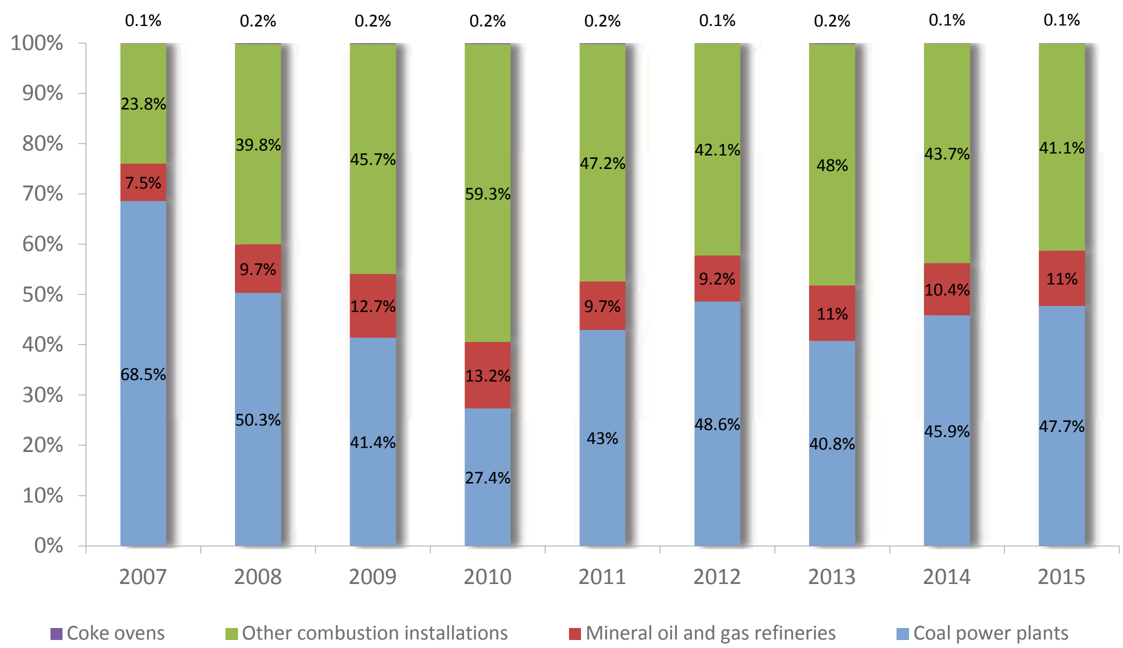


Figure 11 - Annual NOx emissions of thermal power stations and combustion installations in Spain (Source: Own elaboration with data from PRTR-Spain European PRTR)

[54] Primary techniques optimize the combustion process while secondary techniques act directly on the waste gases of that combustion. Most part of the coal plants already have one or more primary techniques. In order to reduce their NOx emissions, As Pontes, Lada, Litoral, Los Barrios, Meirama and Soto de Ribera (G3), are planning or are already carrying out, the necessary works to install these secondary techniques, In particular, Selective Catalytic Reduction (SCR) systems or Selective Non-Catalytic Reduction (SNCR) systems (Source: BOE). On the other hand, Aboño (G2) has already finalized the works for the installation of an SCR system. (Source: EDP Energy).

SO_2 emissions

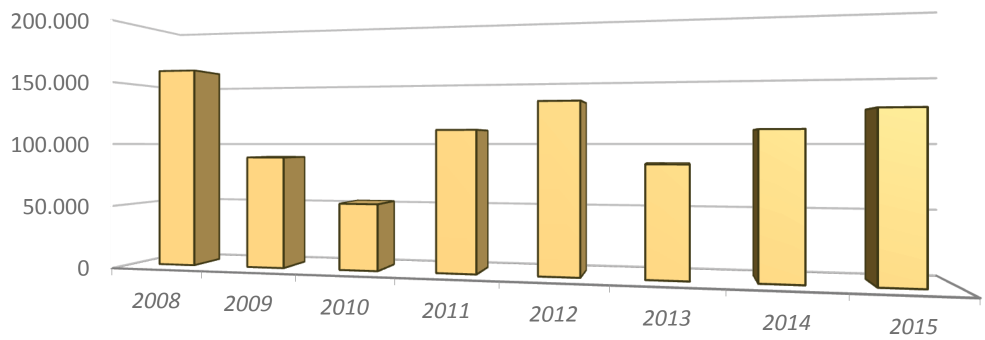


Figure 12 - Annual evolution of SO_2 emissions from coal power plants [tonnes/year] [55]

More than 50% of the SO_2 emissions of combustion plants come from coal power plants (Figure 13) due to the sulphur contained in this fuel. The coal plant of Andorra is responsible for most of the SO_2 emissions[56], as it is the only one which uses black lignite as its main fuel – apart from imported hard coal to a lesser extent. Black lignite contains a high percentage of sulphur in comparison with anthracite and hard coal, which are used in other plants.

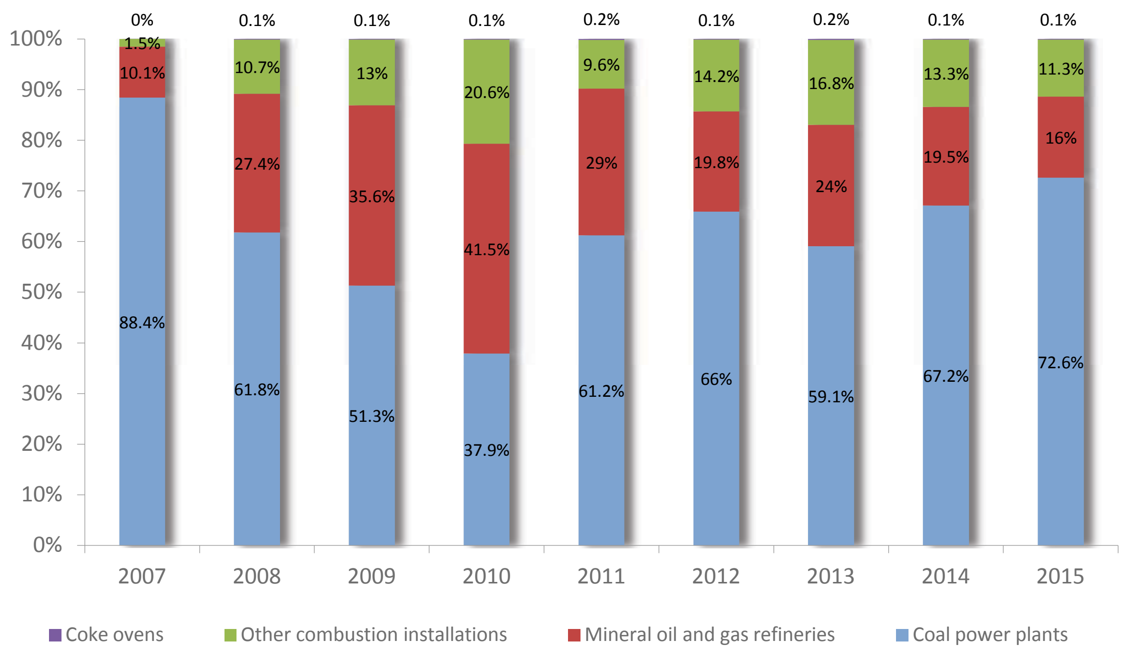


Figure 13 - Annual SO_2 emissions of thermal power stations and combustion installations in Spain (Source: Own elaboration with data from PRTR-Spain European PRTR)

[55] SO_2 emissions from the year 2007 have not been reflected in this chart as they are higher than its scale.

[56] According to data from PRTR-Spain, in 2015 Andorra was responsible for more than 36 thousand tonnes of SO_2 emissions.

PM_{10} emissions

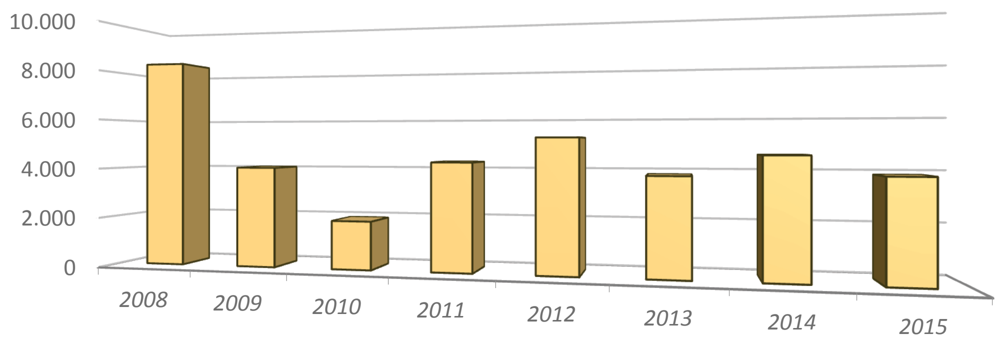


Figure 14 - Annual evolution of PM_{10} emissions from coal power plants [tonnes/year][57]

Coal plants are responsible for most part of PM_{10} emissions within the whole group of combustion installations in Spain (Figure 15). Nevertheless, all of these coal plants have already installed techniques to reduce these emissions. In particular, electrostatic precipitators, which are considered as a *Best Available Technique* (BAT)[58] as they guarantee a removal efficiency of more than 99%[59] of emissions.

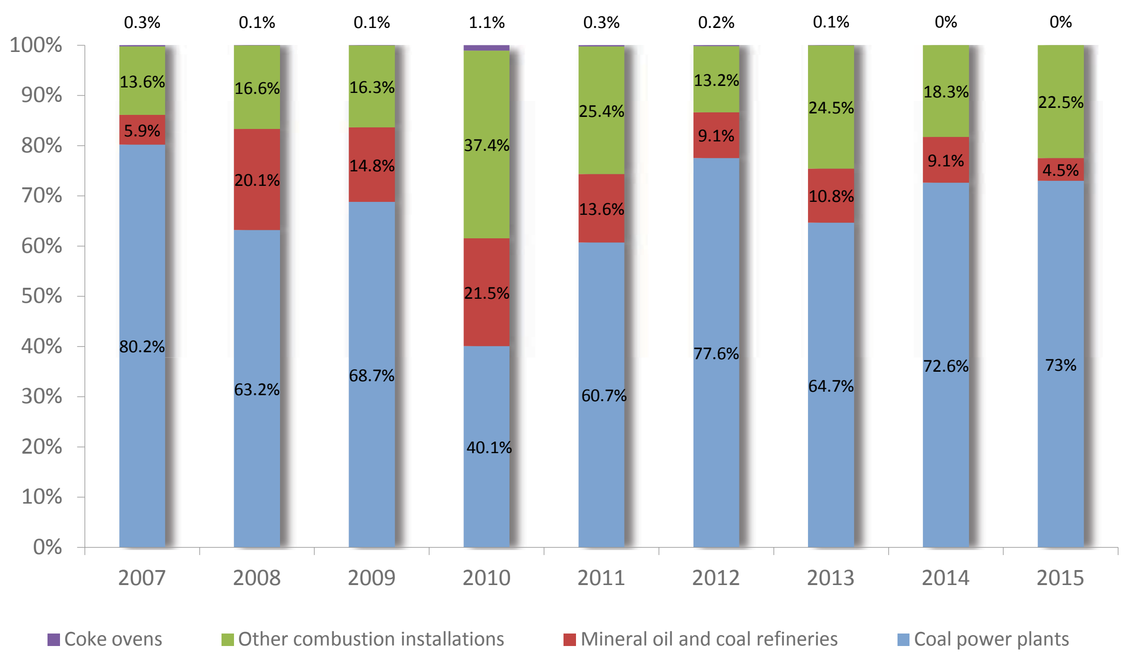


Figure 15 - Annual PM_{10} emissions of thermal power stations and combustion installations in Spain (Source: Own elaboration with data from PRTR-Spain European PRTR)

[57] PM_{10} emissions from the year 2007 have not been reflected in this chart as they are higher than its scale. In addition, depending on the year, PM_{10} emission data was not available for some plants. Thus, *total suspended particulates* (TSP) have been considered instead.

