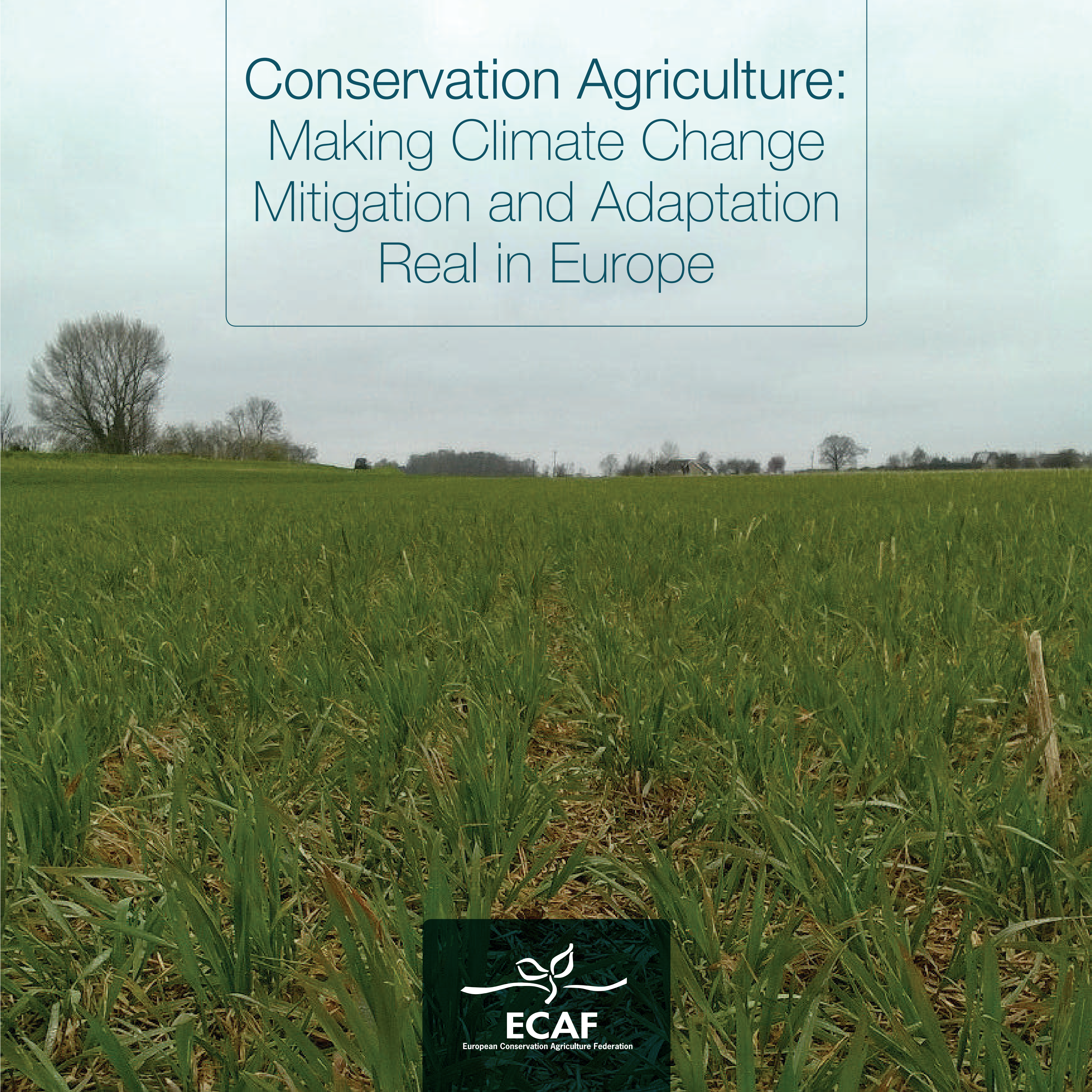
Conservation Agriculture: Making Climate Change Mitigation and Adaptation Real in Europe



ECAF
European Conservation Agriculture Federation

Conservation Agriculture: Making Climate Change Mitigation and Adaptation Real in Europe

ECAF
European Conservation Agriculture Federation

Publisher: European Conservation Agriculture Federation (ECAF)
www.ecaf.org

Authors: Emilio J. González-Sánchez; Manuel Moreno-García, Amir Kassam; Antonio Holgado-Cabrera;
Paula Triviño-Tarradas; Rosa Carbonell-Bojollo; Michele Pisante; Oscar Veroz-González; Gottlieb Basch

ISBN: 978-84-697-4303-4

INDEX

EXECUTIVE SUMMARY

CHAPTER 1: INTRODUCTION TO CLIMATE CHANGE

CHAPTER 2: AGRICULTURE AND CLIMATE CHANGE

CHAPTER 3: CONSERVATION AGRICULTURE

CHAPTER 4: CONSERVATION AGRICULTURE FOR CLIMATE CHANGE MITIGATION

CHAPTER 6: OTHER BENEFITS OF CONSERVATION AGRICULTURE

Executive summary

Agriculture and climate change are closely related. In this report, the European Conservation Agriculture Federation (ECAF) offers its experience and knowledge on how the agricultural sector can respond to climate change through Conservation Agriculture (CA). This experience is based on the development of several European (LIFE) public-funded projects based on the implementation of CA in Europe, and on a literature review on the topic. This document aims to serve as a basis for decision-making based on science and agricultural experimentation in Europe.

Climate change and agriculture

The study of climate is a complex field of investigation and in constant evolution but, since it is influenced by a great number of factors, it is not a static system and therefore it is difficult to forecast its future potential impacts with precision (Fig. 1). However, it is obvious that climate is undergoing rapid changes, where socio-economic development is not corresponding to the limited natural resources. Thus, one of the greatest challenges is to respond to the need to produce enough food, feed and fiber in a sustainable way while satisfying the needs for a growing world population in a changing climate. Agricultural production, and therefore food security, is strongly influenced by changes in rainfall and temperature patterns and other climatic conditions.

In terms of contribution, approximately 10% of greenhouse gases (GHGs) globally emitted come from the European Union (EU). Of these GHGs emitted in Europe, around 10% come from agriculture, which is the fourth largest emitter in the EU after the energy production, transport and industrial combustion sectors. In order to slow down these emissions, the 21st meeting of the Conference of the Parties (COP21) and the 11th meeting of the Conference of the Parties was celebrated at the end of 2015, serving as the *meeting of the Parties with respect to the Kyoto Protocol* (CMP). It concluded with the adoption of a historic agreement to combat climate change and promote measures and investments for a low-carbon, resilient and sustainable future, the so-called Paris Agreement.

Agriculture is a fundamental sector that provides food for both people and animals, produces fibers for the textile sector, and many other products and services essential for the existence of humanity. Like any other economic activity, agriculture is linked to the natural and social environment in which it is developed, and interacts with it. If there is any productive activity that depends directly on the climate and its variability, this is undoubtedly agriculture. A change of temperature and precipitation, or an increase in the concentration of atmospheric CO_2, will significantly affect crop development and performance. At a global level, it is estimated that climate variability is responsible for between 32% and 39% of the variability in yields, an effect that is probably even more pronounced in many regions of Southern Europe.

Today, a multidimensional approach it is essential for measuring agricultural sustainability in order to achieve a balance between preservation and improvement of the environment, social equity and economic viability, and therefore improve the welfare of society. Scientific studies carried out in different agro-ecological regions and countries agree that the less soil is tilled, the more carbon is absorbed and stored in it. Plants absorb carbon dioxide from the air and transform it through the process of photosynthesis into organic carbon. This organic carbon becomes the source for soil organic matter, contributing thus to an enhanced soil fertility and to an improved productive capacity. On the other hand, any action aimed at saving energy and fuel, such as reducing the number of tillage operations, optimizing the use of agricultural inputs and proper execution of operations, directly reduces emissions of greenhouse gases. Therefore, a sustainable agricultural system that responds to these requirements is of particular importance: Conservation Agriculture.

What is Conservation Agriculture?

The principles of Conservation Agriculture are as follows (Fig. 2):

- Minimum soil disturbance. In practice it means no-tillage. At least 30% of the soil must be covered after seeding to effectively protect it against erosion. However, it is recommendable to leave more than 60% of the soil covered to have almost complete control over soil degradation processes.
- Permanent soil cover. In other words, it means to maintain stubble in arable crops and to seed or preserve groundcovers between rows of trees in permanent crops. In this way, soil

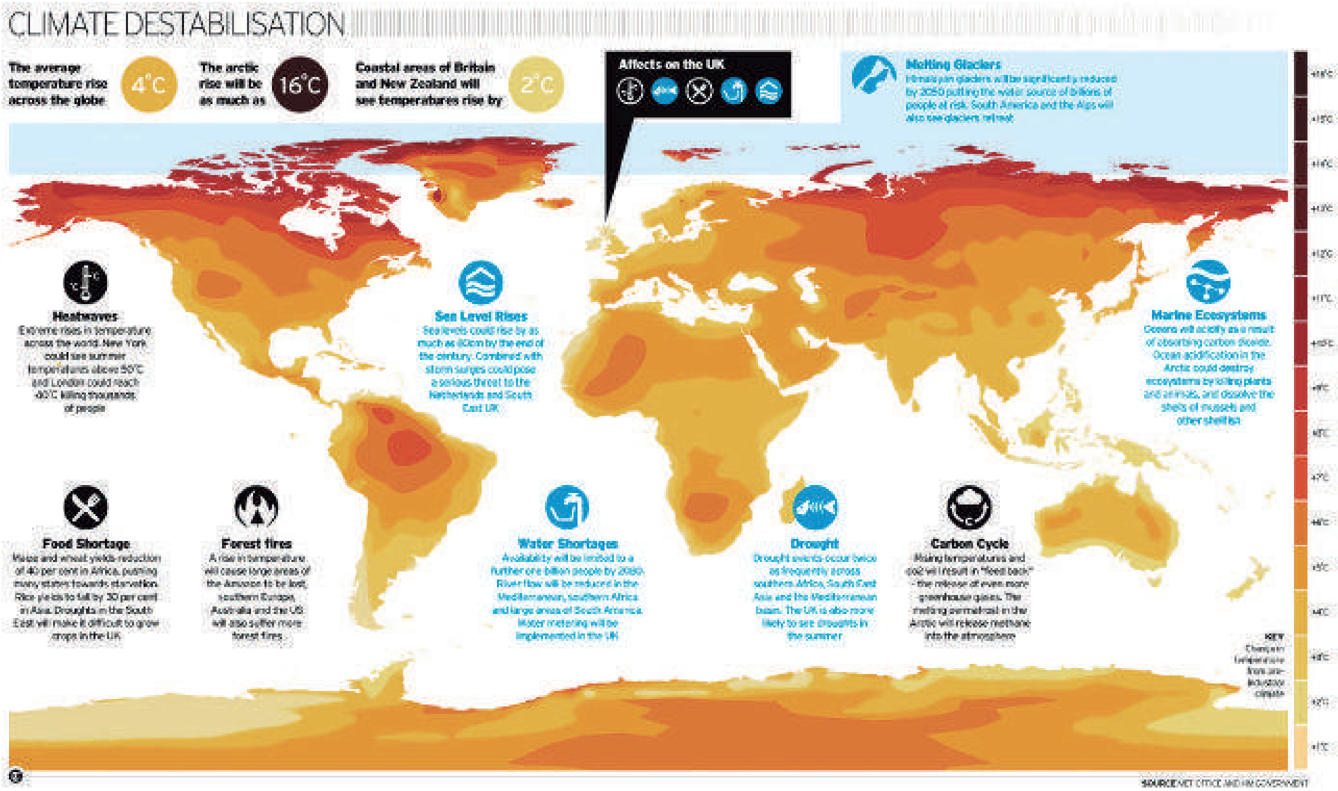


Fig. 1. Global impacts of climate change.

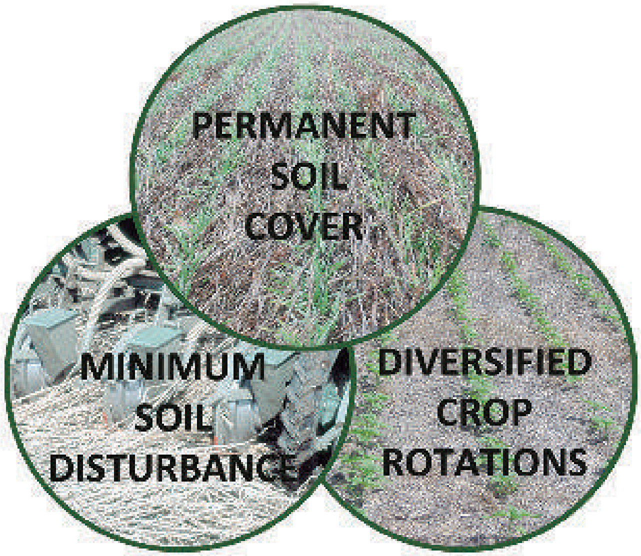
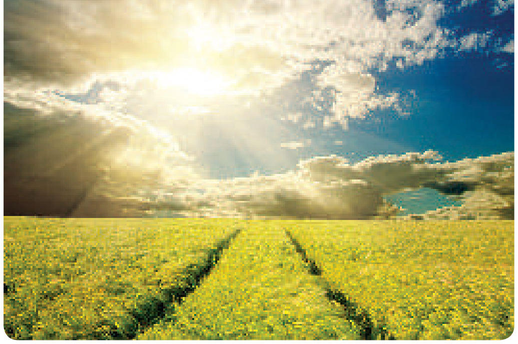


Fig. 2. Principles and benefits of Conservation Agriculture.

For every hectare converted to CA in Europe the emissions of a return flight from London to Athens are removed from the atmosphere.



organic matter and water infiltration into the soil are increasing, weeds are inhibited, and water evaporation from the soil is limited.

- Practicing rotations or crop diversification in annual crops. In this way, pests and diseases are better controlled by breaking cycles that are maintained in monocultures, in addition to including crops that can improve the natural fertility of the soil and biodiversity.

Conservation Agriculture as an integrated approach towards sustainability

Conservation Agriculture offers a considerable environmental improvement of the agricultural ecosystems, without reducing yields. Almost 20% of the European surface suffers soil losses exceeding 10 tons per hectare per year. Taking into account the low rate of soil formation, losses greater than 1 ton per hectare per year can be considered as irreversible. Conservation Agriculture reduces soil erosion by up to 90% compared to conventional tillage, thus reducing soil degradation.

Comparing Conservation Agriculture to tillage based agriculture, the latter increases emissions of CO_2 into the atmosphere, reducing the content of organic matter of the soil, and therefore affecting its quality and fertility. The implementation of Conservation Agriculture leads to the significant improvement of soil physical and chemical properties resulting in a much better soil structure, increases in soil organic matter (CO_2 sequestration) and biodiversity, improved water infiltration and water holding capacity and reduced runoff and direct evaporation from the soil, thus improving the efficiency of water use and the quality of the water (Table 1).

Table 1. Main environmental benefits of Conservation Agriculture.

For the soil	Reduced erosion
	Increase in soil organic matter
	Improvement of structure and porosity
	Greater biodiversity
	Increased soil fertility
For the air	Fixation of atmospheric carbon in the soil
	Reduced CO_2 emissions into the atmosphere
For the water	Reduced runoff
	Better quality
	Increased water holding capacity

Conservation Agriculture has a double effect on the reduction of greenhouse gases concentration in the atmosphere. On the one hand, the changes introduced by CA (more biomass in form of crop residues and cover crops), increase the carbon content in the soil through higher organic carbon inputs (Fig. 3). And, on the other hand, the drastic reduction of tillage operations along with the minimal mechanical soil disturbance, lead to reduction of the CO_2 emissions resulting from energy savings through less fuel consumption, and the reduction of the mineralization processes of the organic matter.

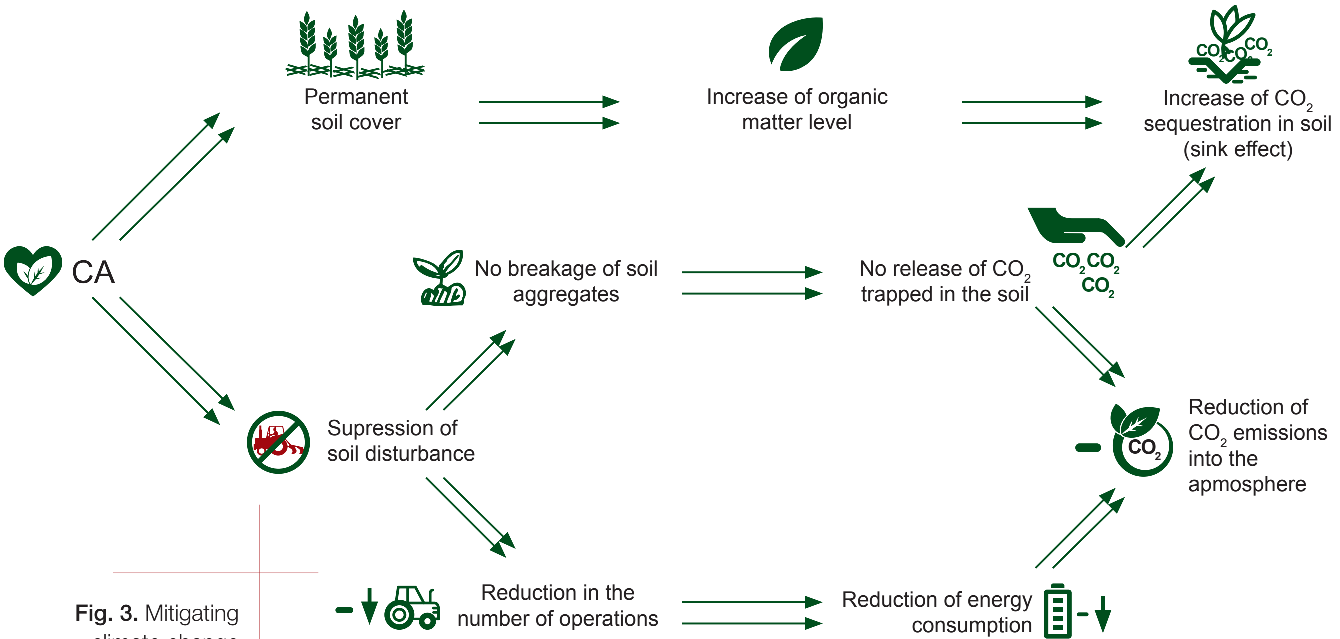


Fig. 3. Mitigating climate change mechanisms through Conservation Agriculture.

