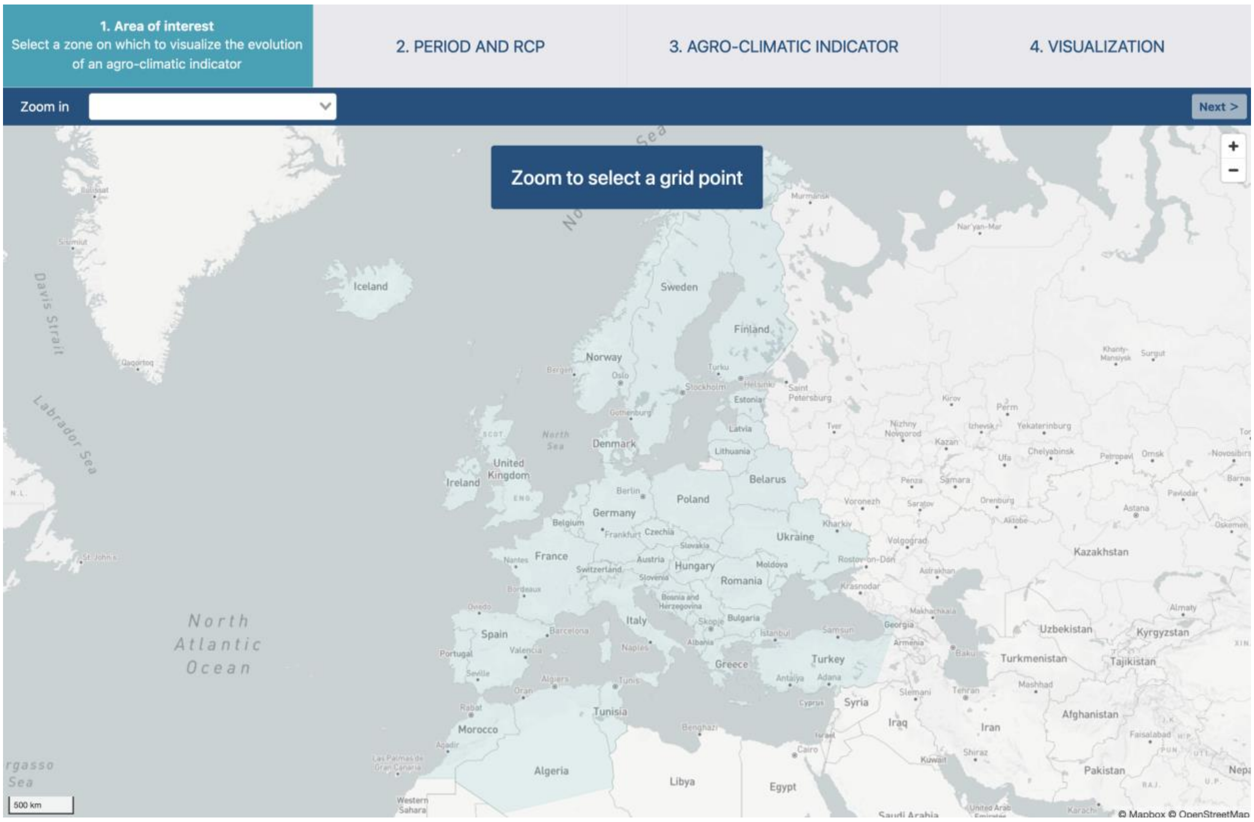
March 2023

CANARI

Climate ANalysis for Agricultural Recommendations and Impacts

CANARI Europe

User Manual 2023 v1



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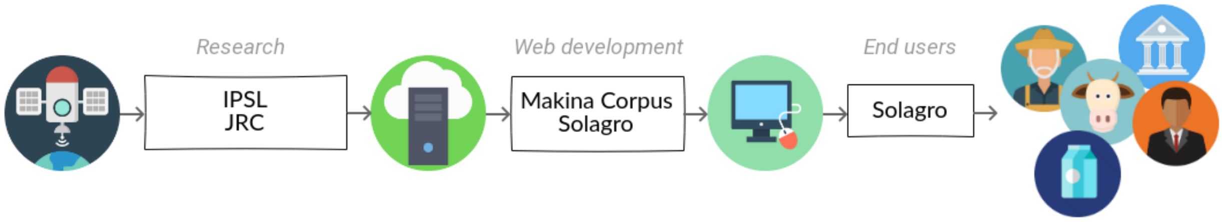
SUMMARY

1 CONTEXT

The CANARI portal is the result of the partnership between Solagro, a specialist in agricultural issues and climate change, and Makina Corpus, a designer of IT solutions and open source web applications. Scientific support on the use of climate projections was requested from the French laboratory IPSL (Institut Pierre Simon Laplace, specialist in climate modelling) but also from the MARS unit of the JRC (Joint Research Center of the European Union) involved on the challenges of adapting agriculture. The consortium put in place has made it possible to associate the complementary skills necessary for the design of an agro-climatic portal making it possible to increase access to agro-climatic indicators for actors in the agricultural sector.



The documentation offered in this CANARI user guide aims to provide the minimum information to be able to use the application correctly. This guide will successively cover the description of the portal, the climate data available in the application, the operating steps for carrying out an indicator calculation, the Agro-Climatic Indicators, the results of the application and finally a Frequently Asked Questions.

2 DESCRIPTION OF CANARI PORTAL

2.1 What are the objectives of CANARI?

How to take climate change into account in the decision-making and production process of the agricultural sector? How to transmit the necessary data to stakeholders in the sector so that they can adapt their practices? This is the main objective of the CANARI (Climate ANalysis for Agricultural Recommendations and Impacts) project.

Climate projections are new information, real starting points for adaptation approaches for the agricultural sector. However, these data are still largely unknown to agricultural stakeholders, difficult to access outside the climate community (climate portal, file format, etc.) and offer climate variables requiring additional calculations to reveal their interests to stakeholders in the field: obtaining agro-climatic indicators (ACI).