[58] For more information regarding BATs please see *Information Box 6* in the complete report in Spanish.

[59] Faculty of Exact Sciences, Engineering and Land Surveying, *Implementation of Electrostatics*.

Air pollution is a major environmental risk to health. By reducing air pollution levels, countries can reduce the burden of disease from stroke, heart disease, lung cancer and both chronic and acute respiratory diseases, including asthma.

World Health Organization

CHAPTER 3

CASE STUDY: THE HEALTH IMPACTS OF COAL POWER PLANTS IN SPAIN DURING 2014

Air pollution is related to the appearance and development of various types of diseases, increasing morbidity and mortality[60] as well as work days lost in the exposed areas. This also entails high economic costs.

Around the world, around 18,000 people die every day as a consequence of air pollution, resulting in 6.5 million deaths by the end of the year[61]. These numbers place air pollution as one of the leading causes of death worldwide, above AIDS, tuberculosis or road traffic accidents. In 2015, air pollution continued to be the main environmental risk factor for health in the EU[62]. As a result of this pollution, around 340,000 premature deaths were quantified[63], life expectancy was reduced in 6 months, and about half the population was exposed to $PM_{2.5}$ levels above 10 µg/m^3, which are the ones recommended by the WHO[64].

Power generation is a major source of air pollution. Coal accounts for three-quarters of the sector's SO_2 emissions, 70% of its NO_X emissions and over 90% of its $PM_{2.5}$ emissions[65]. These pollutants have been mainly linked to adverse health effects. In addition, since 2005, the year in which the last WHO AQGs[66] were published, multiple epidemiological and toxicological studies have been carried out to prove these effects.

These studies indicate that exposure to $PM_{2.5}$ is associated with an increase in the systemic inflammatory response and oxidative stress[67], as well as with variations in the biomarkers of cardiovascular inflammation such as C - reactive protein (CRP)[68] and fibrinogen[69,70].

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[60] Morbidity is defined as the proportion of people who become ill at a given place and time. Mortality, in turn, is the statistics on deaths in a given population.

[61] International Energy Agency (IEA), *Energy and Air Pollution*, World Energy Outlook Special Report (2016), p. 3. Available at: http://www.iea.org/publications/freepublications/publication/WorldEnergyOutlookSpecialReport2016EnergyandAirPollution.pdf.

[62] Ibid, p. 143.

[63] Premature deaths are deaths that occur before a person reaches an expected age. Many of these deaths are considered to be preventable.

[64] International Energy Agency (IEA), *op. cit.*, p. 153.

[65] Ibid, p. 43.

[66] WHO, *AQGs, op. cit.*

[67] Oxidative stress is essentially an imbalance between the production of free radicals and the ability of the body to counteract or detoxify their harmful effects through neutralization by antioxidants. Source: News Medical.

[68] CRP is a protein which can be found in the blood. The level of CRP rises when there is inflammation throughout the body. Thus, it can be considered as a marker of cardiovascular risk.

Long-term exposure promotes the progression of cardiovascular diseases as a whole and has been associated with an increase in total mortality. Particularly, with an increase in cardio-respiratory and lung cancer mortality[71],[72]. It is also related to respiratory diseases[73].

NO_2 is a highly reactive and equally hazardous health pollutant present in the vast majority of urban and industrial areas. These studies show that prolonged exposure to NO_2 can cause damage to the respiratory system and is associated with increased symptoms of bronchitis and asthma, lung function impairment and lung cancer[74]. In fact, numerous epidemiological studies conducted in Europe and the rest of the world conclude that between 5 and 7% of lung cancer cases in ex-smokers and non-smokers may be associated with exposure to high concentrations of this pollutant[75]. It is also related to an increase in mortality.

SO_2 has been associated with an increase in asthma and chronic bronchitis as well as with a decrease in lung function and bronchial inflammation. Hospital admissions due to heart disease as well as mortality increase on days when SO_2 levels are higher[76].

3.1. Objective

The main objective of this study has been to estimate the health impacts - and the associated economic impacts- derived from the emission of pollutants into the atmosphere from coal power plants in Spain during the year 2014.

The methodology has followed a two-phase approach. In the first one, a simulation of the dissemination of NO_2, SO_2 and particulate matter emissions from coal power plants has been carried out using a mathematical model of dispersion (CALPUFF). This has allowed to obtain the space-time variations of the concentrations of these pollutants in the domain of study considered during the year 2014. At a later stage, the results of this simulation have been completed with demographic and epidemiological data in order to quantify the effects of these emissions on health in populations at provincial, regional and national levels. To this extent, the respective *concentration-response functions* (CRFs) have been applied. These functions reflect the relationship between the concentration increase of a given pollutant and its impact on health[77].

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[69] Fibrinogen is a high-molecular weight protein in the blood plasma that by the action of thrombin is converted into fibrin; called also factor I. In the clotting mechanism, fibrin threads form a meshwork for the basis of a blood clot. Most of the fibrinogen in the circulating blood is formed in the liver. Its blood levels may vary under certain conditions. If it increases there can be many diseases associated to this like an infection, a cancer, a lymphoma or inflammatory diseases.

[70] WHO - Regional Office for Europe, *Review of evidence on health aspects of air pollution-REVIHAAP Project*, 2013, p. 7.

[71] WHO - Regional Office for Europe*, Methods and tools for assessing the health risks of air pollution at local, national and international level*, 2014.

[72] Ghassan B. Hamra, Outdoor Particulate Matter Exposure and Lung Cancer: A Systematic Review and Meta-Analysis, *Environmental Health Perspectives*, Vol. 122, N. 9, 2014.

[73] WHO - Regional Office for Europe, *Health risks of air pollution in Europe – HRAPIE project*, 2013.

[74] WHO - Regional Office for Europe, *WHO Expert Consultation: Available evidence for the future update of the WHO Global Air Quality Guidelines*, 2016, p. 17.

[75] Y. Omidi et al., Exposure to PM_{10}, NO_2 and O_3 and impacts on human health, *Environmental Science and Pollution Research*, 2016.

[76] WHO, *Ambient (outdoor) air quality and health*, September 2016.
URL: http://www.who.int/mediacentre/factsheets/fs313/en/.

[77] For more information about the methodology please see Annex I of the complete report.

In addition, a comparison has been made of the all natural cause mortality incidence rates related to an increase in the concentration of $PM_{2.5}$, both at regional and provincial levels. The same analysis has been carried out for NO_2, considering only the autonomic level.

In both cases, the objective has been to estimate the spatial variations of these pollutants and to evaluate the influence of the presence or proximity of one or more coal power plants in the increase of the number of deaths in the population.

3.2. Results

3.2.1. Pollutant dispersion

The space-time variation of hourly concentrations of particulate matter ($PM_{2.5}$[78] and TPM_{10}[79]), NO_2 and SO_2 has been obtained for the whole domain under consideration through the implementation of the CALPUFF model. This data has allowed elaborating maps of the estimated annual average concentration of these pollutants. These show that the area most affected by pollution is the northwestern part of Spain, where most of the coal power plants are located.

The highest concentrations of particulate matter and NO_2 can be found in the areas of Asturias and the north of Castilla y León (Illustrations 2, 3 and 4). It can also be seen that the dissemination of particulate matter occurs on a very widespread surface. That is because, due to their small diameter and lightness, they remain suspended in the air for a long time - several days or weeks - allowing them to travel very long distances to places far away from the sources.

In the case of SO_2, the province of León has the highest annual average concentrations (Illustration 5). There is also numerous concentration of SO_2 in the vicinity of the Andorra coal power plant as it uses a type of fuel with a high percentage of sulfur.

[78] This refers to the sum of primary and secondary $PM_{2.5}$.
[79] TPM_{10} refers to the sum of PM_{10} with primary and secondary $PM_{2.5}$.

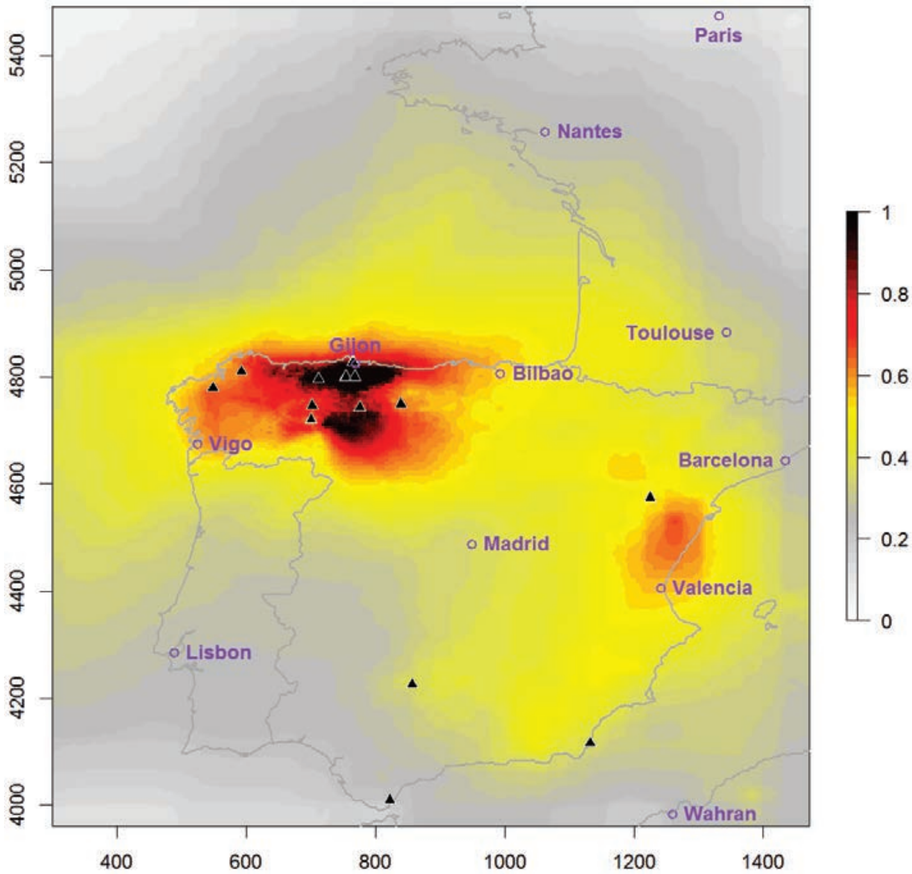


Illustration 2 – Estimation of the annual average concentration (µg/m^3) of $PM_{2.5}$