Adopting Conservation Agriculture

Conservation Agriculture is one of the most studied agro-sciences in the world, as is practiced on almost 160 million hectares according to FAO. Today, CA is performed in annual crops applying the principles of no-tillage, permanent organic soil cover and crop rotations, while in permanent crops, the CA approach is based on groundcovers between the tree crop rows. CA in annual crops is widespread around the world (Fig. 4), being its adoption rather heterogeneous in Europe (Fig. 5).

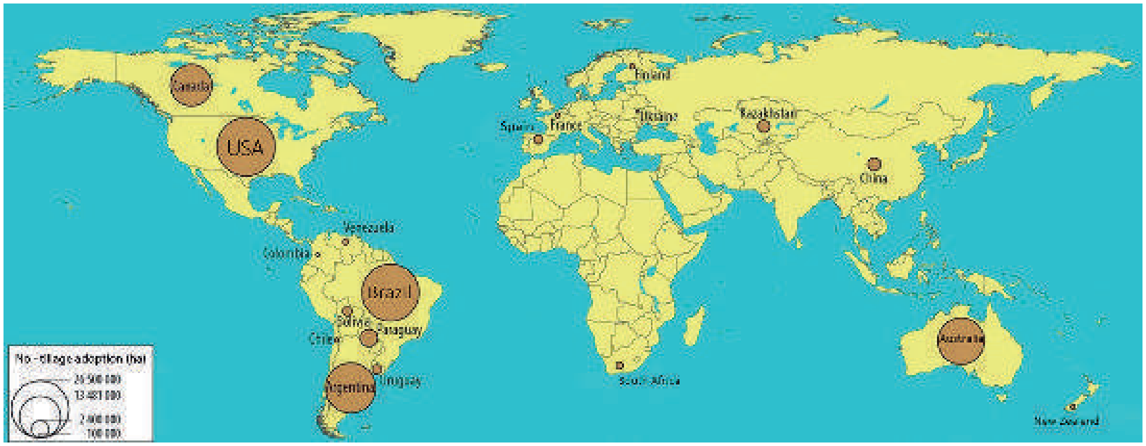
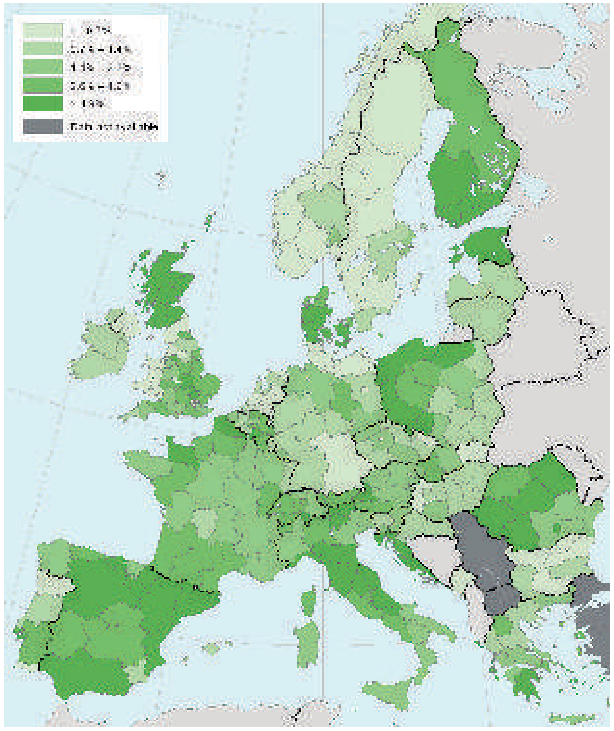


Fig. 4. Worldwide no-tillage adoption.

Fig. 5. Share by European regions of annual crops on which no-tillage is applied.



Soil organic carbon fixation through Conservation Agriculture

Different studies in Europe show that during several years of the application of CA principles it is possible to sequester large amounts of CO_2 per hectare and year in annual crops, compared to tillage-based systems. The estimation for EU-28 countries of the potential soil organic carbon (SOC) sequestration through the adoption of CA in annual crops when compared to conventional tillage systems is given in the Table 2.

Table 2. Area under CA in annual crops in Europe, carbon sequestration potential per biogeographic region or country and actual and potential carbon/CO_2 fixation through CA in annual crops (1 ton of Corg corresponds to 3.7 tons of CO_2).

	Biogeographical region	Increase of soil organic carbon (t ha^{-1} yr^{-1})	NT current area (ha)	Current SOC fixed (t yr^{-1})	Current CO_2 fixed (t yr^{-1})	NT potential area (ha)	Potential SOC fixed (t yr^{-1})	Potential CO_2 fixed (t yr^{-1})
Austria	Continental	0.42	28,330	11,927	43,731	1,232,040	518,670	1,901,791
Belgium	Atlantic	0.32	270	87	320	613,580	198,084	726,308
Bulgaria	Continental	0.42	16,500	6,946	25,470	3,197,800	1,346,225	4,936,160
Croatia	Continental	0.42	18,540	7,805	28,619	832,870	350,626	1,285,627
Cyprus	Mediterranean	0.81	270	219	803	61,770	50,085	183,646
Czech Republic	Continental	0.42	40,820	17,185	63,010	2,373,890	999,372	3,664,363
Denmark	Atlantic	0.32	2,500	807	2,959	2,184,120	705,107	2,585,391
Estonia	Boreal	0.02	42,140	843	3,090	578,660	11,573	42,435
Finland	Boreal	0.02	200,000	4,000	14,667	1,912,710	38,254	140,265
France	Atlantic	0.20	300,000	60,000	220,000	17,166,990	3,433,398	12,589,126
Germany	Continental	0.43	146,300	63,441	232,617	10,904,310	4,728,505	17,337,853
Greece	Mediterranean	0.81	7	6	21	1,600,950	1,298,104	4,759,713
Hungary	Continental	0.42	5,000	2,105	7,718	3,560,130	1,498,761	5,495,456
Ireland	Atlantic	0.32	2,000	646	2,367	999,550	322,688	1,183,190
Italy	Mediterranean	0.77	283,923	219,094	803,344	5,992,540	4,624,243	16,955,559
Latvia	Boreal	0.02	11,340	227	832	1,101,650	22,033	80,788
Lithuania	Boreal	0.02	19,280	386	1,414	2,129,630	42,593	156,173
Luxembourg	Continental	0.42	440	185	679	60,950	25,659	94,083
Malta	Mediterranean	0.81	ND	ND	ND	5,290	4,289	15,727
Netherlands	Atlantic	0.32	7,350	2,373	8,700	670,360	216,415	793,520
Poland	Continental	0.41	403,180	164,632	603,650	9,518,930	3,886,896	14,251,954
Portugal	Mediterranean	0.81	16,050	13,014	47,718	707,490	573,656	2,103,407
Romania	Continental	0.42	583,820	245,779	901,191	7,295,660	3,071,362	11,261,662
Slovakia	Continental	0.42	35,000	14,734	54,026	1,304,820	549,309	2,014,135
Slovenia	Continental	0.42	2,480	1,044	3,828	165,410	69,635	255,329
Spain	Mediterranean	0.85	619,373	526,467	1,930,379	7,998,655	6,798,857	24,929,141
Sweden	Boreal	0.02	15,820	316	1,160	2,324,650	46,493	170,474
United Kingdom	Atlantic	0.45	362,000	161,331	591,548	4,376,000	1,950,237	7,150,870
Total Europe			**3,162,733**	**1,525,598**	**5,593,861**	**90,871,405**	**37,381,131**	**137,064,146**

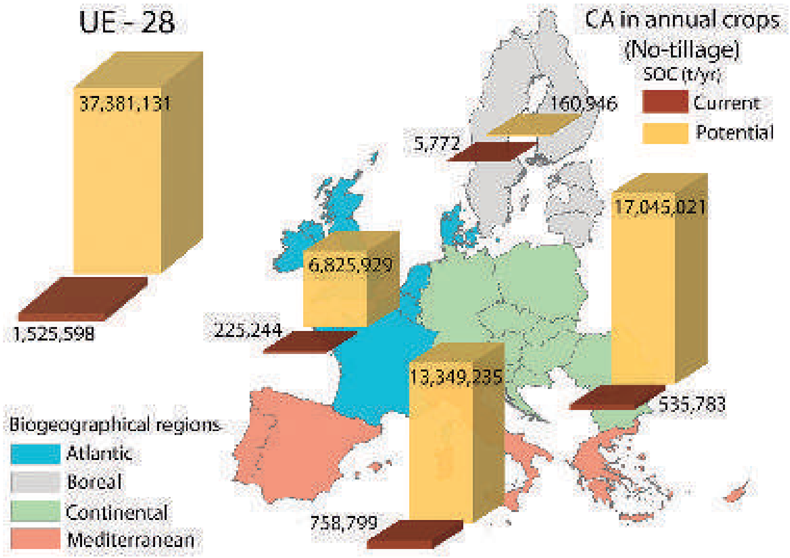
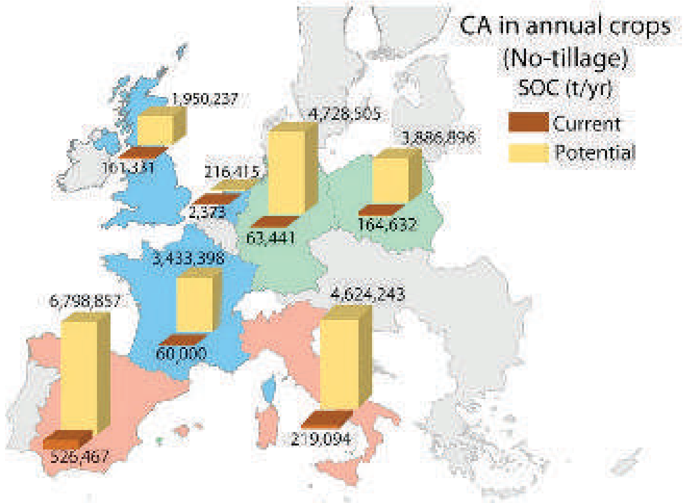


Fig. 6. Current and potential SOC fixed by CA in annual crops compared to systems based on soil tillage in EU-28 and in the different biogeographical regions.

Fig. 7. Current and potential SOC fixed by CA in annual crops compared to systems based on soil tillage in France, Germany, Italy, Netherlands, Poland, Spain and the United Kingdom.



These SOC fixation data are represented by maps for the different biogeographic regions (Fig. 6) as well as for 7 countries in particular (France, Germany, Italy, Netherlands, Poland, Spain and the United Kingdom) (Fig. 7).

In relation to CA in permanent crops (groundcovers), there are no official data for Europe as a whole. Due to that, the data of the adoption of this practice derive from reports of the European national associations of Conservation Agriculture. The available scientific data for carbon sequestration, except for France, only address the Mediterranean biogeographic region. However, with due caution, a calculation of the carbon sequestration potential for EU-28 is provided in Table 3.

Table 3. Area under CA in permanent crops (groundcovers)in Europe, carbon sequestration potential per biogeographic region or country, and actual and potential carbon/CO_2 fixation through groundcovers (1 ton of Corg corresponds to 3.7 tons of CO_2)

	Biogeographical region	Increase of soil organic carbon (t ha^{-1} yr^{-1})	Groundcover current area (ha)	Current SOC fixed (t yr^{-1})	Current CO_2 fixed (t yr^{-1})	Ground-cover potential area (ha)	Potential SOC fixed (t yr^{-1})	Potential CO_2 fixed (t yr^{-1})
Austria	Continental	0.40	ND	ND	ND	80,190	32,076	117,612
Belgium	Atlantic	0.40	ND	ND	ND	38,170	15,268	55,983
Bulgaria	Continental	0.40	ND	ND	ND	143,070	57,228	209,836
Croatia	Continental	0.40	ND	ND	ND	100,290	40,116	147,092
Cyprus	Mediterranean	1.30	ND	ND	ND	32,980	42,973	157,567
Czech Republic	Continental	0.40	ND	ND	ND	60,100	24,040	88,147
Denmark	Atlantic	0.40	ND	ND	ND	32,320	12,928	47,403
Estonia	Boreal	ND	ND	ND	ND	6,210	ND	ND
Finland	Boreal	ND	ND	ND	ND	7,020	ND	ND
France	Atlantic	0.40	ND	ND	ND	1,206,470	482,588	1,769,489
Germany	Continental	0.40	ND	ND	ND	263,270	105,308	386,129
Greece	Mediterranean	1.30	483,340	629,792	2,309,237	1,040,140	1,355,302	4,969,442
Hungary	Continental	0.40	65,000	26,000	95,333	214,430	85,772	314,497
Ireland	Atlantic	0.40	ND	ND	ND	2,530	1,012	3,711
Italy	Mediterranean	1.07	132,900	141,671	519,462	2,409,780	2,568,825	9,419,027
Latvia	Boreal	ND	ND	ND	ND	13,000	ND	ND
Lithuania	Boreal	ND	ND	ND	ND	44,120	ND	ND
Luxembourg	Continental	0.40	ND	ND	ND	1,670	668	2,449
Malta	Mediterranean	1.30	ND	ND	ND	1,650	2,150	7,883
Netherlands	Atlantic	0.40	ND	ND	ND	55,510	22,204	81,415
Poland	Continental	0.40	ND	ND	ND	777,230	310,892	1,139,937
Portugal	Mediterranean	1.30	32,950	42,934	157,424	895,590	1,166,954	4,278,830
Romania	Continental	0.40	ND	ND	ND	446,760	178,704	655,248
Slovakia	Continental	0.40	18,810	7,524	27,588	26,130	10,452	38,324
Slovenia	Continental	0.40	ND	ND	ND	37,080	14,832	54,384
Spain	Mediterranean	1.54	1,275,888	1,964,868	7,204,514	4,961,981	7,641,451	28,018,653
Sweden	Boreal	ND	ND	ND	ND	7,390	ND	ND
United Kingdom	Atlantic	0.40	ND	ND	ND	36,000	14,400	52,800
Total Europe			**2,008,888**	**2,812,789**	**10,313,559**	**12,905,081**	**14,186,143**	**52,015,859**

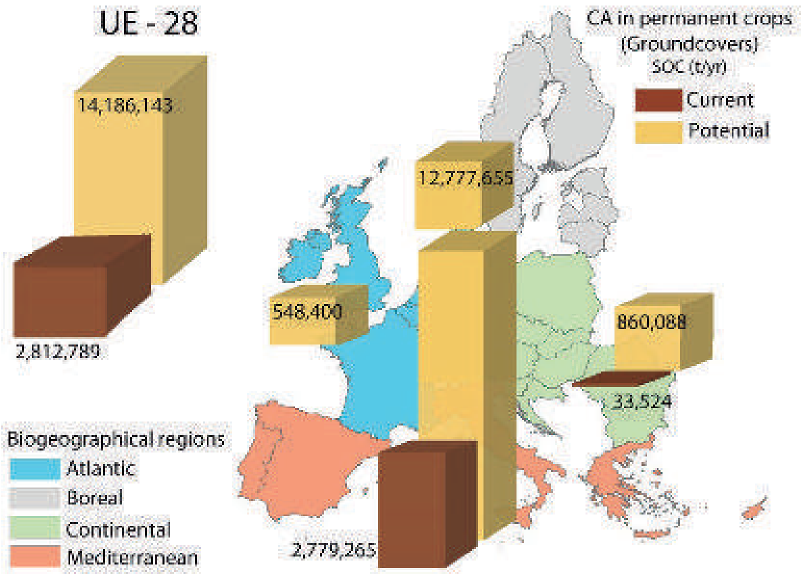
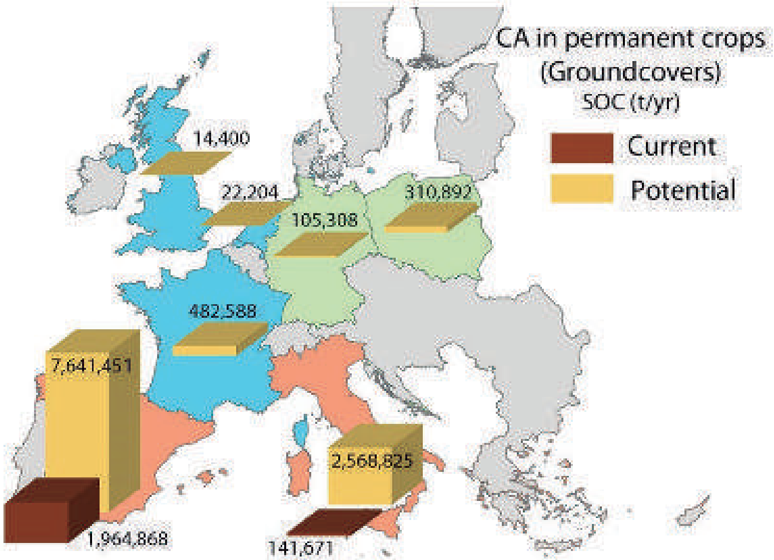


Fig. 8. Current and potential SOC fixed by groundcovers compared to systems based on soil tillage in EU-28 and in the different biogeographical regions.

Fig. 9. Current and potential SOC fixed by groundcovers compared to systems based on soil tillage in France, Germany, Italy, Netherlands, Poland, Spain and the United Kingdom.



These SOC fixation data are represented by maps for the different biogeographic regions (Fig. 8) as well as for 7 countries in particular (France, Germany, Italy, Netherlands, Poland, Spain and the United Kingdom) (Fig. 9).