The CANARI portal was created to increase the access of agricultural actors to ACIs responding to local issues. CANARI allows quick and direct online visualization of more than a hundred Agro-Climate Indicators (ACIs) covering the needs of the different agricultural sectors. Each ACI can be calculated locally over the whole Europe for the period of the Near Future (period 2021-2050) and the Far Future (2051-2100) according to a multi-models approach, making it possible to identify a greater variability of the evolutions future climate.

2.2 What innovations does CANARI offer?

CANARI is a single and unique tool that allows:

- Simply and quickly mobilization of scientifically validated climate projections for the whole Europe
- Selection of multiple ACIs covering the needs of the different agricultural sectors (field crops, livestock, arboriculture, etc.)
- Offering instantaneous calculation of the ACI, the result is obtained in just a few seconds
- Developing these indicators over the period 2020-2050 (near future) to better understand the future variability of the various climate parameters, but also over the period 2050-2100 (far future) to consider long term consequences.
- Offering a multi-models approach for several climate scenarios (RCP4.5 and 8.5)
- Giving the possibility of freely modifying the parameters of each predefined ACI, whether threshold or period, thus to calibrate its request to its local issues.

2.3 Who is the CANARI portal intended for?

The users of the CANARI portal are all the agricultural actors who want to support the farmers of their territory locally in the process of adaptation. There are many agricultural actors: consulting companies and development organizations, insurance companies, training centers, educational establishments, public organizations, farmers' associations, cooperatives, etc.

All these actors are today in search of autonomy for the realization of calculation of customizable ACI. In order to properly use the ACIs offered by CANARI, it is recommended to be already initiated and aware of climate change in agriculture, and in particular to have acquired the following skills:

- Understand what climate change is and its impacts for the agricultural sector
- Understand what climate models and scenarios are and their possible consequences during the 21st century in France
- Know the main Agro-Climate Indicators by production or agricultural sector as well as their local customization in terms of periods of interest and calculation threshold
- Know the principles of an adaptation approach to sustainably support a farmer seeking greater resilience of its farm

If you want to strengthen your knowledge of climate change and adaptation in agriculture before using CANARI, you can go and discover the platform AWA - AgriAdapt Webtool for Adaptation.

3 Climate data

3.1 What is a climate modelling?

Numerical climate models are used to project the possible future course of the climate system as well as to understand the climate system itself. They are built on mathematical descriptions of the governing physical processes of the climate system (eg, momentum, mass and conservation of energy, etc.).

General Circulation Models (GCMs) are global numerical climate models that are used to study global climate change. They describe various components of the Earth system and the nonlinear interactions and feedbacks between them. In order to simulate the past climate, the measured values of atmospheric composition (greenhouse gases, pollutants, anthropogenic aerosols) and land cover are used as forcing data, while for future projections, the values of socio-economic scenarios - economic particulars are used.

Due to the large number of data points and the high complexity of GCMs, their integration requires a large amount of computational resources. The resolution of their horizontal grid currently varies from 50 to 150 km and they provide an output with a temporal frequency of 6 hours. GCMs are therefore insufficient in many respects to estimate climate change and its variability at a finer scale.

A downscaling is therefore necessary to describe the local consequences of global change, which can be done through regional climate models (RCM). RCM integrations are typically run at 10-50 km horizontal resolution over a specific region of interest (eg over Europe in the case of EURO-CORDEX). Through a combination of explicit resolution of significant processes (e.g. mountain circulations, land-ocean contrasts) and parameterization schemes suitable for higher resolutions, RCMs are able to provide more detailed features of the climate. regional to local.

3.2 Climate simulations available in CANARI

Created in 2009, the EURO-CORDEX program is the European branch of the international project CORDEX (Coordinated Regional Downscaling Experiment), a program supported by the World Climate Research Program (WCRP) which aims to organize and coordinate an international production framework regional climate projections for all continental regions of the globe. EURO-CORDEX provides climate simulations based on both models using statistical and dynamic downscaling, forced by the global models used in the 5th IPCC report (CMIP5).

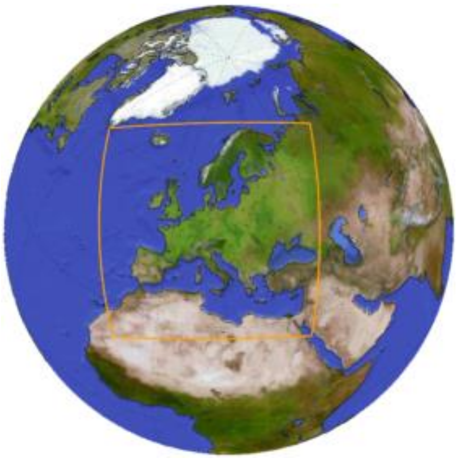


Figure 1 : Cordex EURO Domain (WCRP, Euro Cordex)

The climate simulations offered in CANARI all come from EURO-CORDEX. Each climate model has its own calculation assumptions to represent the climate system. Thus, it is generally recommended by specialists to retain several sets of simulations (from 5 to 6 different models) when using climate projections to explore the variability linked to the different models.

In total, 6 pairs of GCMxRCM simulations were retained for the calculation of indicators in CANARI (see table below). The choice of these different pairs is based in particular on the availability of corrected data (also called Cordex-adjust). Thus, the simulation games selected come from various French, German, Swedish, Danish, etc. institutes.