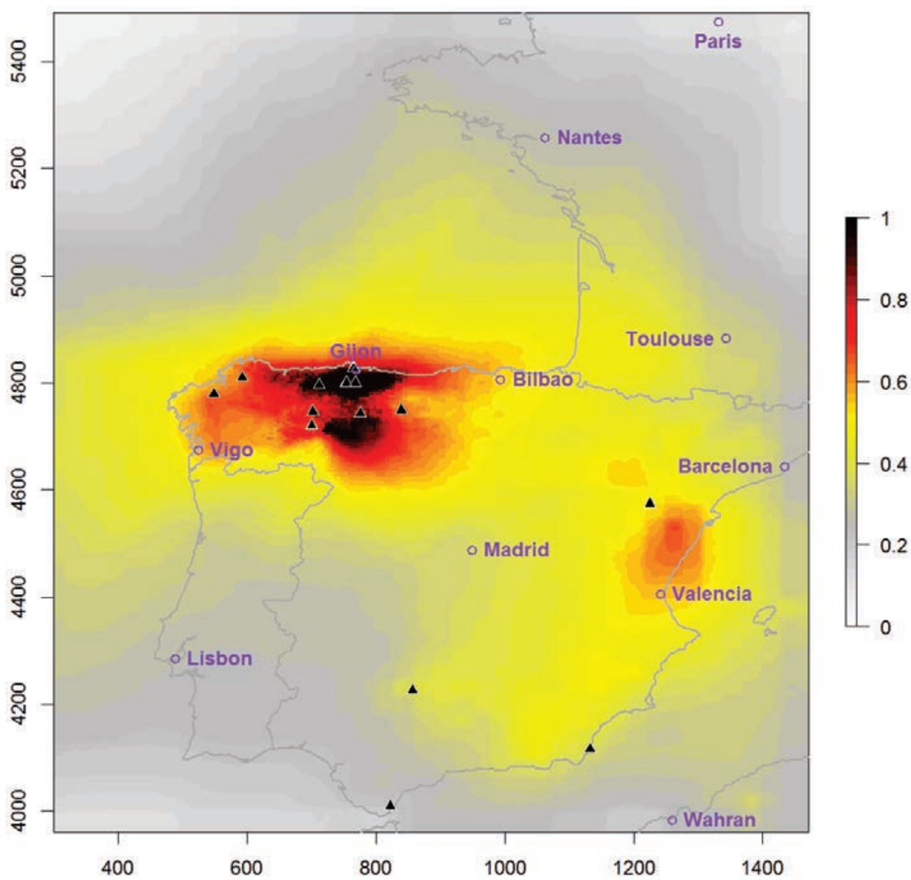


Illustration 3 - Estimation of the annual average concentration (µg/m^3) of TPM_{10}

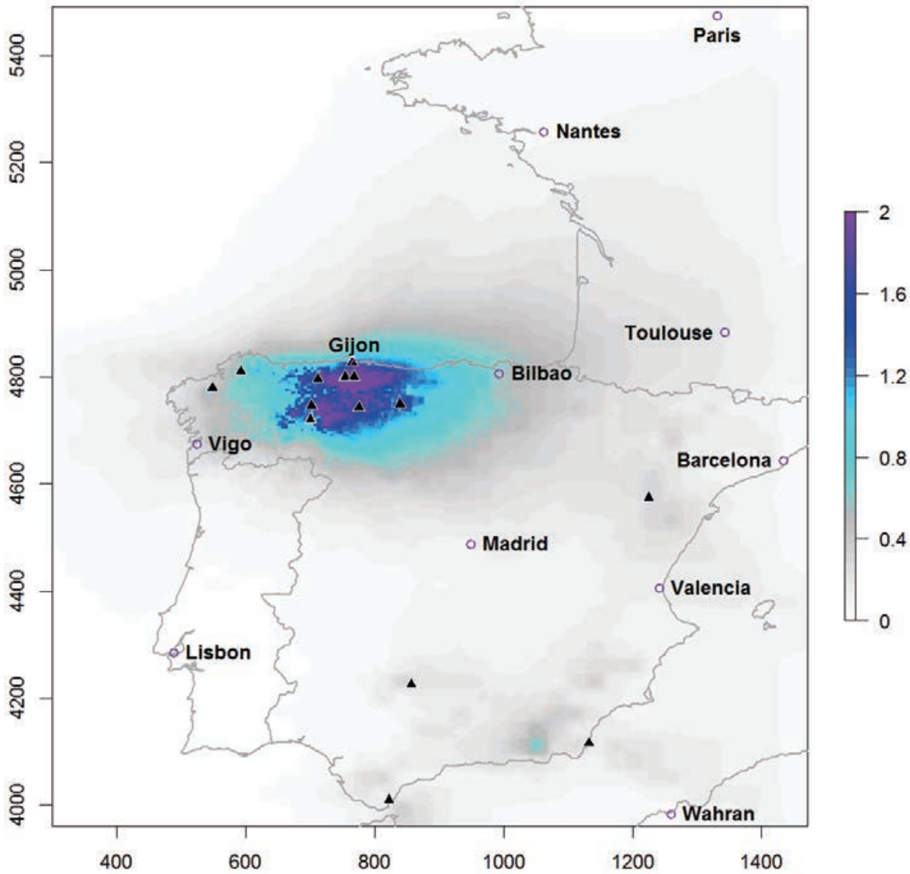


Illustration 4 - Estimation of the annual average concentration (µg/m^3) of NO_2

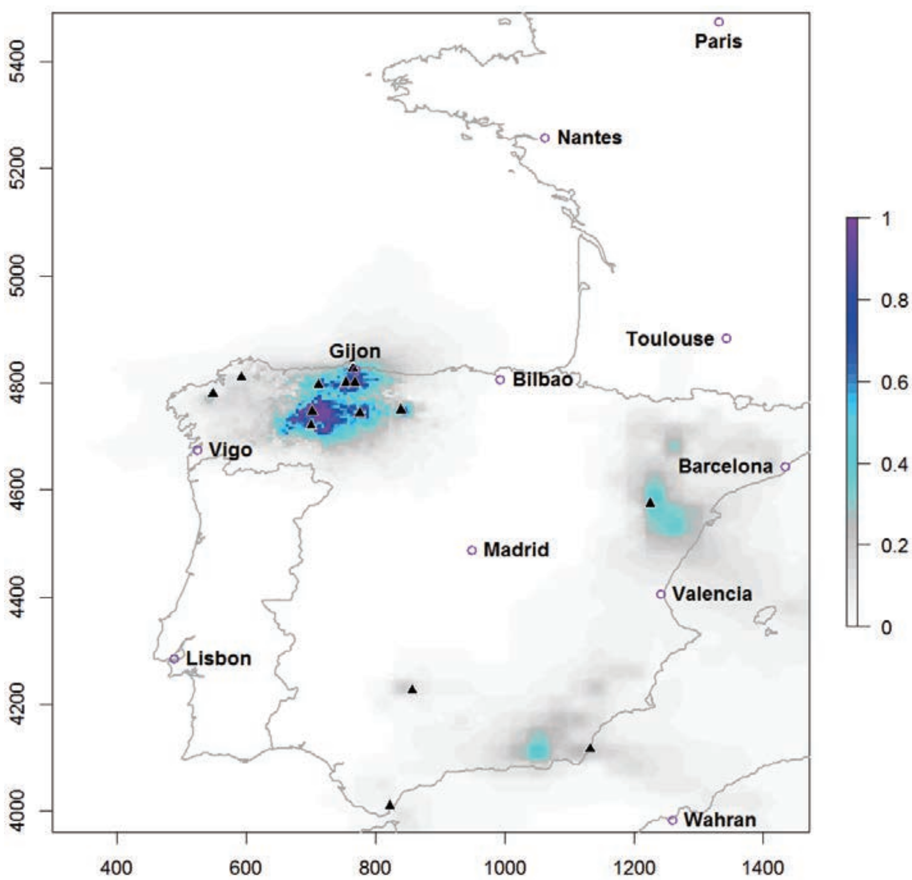


Illustration 5 - Estimation of the annual average concentration (µg/m^3) of SO_2

3.2.2. The impacts on health

In 2014, the emissions from coal power plants can be related to **709 premature deaths, 459 hospital admissions due to cardiovascular and respiratory diseases, 10,521 cases of asthma symptoms in asthmatic children, 1,233 cases of bronchitis in children and 387 cases of chronic bronchitis in adults**. In addition, they were responsible for **747,686 restricted activity days and 163,326 work days lost**.