In order to quantify the CO_2 emission reduction achievable through the values of organic C sequestered in the soil and not released through the microbiological oxidation processes of organic matter, we are using the ratio of 3.7 tons of CO_2 that are generated from 1 ton of C. Therefore, taking into account the increase in soil organic matter (SOM) observed in CA systems (both annual crops and groundcovers in permanent crops) in comparison to the management systems based on tillage, it is possible to calculate the total CO_2 emission offset potential through the implementation of CA in Europe (Table 4).

Implementation of CA in Europe would reduce as much emissions as the closure of 50 coal-fired power plants.

Table 4. Current and potential fixation of CO_2 in Europe.

	Biogeographical region	Current CO_2 fixed through CA (t yr^{-1})	Potential CO_2 fixed through CA (t yr^{-1})	Increase CO_2 fixed through CA (Potential - current) (t yr^{-1})
Austria	Continental	43,731	2,019,403	1,975,672
Belgium	Atlantic	320	782,291	781,971
Bulgaria	Continental	25,470	5,145,996	5,120,526
Croatia	Continental	28,619	1,432,719	1,404,101
Cyprus	Mediterranean	803	341,213	340,410
Czech Republic	Continental	63,010	3,752,510	3,689,499
Denmark	Atlantic	2,959	2,632,794	2,629,835
Estonia	Boreal	3,090	42,435	39,345
Finland	Boreal	14,667	140,265	125,599
France	Atlantic	220,000	14,358,615	14,138,615
Germany	Continental	232,617	17,723,982	17,491,365
Greece	Mediterranean	2,309,258	9,729,155	7,419,897
Hungary	Continental	103,051	5,809,954	5,706,902
Ireland	Atlantic	2,367	1,186,900	1,184,533
Italy	Mediterranean	1,322,806	26,374,586	25,051,780
Latvia	Boreal	832	80,788	79,956
Lithuania	Boreal	1,414	156,173	154,759
Luxembourg	Continental	679	96,532	95,853
Malta	Mediterranean	0	23,611	23,611
Netherlands	Atlantic	8,700	874,935	866,234
Poland	Continental	603,650	15,391,891	14,788,241
Portugal	Mediterranean	205,142	6,382,238	6,177,096
Romania	Continental	901,191	11,916,910	11,015,719
Slovakia	Continental	81,614	2,052,459	1,970,844
Slovenia	Continental	3,828	309,713	305,885
Spain	Mediterranean	9,134,893	52,947,794	43,812,901
Sweden	Boreal	1,160	170,474	169,314
United Kingdom	Atlantic	591,548	7,203,670	6,612,122
Total Europe		**15,907,420**	**189,080,005**	**173,172,585**

Commitments within the Paris Agreement

The Paris Agreement pursues to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty. To comply with the 40% target compared to 1990, an Emission Reduction is planned in two areas:

- Reduction of 43% compared to 2005 emissions in sectors belonging to the EU Emissions Trading Scheme (ETS).
- Reduction of 30% compared to 2005 emissions in sectors outside the EU ETS (non-ETS) system.

Agriculture is included within the second, counting the reduction of its emissions, within the binding objectives to which each of the Member States has committed (Fig. 10).

The amount of CO_2 sequestered in the soil through the application of the CA, would reach the targets committed by 2030 with greater ease. Considering overall European figures, carbon sequestration that could take place on farm land under Conservation Agriculture would help achieve around 22% of the necessary reductions in the non-ETS sectors by 2030, and almost 10% of the total emissions still allowed in the non-ETS sectors. This achievement would could give the signing member countries some margin in the emission reduction in other sectors such as housing or transport.

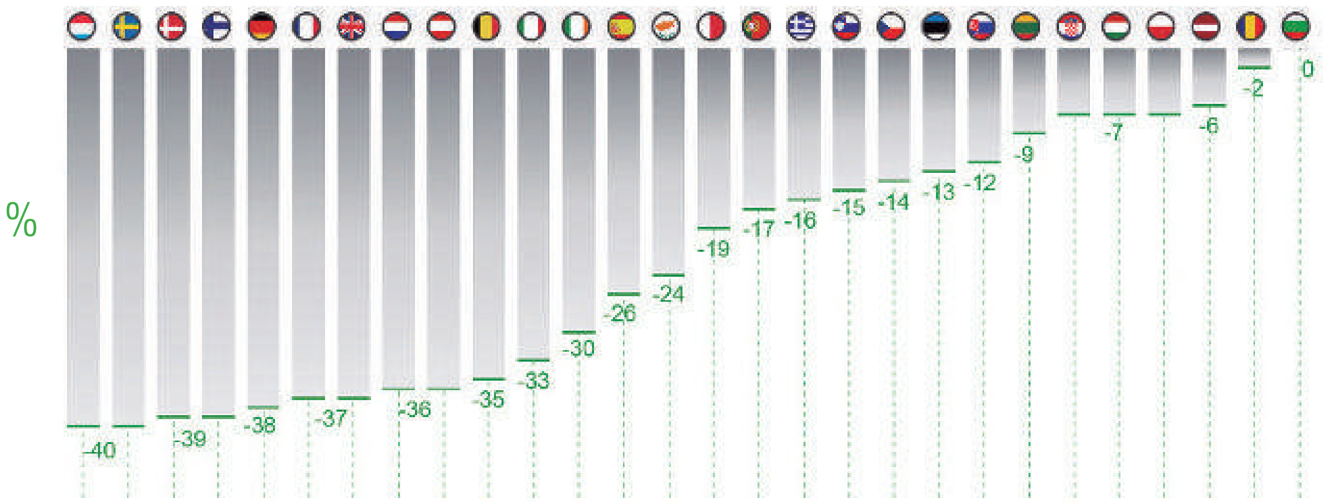


Fig. 10. Percentage reduction of national emissions in sectors outside the EU ETS (non-ETS).

Table 5. Existing relationship between CO_2 sequestration that would occur in the soil when conventional farming system is substituted by Conservation Agriculture on the entire surface, and the emission reduction to be achieved in the non-ETS sectors by 2030. And with respect to Non-ETS emissions allowed by 2030.

	(A) Non-ETS emissions allowed by 2030 (t yr^{-1})	(B) Reduction of emissions by 2030 from non-ETS compared to 2005 (t yr^{-1})	(C) Potential of CO_2 fixed through CA (t yr^{-1})	Percentage of (C) over (B) (%)	Percentage of (C) over (A) (%)
Austria	36,268,800	20,401,200	2,019,403	9.90	5.57
Belgium	50,830,000	27,370,000	782,291	2.86	1.54
Bulgaria	24,570,000	0	5,145,996	-	20.94
Croatia	15,642,600	1,177,400	1,432,719	121.69	9.16
Cyprus	3,176,800	1,003,200	341,213	34.01	10.74
Czech Republic	53,793,000	8,757,000	3,752,510	42.85	6.98
Denmark	24,448,800	15,631,200	2,632,794	16.84	10.77
Estonia	4,724,100	705,900	42,435	6.01	0.90
Finland	20,496,000	13,104,000	140,265	1.07	0.68
France	249,221,700	146,368,300	14,358,615	9.81	5.76
Germany	290,432,800	178,007,200	17,723,982	9.96	6.10
Greece	51,895,200	9,884,800	9,729,155	98.43	18.75
Hungary	43,133,400	3,246,600	5,809,954	178.96	13.47
Ireland	33,264,000	14,256,000	1,186,900	8.33	3.57
Italy	220,523,800	108,616,200	26,374,586	24.28	11.96
Latvia	8,008,800	511,200	80,788	15.80	1.01
Lithuania	9,809,800	970,200	156,173	16.10	1.59
Luxembourg	6,078,000	4,052,000	96,532	2.38	1.59
Malta	834,300	195,700	23,611	12.06	2.83
Netherlands	78,643,200	44,236,800	874,935	1.98	1.11
Poland	163,689,300	12,320,700	15,391,891	124.93	9.40
Portugal	41,109,900	8,420,100	6,382,238	75.80	15.52
Romania	71,569,400	1,460,600	11,916,910	815.89	16.65
Slovakia	19,624,000	2,676,000	2,052,459	76.70	10.46
Slovenia	10,072,500	1,777,500	309,713	17.42	3.07
Spain	173,041,600	60,798,400	52,947,794	87.09	30.60
Sweden	25,740,000	17,160,000	170,474	0.99	0.66
United Kingdom	261,267,300	153,442,700	7,203,670	4.69	2.76
Total Europe	1,991,909,100	856,550,900	189,080,005	22.07	9.49

Key tools for Conservation Agriculture

Machinery

Since Conservation Agriculture avoids tillage, it is necessary to have adequate equipment to establish the crops in conditions with abundant plant residues. Therefore the development specific machinery, especially for seeding, has had special relevance in the implementation of CA. One of the keys to success in Conservation Agriculture are the direct seeders (no-till drills) and its features, which allow farmers to establish the crops successfully under the divers conditions soil types of soils groundcovers. In general, no-till drills must have the following characteristics:

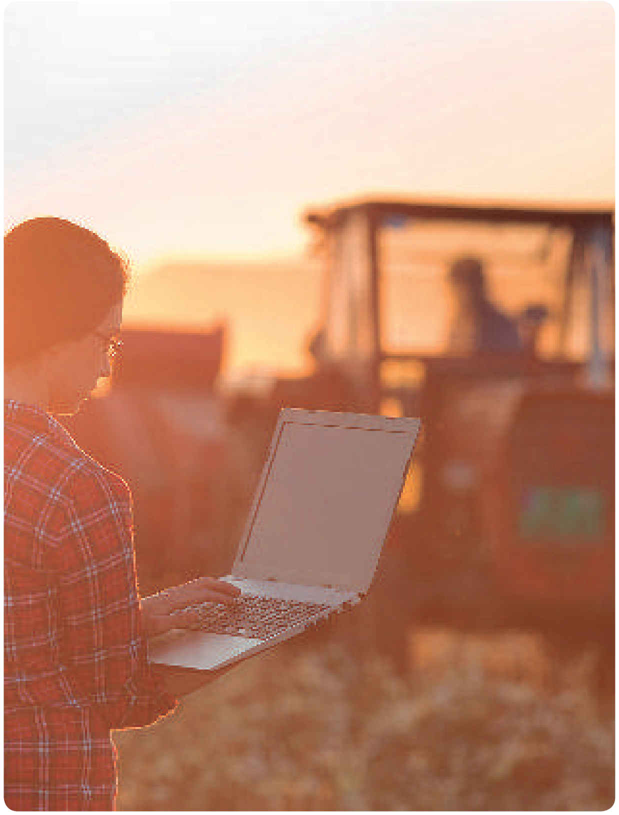
- Enough weight to penetrate under compact soil conditions and cover crops.
- Ability to open a groove wide and deep enough to place the seed at the adequate depth. It will be different if it is used for fine (~ 3 cm) or thick (~ 5 cm) seed.
- Possibility to regulate the rate and spacing of seeds of different size and ensure their adequate covering.
- Possibility to easily modify its settings to adapt to different crops and to amply fertilizers and plant protection products simultaneously.
- Resistance of its elements to withstand heavy duty conditions.

Plant protection

Conservation Agriculture principles, namely crop diversity and rotation and enhanced soil and aboveground biodiversity, help control weeds, pest and diseases. However, some applications of crop protection products may be needed during the season. The numerous plough passes performed in tillage-based agriculture are replaced by an optimized use of phytosanitary treatments. For that reason, herbicides have been, and remain, a crucial element in the development of CA systems. The active ingredients used in the pre-seeding weed control are diverse, but normally glyphosate alone or in combination with other herbicides, such as hormonal ones are a common choice among farmers. Glyphosate controls many weeds and leaves no residue in the soil that could prevent or delay seeding. The low toxicological characteristics of this herbicide, its excellent weed control, and the easy availability of numerous brands commercialized by many companies -since its patent expired in 2000- make treatments with this active ingredient safe, inexpensive and well-known all around the world. Without glyphosate the maintenance and spread of the area under CA in Europe would be at risk, or would depend on the use of other herbicides with a less favourable ecotoxicological profile and at a higher cost to the farmers. It is also important to stress that the application of any plant protection product in CA is much safer when compared to the application in conventional agriculture, as the risk of any off-site transport is much lower and the degradation rate of the products applied is enhanced due to a much higher soil microbial activity.

Facts and figures

Calculations for the following "facts and figures" are based on the total European CO_2 sequestration potential (189 Mt ha^{-1} yr^{-1}) and on the average CO_2 sequestration rate per hectare (1.82 t ha^{-1} yr^{-1}) that could be achieved in Europe by shifting from conventional tillage to Conservation Agriculture the whole European area suitable for CA (103 Mha).

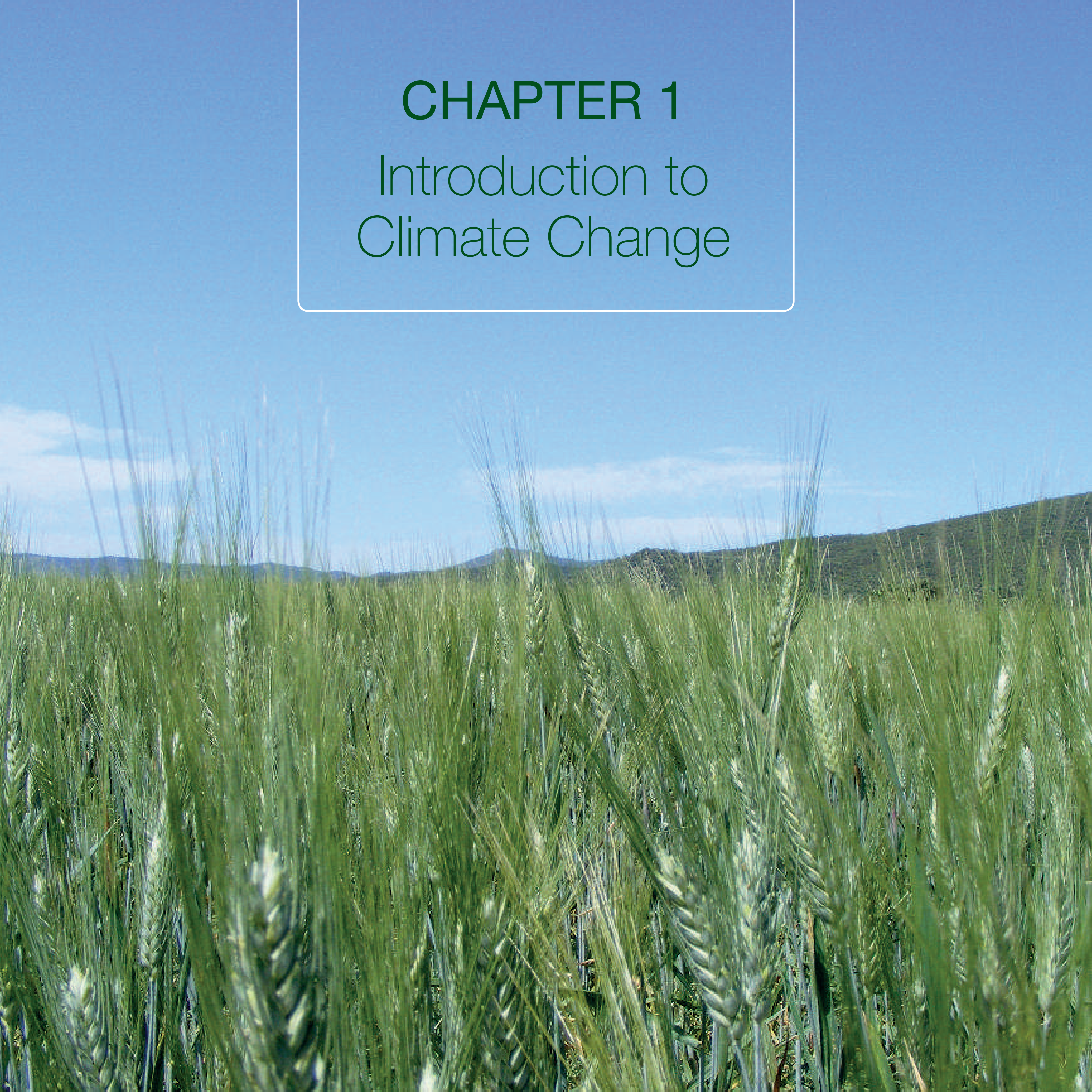


- Just 4 hectares under CA would negate the average annual emissions of a European citizen. (1)
- One hectare under CA would compensate emissions equivalent to 14 car journeys from Paris to Berlin. (2)
- Adoption of CA across Europe would sequester the CO_2 emitted by 18 million households. Or the emissions from electricity generation for 25 million households. (3)
- The carbon sequestration due to the adoption of CA across Europe would be equivalent to the emissions saving obtained by the installation of over 43,000 wind turbines. (3)
- Implementation of CA in Europe would reduce as much emissions as the closure of 50 coal-fired power plants. (3)
- If all European farmland was converted to CA, it would reduce atmospheric carbon by as much as planting 65 million hectares of forest. (3)
- For every hectare converted to CA in Europe the emissions of a return flight from London to Athens are removed from the atmosphere. (2)

According to: (1) Eurostat; (2) Naturefund CO_2 Calculator; (3) EPA Greenhouse Gas Equivalencies Calculator.

CHAPTER 1

Introduction to Climate Change



1.1. Introduction

The study of climate is a complex field of investigation which is in constant evolution due to the large number of factors involved. Therefore, it is not a static system which makes it difficult to determine its effects. Any circumstance that induces temporal and / or spatial fluctuations of one or several components of the climate will cause climatic variation regionally and globally, leading to climate change. As a result of changes in the energy balance, the climate has been subject to variations on all time scales, from decades to thousands and millions of years. There is a scientific, almost generalized consensus, that alterations of the energy consumption and our way of production are generating a global climatic variation, causing not only environmental effects on Earth but also making serious impacts on countries' socio-economic systems.