Table 1 : Pairs of GCMxRCM simulations available in CANARI

Domains	Regional Climate Models (RCM)	Driving Global Coupled Models (GCM)		
		MPI-M-MPI-ESM-LR (Germany)	ICHEC-EC-EARTH (Irland)	IPSL-IPSL-CM5A-MR (France)
EUR-11	CCLM4-8-17 (ETH + BTU) EU	RCP 4.5 and 8.5	RCP 4.5 and 8.5	
	RCA4 (SMHI) Sweden		RCP 4.5 and 8.5	RCP 4.5 and 8.5
	RACMO22E (KNMI) Netherlands		RCP 4.5 and 8.5	
	HIRHAM5 (DMI) Denmark		RCP 4.5 and 8.5	

3.3 Characteristics of CANARI simulations

- Geographical resolution: all the simulations proposed correspond to the finest geographical resolution proposed by EURO-CORDEX (0.11 degrees, EUR-11), ie grid points of approximately 12.5 km on each side.
- Climate scenarios: two RCP (for Representative Concentration Pathway) scenarios are available, RCP4.5 (intermediate scenario), and scenario 8.5 (pessimistic scenario).
- Climatic variables: many climatic variables are available for each GCMxRCM couple. Systematically, the variables precipitation, minimum temperature, maximum temperature, average temperature and average wind speed are available. Other variables are only available randomly depending on the simulation game selected: specific humidity, relative humidity, maximum wind speed, radiation, etc.
- Available time period: for each of the modelling sets, the available time period is between 1985 and 2100.
- Time frequency: for each climatic variable, the data are daily.

3.4 Summary of simulations available in CANARI

Table 2 : Summary of simulations available in CANARI

Simulation	Institution	GCM	RCM	Ensemble	Scenarios	Periode	Climate variables
Simulation 1	CLMcom	MPI-M-MPI-ESM-LR	CCLM4-8-17	r1i1p1	RCP 4.5 and 8.5	1985 to 2100	12
Simulation 2	SMHI	ICHEC-EC-EARTH	RCA4	r12i1p1			14
Simulation 3	CLMcom	ICHEC-EC-EARTH	CCLM4-8-17	r12i1p1			12
Simulation 4	KNMI	ICHEC-EC-EARTH	RACMO22E	r1i1p1			13
Simulation 5	SMHI	IPSL-IPSL-CM5A-MR	RCA4	r1i1p1			14
Simulation 6	DMI	ICHEC-EC-EARTH	KIRHAM5	r3i1p1			13

CLMcom: CLM Community with contributions by BTU (Chair of Environmental Meteorology, Brandenburg University of Technology (BTU) Cottbus, Germany), DWD (German Weather Service), ETHZ (Swiss Federal Institute of Technology Zurich (ETH Zürich)), UCD (Meteorology and Climate Centre, School of Mathematical Science, University College Dublin) WEGC (Wegener Center for Climate and Global Change, University of Graz, Austria)

DMI: Danish Meteorological Institute

KNMI: Royal Netherlands Meteorological Institute, Ministry of Infrastructure and the Environment

SMHI: Swedish Meteorological and Hydrological Institute

4 USE OF CANARI

4.1 IT prerequisites

Technical characteristics
Makina Corpus develops all of its applications based exclusively on free software. Guarantors of independence, sustainability, economic benefits and technical quality, open-source technologies are the basis of Makina Corpus' achievements.
For CANARI, Makina Corpus relied on its expertise in dataviz to improve and optimize the understanding of data and calculations.
The application is developed in Python, a versatile and free language, used in particular in the scientific community. Makina Corpus, on the strength of its several years' experience with Django, a web framework based on Python, therefore naturally turned to this language for the application.
For the first time, the Climate Data Operator (CDO) library of the Max Planck Institute, recognized in the scientific community, was used for setting up the IACs. Data processing was carried out upstream to optimize the calculations and minimize the waiting time to obtain the display of the results.

Technical advice
The proper functioning of the CANARI application is guaranteed on Chrome and Firefox browsers.

Other remarks
The CANARI application is an open-source software under a double license: GPL and CeCILL (https://aful.org/ressources/licences-libres).

CANARI project partners comply with RGPD recommendations. Data collected with Cloudflare Web Analytics is for the sole purpose of improving the CANARI application. For more information, the user also read the legal notices via the CANARI application for more information

4.2 Creating a user account

The first step for the user will be the creation of a user account (see Figure 2) specifying in particular the following information: surname, first name, email, name of the professional body.
It is possible to tick the agricultural sector(s) of interest. This selection will not affect the proposed operation of CANARI.
Once the information has been specified, the user must click on the Registration button to validate. An email will then be sent to him allowing him to connect to CANARI.