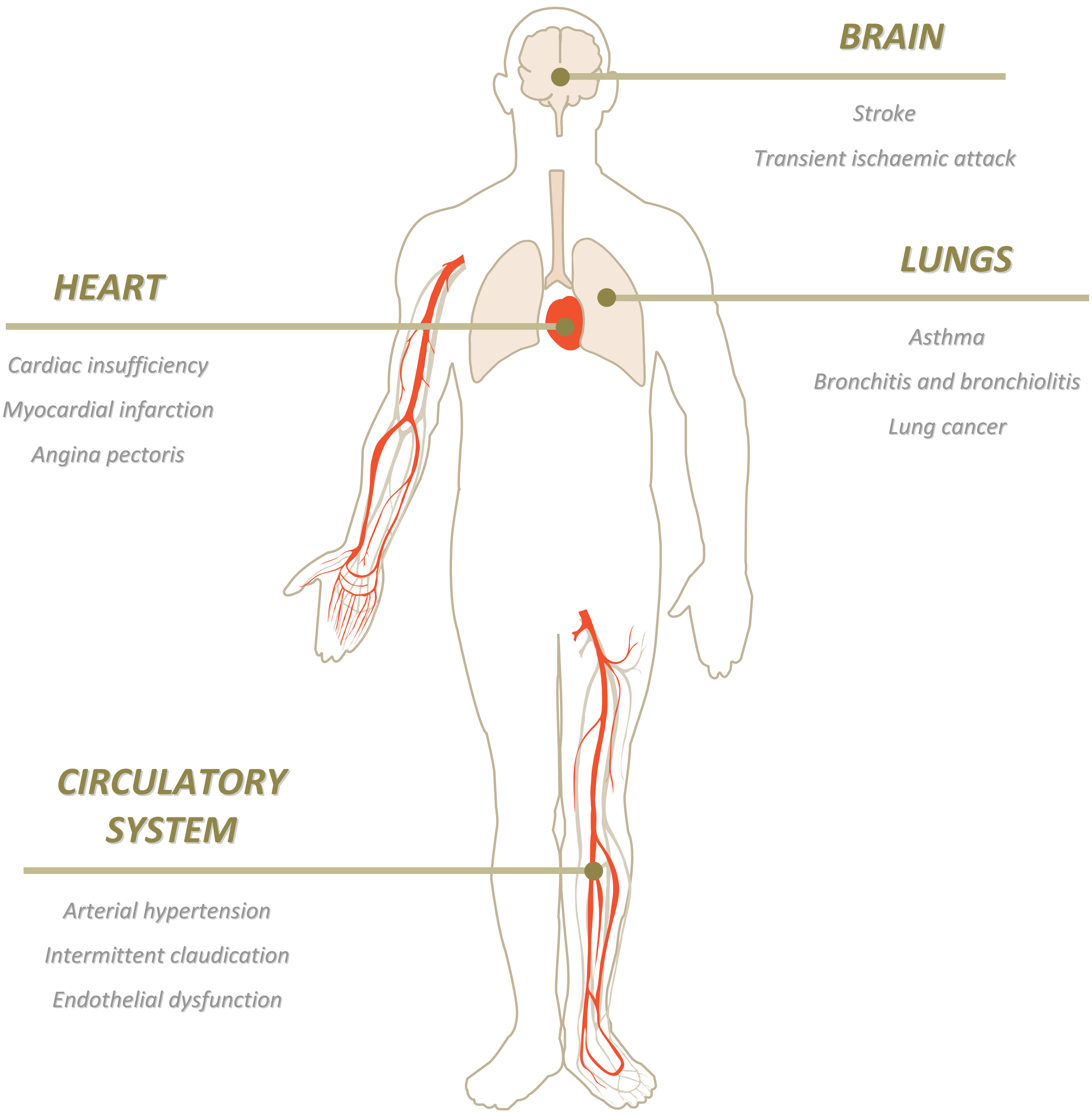


Illustration 6 – Health risks due to pollution caused by the burning of coal

Pollutant and effects on health		Type of exposure	Age range of population at risk (years)	Fraction of population at risk (%)	Total No. of cases	No. of cases due to coal
$PM_{2.5}$	Mortality (all natural causes)	Long term	≥ 30	69.28	378,237	586
$PM_{2.5}$	Mortality (cardiovascular diseases)	Long term	≥ 30	69.28	69,257	170
$PM_{2.5}$	Mortality (respiratory diseases)	Long term	≥ 30	69.28	16,853	42
$PM_{2.5}$	Mortality (lung, traquea and bronchial cancer)	Long term	≥ 30	69.28	20,308	45
$PM_{2.5}$	Mortality (cerebrovascular diseases)	Long term	≥ 30	69.28	26,726	164
$PM_{2.5}$	Stroke events (fatal and non-fatal)	Long term	≥ 30	69.28	112,944	353
$PM_{2.5}$	Hospital admissions (cardiovascular diseases)	Short term	All ages	100.00	-	120
$PM_{2.5}$	Hospital admissions (respiratory diseases)	Short term	All ages	100.00	-	219
$PM_{2.5}$	Restricted activity days[80]	Short term	All ages	100.00	-	747,686
$PM_{2.5}$	Work days lost	Short term	20 – 65	37.18	-	163,326
PM_{10}	Mortality (lung, traquea and bronchial cancer)	Long term	≥ 30	69.28	378,237	40
PM_{10}	Post-neonatal mortality (all natural causes)	Long term	1-12 months	0.91	1,130	1
PM_{10}	Mortality (cerebrovascular diseases)	Long term	≥ 30	69.28	26,726	53
PM_{10}	Stroke events (fatal and non-fatal)	Long term	≥ 30	69.28	112,944	170
PM_{10}	Prevalence of bronchitis in children	Long term	6-12	14.84	623,718	1,053
PM_{10}	Incidence of chronic bronchitis in adults	Long term	≥ 18	80.20	148,743	387
PM_{10}	Incidence of asthma symptoms in asthmatic children	Short term	5 – 19	0.73	-	10,521
NO_2	Mortality (all natural causes)	Long term	≥ 30	69.28	378,237	107
NO_2	Prevalence of bronchitis symptoms in asthmatic children	Long term	5 – 14	0.5	76,009	180
NO_2	Hospital admissions (respiratory diseases)	Short term	All ages	100.00	-	120
SO_2	Mortality (all natural causes)	Short term	All ages	100.00	380,927	16

Table 5 – Estimated impacts on health from coal power plant emissions in Spain during 2014

[80] A *restricted activity day* (RAD) is defined as a day where a person needs to change his/her normal activities because of (ill-) health. RADs include days when a person needs to stay in bed and days when a person stays off work or school but does not need to stay in bed. (Source: Holland M., *Implementation of the HRAPIE Recommendations for European Air Pollution CBA work*, 2014).

3.2.2.1 Particulate Matter

The majority of deaths attributable to coal, in particular **586** out of 709, **are related to $PM_{2.5}$**. As for cause-specific mortality caused by this pollutant, it can be seen that **170** premature deaths were caused by acute and chronic atherosclerotic **cardiovascular diseases**[81] - strokes, acute myocardial infarction, hypertensive diseases, heart failure and angina pectoris[82]. The link between $PM_{2.5}$ and mortality due to cardiovascular diseases was obtained using a CRF from a study that the WHO published in 2014. However, there is further evidence linking exposure to particulate matter with strokes, establishing a more significant statistical association[83]. Using this last information, it has been estimated that $PM_{2.5}$ and PM_{10} were associated with **164 and 53 deaths by stroke**, respectively. It is important to estimate the effects of $PM_{2.5}$ and PM_{10} separately as the former are much more hazardous, essentially due to their smaller size.

$PM_{2.5}$ is also more harmful than PM_{10} at a respiratory level. While the latter is usually retained in the upper areas of the respiratory tree (trachea and primary bronchi), $PM_{2.5}$ penetrates to deeper areas, reaching the terminal bronchiole and being deposited in the lungs. Thus, $PM_{2.5}$ is related to a higher increase in bronchitis, bronchiolitis, asthma and airway obstruction. In addition, the smaller fraction with a diameter of 0.1 µm or less, the so-called ultrafine particles ($PM_{0.1}$), reach the alveoli, where gas exchange takes place, and can therefore pass into the blood stream and cause more detrimental effects to health (Illustration 7). In 2014 **$PM_{2.5}$ caused 42 deaths from respiratory diseases, including chronic lower respiratory diseases, asthma and respiratory failure.**

A 2013 assessment by WHO’s International Agency for Research on Cancer (IARC) concluded that outdoor air pollution is carcinogenic to humans, with the particulate matter component of air pollution most closely associated with increased cancer incidence, especially lung cancer[84]. **Deaths due to malignant tumor of the trachea, bronchi and lung** caused by $PM_{2.5}$ and PM_{10} emissions from coal power plants in Spain during 2014, were estimated to be around **45 and 40**, respectively.

[81] Cardiovascular disease is a broad term for heart and blood vessel problems which is often due to atherosclerosis. It occurs due to the progressive narrowing of the blood vessels by accumulation in their walls of atheroma plaques (mainly formed by bad cholesterol -LDL- and cells).

[82] WHO, *Cardiovascular diseases*, January 2015.

[83] Scheers H. et al., *Long-Term Exposure to Particulate Matter Air Pollution Is a Risk Factor for Stroke. Meta-Analytical Evidence*, 2015, p. 3064.

[84] OMS, *Ambient (outdoor) air quality and health*, *op. cit.*

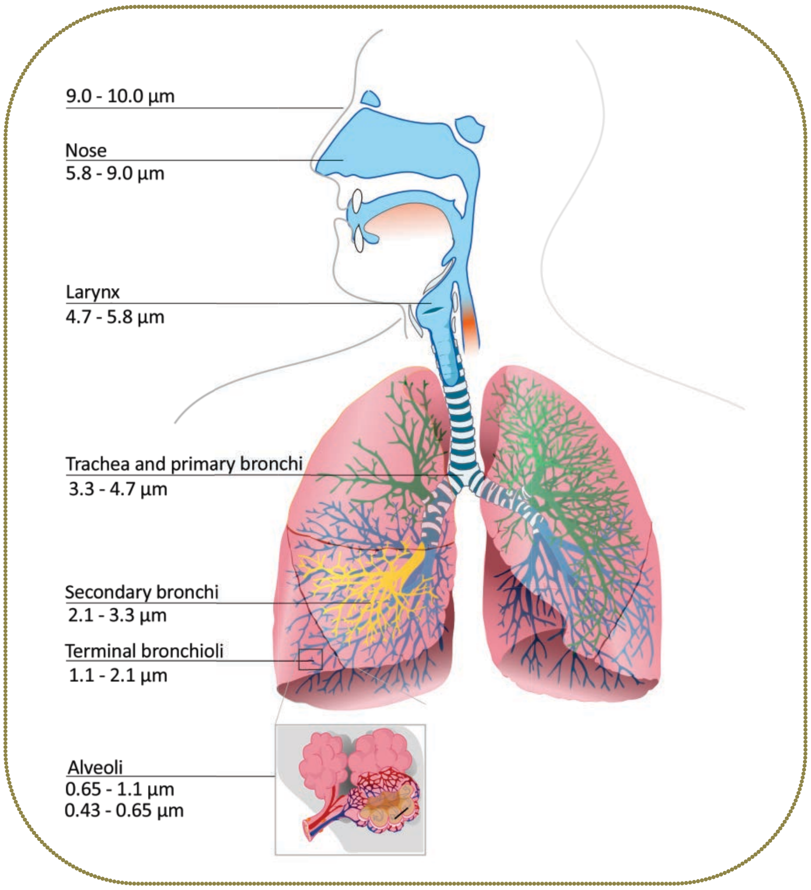


Illustration 7 – Penetration of particulate matter in the respiratory system

As for **non-fatal strokes**[85], **189 cases** were estimated to be caused by long term exposure to $PM_{2.5}$ and **117** due to long-term exposure to PM_{10}.

With regards to respiratory diseases, **1,053 cases of bronchitis have been quantified in children** between 6 and 12 years of age. There were also **387 new cases of chronic bronchitis in adults**. Both were caused by PM_{10} emissions from coal power plants.

Short-term exposures to $PM_{2.5}$ caused **120 hospital admissions due to cardiovascular diseases**[86] and **219 due to respiratory diseases**. In addition this pollutant was responsible for **747,686 RADs and 163,326 work days lost**[87].

Finally, **10,521 cases of asthma symptoms have been estimated in asthmatic children**[88] between the ages of 5 and 19, as there is a clear relationship between short-term exposures to PM_{10} and the onset of episodes of asthma[89].

[85] These include stroke and transient ischaemic attack (temporary closure of the blood supply of an area of the brain with alteration of the cerebral functions of this zone during a short period of time).
[86] Hospital admissions due to cardiovascular diseases also include cerebrovascular diseases.
[87] In order to calculate this, a 60% employment rate in a population between 20 and 64 years of age has been taken into account (Source: Eurostat).
[88] "Asthmatic children" must be understood as those which have a chronic condition of this disease.
[89] Weinmayr et al., *Short-Term Effects of PM_{10} and NO_2 on Respiratory Health among Children with Asthma or Asthma-like Symptoms: A Systematic Review and Meta-Analysis*, 2010.

3.2.2.2 NO_2

In order to consider if there is a relationship between mortality and long-term exposure to NO_2 it must be noted that, according to the WHO[90], the impacts should only be calculated in areas which have an annual average concentration of NO_2 above 20 µg/m^3. In addition, NO_2 intervenes in several chemical reactions which take place in the atmosphere, generating other substances, such as secondary $PM_{2.5}$. Therefore, when calculating the number of premature deaths which can be related to NO_2 emissions there may be a possible overlap with mortality linked to a long-term exposure to $PM_{2.5}$. Taking this into consideration, it is estimated that NO_2 emissions from coal power plants caused around **107 premature deaths** in Spain during 2014[91].

Moreover, these emissions were responsible for **180 cases of acute bronchitis**[92] **in asthmatic children** between 5 and 14 years old. Most of these cases occurred in locations with a higher number of coal power plants near to each other or in neighbouring territories. In particular, Asturias was the most affected Autonomous Community, where 9.4 out of 1,000 asthmatic children experienced bronchitis symptoms caused by a long-term exposure to NO_2. The following most affected AA.CC were Cantabria (4.5 out of 1,000), Castilla y León (2.7 out of 1,000) and the Basque Country (2 out of 1,000)[93].

3.2.2.3 SO_2

The existence of a short-term relationship between daily concentrations of SO_2 emissions from coal power plants and daily mortality has been considered in this study.