In recent years, the changes that climate conditions are experiencing and their consequences were some of the most common topics. However, our planet has experienced climate variability not always provoked by human activity, such as the global warming that occurred during the Jurassic Period with average temperatures of 5 ºC above the current ones, the Pleistocene glaciations, where great parts of North America, Europe and North Asia were covered with a thick layer of ice and, more recently, the so-called Little Ice Age that occurred from the 14th to the 19th century.

Climate change is a significant and lasting permutation of local or global climate patterns. The causes that affect

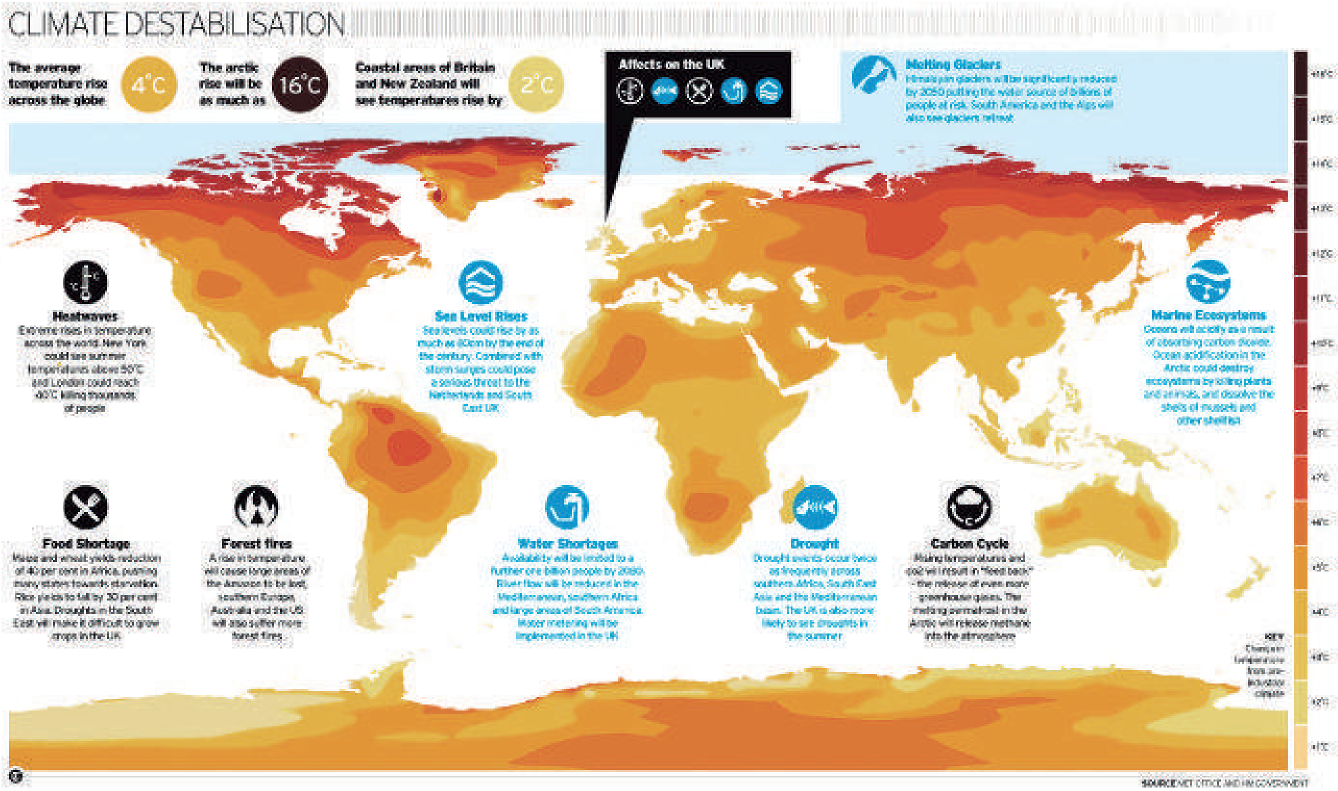


Fig. 1.1. Global impacts of climate change. *Met Office, 2009.*

climate can be natural (energy variations of the sun, volcanic eruptions, ocean circulation, biological processes, etc.) and anthropic (increase in CO_2 emissions and other greenhouse gases, alteration of large parts of soil, etc.). Climate change affects us all, because of its excessive potential impact, with predictions of lack of drinking water, big changes in food production conditions and increase in mortality rates caused by floods, storms, droughts and heat waves. However, these effects not only affect the environment but they also lead to economic and social consequences around the world (Fig. 1.1). Therefore, it is necessary to take a series of measures to mitigate climate change and, at the same time, to adapt to the possible scenarios which are a consequence of global warming.

The United Nations Framework Convention uses the term climate change to refer to changes occurring in the present and only directly or indirectly attributed to human activity which alters the composition of the global atmosphere and can be related to the natural variability of the climate observed over comparable periods. During the meeting, a

The global climate is currently undergoing rapid changes, where economic and social development is not respecting limited natural resources.

very important international treaty about environment was confirmed: the Montreal Protocol, established in 1987, under which members states are obliged to act in the interests of human security, including lack of scientific certainty.

The main achievement of the Convention was to recognize, for the first time, that the problem of climate change is real. It helped raise awareness of all the countries of the issue and encouraged them to start taking measures to avoid it. The United Nations Framework Convention on Climate Change (UNFCCC) entered into force on the 21st of March 1994. Today, a large number of member states makes it almost universal. The 197 countries that have ratified the Convention are called "Parties to the Convention". The Convention is a framework document that has been developed over time in order to discover and establish the most effective strategies in the fight against climate change. Updates have been taking place periodically within the framework of COP22 (Conferences of the Parties). During COP meetings, Parties to the Convention ratify agreements on the reduction of greenhouse gas emissions while evaluating their commitments.

The first addition to the original treaty was the Kyoto Protocol, adopted in 1997 at COP3. This treaty involved the implementation of the Convention, in which industrialized countries have been committed to stabilizing greenhouse gas emissions (CHG). This treaty set binding emission reduction targets for 37 industrialized countries and the European Union, recognizing that they are primarily responsible for the high levels of GHG emissions currently present in the atmosphere, which are the result of burning fossil fuels for more than 150 years.

At the last conference about climate change held in Marrakech (November 7th-18th, 2016), COP22, Parties, including all the countries of the European Union, have reaffirmed their commitment to the fight against climate change by signing the Paris Agreement, which was reached at COP21. They committed to promoting investments in low-carbon, climate-resilient green economy, contributing to economic growth and creating employment. The last two conferences have highlighted the important role that agricultural soils can have as a carbon sink, resulting in the launch of the "4/1000 Initiative: Soils for Food Security and Climate", which is aimed at mitigating GHG levels through an annual increase of 4 per 1000 (0.04%) of the organic carbon in all the planet's soils. The subtraction of atmospheric carbon that can occur in agricultural soils through proper management is particularly important.

1.2. Global impact

The global climate is currently undergoing rapid changes, where economic and social development is not respecting limited natural resources. Global human population growth and the way to feed it without depleting natural resources will undoubtedly be a complex challenge to confront in the constantly changing climatic conditions. The World Commission on Environment and Development drafted the Brundtland report (*Brundtland Inform, 1987*), which states that the path taken by society is destroying the environment which is significantly affecting less developed countries. The concordance between social equality, environmental protection and economic development are fundamental pillars which should be taken into account in the fight against climate change. However, there is still a lot to be done. Progress in international cooperation, near-real-time data exchange, and progress in the science of climate attribution are allowing scientists to investigate the influence of climate change on human activities.

Regarding climate, a recent report has confirmed that the temperatures recorded in 2016 beat all modern records. 2016 has officially been declared the warmest year on record to date (since 1860). It should be noted that at the global level, the warmest years, since records have been kept, were in the period between 1998 and 2009. In the report published by the WMO (the specialized agency of the United Nations), global temperatures from January to September 2016 were 0.88°C above the average temperatures recorded in the period 1961-90 and about 1.2 °C above those of the pre-industrial period (1850-1999). The consequences can be observed in the increase of extreme weather and climate events (Fig. 1.2).

In many Arctic and Subarctic regions of Russia, Alaska and northwest of Canada, values of 3 °C above average were recorded. In the tropics and in 90% of the terrestrial areas of the northern hemisphere, recorded values where of 1 °C above average. However, global surface temperature anomalies were less extreme in the southern hemisphere, but many areas were still 1 °C or more above average in the case of the American continent, Eastern Australia and South Africa. The only area where below-average temperatures were recorded was in the subtropical zone of South America (Argentina, Paraguay and Bolivia).

Continental-scale temperature variability shows that 2016 was the warmest year in North America and Asia. However, Africa was also near to reach record levels in 2016. Asia had its warmest spring and summer while Oceania had its warmest summer and autumn. In the case of the American continent, South America recorded its warmest summer, while North America had its warmest winter. At a global level, it can be seen that the most intense long-term temperature increases occurred in Russia, Western Sahara, Brazil and Canada (Fig. 1.3).

With regard to the climatic data provided by the *WMO (2017)*, Russia recorded the hottest year to date, with temperature values of 2.16 °C above average. China

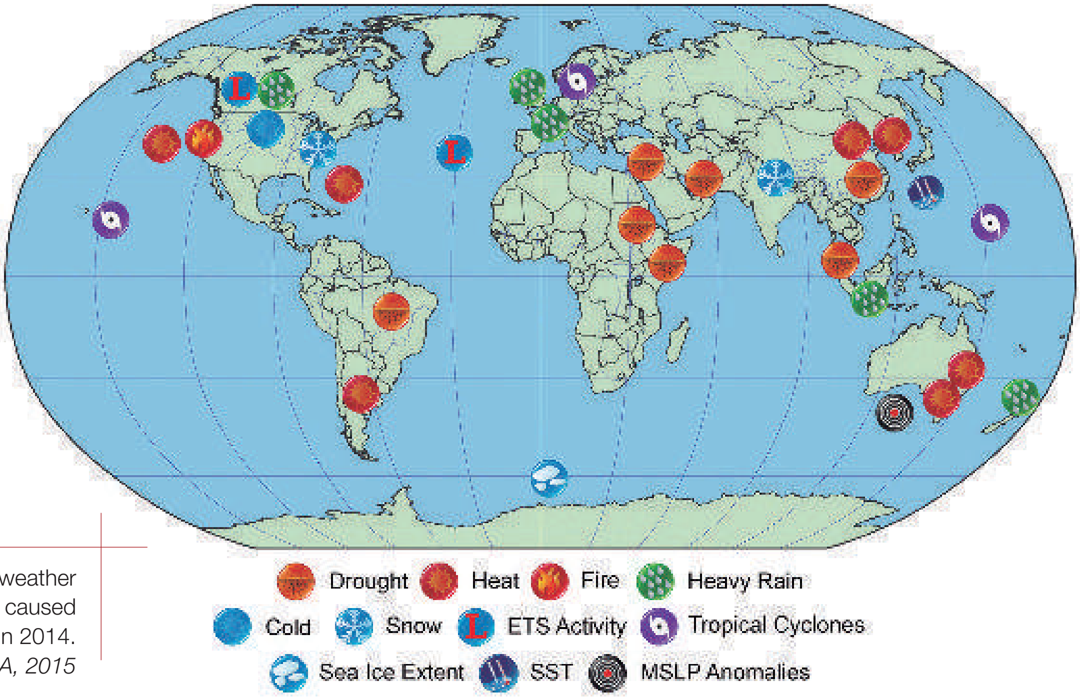


Fig. 1.2. Extreme weather and climate events caused by climate change in 2014. Source: *NOAA, 2015*

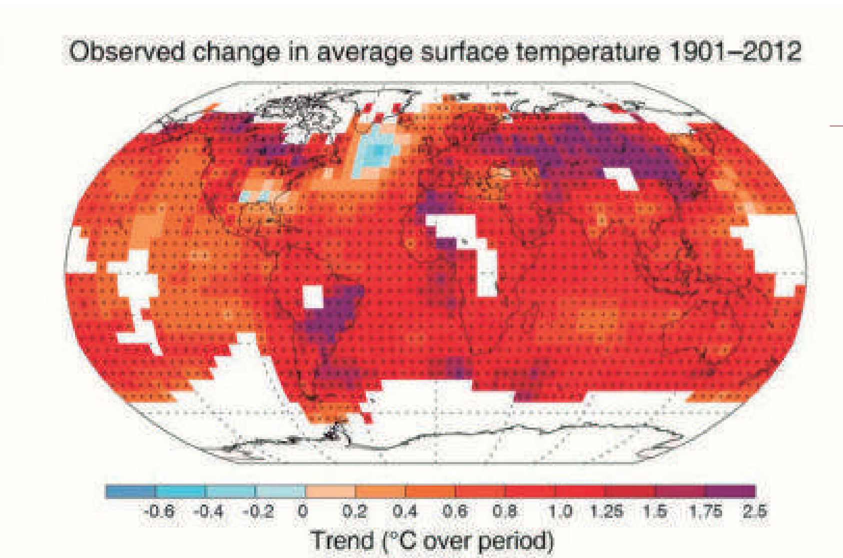


Fig. 1.3. Observed change in average surface temperature 1901-2012. Source: *IPCC, 2014.*

also recorded temperature values different from previous data in 10 provinces.

Africa and Oceania also recorded high temperature values. 2015 was the second warmest year to date. On the other hand, in a few land areas cold conditions were observed. Antarctica is one of the examples, where the positive phase of the Southern Annular Mode lasted several months with the west winds intensifying and contracting towards the Antarctic, which caused a cooling in the Antarctic East and at the same time a warming in the Antarctic Peninsula. In October there was a change towards less extreme values until the end of the year and a warming compared to the continent's average. Some areas of North-East North America reached colder temperatures than normal during the year.

The Intergovernmental Panel on Climate Change *(IPCC, 2014)* predicted that the temperatures at the end of the 21st century will be between 1.1 ºC at best, and 6.4 °C at worst, warmer than at pre-industrial levels in the late 1800s. These may appear to be small thermal increases, but it is worth mentioning that the increase in temperatures propitiating the last ice age on the planet was only 5 °C lower than current temperature. The polar ice cap during the ice age was covering the majority of Europe, Asia and North America.

As temperatures continue to rise, more and more water vapor will evaporate into the atmosphere. On the one hand, this increase in evaporation will affect the freshwater reserves, between 11% and 38% of ecosystems, while increasing the volume of drylands that can be categorised as being at risk of desertification. The disappearance of glaciers will have a negative impact on mountainous streams in areas such as the United Kingdom, Denmark and the United States. This phenomenon will be especially relevant in the southern parts of Europe, leading to longer periods of drought and increasing the frequency of heat waves. On the other hand, rising temperatures will cause an increase in precipitation.

It should be noted that global warming is influencing the temperature of the oceans, which requires more space and therefore increases the volume causing sea level to rise. On the other hand, the melting of glaciers and ice sheets is causing an increased water discharge into the oceans, which increases the risk of landslides and reduces the amount of fresh water.

Analysis of the data shows that sea level rise is currently occurring (Fig. 1.4). In the 20th century, the average sea level rose at a speed of 1.7 mm yr^{-1}. However, observations made by satellite have shown that this increase was around 3 mm yr^{-1} from 1993 onwards. Projected global average sea level rise at the end of the 21st century could be between 26 and 82 centimeters above the current levels, greater than in 2007, when there was an expected increase of between 18 and 59 centimeters. Glaciers and layers of Antarctic ice and Greenland will have particularly significant impacts on coastal areas in the form of flooding, erosion and saltwater intrusion into watersheds.

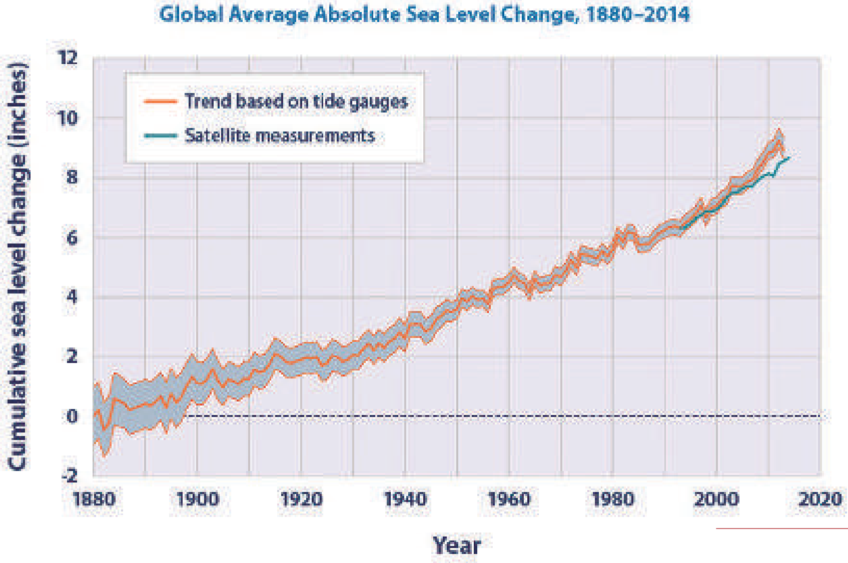


Fig. 1.4. Global Average Absolute Sea Level Change, 1880-2014. Source: *CSIRO, 2015* and *NOAA, 2015.*

Therefore, it is estimated that the Arctic ice melting will continue to rise, which means that, by the end of the summer in the next 15 or 20 years, the melting of the north pole ice sheet will be around 43% at best and 94% at worst. Contrary to the decrease that has occurred in the increase of the surface temperature, sea level rise is accelerating according to the models managed by the IPCC. In all analyzed scenarios it is very likely that the rate of sea level rise will be higher than in the last 40 years. From 1901 to 2010 sea level rose by around 19 centimeters, much faster than in the previous two millennia.