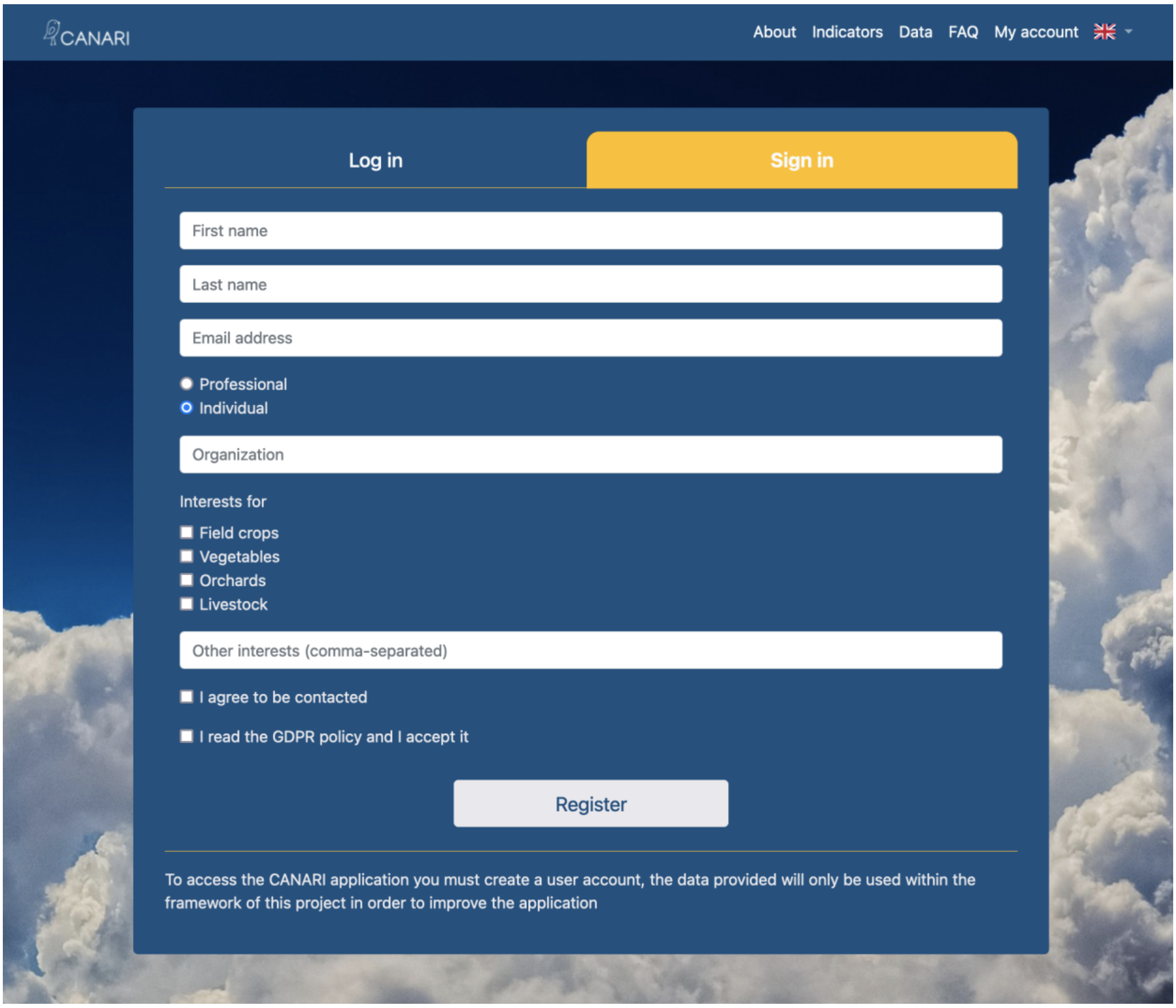


Figure 2 : Register on CANARI platform

Once the user account has been configured, it is then possible for the user to connect via his email and password (see Figure 3). If you forget the password, the "Forgotten password" feature will allow you to recover it.

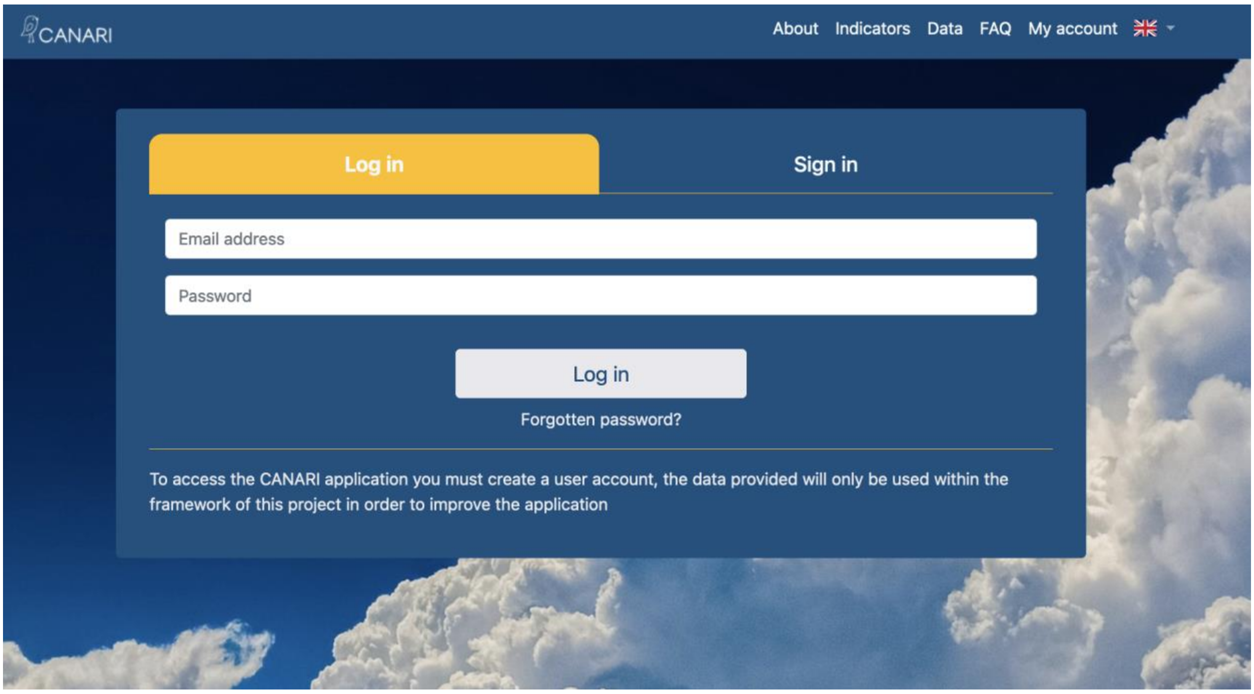


Figure 3 : Connect to CANARI platform

4.3 Steps for displaying an indicator

The procedure for calculating an indicator is accessible from the application's home page (see Figure 4), by clicking on the yellow button "Calculation of ACI".