There is more evidence of an association between this pollutant and short-term mortality because its half-life in the atmosphere is short; about 2 to 4 days[94]. It is important to remember that health effects from an acute exposure to a pollutant do not necessarily occur on the day of exposure. In fact, there is scientific evidence showing that cardiovascular mortality is more likely to occur within a time interval of 0 to 1 days after exposure to SO_2, while mortality due to respiratory causes is higher between 2 to 5 days after the exposure[95]. Taking this into account, it can be concluded that in 2014 coal produced **16 deaths resulting from an exposure to daily SO_2 concentrations.**

[90] WHO – Regional Office for Europe, *Health, op. cit*.
[91] In order to quantify the number of premature deaths caused by a long-term exposure to NO_2, an overlap of 33% has been taken into account with respect to the mortality derived from a long-term exposure to $PM_{2.5}$ (Source: Ibid., p.10).
[92] Acute bronchitis is swelling and irritation in a child's air passages. This irritation may cause coughing or other breathing problems. Acute bronchitis lasts about 2 weeks and is usually not a serious illness. (Source: Holland M., *op. cit*, p. 12).
[93] In the absence of data it is assumed each affected child experiences bronchitis once in a year, and that this does not lead to additional complications. Both assumptions seem conservative. (Source: Holland M., *op. cit.*, p. 35.)
[94] Source: Center of Environmental Resources of Navarra (*Centro de Recursos Ambientales de Navarra-CRANA*).
[95] Zeka A. et al, *Mortality Impacts of Sulphur Concentrations in Air in 20 European Cities in the Aphekom Project: A Case Cross-Over distributed Lag Approach*.

3.2.3. Health costs

When producing electricity, energy companies bear costs -called *internal costs*- which they recover with a certain profit margin when selling this good. However, apart from electricity, these companies may produce a series of negative effects on third parties, such as impacts on the health of the population, which arise from the air pollution that their power plants have generated. These health impacts have associated **health costs** that companies do not compensate in any way. These are known as *external costs or negative externalities*. Nowadays it is the society that covers them, through expenses such as medicines, consultations with specialists, hospitalization and laboratory analysis', among others.

The **health costs** associated to health impacts caused by coal power plants during 2014, together with the economic losses due to absence from work, reached an amount between **880 and 1,667 million Euros.**

Pollutant and effects on health		No. of cases due to coal	Unit costs (€) (Spanish prices 2013)	Total costs due to coal (millions €)	Source[96]
$PM_{2.5}$ NO_2 SO_2	Mortality (all natural causes)	709	1,080,000 – 2,190,000	765.72 – 1,552.71	Holland 2014
$PM_{2.5}$	Non-fatal strokes	189	16,195	3.060	Truelsen et al. 2005
$PM_{2.5}$	Hospital admissions (cardiovascular diseases)	120	2,192	0.263	Holland 2014
$PM_{2.5}$ NO_2	Hospital admissions (respiratory diseases)	339	2,192	0.743	Holland 2014
$PM_{2.5}$	Restricted activity days	747,686	91	68.039	Holland 2014
$PM_{2.5}$	Work days lost	163,326	128	20.905	Holland 2014
PM_{10} NO_2	Bronchitis in children	1,233	575	0.708	Holland 2014
PM_{10}	Chronic bronchitis in adults	387	52,984	20.504	Holland 2014
PM_{10}	Asthma symptoms in asthmatic children	10,521	41	0.431	Holland 2014

TOTAL HEALTH COSTS CAUSED BY COAL: between 880 and 1,667 MILLION EUROS

Table 6 – Health costs caused by emissions from coal power plants in Spain during 2014

[96] For more information on the unit costs, please see CAN Europe, HEAL, WWF European Policy Office, Sandbag, "Europe's Dark Cloud: How coal-burning countries are making their neighbours sick", 2016.
Available at: http://env-health.org/IMG/pdf/dark_cloud-full_report_final.pdf.

3.2.4. Comparative between incidence rates from $PM_{2.5}$ at a regional level

The comparative between the annual mortality incidence rates caused by $PM_{2.5}$ emissions from coal power plants reflects that the AA. CC with the highest incidence rates have been, once again, those were the majority of coal power plants are located or those which are nearby (Table 7).

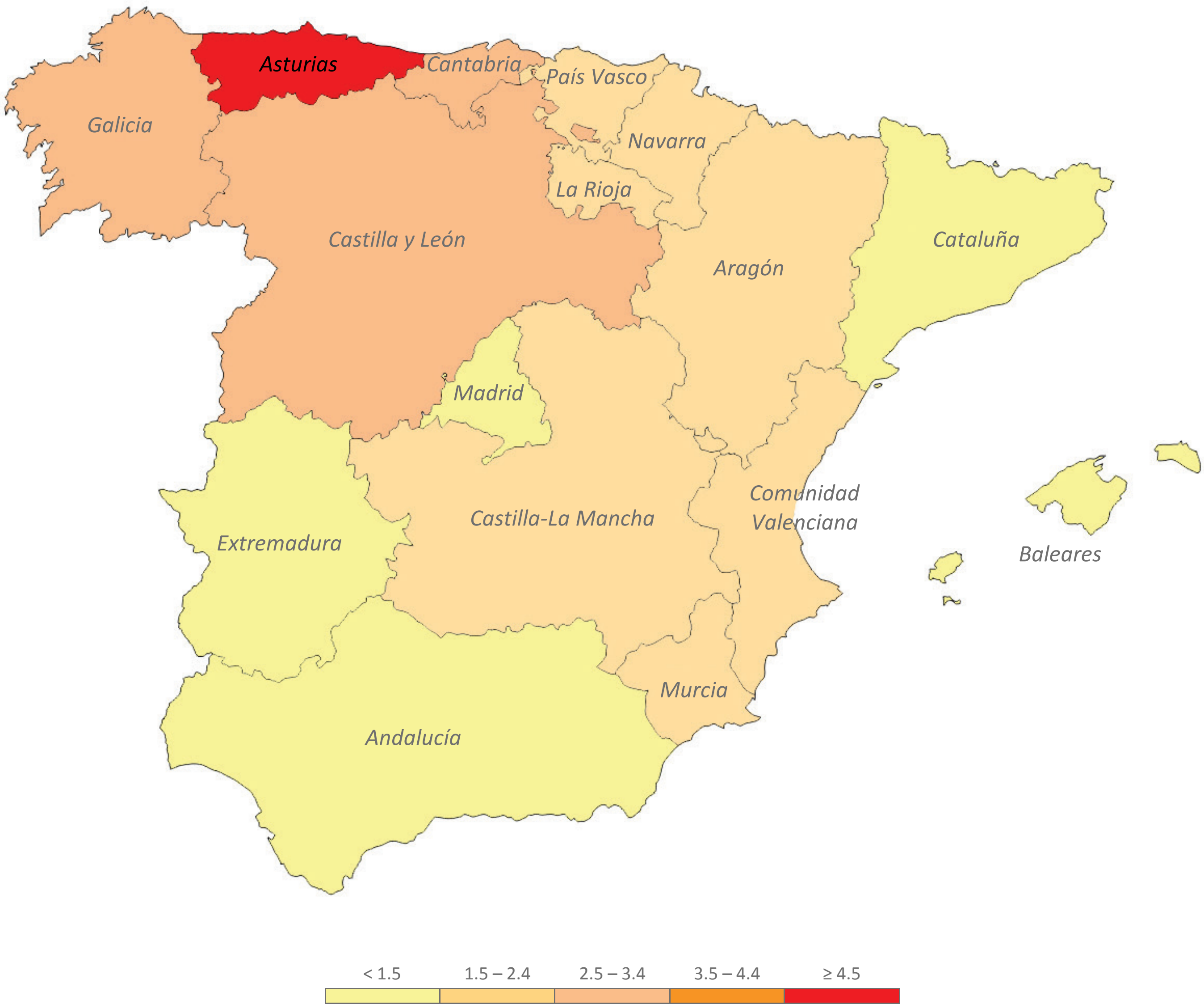


Illustration 8 – Spatial variation of annual (all natural cause) mortality incidence rates due to $PM_{2.5}$ emissions from coal power plants (Spain)

AA.CC	Annual average concentration of $PM_{2.5}$ ($\mu g/m^3$)	Annual all natural cause mortality ($PM_{2.5}$) caused by coal	Population at risk (≥ 30 years)	Incidence rate due to coal (cases per 100,000 population at risk)
Andalucía	0.158	62.42	5,210,585	1.12
Asturias	0.746	56.31	807,853	6.97
Aragón	0.266	23.21	945,239	2.45
Baleares	0.185	9.08	759,757	1.19
Cantabria	0.399	14.69	426,460	3.44
Castilla y León	0.321	62.86	1,838,320	3.41
Castilla la Mancha	0.208	29.34	1,398,643	2.09
Cataluña	0.173	62.15	5,116,990	1.21
Comunidad Valenciana	0.311	75.95	3,434,744	2.21
Extremadura	0.125	8.61	749,174	1.15
Galicia	0.389	63.04	2,043,112	3.08
La Rioja	0.256	4.67	221,612	2.11
Madrid	0.183	49.98	4,386,650	1.14
Murcia	0.251	16.43	951,527	1.73
Navarra	0.252	8.74	441,162	1.98
País Vasco	0.293	38.38	1,576,706	2.43

Table 7 – Annual (all natural cause) mortality incidence rates due to $PM_{2.5}$ from coal power plants (Spain)

Among the AA.CC where coal plants are located, Asturias has the highest number of deaths -6.97 per 100,000 population at risk- followed by Castilla y León (3.41) and Galicia (3.08). Even though there are no coal power plants in Cantabria, it has a high incidence rate (3.44) as it is considerably affected by the emissions from the nearby Asturias. In general, the incidence rate decreases when moving further away from the regions where coal power plants are located. Therefore, some of the lowest incidence rates can be found in Madrid (1.14), Extremadura (1.15) and Cataluña (1.21)[97].

[97] Even though, according to the results of this study, the incidence rate in Balearic Islands is 1.19 we cannot take it as an example because there is one coal plant located there which has not been taken into account in this analysis. Thus, its results do not reflect real values.

The AC of Andalucía has the lowest incidence rate (1.12) even though there are three coal power plants located there. This may be due to the wide extension of this territory or the big distance between the three plants, which does not allow for a significant accumulation of pollutants in the air. Another cause may be that these plants emit a smaller quantity of pollutants in comparison with the ones located in other AA.CC.

A higher incidence rate means that the population of one AC has a higher risk of mortality compared to the population of another AC. For example, the probability of an inhabitant of Asturias dying is 6.1 times higher than those of an inhabitant of Madrid, while those living in Castilla y León have a risk 3 times higher than the population of Extremadura.

A comparative of the risks of mortality due to $PM_{2.5}$ emissions from coal between AA.CC is shown in Table 8. It should be emphasized that, in order to establish this probability index, it is not possible to take as a reference element the mere number of deaths, since in this parameter the size of the population at risk influences the result considerably.

A very evident example is that of Cataluña: although it has an average pollution level of $PM_{2.5}$ approximately 2 times lower than that of Castilla y León – 0.173 and 0.321 µg / m^3 respectively - in both cases there is a similar number of deaths. This could lead to the erroneous conclusion that coal causes the same impacts in both AA.CC. However, this happens because in Cataluña there is a higher population density than in Castilla y León. In the first one there are 5,116,990 inhabitants at risk while in the second there are 1,838,320. This shows that a similar number of deaths can occur in an area where there is a bigger population exposed to low levels of pollution and in an area where there is a much higher level of pollution but where the number of inhabitants is lower.