More recent studies predict that due to climate change, more intense and localized precipitation episodes are likely to increase in the coming years. At higher temperature, air masses are able to retain a greater amount of water vapor, which, under changing conditions of pressure or temperature, will precipitate intensely and cause torrential rains in localized areas. The pattern of future precipitation is less clear than that of temperatures. According to the latest research, in the 20th century precipitation increased in the middle latitudes of the northern Hemisphere, decreasing in subtropical and tropical regions. *The IPCC (2014)* predicts that the global concentration of water vapor and precipitation will increase during the 21st century. In the second half of the twenty-first century, winter precipitation is likely to increase in mid-high

latitudes and Antarctica. In low latitudes there will be both regional increases and decreases according to different areas (Fig. 1.5). In most areas, interannual variations are expected.

Therefore, the incidence of climate change will not only affect the total amount of precipitation, but its spatial-temporal distribution patterns will also be modified (Fig 1.6). All of this will lead to more intense and frequent extreme weather conditions, such as floods and storms. According to scientists, these changes cannot be explained if the human impact on climate change is ignored, because human activities may have already had significant effects on ecosystems, agriculture and human health in regions that are sensitive to precipitation changes.

Other less obvious effects of global warming are changes in the distribution of the planet's flora and fauna. However, some of the benefits that climate change could bring with thermal and CO_2 concentrations on ecosystem productivity are positively valued. But, on the other hand, one of the IPCC models determines that higher concentrations of CO_2 could instigate the flora in areas where the limiting factors are water and nutrients, even reversing the beneficial effect.

Regarding fauna, the thermal changes of the climate cause morphological modifications of many animals. This is the case of the polar bear or some species of amphibians that are adapting to the new environmental conditions in order to survive. Examples include the skull size reduction in polar bears, ultimately caused by

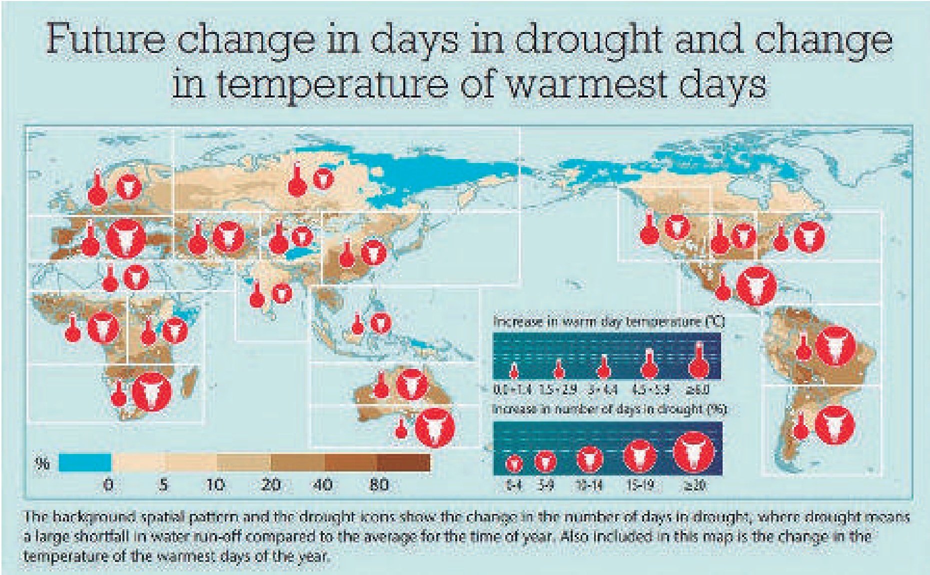
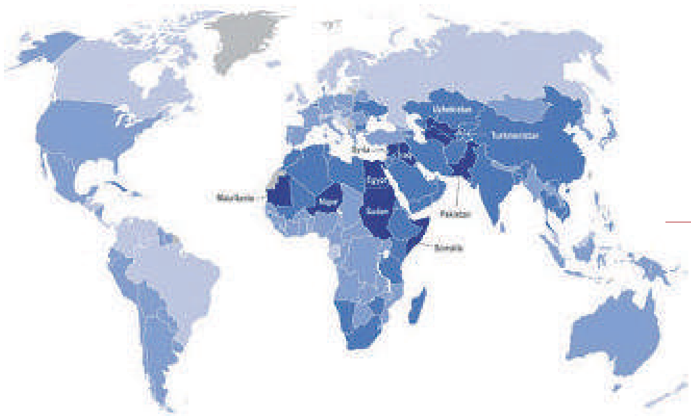


Fig. 1.5. Climate change brings higher temperatures and longer droughts. Source: *Met Office, 2014.*



Legend	
Extreme risk	
High risk	
Medium risk	
Low risk	
No Data	

Rank	Country	Rating
1	Somalia	Extreme
2	Mauritania	Extreme
3	Sudan	Extreme
4	Niger	Extreme
5	Iraq	Extreme

Rank	Country	Rating
6	Uzbekistan	Extreme
7	Pakistan	Extreme
8	Egypt	Extreme
9	Turkmenistan	Extreme
10	Syria	Extreme

Fig. 1.6. Water Security Risk Index. Source: *Maplecroft, 2010.*

ice melting, or the rate of parasitic infestation suffered by the lemur population in Madagascar, where parasitic proliferation poses a threat to the species, as well as to public health given that Lemurs are disease vectors for maladies that can affect human beings.

The global temperature rise will affect the variation in the distribution of flora and fauna which will imply expanding the range of diseases carried by the fauna. The search for favorable conditions will allow the proliferation of diseases such as malaria, dengue or yellow fever. It will also affect some species that colonize new regions, either by the escape from their habitat or because the new climatic conditions allow their expansion to new places. This is happening with the arrival of species from the tropical countries to France or Belgium, as is the case of the black widow *(Latrodectus mactans)*.

With regard to the world's main food source, agriculture is extremely vulnerable and plays a key role in mitigating climate change (Fig. 1.7). Among the most serious environmental threats related to agriculture are soil degradation, loss of biodiversity, water quality and availability, and mitigation and adaptation to climate change. In underdeveloped or developing countries, climate change will affect the yield of major crops, leading to additional price increases in crops such as

rice, wheat, maize and soybeans. This also affects the costs of animal feed, resulting in an increase in meat prices.

Long-term climate change effects could affect agriculture in various ways, and almost all of them are a risk to food security for the world's most vulnerable people:

- It would complicate the planning of agricultural activities.

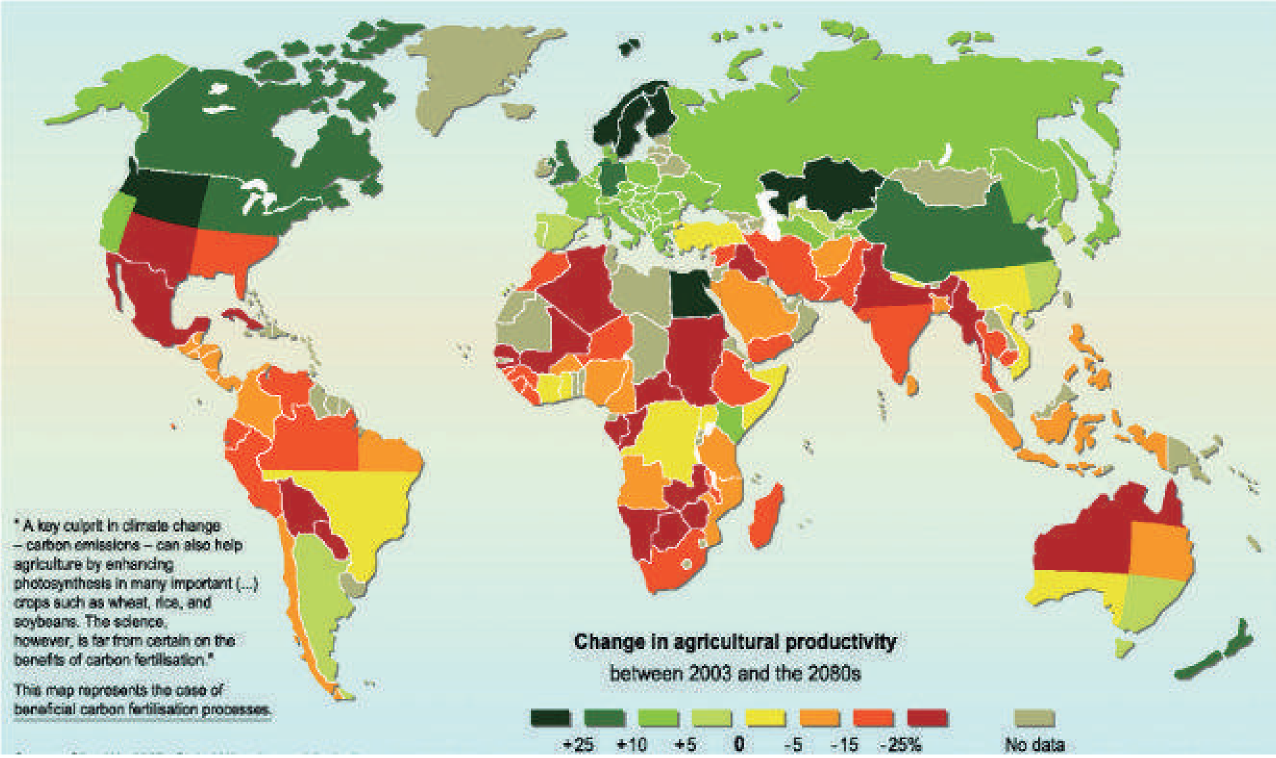


Fig. 1.7. Climate change Impact on agriculture. Source: *Cline, 2007.*

- Increased pressure on fragile farming systems
- Agricultural area loss due to sea level rise.
- Reduction of biological diversity in mangroves and tropical forests.
- Modification of climatic and agro-ecological zones.
- Productive imbalance of food in temperate, cold, tropical and subtropical regions.
- Increase of crops pests and diseases.

Agricultural production, and therefore food security, is influenced by variations in the periods of rainfall, thermal and other climatic conditions. Areas such as Asia and South America are prone to climate change. Extreme climatic events such as storms, floods, droughts, etc., continue to increase and have serious effects on agriculture. It is estimated that their frequency and magnitude will increase and are likely to affect considerably all regions of the planet. There is a serious risk of future conflicts over habitable lands and natural resources. Climate change is affecting the distribution of plants, invasive species, pests and diseases and may increase incidence and geographic location.

1.3. Impact at European level

Just as the climate is changing globally, it is changing in Europe, with different impacts on our health, ecosystems and economy. The effects are likely to be more severe in the coming decades. If the processes that generate them are not mitigated, they could have a very costly impact on human health, ecosystem conservation and the maintenance of goods and infrastructures. The latest climate change report published by the European Environment Agency (Climate Change, impacts and vulnerability in Europe 2016) contains the latest news on the impact of climate change on our continent. These impacts have been estimated through a wide range of observations and simulation models, identifying regions that are experiencing especially severe changes.

It is noted that the main conclusions on the impact of climate change in Europe, published by the European Environment Agency report in 2012, are still valid. Earth's and sea temperatures continue to rise, while precipitation patterns are changing, generally making moist regions more humid, particularly in winter, and making dry regions drier, especially in summer. On the other hand, sea ice extent, the volume of glaciers and snow cover extent are decreasing. Sea level is rising and extreme climatic conditions such as heat waves, heavy precipitation and droughts are increasing in many regions, setting new records for some climatic variables, such as average temperatures in Europe in 2014 and again in 2015, the global sea level in 2015 and the Arctic sea ice extent in winter in 2016. Moreover, the rise in sea level has increased flood risks and contributed to erosion along European coasts.

The observed changes in the climate system are already having wide-ranging impacts on ecosystems, economic sectors and human health and well-being in Europe. Recent studies show that various observed changes in the environment and society, such as changes in forest species, the establishment of invasive alien species and disease outbreaks, have been caused or enhanced by global climate change. Ecosystems and protected areas are particularly suffering from these impacts, threatening their biodiversity and affecting forestry, fishery and agriculture. In response to climate change, many land-based animal and plant species are changing their life cycles and are migrating northwards and / or to higher altitudes. On the other hand, regional extinctions have been observed and various invasive alien species have established themselves or have expanded their range. Regarding marine species, it has been noticed that commercially important fish stocks are migrating northwards.

The increase in heat waves has had significant impacts on human health, especially in the cities of Southern Europe. Heat waves are also increasing the risk of

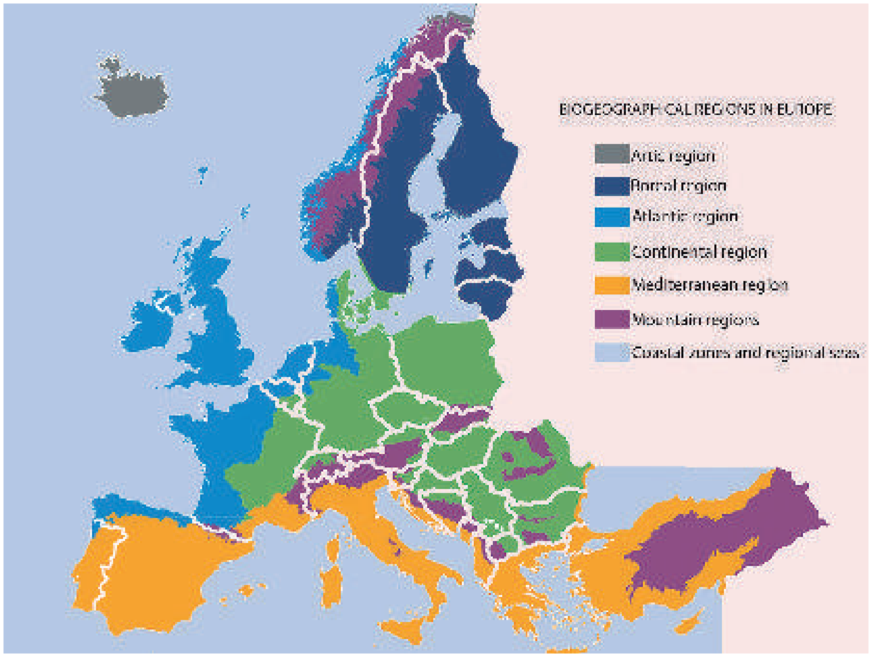


Fig. 1.8. Biogeographical regions in Europe. *Source: EEA, 2012*

electricity blackouts and forest fires in summer months, therefore affecting transport and tourism. Particularly important was the heat wave that affected southern France in the summer of 2003, which led to a significant increase in mortality of elderly people.

Urban areas, where four out of five Europeans live, are being tested in order to determine their exposure to heat waves, floods and sea level rise. Those areas are usually not well prepared for the afore mentioned phenomena.

In addition to the climate change impacts, it should be borne in mind that in the near future such effects will interact with other socio-economic developments, such as population growth and increased urbanisation across Europe.

Climate change is affecting all regions in Europe, but the impacts are not uniform. Southern and Central Europe are increasingly suffering from heat waves, forest fires and droughts. The Mediterranean area is becoming increasingly dry, making it even more vulnerable to drought and fires. On the other hand, Northern Europe is clearly becoming an increasingly humid area and floods in winter may be more frequent. The most significant impacts are projected to occur in the different European biogeographical regions (Fig. 1.8). As can be seen although the negative effects predominate, there are some positive variations observed in Northern Europe.

Arctic region

- Temperatures rise much larger than global average
- Decrease in Arctic sea ice coverage
- Decrease in Greenland ice sheet
- Decrease in permafrost areas
- Increasing risk of biodiversity loss
- Some new opportunities for the exploitation of natural resources and for sea transportation
- Risks to the livelihoods of indigenous peoples

Boreal region

- Increase in heavy precipitation events
- Decrease in snow, lake and river ice cover
- Increase in precipitation and river flows
- Increasing potential for forest growth and increasing risk of forest pests
- Increasing damage risk from winter storms
- Increase in crop yields
- Decrease in energy demand for heating
- Increase in hydropower potential
- Increase in summer tourism

Atlantic region

- Increase in heavy precipitation events
- Increase in river flow

- Increasing risk of river and coastal flooding
- Increasing damage risk from winter storms
- Decrease in energy demand for heating
- Increase in multiple climatic hazards

Continental region

- Increase in heat extremes
- Decrease in summer precipitation
- Increasing risk of river floods
- Increasing risk of forest fires
- Decrease in economic value of forests
- Increase in energy demand for cooling

Mediterranean region

- Large increase in heat extremes
- Decrease in precipitation and river flow
- Increasing risk of droughts
- Increasing risk of biodiversity loss
- Increasing risk of forest fires
- Increased competition between different water users
- Increasing water demand for agriculture
- Decrease in crop yields
- Increasing risks for livestock production
- Increase in mortality from heat waves
- Expansion of habitats for southern disease vectors
- Decreasing potential for energy production
- Increase in energy demand for cooling
- Decrease in summer tourism and potential increase in other seasons
- Increase in multiple climatic hazards
- Most economic sectors negatively affected
- High vulnerability to spillover effects of climate change from outside Europe

Mountain regions

- Temperature rises larger than European average
- Decrease in glacier extent and volume
- Upward shift of plant and animal species
- High risk of species extinctions
- Increasing risk of forest pests
- Increasing risk from rock falls and landslides
- Changes in hydropower potential
- Decrease in ski tourism

Coastal zones and regional seas

- Sea level rise
- Increase in sea surface temperatures
- Increase in ocean acidity
- Northward migration of marine species
- Risks and some opportunities for fisheries
- Changes in phytoplankton communities
- Increasing number of marine dead zones
- Increasing risk of water-borne diseases

The increase in heat waves has had significant impacts on human health

1.4. National scale climate change impacts

1.4.1. France

Climate change has different impacts in France, ranging from affecting ecosystems to the health of the population. The factors that have the greatest impact on the health of French people are heat waves, allergies and exotic diseases. The southeastern part of the country, located in the Mediterranean region, will be mostly affected by the increase in the frequency, amplitude and duration of heat waves. In addition to the direct effects of heat on people at risk (patients, babies, the elderly, etc.), heat waves provoke the development of allergic reactions, such as rhinitis, conjunctivitis and asthma attacks. The worrying fact is that concentration of pollen could quadruple by the year 2050. Another possible consequence is the expansion of exotic species, such as the tiger mosquito, carrier of tropical diseases like dengue, which is estimated to become widespread in France by 2050.