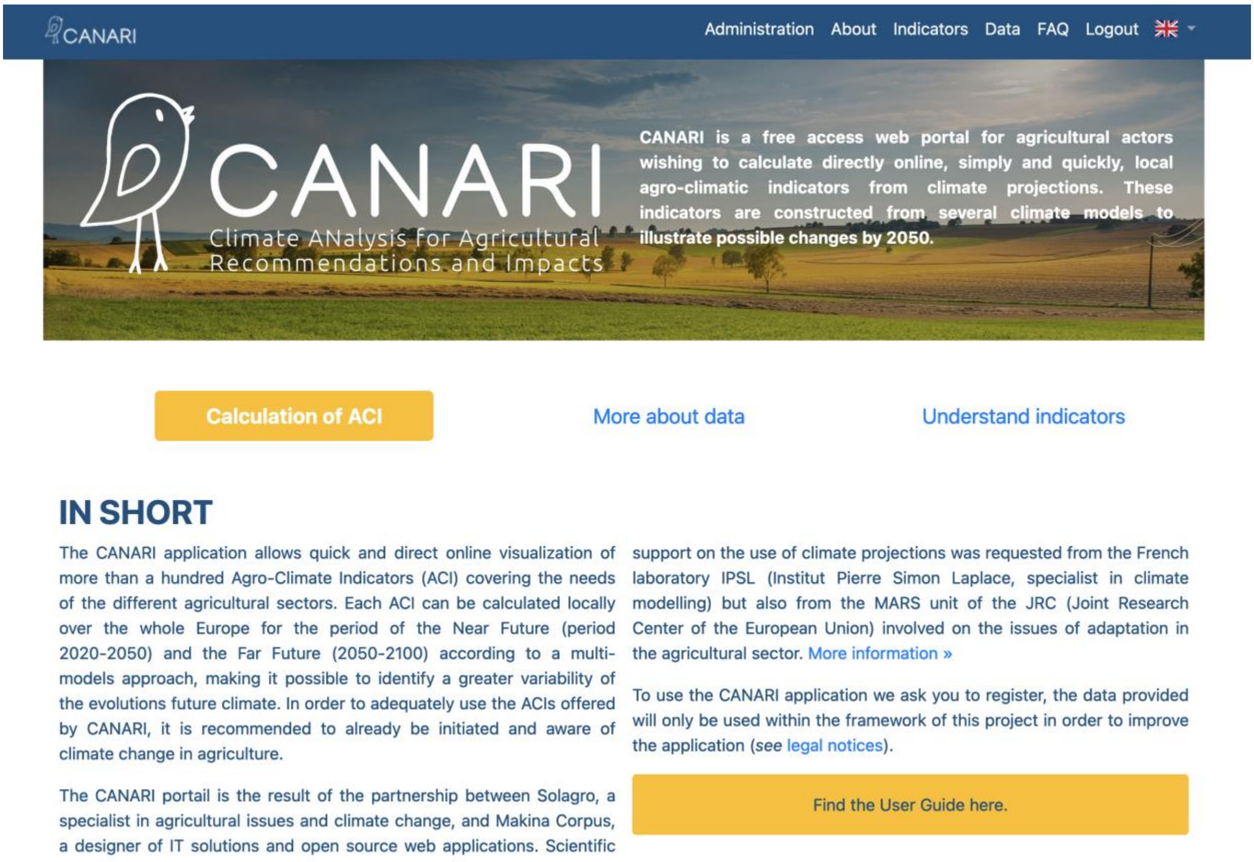


Figure 4 : CANARI Homepage

The procedure is then initiated and takes place through 4 successive stages:

1. Selection of the geographical area of interest
2. Selection of the future period (near or far) and of the GHG emission scenario (intermediate or pessimistic)
3. Selection and configuration of an ACI
4. Visualization of the ACI

The first step consists of a cartographic entry, with two additional possibilities offered to the user (see Figure 5):

- Enter the name of the municipality of interest in the search module at the top left of the screen. The recognized proposal(s) appear in the menu as the user enters it. Select only one proposal if several possibilities.
- Use of the zoom in (“+” button at the top right of the screen or mouse wheel) to get closer to the geographical location of interest.