	Andalucía	Asturias	Aragón	Baleares	Cantabria	Castilla y León	Castilla-La Mancha	Cataluña	Com. Valenciana	Extremadura	Galicia	La Rioja	Madrid	Murcia	Navarra	País Vasco
Andalucía	-	x 0.2	x 0.5	x 0.9	x 0.3	x 0.3	x 0.5	x 0.9	x 0.5	x 1.0	x 0.4	x 0.5	x 1.0	x 0.6	x 0.6	x 0.5
Asturias	x 6.2	-	x 2.8	x 5.9	x 2.0	x 2.0	x 3.3	x 5.8	x 3.2	x 6.1	x 2.3	x 3.3	x 6.1	x 4.0	x 3.5	x 2.9
Aragón	x 2.2	x 0.4	-	x 2.1	x 0.7	x 0.7	x 1.2	x 2.0	x 1.1	x 2.1	x 0.8	x 1.2	x 2.1	x 1.4	x 1.2	x 1.0
Baleares	x 1.1	x 0.2	x 0.5	-	x 0.3	x 0.3	x 0.6	x 1.0	x 0.5	x 1.0	x 0.4	x 0.6	x 1.0	x 0.7	x 0.6	x 0.5
Cantabria	x 3.1	x 0.5	x 1.4	x 2.9	-	x 1.0	x 1.6	x 2.8	x 1.6	x 3.0	x 1.1	x 1.6	x 3.0	x 2.0	x 1.7	x 1.4
Castilla y León	x 3.0	x 0.5	x 1.4	x 2.9	x 1.0	-	x 1.6	x 2.8	x 1.5	x 3.0	x 1.1	x 1.6	x 3.0	x 2.0	x 1.7	x 1.4
Castilla-La Mancha	x 1.9	x 0.3	x 0.9	x 1.8	x 0.6	x 0.6	-	x 1.7	x 0.9	x 1.8	x 0.7	x 1.0	x 1.8	x 1.2	x 1.1	x 0.9
Cataluña	x 1.1	x 0.2	x 0.5	x 1.0	x 0.4	x 0.4	x 0.6	-	x 0.5	x 1.1	x 0.4	x 0.6	x 1.1	x 0.7	x 0.6	x 0.5
Com. Valenciana	x 2	x 0.3	x 0.9	x 1.9	x 0.6	x 0.6	x 1.1	x 1.8	-	x 1.9	x 0.7	x 1.0	x 1.9	x 1.3	x 1.1	x 0.9
Extremadura	x 1.0	x 0.2	x 0.5	x 1.0	x 0.3	x 0.3	x 0.6	x 1.0	x 0.5	-	x 0.4	x 0.5	x 1.0	x 0.7	x 0.6	x 0.5
Galicia	x 2.8	x 0.4	x 1.3	x 2.6	x 0.9	x 0.9	x 1.5	x 2.5	x 1.4	x 2.7	-	x 1.5	x 2.7	x 1.8	x 1.6	x 1.3
La Rioja	x 1.9	x 0.3	x 0.9	x 1.8	x 0.6	x 0.6	x 1.1	x 1.7	x 1.0	x 1.8	x 0.7	-	x 1.9	x 1.2	x 1.1	x 0.9
Madrid	x 1.0	x 0.2	x 0.5	x 1.0	x 0.3	x 0.3	x 0.5	x 0.9	x 0.5	x 1.0	x 0.4	x 0.5	-	x 0.7	x 0.6	x 0.5
Murcia	x 1.5	x 0.2	x 0.7	x 1.5	x 0.5	x 0.5	x 0.8	x 1.4	x 0.8	x 1.5	x 0.6	x 0.8	x 1.5	-	x 0.9	x 0.7
Navarra	x 1.8	x 0.3	x 0.8	x 1.7	x 0.6	x 0.6	x 0.9	x 1.6	x 0.9	x 1.7	x 0.6	x 0.9	x 1.7	x 1.1	-	x 0.8
País Vasco	x 2.2	x 0.3	x 1.0	x 2.0	x 0.7	x 0.7	x 1.2	x 2.0	x 1.1	x 2.1	x 0.8	x 1.2	x 2.1	x 1.4	x 1.2	-

< 1	1	1.1 – 1.9	2 – 2.9	3 – 3.9	≥ 4

Table 8 – Comparative between Autonomous Communities of the risks of (all natural cause) mortality due to $PM_{2.5}$ emissions from coal plants

3.2.5. Comparative between incidence rates from $PM_{2.5}$ at a provincial level

The impacts caused by coal plants can also be seen at a provincial level. A brief analysis of the health impacts in the provinces where coal plants are located -with the exception of Asturias -can be seen below. Asturias only has one province, therefore its incidence rate is already shown in Table 7.

Castilla y León

Castilla y León is the most representative case to show how the presence of a coal power plant may be associated with an increase in mortality risk. In this AC, the highest incidence rates are found in the two provinces where coal plants are located: León (5.80) and Palencia (4.55). However, Zamora presents a similar value to Palencia despite not having any coal power plants. This is because it is affected by the emissions of plants located in León. When comparing the two provinces with the highest incidence rate (León) and the lowest one (Salamanca), it can be seen that the population of León is subject to a risk of death 3.37 times higher.

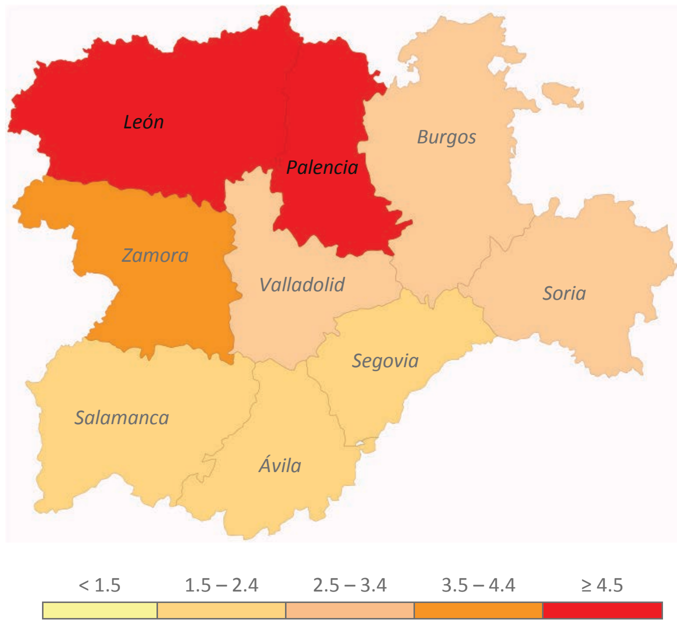


Illustration 9 – Spatial variation of the annual all natural cause mortality incidence rates due to $PM_{2.5}$ emissions from coal plants (Castilla y León)

AC	Province	Annual average concentration of $PM_{2.5}$ (µg/m³)	Annual all natural cause mortality ($PM_{2.5}$) due to coal	Population at risk (≥ 30 years)	Incidence rate due to coal (cases per 100,000 population at risk)	No. of existing coal plants
Castilla y León	Ávila	0.193	2.49	121,398	2.05	0
	Burgos	0.318	7.75	265,605	2.92	0
	León	0.568	21.16	364,994	5.80	3
	Palencia	0.412	5.67	124,450	4.55	1
	Salamanca	0.185	4.36	253,461	1.72	0
	Segovia	0.233	2.55	112,861	2.26	0
	Soria	0.252	1.80	67,564	2.66	0
	Valladolid	0.384	11.19	385,475	2.90	0
	Zamora	0.351	5.90	142,511	4.14	0

Table 9 - Annual all natural cause mortality incidence rates due to $PM_{2.5}$ emissions from coal plants (Castilla y León)

Aragón

The AC of Aragón shows a less marked variation of incidence rates between provinces since all three of them reflect quite similar values. However, Teruel has the highest one (3.15), while Zaragoza and Huesca have values of 2.38 and 2.30 respectively. This means that the entire population of Aragon, regardless of the province, is subject to a similar risk, which could be due to the wind pattern in the region. In fact, during the summer months, in the areas near the power plant of Andorra, winds usually move in North/Northwest direction, transporting the pollution to the other two Aragonese provinces. However, the pollution from this plant is not only concentrated in the AC of Aragón. Much of it travels to the Comunidad Valenciana, mainly due to the fact that during most of the year, the winds near the municipality of Andorra blow in the Southeast direction. In fact, the incidence rate in Castellón, located in Comunidad Valenciana is 3.19 per 100,000 population at risk, higher than in any of the provinces of Aragón[98].

Illustration 10 - Spatial variation of the annual all natural cause mortality incidence rates due to $PM_{2.5}$ emissions from coal plants (Aragón)

AC	Province	Annual average concentration of $PM_{2.5}$ (μg/m³)	Annual all natural cause mortality ($PM_{2.5}$) due to coal	Population at risk (≥ 30 years)	Incidence rate due to coal (cases per 100,000 population at risk)	No. of existing coal plants
Aragón	Huesca	0.233	3.69	160,341	2.30	0
	Teruel	0.297	3.14	99,676	3.15	1
	Zaragoza	0.270	16.37	685,222	2.38	0

Table 10 - Annual all natural cause mortality incidence rates due to $PM_{2.5}$ emissions from coal plants (Aragón)

[98] The statistics of wind patterns have been obtained from the *Windfinder* database.

Galicia

In the case of Galicia, pollution especially affects the province of Lugo, which shows an incidence rate of 5.47, even though coal plants are only located in the province of La Coruña. The province of Orense is also notably affected as it also presents a higher rate than La Coruña: 3.64 and 3.46 respectively. As for Pontevedra, it has an incidence rate of 1.51.

The fact that Lugo and Orense, provinces where there are no coal plants, have higher incidence rates than La Coruña may be explained due to two reasons. Firstly, because the predominant winds in this region blow in East or Southeast direction. Secondly, because of the orography of the area.

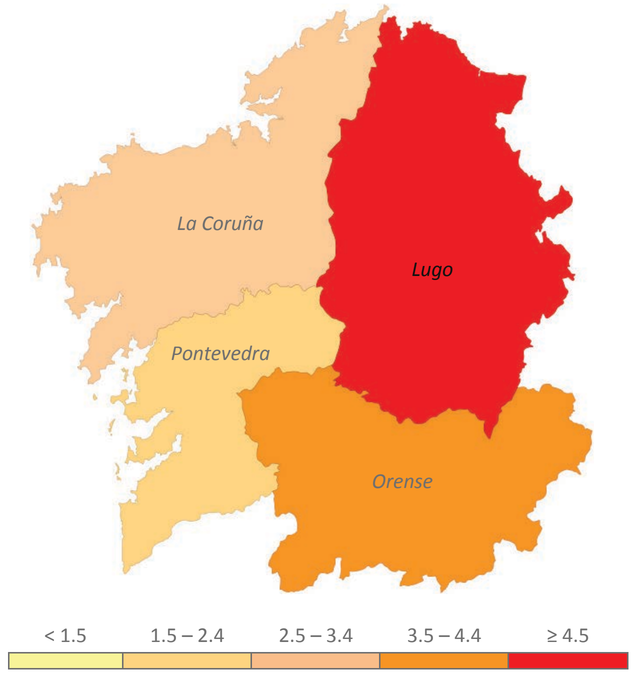


Illustration 11 - Spatial variation of the annual all natural cause mortality incidence rates due to $PM_{2.5}$ emissions from coal plants (Galicia)

AC	Province	Annual average concentration of $PM_{2.5}$ ($\mu g/m^3$)	Annual all natural cause mortality ($PM_{2.5}$) due to coal	Population at risk (≥ 30 years)	Incidence rate due to coal (cases per 100,000 population at risk)	No. of existing coal plants
Galicia	La Coruña	0.386	29.19	844,048	3.46	2
	Lugo	0.471	14.43	263,692	5.47	0
	Orense	0.327	9.07	249,101	3.64	0
	Pontevedra	0.373	10.35	686,270	1.51	0

Table 11 - Annual all natural cause mortality incidence rates due to $PM_{2.5}$ emissions from coal plants (Galicia)

Andalucía

The highest incidence rates have been detected in the eastern part of Andalucía, specifically in the provinces of Jaén (1.83), Granada (1.61) and Almería (1.52). This is due to the fact that the emissions of the Litoral coal power plant, located in Almería, are distributed in a relatively homogeneous way between these three provinces, because of the direction of the winds and the orography of the area. However, these same emissions also reach the AC of Murcia, which has an even higher incidence rate than the ones in Granada and Almería. Additionally, wind currents near the area where the coal plant of Puente Nuevo is located usually blow eastwards[99]. This causes the emissions of this plant to be directed towards Jaén, the Andalusian province with the highest incidence rate.