Agriculture is another important sector affected by climate change. Particularly serious may be the effects on the Bordeaux wine fields, where grapes are ripening 15-20 days earlier than normal. This is benefiting the harvest right now, but by 2050, it is expected that drought and high temperatures could damage leaves and grapes, consequently reducing wine quality.

Furthermore, electro-nuclear production will also be affected by climate change because nuclear power plants need water to feed their turbines and cool their reactors. Reducing river flows and increasing the temperature of water, by reducing rainfall and increasing evapotranspiration, may jeopardize the proper functioning of such plants. In fact, 28 °C is the established temperature limit of river waters used in electro-nuclear production processes, and the activity of the reactors should be stopped or reduced when the limit is exceeded.

The impact of climate change on biodiversity in France depends on species. Some will benefit from the increase in temperature by finding new territories, while others will gradually change their distribution migrating northwards, so they might disappear from the country, or even become extinct if the change is too extreme. The flora is the most affected by abrupt heating, especially the one that has its habitat in the high altitude bioclimatic areas, since they do not have the possibility to expand northwards. The consequences do not only affect environment, but also local economies. For example, in Aquitaine, where the extensive Landes forest is likely to be particularly affected by increased aridity and drought, there are 74,000 forestry-related jobs (40,000 silviculturists + 34,000 jobs related to direct work).

1.4.2. Germany

According to a study by the German Ministry for the Environment, Nature Conservation, Building and Nuclear Safety *(Zebisch et al., 2005)*, the most

widespread risks of climate change are related to flooding processes, predicting highly damaging effects. These events will cause serious problems in agriculture and infrastructures and are especially strong in the area of the Alps.

Regarding water availability problems, the southwestern regions of the country have the greatest vulnerability to climate change, because those are the areas with the most arid territory and the poorest soils. This part of Germany will be more affected by water scarcity due to the expected decrease in precipitation in summer, followed by greater evaporation which is the consequence of temperature increase. Agriculture and forestry will be particularly affected by the lack of water and the rise of diseases and pests, which will benefit from a more favorable climate for them. It is precisely in this zone of the south-west of Germany that maximum temperatures have been recorded year after year. Temperatures are expected to continue rising, causing problems, and having negative impact on human health. Also, new climatic conditions could increase the risk of forest fires.

In addition to the aforementioned agricultural and forestry sectors, the major river transport sector in Germany is expected to be highly affected by extreme climate events (extreme storms and precipitation) as well as extreme heat waves in summer. The effects would affect both the traffic flow and the infrastructures which would be affected by important fluctuations in the water levels of the rivers.

In the Alpine region, in addition to the risk of floods, endemic species of flora with a very restricted distribution might disappear, because they have a low capability of adaptation to rapid climate changes. Furthermore, animal species will have less possibilities of migration, due to the fragmentation of the territory. Moreover, winter tourism is expected to get affected by climate change, because of reduced snowfall in ski resorts.

Northwestern Germany has the lowest vulnerability to climate change, where conditions for agriculture may be even improved, as well as coastal areas, which, despite being threatened by rising sea levels, could benefit from the increase of sunny days and temperatures, which would improve summer tourism and increase the agricultural yield.

1.4.3. Italy

Italy is also expected to be affected by climate change, with heterogeneous consequences due to the intrinsic characteristics of the country. The most important consequences according to *Sgobbi and Carraro, (2008)*, will be located in the Alpine region, the Po basin, coastal areas and regions at risk of desertification.

In the Alpine region, an increase in temperatures is anticipated, with the consequent reduction in the amount of snowfall and even complete lack of it. This will seriously affect the winter tourism industry. On the other hand, as the attractiveness of the alpine ecosystems diminishes, summer tourism can be affected as well. Furthermore, composition of plant and animal species will be altered, which will tend to go higher in both altitude and latitude, thus leading to a loss of biodiversity. Moreover, climate change will increase the probability of forest fires.

On the other hand, the risk of floods and landslides in the Po river basin is expected to increase, due to increased torrential precipitation and the melting of the alpine mountains. These floods, in addition to the economic cost and human lives, can result in the spread of water-related diseases and pollution. Moreover, it can also increase an important risk of deterioration and / or disappearance of the large cultural patrimony of the region.

Coastal areas are important assets for Italy, with many economic activities linked to tourism, agriculture and industry. Sea level is expected to raise in such areas, as well as an increased incidence of extreme weather events. In addition to impacts on human activities, further coastal erosion and a decline in biodiversity are also expected.

About 5.5% of Italian territory (16,500 km^2) is currently at risk of desertification. This area is mainly located in five regions: Apulia, Basilicata, Calabria, Sicily and Sardinia. It is predicted that climate change will worsen the risk of desertification already observed in these areas, leading to greater soil degradation. Agriculture, livestock and tourism will be significantly affected. Urban areas will have problems with electricity and water supply, while in natural ecosystems the risk of fires will be even greater.

1.4.4. Netherlands

The expected climate changes in the Netherlands concern temperature, precipitation, evaporation, and weather extremes *(Schipper et al., 2014)*. How the climate changes largely depends on the temperature increase across the globe and on the changes in air flow patterns in Western Europe, accompanying changes in wind speed and direction. Table 1.1 provides an overview: on the left are the results for the target year 2050 and on the right, for the year 2100.

All climatic models' scenarios have the same results, where climate change keep emerging to some degree:

- The warming persists, so mild winters and warm summers occur more frequently. (Fig. 1.9)
- On average, the winters are wetter and extreme amounts of rainfall increase (Fig. 1.9)
- The intensity of extremely heavy rainfall in summer increases while the number of rainy summer days actually decreases.
- The calculated changes in wind climate are small if compared to the natural unpredictability.
- Forecasts for changes in precipitation patterns for coastal areas are different to forecasts for the interior.
- The sea level rise is a very important risk for particular conditions of Netherlands.

1.4.5. Poland

In Poland, the effects of climate change are expected to be reflected in the increase and intensity of extreme weather events: droughts, winds and hail. Most of the Polish regions will be affected by wind storms, increasing the risks of infrastructure and the integrity of people.

Regarding precipitation, in eastern Poland, the rainless period has been prolonged up to 5 days per decade. This area has been affected by several droughts in recent decades. At the same time, in most of the Polish regions, an increase in the number of days per decade with heavy precipitation events have been observed. The combination of these two phenomena is especially dangerous for agriculture, which could be affected by reduced availability of water and loss of crop due to flooding.

On the other hand, the southwest of Poland is expected to be the most affected by the effect of rising temperatures due to climate change. In fact, heat waves have been recently affecting this part of the country. Rising temperatures, in most of Poland, have led to a decrease in the number of cold and very cold days.

Generally speaking, forecasts show that climate change will produce an overall increase in temperatures across the country. This increase will be reflected in all climatic factors based on this variable. For example, there are less days with a minimum temperature below 0 °C, while there are more days with maximum temperature above 25 °C. Regarding precipitation, forecasts estimate longer periods without precipitation, more frequently maximum rainfall events, and shorter periods of snow cover.

1.4.6. Spain

As regards to Spain, given its geographical and socio-economic characteristics, it is especially vulnerable to climate change. In the last century, the average temperature has been increased by 1.5 ºC, which is twice the global thermal average. The models predict that Spain has a greater risk of heat waves, fires and floods. The temperature will increase by 3 and 4 ºC during winter and by 5 and 7 ºC in the summer. These conditions will be more pronounced in the peninsular

Table 1.1. Results of climatic models for the Netherlands. Source: *Shipper et al., 2014.*

		2050				2100			
		G	G+	W	W+	G	G+	W	W+
Global rise in temperature		+ 1ºC	+ 1ºC	+ 2ºC	+ 2ºC	+ 2ºC	+ 2ºC	+ 4ºC	+ 4ºC
Changes in air flow patterns Western Europe		no	yes	no	yes	no	yes	no	yes
Winter	Average temperature	+ 0.9ºC	+ 1.1ºC	+ 1.8ºC	+ 2.3ºC	+ 1.8ºC	+ 2.3ºC	+ 3.6ºC	+ 4.6ºC
	Coldest winter day of the year	+ 1.0ºC	+ 1.5ºC	+ 2.1ºC	+ 2.9ºC	+ 2.1ºC	+ 2.9ºC	+ 4.2ºC	+ 5.8ºC
	Average precipitation	+4%	+7%	+7%	+14%	+7%	+14%	+14%	+28%
	Number of wet days (≥0.1 mm)	0%	+1%	0%	+2%	0%	+2%	0%	+4%
	Highest day-average wind speed per annum	0%	+2%	-1%	+4%	-1%	+4%	-2%	+8%
Summer	Average temperature	+ 0.9ºC	+ 1.4ºC	+ 1.7ºC	+ 2.8ºC	+ 1.7ºC	+ 2.8ºC	+ 3.4ºC	+ 5.6ºC
	Warmest summer day of the year	+ 1.0ºC	+ 1.9ºC	+ 2.1ºC	+ 3.8ºC	+ 2.1ºC	+ 3.8ºC	+ 4.2ºC	+ 7.6ºC
	Average precipitation	+3%	-10%	+6%	-19%	+6%	-19%	+12%	-38%
	Number of wet days (≥0.1 mm)	-2%	-10%	-3%	-19%	-3%	-19%	-6%	-38%
	Potential evaporation	+13%	+8%	+7%	+15%	+7%	+15%	+14%	+30%
Sea level	Absolute increase (cm)	15-25	15-25	20-35	20-35	35-60	35-60	40-85	40-85

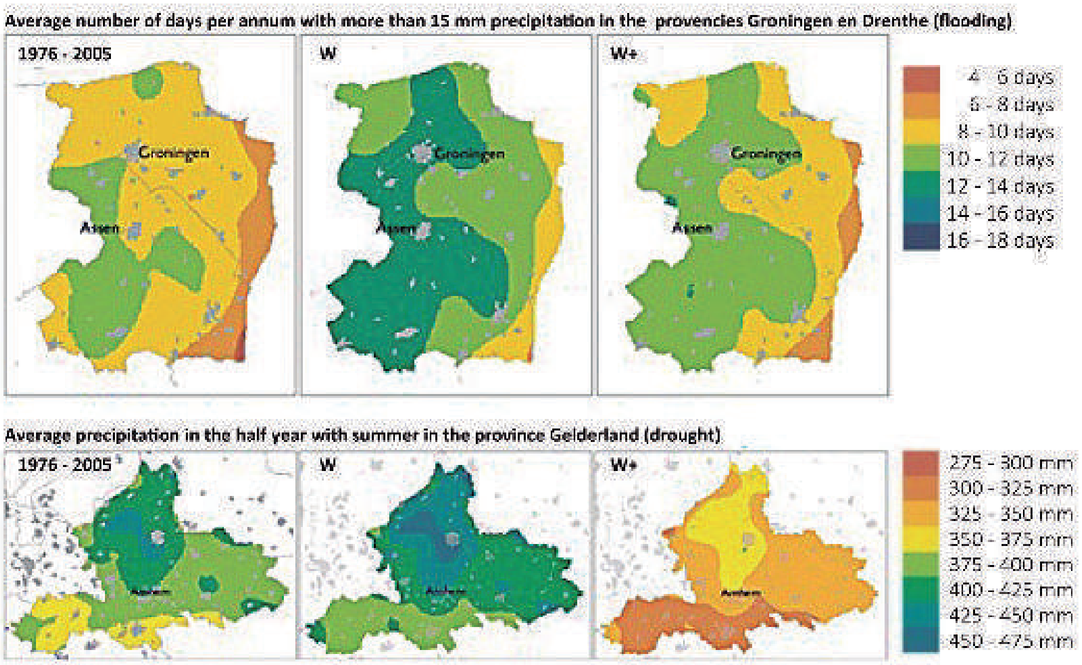


Fig. 1.9. Predictions of flooding and drought days in different regions of Netherlands. Source: *Schipper et al., 2014.*

interior than in the coastal areas. The frequency of maximum temperatures will increase which will affect water resources by decreasing its amount and time periodicity.

The year 2015 was one of the warmest years on record in Spain and the year 2016 has been even warmer than the previous one. Between May and September 2016, the peninsula was affected by a heat wave during the month of May that set a new monthly record. The temperatures reached 42.6 ºC at Lanzarote airport and Valencia surpassing by 6 ºC the previous maximum temperatures recorded in May. Spain's longest heat wave recorded lasted from June to July (from 27 to 22, respectively). November and December were exceptionally warm months in Spain. Unprecedented high temperatures were recorded in December.

Regarding sea level, in areas such as the Cantabrian and Atlantic coasts, sea level rise has an annual rate of 1 to 1.5 mm and 0.7 mm in the Mediterranean part. The increase of the oceans, which has rates between 10 and 68 cm, will cause the disappearance of the deltas of the rivers. In addition, during the last century the Pyrenean glaciers have experienced a retreat of 75%.

The models project for Spain a progressive reduction of precipitations that will be more pronounced in the second part of 21st century. Reductions of more than 20% of surface and groundwater resources could be reached, especially in the south, 5% in the north half, and near 10% in the southwest between 2011-2040, until reaching, in the last third of the century (2070-2100), reductions in average annual precipitation from 15% to 25% in the regions of the northern half and 20% to 30% in the southern third of the peninsula. On the other hand, irregularities in floodwaters in the interior and Mediterranean basins will increase. Erosive processes will also increase, aggravating the desertification conditions where they already exist.

In 2015, January was a rainy month in great part of northern Spain. Between 20 and 24 March, 300 mm of rain fell in some areas of the province of Castellón. In northern Spain, snowfall has been reduced by 50% since 1975. Active glaciers in the Pyrenees have lost almost 90% of their area since the beginning of the 20^{th} century. Only eighteen of the thirty-four glaciers described in 1982 persist.

Regarding agriculture, global warming has already altered the duration of the growing season of crops in much of the peninsula. In other words, it advances the time of flowering and harvest of the cereals by a few days. These changes are likely to continue in many regions.

Climate change will reduce agricultural production although the effects will not be the same in all areas. Due to the global concentrations of CO_2 in the atmosphere, temperatures will increase, and this will positively affect cultivated plants, stimulating photosynthesis. However, in the south of the peninsula these temperature scenarios will increase the rate of evapotranspiration which will negatively affect the photosynthetic rates, increasing the irrigation needs in some cases. Simultaneously, the temperature rise will lead to an increase in phytopathologies due to harmful insects.

The extent of pests and diseases of crops is variable according to Spanish geography. Changing temperatures can lead to displacement towards higher latitudes of some diseases. All these factors will cause fluctuations in crop yields and local food supply.

1.4.7. United Kingdom

A representative selection of threats and opportunities for the United Kingdom are summarised in Figure 1.10 (*DEFRA, 2012*). This lists potential risks according to whether they are regarded as a threat or opportunity; classifies each risk according to a broad 'order of magnitude' score from either an economic, social or environmental perspective; and also indicates whether confidence in the direction and magnitude is "low", "medium" or, "high".

A clear example of the changes taking place in the climate of the United Kingdom was heavy precipitation in the winter of 2013/2014 (Fig. 1.11). Many UK areas were struck by floods as a consequence of extreme storms. In southern England extreme precipitation caused widespread flooding, electricity blackouts and major disruptions to transport systems. Economically, the most affected areas were Somerset, Devon, Dorset and Cornwall in the southwest and the Thames Valley in the southeast of England.

Fig. 1.10. A selection of potential risks (threats and opportunities) for the UK based on the Medium emissions scenario. Source: *DEFRA, 2012.*

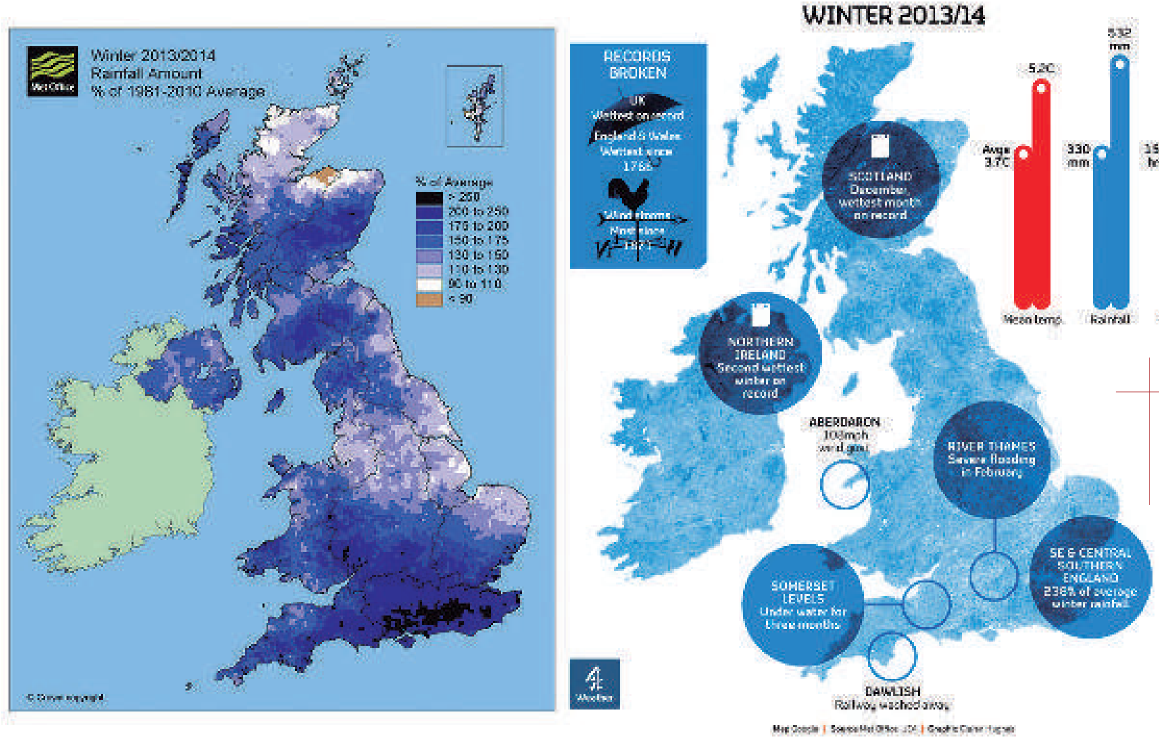


Fig. 1.11. Precipitation in the UK during the winter of 2013/2014 and its most important effects. Source: *Met Office, 2014* and *www.channel4.com, 2014.*

1.5. References

Brundtland Inform. (1987). World Commission on Environment and Development. Our common future (Ed: Oxford University Press).