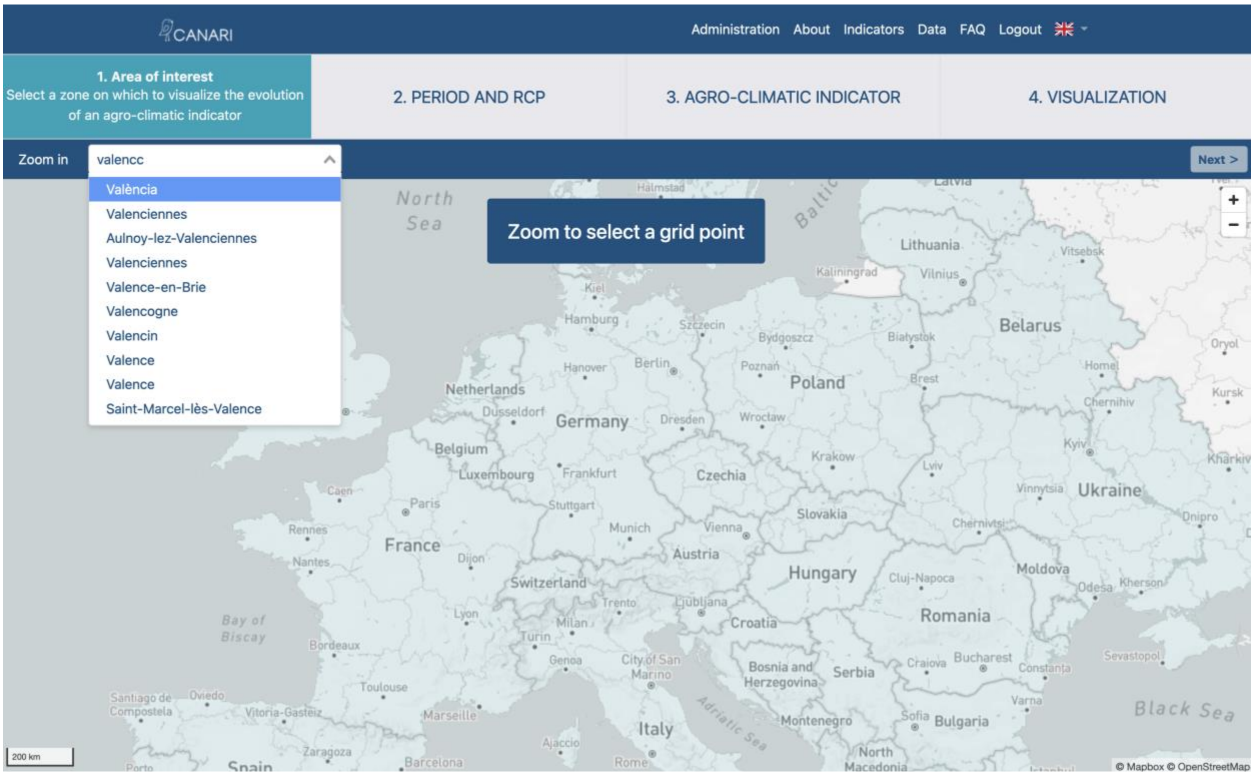


Figure 5 : First step of the process to display an indicator

Approaching a place of geographical interest then displays the layer of available grid points on the screen. Once appeared, the user can then select the one that interests him with a simple click of the mouse or the pad. The selected grid point is visually distinguished from the others by a blue background. The user can finally click on the “Next” button located at the top right of the screen.

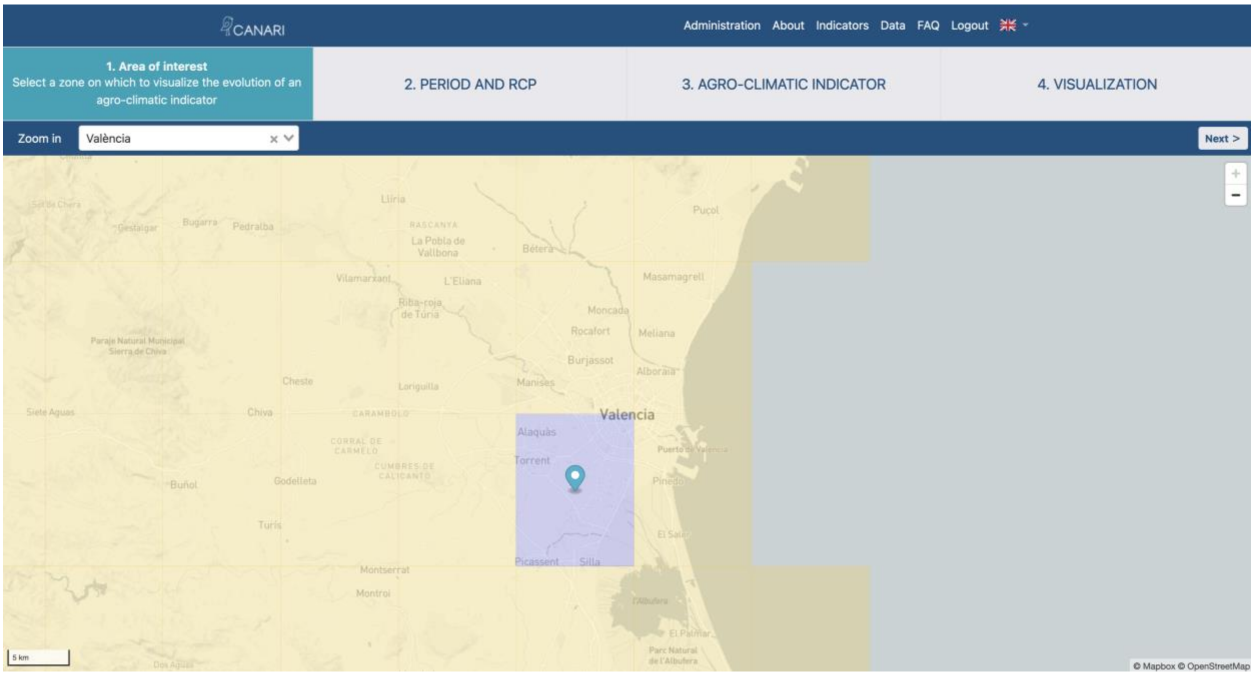


Figure 6 : Selection of the geographical grid point of interest

<u>Step 1 :</u>

Grid points are available for the whole Europe
Each grid point is about 12 km on a side
Each grid point is associated with a unique set of climate simulations

During the second step, the user will be able (see Figure 7):

- Select the future time period for which he wishes to view his indicator. Two choices are possible: Near Future only (period 2020-2050), or Near Future and Far Future (2050-2100). To exercise his choice, the user must click on Far Future.
- Select the GHG emission scenario: the user can select either the intermediate scenario (or RCP 4.5) or the pessimistic scenario (or RCP 8.5). To exercise his choice, the user must click in the area at the bottom of the screen on “RCP 4.5” or “RCP 8.5”. The selected time period then appears on a blue background, while remains greyed out.

To validate his choice and move on to the third step, the user must click on the “Next” button at the top right.