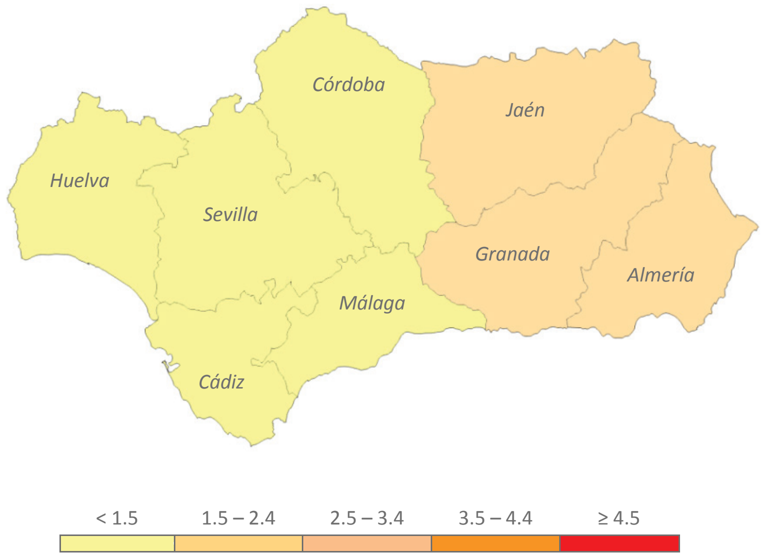


Illustration 12 - Spatial variation of the annual all natural cause mortality incidence rates due to $PM_{2.5}$ emissions from coal plants (Andalucía)

AC	Province	Annual average concentration of $PM_{2.5}$ (µg/m^3)	Annual all natural cause mortality ($PM_{2.5}$) due to coal	Population at risk (≥ 30 years)	Incidence rate due to coal (cases per 100,000 population at risk)	No. of existing coal plants
Andalucía	Almería	0.229	6.77	444,795	1.52	1
	Cádiz	0.102	5.98	819,168	0.73	1
	Córdoba	0.167	7.52	533,209	1.41	1
	Granada	0.204	9.85	610,885	1.61	0
	Huelva	0.106	2.91	346,014	0.84	0
	Jaén	0.206	7.96	434,431	1.83	0
	Málaga	0.129	9.86	1,094,842	0.90	0
	Sevilla	0.124	11.56	1,273,255	0.91	0

Tabla 12 - Annual all natural cause mortality incidence rates due to $PM_{2.5}$ emissions from coal plants (Andalucía)

[99] Source: *Windfinder*.

3.2.1. Comparative between incidence rates from NO_2 at a regional level

As noted above, the relationship between mortality and long-term exposure to NO_2 may only be quantified in areas which have an annual average concentration of NO_2 above 20 µg/m^3 [100]. To be able to determine the areas whose concentration was above this threshold during 2014, the measurements obtained by the stations that are part of the air quality monitoring networks in Spain have been analyzed.

The results show that the AC most affected by NO_2 emissions has been Asturias. This pollutant caused 4.34 deaths per 100,000 population at risk. However, the emissions of the plants located in Asturias not only affected this territory. They also impacted neighbouring AA.CC, such as Cantabria and Basque Country which show incidence rates of 1.55 and 1.09 deaths, respectively.

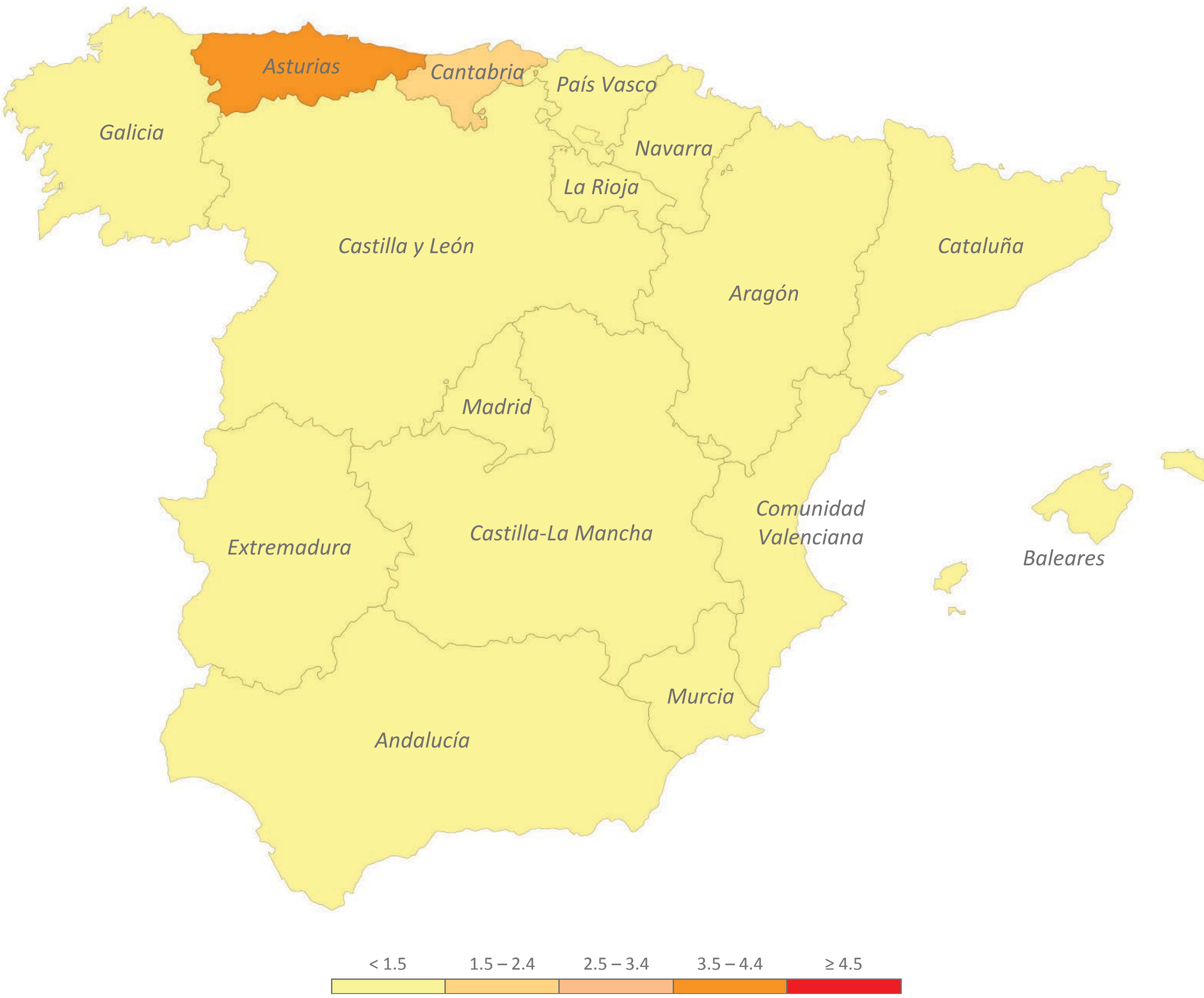


Illustration 13 – Spatial variation of annual (all natural cause) mortality incidence rates due to NO_2 emissions from coal power plants (Spain)

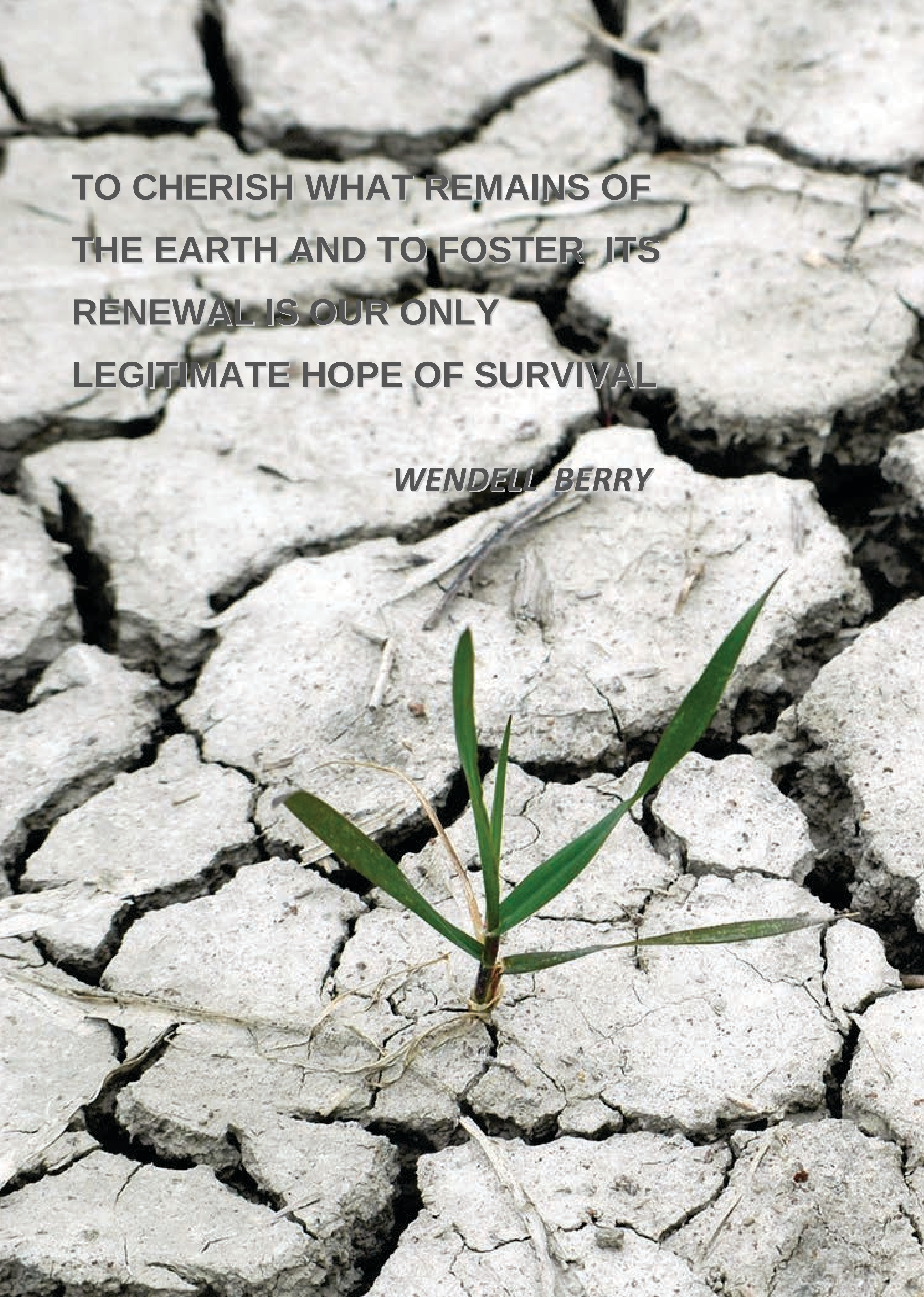
[100] This usually occurs in high industrialized areas or in urban areas, as the transport sector is the main source of NOx emissions.