Channel4. (2014) https://www.channel4.com

Cline, W. (2007). Global warming and agriculture: Impact estimates by country. *Columbia University Press.*

CSIRO. (2015). Annual-report 2013-2014.

DEFRA. (2012). The UK Climate Change Risk Assessment 2012 Evidence Report.

European Environment Agency (EEA) (2012). Climate Change, impacts and vulnerability in Europe 2012 Inform.

European Environment Agency (EEA) (2016). Climate Change, impacts and vulnerability in Europe 2016 Inform.

International Panel on Climate Change (IPCC) (2001). Cambridge University Press; Cambridge, UK. Climate change: the scientific basis. Contribution of working group I to the third assessment report of the intergovernmental panel on climate change.

International Panel on Climate Change (IPCC) (2013). Climate change. Physical bases. Summary for policy makers. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

International Panel on Climate Change (IPCC) (2014). Climate change. Impact, adaptation and vulnerability. Summary for policy makers. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Maplecroft. (2010). Water Security Risk Index. https://maplecroft.com/about/news/ccvi.html.

Met Office. (2009). http://i.telegraph.co.uk/multimedia/archive/01508/Climate-ChangeNEW_1508747a.jpg

Met Office. (2014). http://www.metoffice.gov.uk/climate-guide/climate-change/impacts/human-dynamics.

NOAA. (2015). http://www.noaanews.noaa.gov/stories2015/110515-new-report-human-caused-climate-change-increased-the-severity-of-many-extreme-events-in-2014.html

Schipper P., Reidsma, P., Van Hattum T. (2014). Effects of climate change on agriculture. *Deltafact.*

Sgobbi, A. and Carraro, C. (2008). Climate change impacts and adaptation strategies in Italy: an economic assessment. Fondazione Eni Enrico Mattei.

WMO. (2017). World Meteorological Organization. https://public.wmo.int/en/media/press-release/climate-breaks-multiple-records-2016-global-impacts.

Zebisch, M., Grothmann, T., Schröter, D., Hasse, C., Fritsch, U., Cramer, W. (2005). Climate change in Germany. Vulnerability and adaptation of climate sensitive sectors/Klimawandel in Deutschland–Vulnerabilität und Anpassungsstrategien klimasensitiver Systeme. Federal Environmental Agency Germany/Umweltbundesamt, Dessau, Report, 201, 41-253.

CHAPTER 2
Agriculture and Climate Change

2.1. Relationship between climate change and agriculture

The agricultural sector contributes to climate change and is affected by it. However, agriculture can act as a mitigating activity because CO_2 emissions can be reduced due to the use of less productive factors, and because, if properly managed, soil can fix carbon.

In 2012, approximately 10% of global greenhouse gas (GHG) emissions came from the European Union (EU). Of these GHGs emitted by the EU, about 10% came from agriculture, which is the fourth largest emitter activity in the EU, behind the energy, transport and industrial combustion sectors *(European Environment Agency, 2011).*

For the end of the 21st century, the vast majority of climate models point to global warming (from 2 °C to 5 °C) and to an increase in global precipitation ranging from 5% to 25% (*IPCC, 2007*). Furthermore, there are projected changes in the distribution, intensity and frequency of extreme phenomena such as heat waves and droughts. However, large regional differences should be taken into account. In Europe, the *CLIMATECOST* project modeled the changes in crop productivity of different European agro-climatic regions. For this purpose, a set of projected scenarios for different representative emission paths and different climate models for the 2080s have been considered.

2.2. Climate change effects on agriculture

If there is any productive activity that depends directly on the climate and its variability, it is undoubtedly agriculture. Changes in temperature and precipitation patterns and increases in the concentration of atmospheric CO_2, will significantly affect crop development. Global climate variabilities are estimated to be responsible for 32% to 39% of yield variability (*Ray et al., 2015*), an effect that is more pronounced in areas such as The Iberian Peninsula.

While some aspects of climate change, such as increased growth seasons and rising temperatures may be beneficial, lack of water availability as well as extreme weather conditions will more often have negative impacts and adverse effects on agriculture. However, climate change may pose opportunities or risks for the agricultural sector depending on the considered area, based on the climatic characteristics of the region, crops and potential changes that may occur. The effect of climate change on a region's crops can be positive or negative depending on climate characteristics, current crops and potential changes.

As an example, the production of cereals at an African continental scale in 2080 (Fig. 2.1) is projected to be higher in the equatorial areas and lower in the tropical areas. At first glance, the effects seem to be balanced, but in fact, tropical areas are very vulnerable because they are already arid (perimeters of the Sahara and Kalahari deserts). Reducing harvests in these areas could pose a significant risk to the food supply.

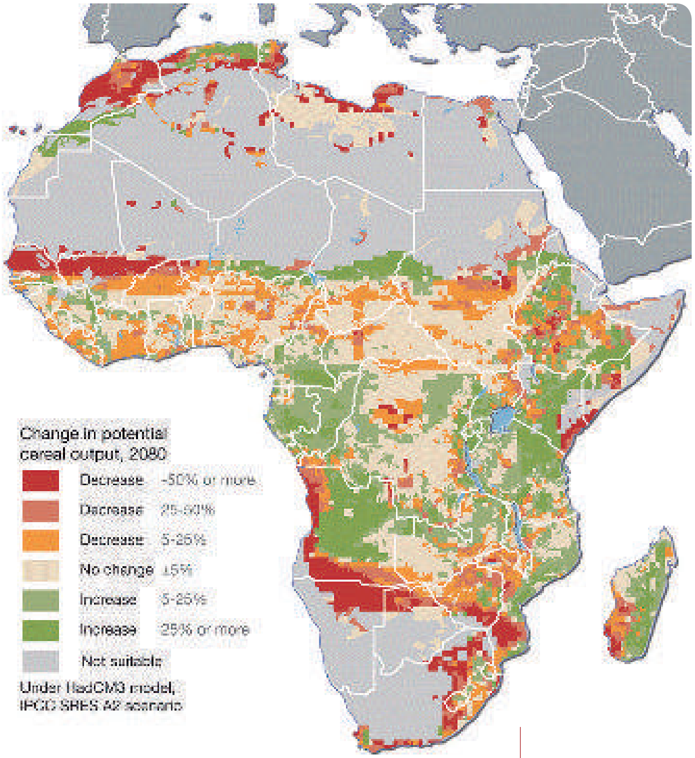


Fig. 2.1. Model of climate change effects on cereal crops in Africa. *Source: Geothinking, 2012.*

Another model, designed to predict global food supply security (Fig. 2.2), shows, in general, an increase in food supply insecurity, especially in tropical areas where current food supply problems will be accentuated.

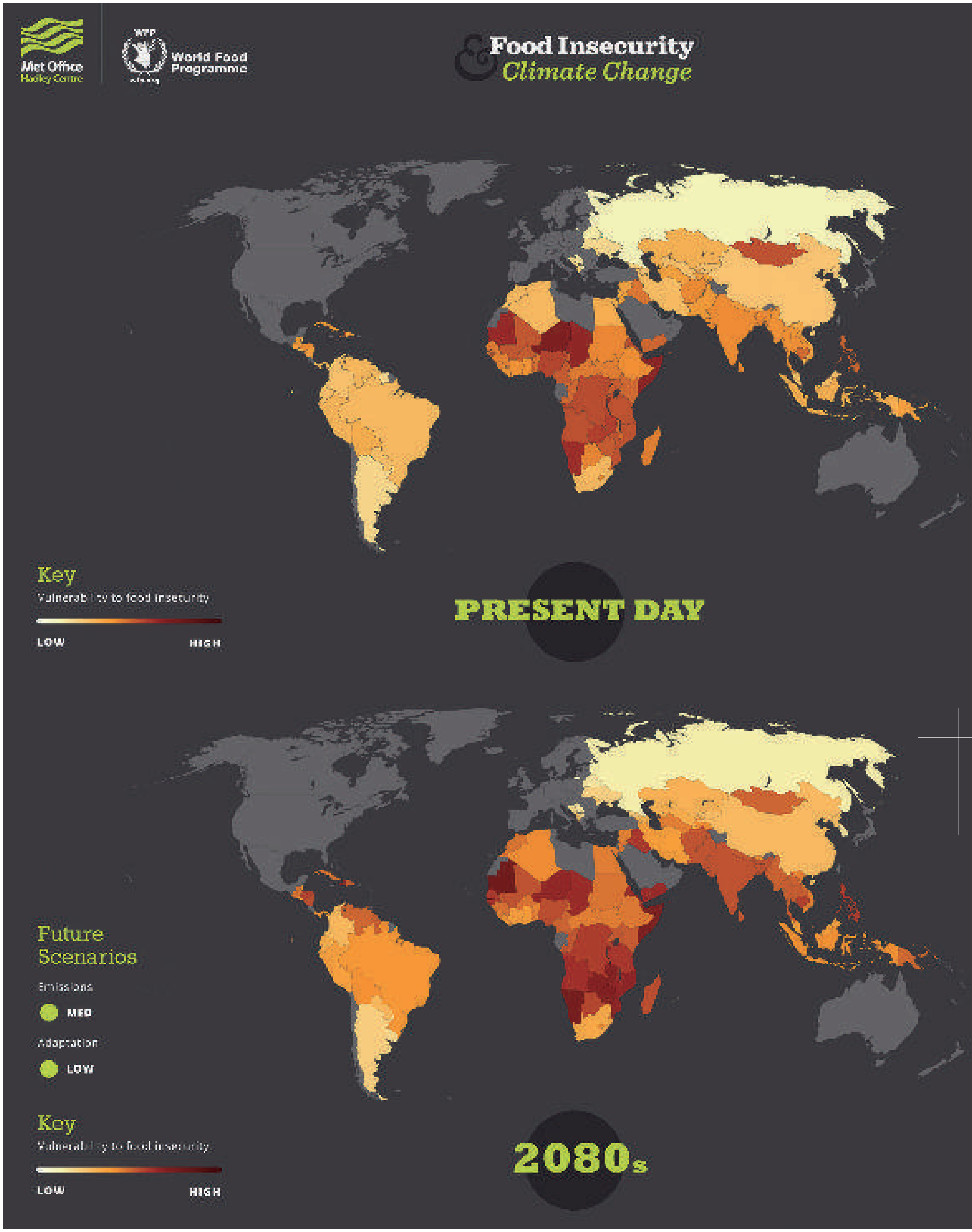


Fig. 2.2. Comparison between current food insecurity and that expected in the 2080's (considering medium emissions and low adaptation). Source: *Global Food Insecurity Index (Met Office and World Food Program)*.

Regarding Europe, the northern regions will experience warmer, drier summers and wetter winters, in addition to sea level rise. This will result in longer growing seasons, but also an increased risk of flooding. Meanwhile, the Mediterranean regions will be affected mostly by high temperatures and by the decrease in precipitation, with more torrential rainfall events. All this will lead to a decrease in the soil surface suitable for cultivation, not only because of adverse climatic conditions, but also because of the increase in erosion, soil loss and water quality due to extreme rainfall events.

At first sight, it could be considered that the increase in CO_2 concentration in the atmosphere could favor agricultural productivity, increasing its biomass and water-use efficiency; nevertheless recent studies point out that the direct CO_2 phenomena occur in crop conditions where the plants are influenced by other limiting factors that lead to lower final productions. The temperature increase of 1 to 3 ºC, results in a lower water availability for the plant, an increase in the incidence of crop pests and diseases, and worsening soil and water quality. The Table 2.1 summarizes the possible positive and negative effects that climate change could have on the productive capacity of crops.

Obviously, the potential positive and negative effects described in Table 2.1 will not occur in all regions but will largely depend on the variations produced by climate change with regard to the baseline conditions of each region.

A quick analysis of the situation might show that, in general, there would be changes in the zoning and productivity of crops, resulting in a shift of the optimal areas of development to more northern areas, establishing a new map of crops, in which the colder countries will take over the agricultural role that hot and temperate countries had until now.

Table 2.2 shows the degree of certainty for each of the risks and opportunities posed by climate change in Europe according to the considered agro-climatic zone.

Table 2.1. Possible positive and negative effects of climate change. Source: *Iglesias et al., 2007.*

Change factor	Potential positive effects	Potential negative effects
Temperature rise	• Longer growth periods. • Faster growth times. • New crops in cold areas.	• Increased thermal stress due to ambient temperatures. • Increase in weeds, pests and diseases. • Problems with flowering and curdling due to vernalization damage.
Precipitation variations	• Increased productivity. • Decreased demand for water. • Increased guarantees of water supply.	• Increased flooding and salinization. • Increased frequency of droughts. • Increase in weeds, pests and diseases. • Increased erosion.
Increased GHG concentrations	• Increase in fertilization due to the higher concentration of atmospheric CO_2.	• Negative effects of other gases.

Just 4 hectares under CA would negate the average annual emissions of a European citizen.

2.3. The impact of agriculture on climate change

Agriculture, traditionally, has carried tillage operations. Until a few decades ago, tillage, due to the scarce means available to farmers, did not pose a serious problem on soil sustainability. However, development and adaptation of powerful machinery to the agricultural sector have led to more intense tillage actions, both in depth within the edaphic profile and in the extension of tilled surface. Bearing in mind that this development has made it possible to provide the world's population with food as it had not been previously achieved, the processes of intensification of agricultural activity have increased soil vulnerability to erosion, what has led to annual substantial soil losses, on a global scale, therefore, drawing a worrisome

Table 2.2. Degree of certainty for risks and opportunities posed by climate change in Europe. Source: *Iglesias et al, 2007.*

Consequences of Climate Change	Type of weather				
Description	Boreal	Atlantic	Continental	Alpine	Mediterranean
RISK					
Changes in crop area, due to a decrease in optimal conditions for its development		Medium	Medium	Medium	High
Decreased crop productivity		Medium	Medium	Medium	Medium
Increased risk of agricultural pests, diseases, weeds	High	High	High	Medium	High
Decreased crop quality		Medium	Medium		High
Increased risk of flooding	High	High	High	High	
Increased risk of drought and water shortage		High	High	High	High
Increased irrigation needs		Medium	High		High
Deterioration of water quality	High	High		High	
Soil erosion, salinization, desertification	High	Medium	High	High	High
Loss of glaciers and permafrost (soils with ice, which act as a water reservoir)	Medium			High	
Deterioration of the conditions for livestock production	High	Low	Low	High	Medium
Sea level rise	High	High	High		High
OPPORTUNITIES					
Changes of crops distribution to increase agriculture in optimal conditions	High	Medium	High	High	Medium
Increased crop productivity	Medium	Medium		High	
Water availability	High	High		Medium	
Decreased energy costs for greenhouses	Medium	Medium	Medium		Medium
Improvement of livestock productivity	High	High	High	High	

horizon to ensure the food supply for world population in continuous growth.

In addition to facilitating erosion, tillage decreases the organic carbon stored in the soil. This is because organic carbon is released when ploughing and, through oxidation, it becomes CO_2 and is no longer available for crops. Soil can act as an atmospheric carbon sink (Fig. 2.3) if tillage is removed and is permanently covered, what allows the accumulation in the edaphic profile of the atmospheric carbon that crops have got from the atmosphere though photosintesis. On the opposite, when soil is tilled, the process is reversed, there are losses of soil carbon and levels of CO_2 in the atmosphere are increased. This favours climate change which, as explained in the previous section, has an impact on the crops.

One of the consequences of management systems based on tillage is the reduction of the soil sink effect, whose direct consequence is the reduction of the organic carbon content, the main component of organic matter. This organic matter is fundamental in all the processes that occur in the soil and affects its quality, because it improves soil structure, fertility and water holding capacity, and it is, therefore, widely accepted as an indicator of soil quality. Several authors agree that soil alteration through tillage is one of the main causes of soil organic carbon decline *(Six et al., 2004). Reicosky (2011)* argues that intensive agriculture has contributed to the loss of 30% to 50% of soil organic carbon in the last two decades of the 20th century.

Another consequence of intesive tillage is the production of higher emissions of CO_2 into the atmosphere,

both in short-term (inmediately after tillage) and long-term (during the crop season). This is because tillage stimulates the production and accumulation of CO_2 in the porous structure of the soil through processes of mineralization of organic matter. The mechanical action of tillage breaks soil aggregates, with the consequent release of CO_2 stored in the soil and its subsequent emission into the atmosphere *(Pisante et al., 2015).*

Finally, as shown in Figure 2.3, in addition to the CO_2 emissions from soil aggregates breakdown, tillage also implies a higher consumption of fossil fuels, since it includes greater number of tillage passes and a higher mechanical resistance of the soil. Consequently, more emissions are released into the atmosphere, with the potential effect on global climate change.

2.4. International initiatives

In recent years, the attention of decision-makers in the fight against climate change and its consequences has increased the interest in this issue, although there have been some conflicts and reluctance from some people, until scientific evidences have persuaded them.

Scientists were the first to raise the alarm about the threats of climate change. Since the beginning of the nineteenth century natural changes began to be discovered in the paleoclimate and the natural greenhouse effect was identified. From the mid-twentieth century onwards, the increase in CO_2 concentrations in the atmosphere was observed, an increase that has continued up until the present day.