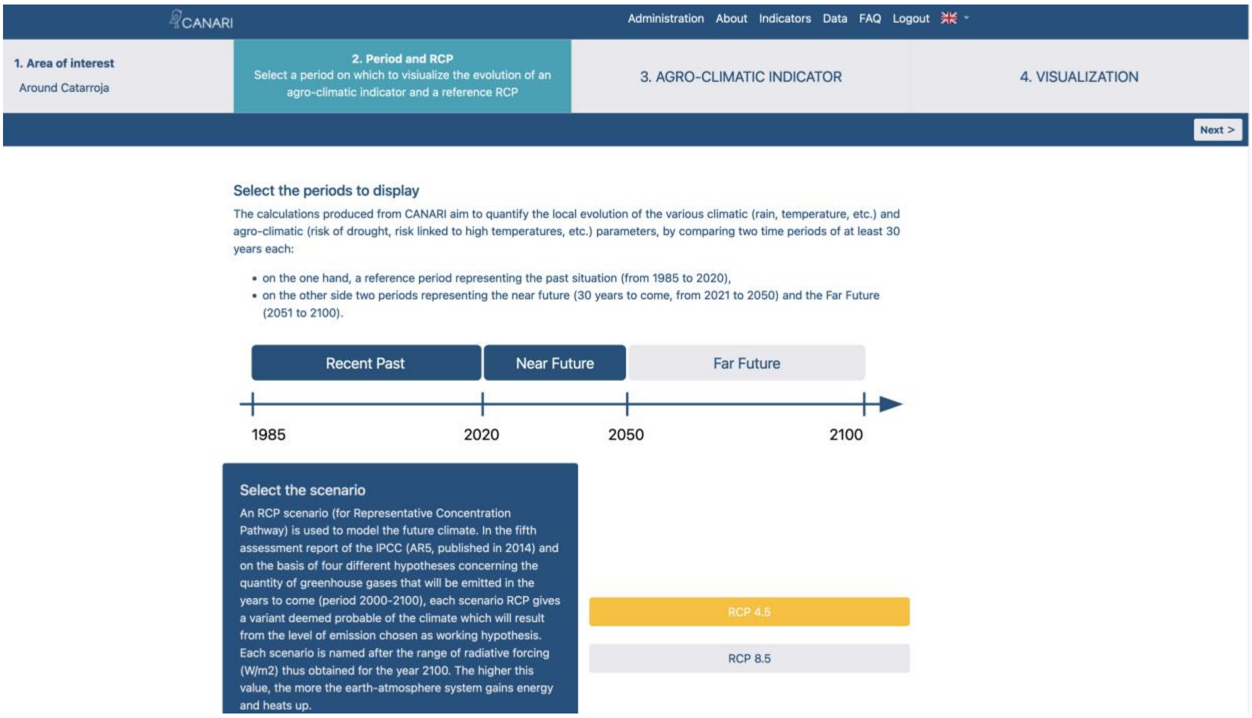


Figure 7 : Second step of the process to display an indicator

<u>Step 2 :</u>

The Near Future (2020-2050) is to be favoured as a first step so that economic actors can project themselves into an adaptation process

Once the logic of the indicators will be acquired, it is then possible to present representations on the Far Future (2050-2100)

The choice of the RCP 4.5 or 8.5 scenario is not very discriminating for the Near Future but becomes essential for the Far Future.

The third step will allow the user to select an indicator from the many proposals offered in CANARI (see Figure 8).

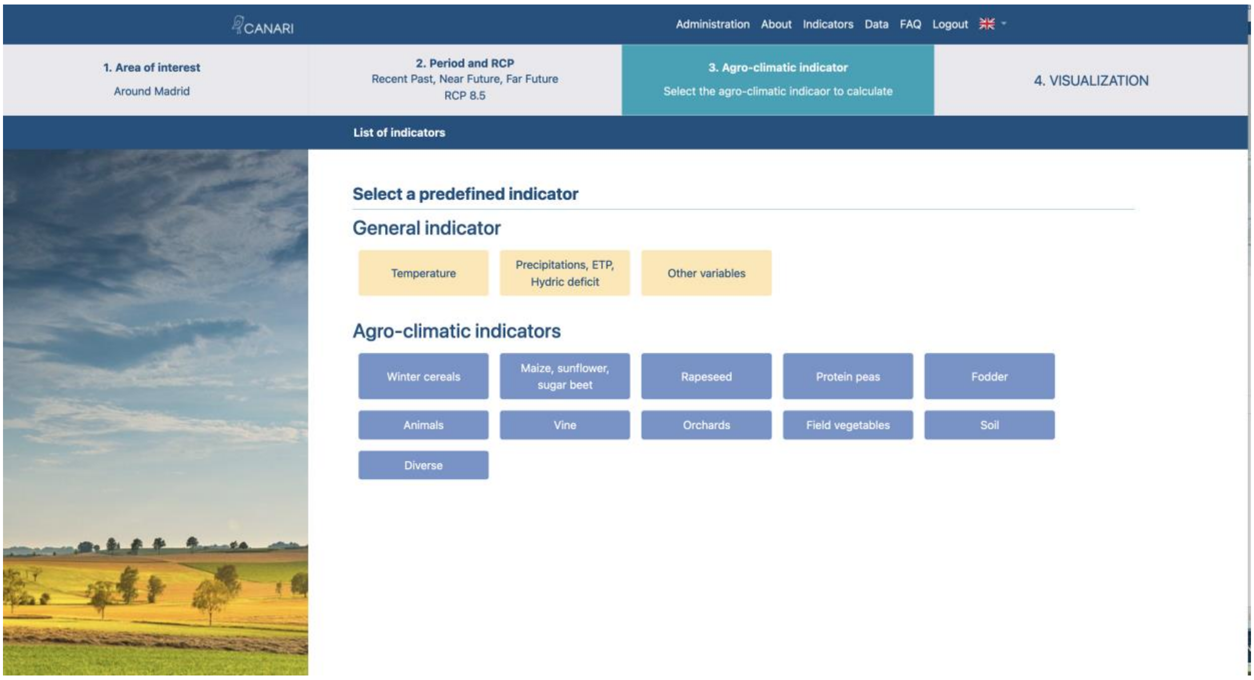


Figure 8 : Third step of the process to display an indicator

The indicators are organized under different headings by theme: winter cereals, animals, etc. (see Figure 9). Navigation is simple, just click on one of them to see the proposed indicators appear.
Within a heading, the user can select one of the proposed indicators with a single click. A description of the calculation sought by the indicator then appears in blue on the right of the screen.
If the user wishes to consult another heading and go to another indicator, it is possible to return to the main screen offering all the headings by clicking on the active link “List of indicators”.
Once the indicator sought by the user has been selected, click on the “Next” button located at the top right of the screen.