AA.CC	Air quality network stations above the 20 µg/m³ threshold of NO_2[101]		Annual all natural cause mortality (NO_2) due to coal	Population at risk (≥ 30 years)	Incidence rate due to coal (cases per 100,000 population at risk)
Andalucía	15/90	(16.7%)	7.49	5,210,585	0.13
Asturias	11/21	(52.4%)	35.10	807,853	4.34
Aragón	2/17	(11.8%)	3.30	945,239	0.35
Baleares	2/18	(11.1%)	0	759,757	0
Cantabria	3/11	(27.3%)	6.63	426,460	1.55
Castilla y León	6/41	(14.6%)	1.35	1,838,320	0.07
Castilla la mancha	1/14	(7.1%)	0.82	1,398,643	0.06
Cataluña	39/124	(31.5%)	10.38	5,116,990	0.20
Comunidad Valenciana	11/63	(17.5%)	1.82	3,434,744	0.05
Extremadura	0/7	(0%)	-	-	-
Galicia	5/44	(11.4%)	4.28	2,043,112	0.21
La Rioja	0/5	(0%)	-	-	-
Madrid	35/50	(70%)	16.27	4,386,650	0.37
Murcia	4/8	(50%)	0.33	951,527	0.03
Navarra	3/7	(42.9%)	1.88	441,162	0.43
País Vasco	23/29	(79.3%)	17.15	1,576,706	1.09

Table 13 - Annual (all natural cause) mortality incidence rates due to NO_2 from coal power plants (Spain)

In the rest of territories where coal plants are located, the impacts of NO_2 emissions from coal have not been so high. This is mainly because in most of them, the annual average concentration of NO_2 has been below the threshold established by the WHO. Therefore, the evidence of a relationship between this pollutant and mortality is lower.

[101] European Environment Agency, *Air Data Explorer*, 2014.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WENDELL BERRY

CHAPTER 4

CONCLUSIONS

The results of this study demonstrate the many negative impacts on health caused by emissions into the air from coal-power plants, as well as the significant associated economic impacts. Energy companies alone are not responsible for these impacts: the political and administrative decisions taken so far are also accountable, since they authorize coal plants in Spain to pollute above the emission limit values provided for in the European Union legislation.

The Government of Spain, as well as the regional and municipal one have the duty to safeguard public health. As a consequence, they must take urgent measures to reduce levels of air pollution, including ensuring that power plants comply with those emission limit values, without allowing them to opt, yet again, for derogations which allow them to emit above the legally established ELVs. By 2021, the plants that remain operational should have installed the best available techniques (BATs) provided for in the new LCP BREF - approved in May 2017[102] - in order to comply with the emission limit values associated to BATs included therein, which are stricter than those set out in the Industrial Emissions Directive[103]. Compliance with stricter ELVs will lead to a reduction in emissions and, consequently, in health impacts. It is important to emphasize that currently, there is no publicly available data which includes information on real-time emissions from coal power plants, although this would be possible. In fact, these plants are required by law to continuously measure concentrations of NOx, SO_2 and particulate matter present in their combustion gases, as they are combustion plants with a total rated thermal input equal to or above 100 MW[104]. Therefore, in order to promote transparency, this information should be made public without the need for a prior request. Some countries, such as China, already provide this type of information to their citizens through electronic applications[105].

In the XXI century, an energy model based on the burning of fossil fuels cannot be the basis of a country's economic development since it must be respectful to the environment and compatible with the improvement in the quality of life. Therefore, it is necessary to commit to a **more sustainable energy model**, based on **energy efficiency** and on a **greater use of renewable energy**. In this regard, the European Commission presented at the end of November 2016 the so-called

[102] Source: European Commission.
[103] All permit conditions for the installation concerned must be reconsidered, and if necessary, updated within 4 years of the publication of decisions on BAT conclusions (Art. 21(3) IED).
[104] IED, Annex V, part 3, section 1.
[105] *Blue Map* offers real-time data of emissions into the atmosphere from point sources of pollution, among others. Available at: http://wwwen.ipe.org.cn/MapPollution/Pollution.aspx?q=3&type=1.

Winter Package, a plan of measures to promote energy transition[106] and to fulfill the objectives of the Paris Agreement. These measures show low ambition as they are aimed at achieving a reduction of at least 40% in pollutant emissions with respect to 1990, as well as increasing the share of renewables by over 27% and a 30% improvement in energy efficiency by 2030. In order to meet these objectives, the Government of each Member State should submit in 2019 an integrated energy and climate plan assessing the penetration of renewable energy as well as the reduction of CO_2 emissions by 2030. They must also submit their road map to reach zero-emissions by 2050.

In the case of Spain, it is essential that this plan guarantees the **decarbonization of the energy model** starting with a **coal phase-out plan which ensures the progressive closure of all coal power plants in Spain by 2025** without leaving the market itself to decide, following the recommendations of the International Energy Agency[107]. **This plan must take full account of the negative externalities associated with the generation of electricity through the burning of coal, ensuring that energy companies bear with the external costs they cause**[108]. Doing so, the price of electricity from this fuel would be double or triple[109], making it economically unfeasible and making forms of clean energy generation more competitive. In addition, and paradoxically, in Spain coal power plants have been receiving different subsidies from the Government, as has been said before.

Coal phase-out offers without a doubt a unique opportunity to reduce pollutant emissions and to mitigate climate change. In addition, the improvement in air quality would lead to a higher level of protection of human health, avoiding the premature death of hundreds of people every year.

The process towards a more sustainable and carbon low, energy model must be necessarily supported by **just transition measures**. Both Governments and companies should conduct an orderly process of dismantling the fossil industry and ensuring new employment opportunities for all affected workers.

With regards to renewables, more investments should be made in order to increase electricity production from these sources as scientific and technological developments make this type of generation increasingly competitive with regards to other conventional technologies. Specifically, in Spain it seems logical to increase production with solar photovoltaic, taking advantage of the high number of hours of daylight that our country has per year. At the same time, greater use of renewable energy would lead to less dependence on energy from abroad, since renewables are indigenous sources of energy and would favor the creation of jobs. Even though they are intermittent sources, as they are directly dependent on meteorology and day-night cycles, the rapid progress experienced by energy storage technologies will increasingly minimize this

[106] "Energy transition" is the transition to a sustainable economy through renewable energy, energy efficiency and sustainable development. The ultimate objective is the phase-out of coal, nuclear energy and other non-renewable resources, so that the energy mix is composed solely of renewable energy.

[107] Governments must support renewables... if we leave it to economics, coal will win, Irish *Independent*, 7.03.2015. URL: http://www.independent.ie/business/irish/governments-must-support-renewables-if-we-leave-it-to-economics-coal-will-win-35435608.html.

[108] It should be emphasized that in addition to negative externalities associated with health impacts, coal power plants also produce negative externalities on vegetation and biodiversity, such as acidification of soils or eutrophication of inland waters due to excessive deposition of nitrogen compounds.

[109] Epstein P. R. et al., *op. cit*.

circumstance, making it possible to increase the participation from these sources in the electricity system.

All individuals have **the right to live in an environment adequate to their health and well-being**[110]. In particular, in Spain we all have the right to enjoy an environment suitable for personal development, as well as the duty to preserve it, as established in article 45 of the Spanish Constitution. Therefore, it is necessary that political decisions adopted in the short, medium and long term are coherent with the commitment to fight against climate change. They must also be directed towards achieving an economic growth which is sustainable and respectful towards health and the environment, without damaging the well-being of present and future generations.

[110] Resolution 45/94 of the General Assembly of the United Nations.
Available at: http://www.un.org/es/comun/docs/?symbol=A/RES/45/94.

BIBLIOGRAPHY

Cruzten, P.J., "Geology of mankind: the Anthropocene", *Nature* vol. 415, 2002, p. 23.

Epstein P. R. et al., "Full cost accounting for the life cycle of coal", *Annals of the New York Academy of Sciences*, Vol. 1219, Ecological Economics Reviews Pages, 2011, p. 73–98.

Ghassan B. Hamra, "Outdoor Particulate Matter Exposure and Lung Cancer: A Systematic Review and Met-Analysis", *Environmental Health Perspectives*, Vol. 122, N. 9, 2014.

Hamilton, C., "The Antropocene as rupture"*, The Antropocene Review* vol. 3, no. 2, 2016, p. 1–14.

Holland M., "Implementation of the HRAPIE Recommendations for European Air Pollution CBA work", January 2014.

International Energy Agency (IEA), *Energy and Air Pollution*, World Energy Outlook Special Report, 2016.

Red Eléctrica de España, *El sistema eléctrico español – Avance 2016*, diciembre 2016.

Red Eléctrica de España, *El sistema eléctrico español 2013*, julio 2014.

Red Eléctrica de España, *El sistema eléctrico español 2014,* julio 2015.

Red Eléctrica de España, *El sistema eléctrico español 2015,* junio 2016.

Rockström, J., Steffen W., Noone, K., Persson, Å., *et al*., "Planetary boundaries: exploring the safe operating space for humanity", *Ecology and Society* vol. 14, no. 2, art. 32, 2009.

Scheers H. et al., "Long-Term Exposure to Particulate Matter Air Pollution Is a Risk Factor for Stroke. Meta-Analytical Evidence", *Stroke*, Vol. 46, Issue 11, 2015, p. 3064.

SolarPower Europe, "*Solar Photovoltaics Jobs & Value Added in Europe*", November 2015.

Steffen, W., Crutzen, P.J., and McNeill, J.R., "The Antropocene: are humans now overwhelming the great forces of Nature?", *Ambio* vol. 36, 2007, p. 614-621.

WHO-Regional Office for Europe, *Health risks of air pollution in Europe – HRAPIE project*, 2013.

WHO-Regional Office for Europe*, Methods and tools for assessing the health risks of air pollution at local, national and international level*, 2014.

WHO-Regional Office for Europe, *Review of evidence on health aspects of air pollution-REVIHAAP Project*, 2013, p. 7.

WHO-Regional Office for Europe, *WHO Expert Consultation: Available evidence for the future update of the WHO Global Air Quality Guidelines*, 2016, p. 17.

World Health Organization, *Guías de calidad del aire de la OMS relativas al material particulado, el ozono, el dióxido de nitrógeno y el dióxido de azufre*: *Resumen de evaluación de los riesgos: Actualización mundial 2005*, 2006.

Weinmayr et al., "Short-Term Effects of PM_{10} and NO_2 on Respiratory Health among Children with Asthma or Asthma-like Symptoms: A Systematic Review and Meta-Analysis", *Environmental Health Perspectives*, Vol. 118, N. 4, 2010, p.449.

Y. Omidi et al., "Exposure to PM_{10}, NO_2 and O_3 and impacts on human health", *Environmental Science and Pollution Research*, 2016.

Zeka A. et al, *Mortality Impacts of Sulphur Concentrations in Air in 20 European Cities in the Aphekom Project: A Case Cross-Over distributed Lag Approach*.

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