The actions taken at the global level in the fight against climate change by countries members of the IPCC are shown in chronological order in Table 2.3.

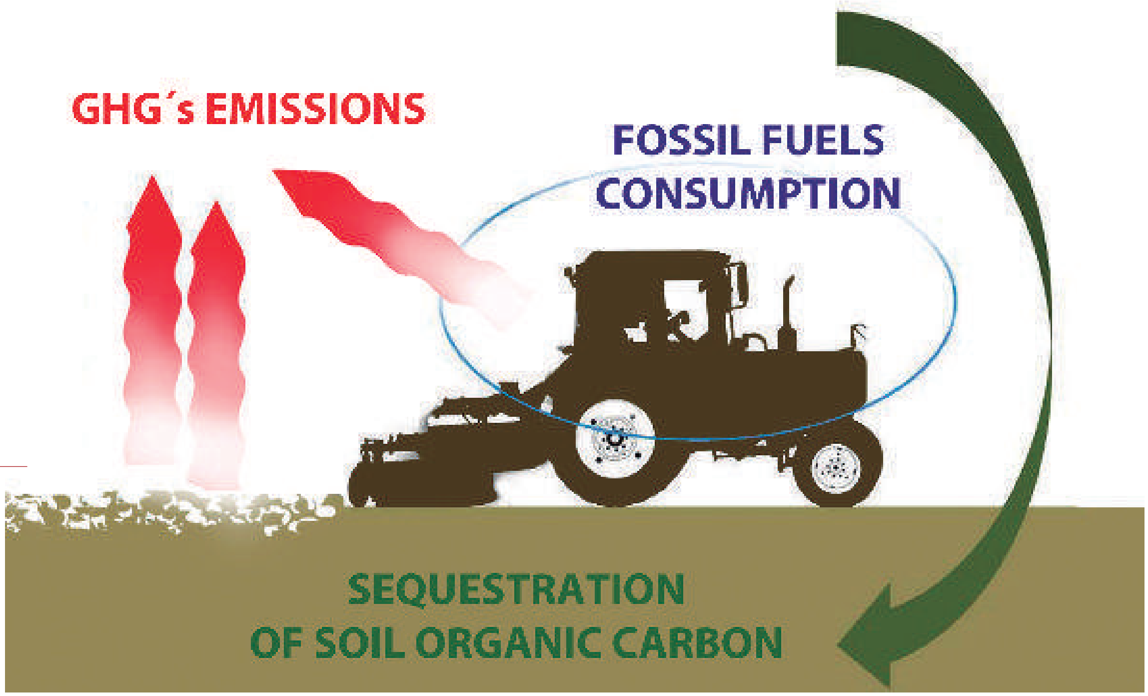


Fig. 2.3. Main greenhouse gasses fluxes and related processes in agriculture, Source: Own elaboration.

The 21st session of the Conference of the Parties (COP21) and the eleventh session of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol (CMP) were held in Paris at the end of 2015. COP21 concluded with the adoption of a landmark agreement to fight climate change and take measures and investments for a low-carbon, resilient and sustainable future.

The main objective of the agreement was to keep the temperature rise in this century below 2 °C above pre-industrial levels and to encourage joint efforts to limit temperature rise even below 1.5 °C, greatly reducing the risks and impacts of climate change. In addition, the agreement sought to strengthen the capacity of society to address the consequences of climate change, while providing developing countries with better and more permanent international aid for the adaptation.

The restoration of degraded agricultural land and the increase in soil carbon emissions play an important role in addressing the threefold challenge of food security, the adaptation to climate change of food systems and people, and the mitigation of human emissions. In this context, the "4/1000 Initiative: Soils for Food Security and Climate", launched by the Government of France at COP21, makes sense.

The 4/1000 Initiative aims to ensure that agriculture plays an important role in the climate change mitigation and adaptation. With the annual growth of 4/1000 (0.4%) of soil organic carbon (SOC), it is sought to show that even a small increase in carbon storage in soils is crucial to improve soil fertility and agricultural production and to contribute to achieving the long-term goal of limiting the global average temperature increase to a maximum of 1.5 or 2 °C. By joining the "4/1000 Initiative", stakeholders are committed to making a transition to resilient agriculture through sustainable soil management, that generates jobs and gains, and ensures sustainable development.

At COP22 (Marrakesh, 2016) progress has been made in drafting the implementation rules, or manual, of the Paris Agreement. The agreement requires a significant improvement in the transparency of actions, including, among others, the measurement and accounting of emission reductions or the provision of funding to address climate change, and technology development and transfer.

It also includes designing communications on adaptation, which is the main vehicle for sharing individual adaptation efforts and meeting needs within the framework of the Paris Agreement.

Table 2.3. Chronology of global actions on climate change. Source: *website of the United Nations Framework Convention on Climate Change (UNFCCC). http://unfccc.int/.*

Climate process in retrospect	
1979	The first World Climate Conference is held.
1988	The Intergovernmental Panel on Climate Change (IPCC) is established.
1990	The first IPCC evaluation report is published. The IPCC and the second World Climate Conference call for a global treaty on climate change. Negotiations of the General Assembly of the United Nations begin on a framework convention.
1991	The first meeting of the Intergovernmental Negotiating Committee (ICN) is held.
1992	The ICN adopts the text of the Climate Convention. At the Rio de Janeiro Earth Summit, the UN Framework Convention on Climate Change (UNFCCC) is now ready for signature in conjunction with the Convention on Biological Diversity (UNCBD) and the Convention to Combat Desertification (UNCCD).
1994	The United Nations Framework Convention on Climate Change enters into force.
1995	The first Conference of the Parties (COP1) is held in Berlin.
1996	The secretariat of the Convention is established to support the actions of the Convention.
1997	The Kyoto Protocol is officially adopted at COP3 in December.
2001	The third IPCC evaluation report is published. The Bonn Agreements are adopted following the 1998 Buenos Aires Plan of Action. The Marrakech Accords are adopted at COP7, which details the rules for implementing the Kyoto Protocol. The Buenos Aires Program of Work on adaptation and response measures at COP10 is agreed.
2004	The Work Program of Buenos Aires on adaptation and response measures at COP10 is agreed.
2005	Kyoto Protocol enters into force. The first meeting of the Parties on the Kyoto Protocol (CMP1) is held in Montreal. In accordance with the requirements of the Kyoto Protocol, the Parties start negotiations on the next phase of the Kyoto Protocol under the Special Working Group on Further Commitments of Annex I Parties under the Kyoto Protocol (GTE- PK).
2006	The Nairobi work program is adopted.
2007	The fourth assessment report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) is published. The public is sensitized about the science of climate change. At COP13, the Parties agree on the Bali Road Map, which marks the path towards an improved situation after 2012 through two working streams: the Ad Hoc Working Group on New Commitments under the Kyoto Protocol (GTE-PK) and another working group established under the Convention, the Ad Hoc Working Group on Long-term Cooperation (AWG-LCA).
2009	The drafting of the Copenhagen Accord at the COP15 in Copenhagen begins. The Conference of the Parties “takes note” of it and subsequently countries submit non-binding emission reduction pledges or promises of mitigation measures.
2010	The Cancun Agreements are drafted and widely accepted by the COP at COP16. In these agreements the countries formalize the promises they had made in Copenhagen.
2011	Seventeenth Conference of the Parties (COP17) in Durban, South Africa.
2012	Eighteenth Conference of the Parties (COP18) in Doha, Qatar. The Doha amendment on the Kyoto Protocol is adopted by the WPC at WPC 8. A number of decisions are made to open a door to greater ambition and action at all levels.
2013	The key decisions taken at COP19 / CMP 9 in Warsaw include decisions on the progress of the Durban Platform, the Green Fund for Climate and Long-term Finance, the Warsaw Framework for REDD Plus and the International Mechanism for Loss and Damage. Under the Durban Platform, Parties agree to submit “planned national contributions”, known as INDC.
2014	At COP20 hold in Lima in 2014, Parties adopt the “Call to Action in Lima”, which develops key elements of the next agreement in Paris.
2015	In December 2015, intensive negotiations are held within the framework of the Ad Hoc Group on the Durban Platform for Action for the period 2012-2015, culminating in the adoption of the Paris Agreement (COP21).
2016	As a continuation of the Paris Agreement the COP22 is celebrated in Marrakech.

Scientists were the first to raise the alarm about the threats of climate change

2.5. Agriculture and the Paris Agreement in numbers

The Paris Agreement *(UN, 2015)* aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:

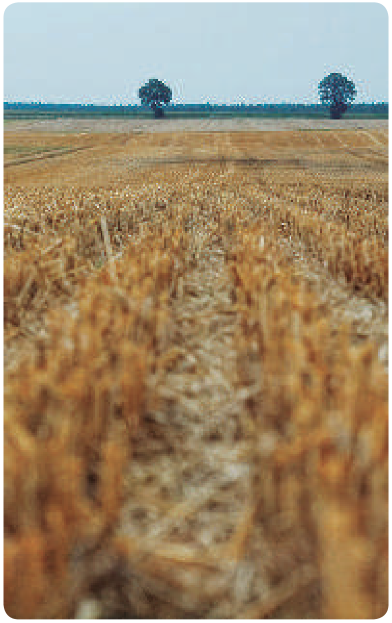
1. Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;
2. Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production; and
3. Making finance flows consistent with a pathway towards climate-resilient development and low greenhouse gas emissions.

The EU has committed itself to a binding target of reducing greenhouse gas emissions by 40 % from 1990 levels by 2030. With this commitment, the EU intends to:

- Take measures to achieve its long-term goal of reducing emissions by 80-95% by 2050.
- Make a fair and ambitious contribution to the new international climate agreement, to take effect in 2020.

To achieve reduction target of at least 40% by 2030, compared to 1990 levels, a reduction in emissions has been planned in two areas:

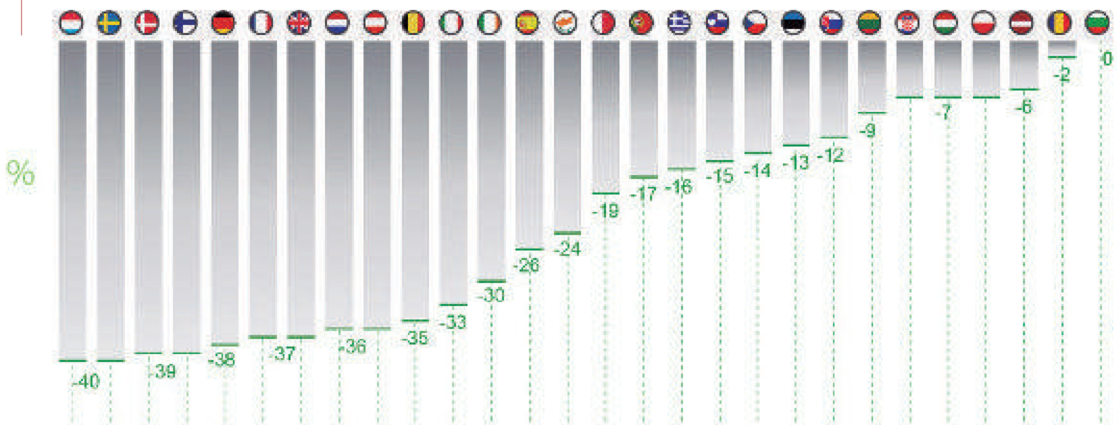
- EU Emissions Trading System (ETS) sectors should reduce emissions by 43% by 2030 compared to 2005.
- EU non-Emissions Trading System (non-ETS) sectors should reduce emissions by 30% by 2030 compared to 2005.



Agriculture is a non-ETS sector and, by reducing its emissions, it collaborates to reach the binding objectives to which each of the Member States has committed in non-ETS sectors (Fig. 2.4) (Table 2.4).

In Table 2.4 are shown figures of emissions and reduction of emissions for non-ETS sectors and specifically for agriculture, where the implementation of CA would have a direct impact.

Fig. 2.4. Percentage reduction of national emissions from sectors not included in the EU ETS (non-ETS). Source: *Euroefe, 2017.*



2.6. References

CLIMATECOST. http://www.climatecost.cc

EC. (2016). European Commission Factsheet on the Commission's proposal on binding greenhouse gas emission reductions for Member States (2021-2030).

Euroefe, (2017). http://euroefe.euractiv.es/5533_dosieres/3839211_las-nuevas-medidas-de-la-ce-para-reducir-las-emisiones.html

European Environment Agency (EEA) (2011). Technical Report N13/2012. Approximated EU GHG inventory: Early estimates.

Eurostat. (2016a). http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=t2020_35&plugin=1

Eurostat (2016b). http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do

Food Insecurity Index. Met Office and World Food Program. http://www.metoffice.gov.uk/food-insecurity-index/

Geothinking (blog). http://benjigyampoh.blogspot.com.es/2012/08/climate-change-and-agriculture.html

Table 2.4. 2005 non-ETS emissions in 28 EU member countries, binding reductions of member countries and emission commitments by 2030. *Sources: Eurostat, 2016a; Eurostat, 2016b; EC, 2016 and own calculations.*

	Non-ETS emissions in 2005 (t)	Agriculture emissions in 2005 (t)	Reduction (%)	Non-ETS Reduction (t)	Non-ETS emissions by 2030 (t)	Agriculture reduction (t)	Agriculture emissions by 2030 (t)
Austria	56,670,000	7,017,070	36	20,401,200	36,268,800	2,526,145	4,490,925
Belgium	78,200,000	10,243,990	35	27,370,000	50,830,000	3,585,397	6,658,594
Bulgaria	24,570,000	5,023,300	0	0	24,570,000	0	5,023,300
Croatia	16,820,000	2,951,820	7	1,177,400	15,642,600	206,627	2,745,193
Cyprus	4,180,000	630,240	24	1,003,200	3,176,800	151,258	478,982
Czech Republic	62,550,000	8,334,900	14	8,757,000	53,793,000	1,166,886	7,168,014
Denmark	40,080,000	10,965,760	39	15,631,200	24,448,800	4,276,646	6,689,114
Estonia	5,430,000	1,083,230	13	705,900	4,724,100	140,820	942,410
Finland	33,600,000	6,413,810	39	13,104,000	20,496,000	2,501,386	3,912,424
France	395,590,000	78,482,950	37	146,368,300	249,221,700	29,038,692	49,444,259
Germany	468,440,000	62,919,510	38	178,007,200	290,432,800	23,909,414	39,010,096
Greece	61,780,000	8,769,530	16	9,884,800	51,895,200	1,403,125	7,366,405
Hungary	46,380,000	6,127,520	7	3,246,600	43,133,400	428,926	5,698,594
Ireland	47,520,000	19,192,190	30	14,256,000	33,264,000	5,757,657	13,434,533
Italy	329,140,000	33,124,200	33	108,616,200	220,523,800	10,930,986	22,193,214
Latvia	8,520,000	2,270,810	6	511,200	8,008,800	136,249	2,134,561
Lithuania	10,780,000	3,747,480	9	970,200	9,809,800	337,273	3,410,207
Luxembourg	10,130,000	637,120	40	4,052,000	6,078,000	254,848	382,272
Malta	1,030,000	102,900	19	195,700	834,300	19,551	83,349
Netherlands	122,880,000	18,746,440	36	44,236,800	78,643,200	6,748,718	11,997,722
Poland	176,010,000	29,322,120	7	12,320,700	163,689,300	2,052,548	27,269,572
Portugal	49,530,000	7,297,630	17	8,420,100	41,109,900	1,240,597	6,057,033
Romania	73,030,000	19,756,660	2	1,460,600	71,569,400	395,133	19,361,527
Slovakia	22,300,000	3,113,680	12	2,676,000	19,624,000	373,642	2,740,038
Slovenia	11,850,000	1,781,970	15	1,777,500	10,072,500	267,296	1,514,675
Spain	233,840,000	38,086,750	26	60,798,400	173,041,600	9,902,555	28,184,195
Sweden	42,900,000	7,228,670	40	17,160,000	25,740,000	2,891,468	4,337,202
United Kingdom	414,710,000	45,813,070	37	153,442,700	261,267,300	16,950,836	28,862,234
Total Europe	2,848,460,000	439,185,320		856,550,900	1,991,909,100	127,594,678	311,590,642

Iglesias, A., Avis, K., Benzie, M., Fisher, P., Harley, M., Hodgson, N., Horrocks, L., Moneo, M., Webb, J. (2007). Adaptation to Climate Change in the Agricultural Sector. AGRI-2006-G4-05. Report to European Commission Directorate-General for *Agriculture and Rural Development*. ED05334. Issue Number 1. AGRI/2006-G4-05.

International Panel on Climate Change. (IPCC) (2007). Cambridge University Press; Cambridge, UK. Climate change: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Paris Agreement. (2015). United Nations. http://unfccc.int/paris_agreement/items/9485.php

Pisante, M., Stagnari, F., Acutis, M., Bindi, M. Brilli, L., Di Stefano, V., Carozzi, M. (2015). Conservation Agriculture and climate change (Chap.22: 579-620). In: Farooq, M., Siddique, K.H.M. *(eds.), Conservation Agriculture*, DOI 10.1007/978-3-319-11620-4_22

Ray, D.K., Gerber, J.S., MacDonald, G.K., West, P.C. (2015). Climate variation explains a third of global crop yield variability. *Nat. Commun.* 6:5989 doi: 10.1038/ncomms6989.

Reicosky, D.C. (2011). Conservation Agriculture: Global environmental benefits of soil carbon management. *In 'Fifth World Congress on Conservation Agriculture'.* Vol. 1. pp. 3–12.

Six, J., Ogle, S.M., Breidt, F.J., Conant, R.T., Mosiers, A.R., Paustian, K. (2004). The potential to mitigate global warming with no-tillage management is only realized when practiced in the long term. *Global Change Biology* 10: 155-160.

United Nations Framework Convention on Climate Change (UNFCCC), (2016). http://unfccc.int/essential_background/items/6031.php.