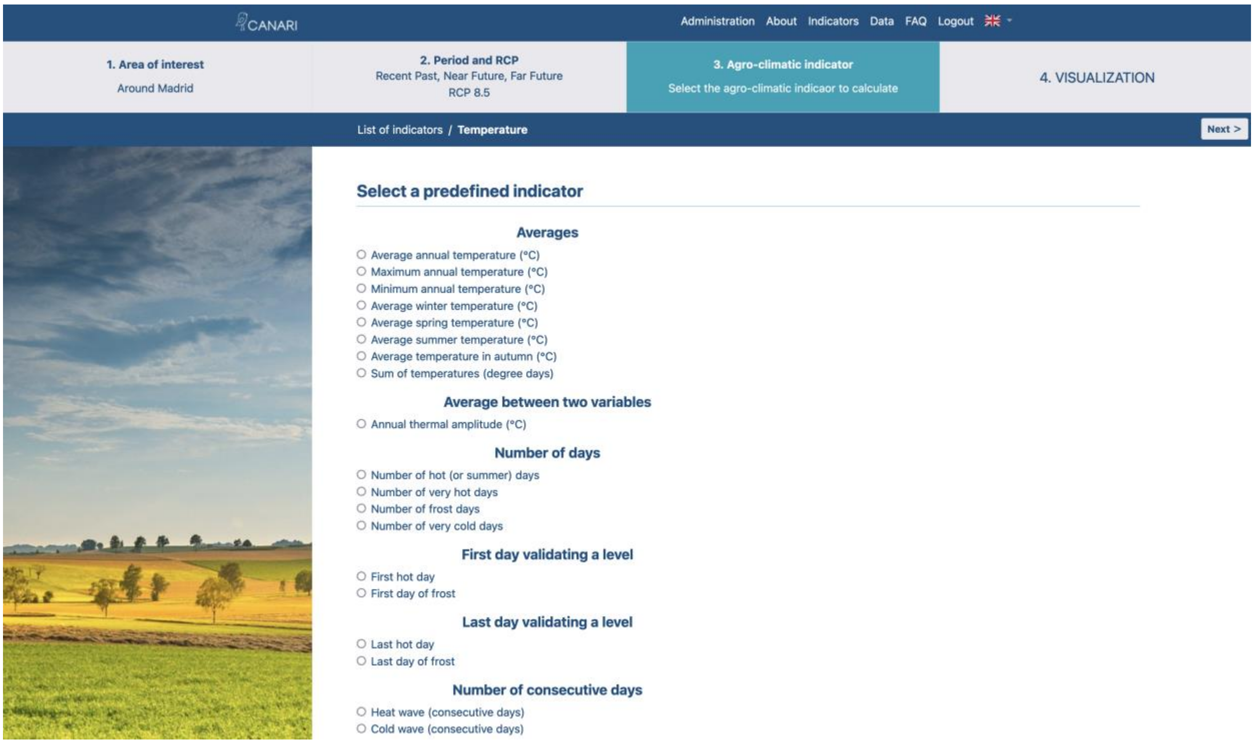


Figure 9 : Choosing an indicator within a heading

For each indicator selected, the user will be able to change its calculation period, as well as the calculation threshold for the indicators that require it (see Figure 10).
Regarding the calculation period, the start and end date is fully adjustable by the user by specifying the day of the month and the month concerned.
If there is no entry for the period, the application will automatically assign January 1st for the start date and December 31st for the end date.
Depending on the choices applied by the user for the period and the calculation threshold, the definition of the indicator is automatically updated in the area with a blue background.
Once the calibration of the indicator is complete, click on the “Launch the calculation” button located at the top right of the screen.

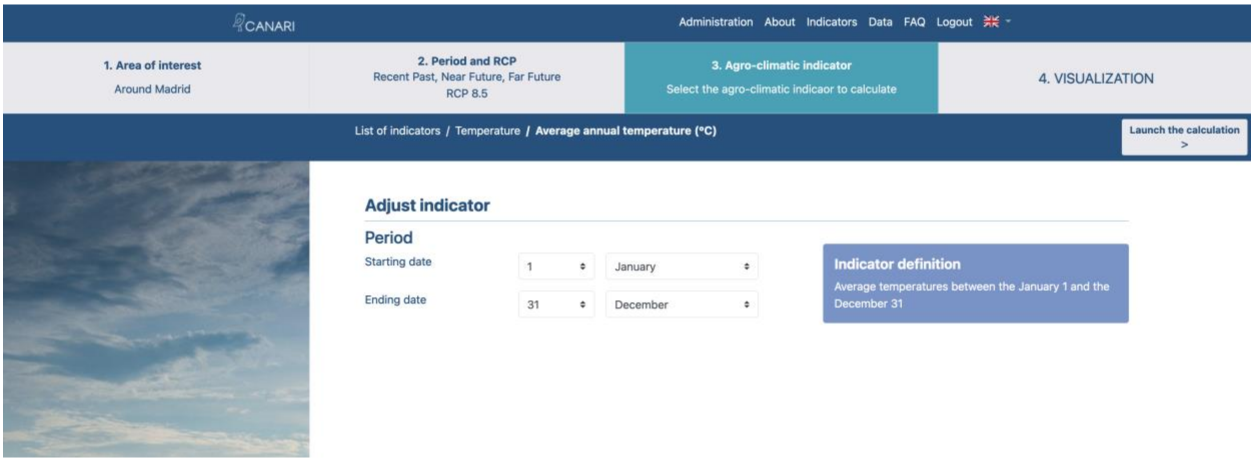


Figure 10 : Adjustment of the indicator (period and calculation threshold)

Step 3 :

The proposed periods and thresholds correspond to situations of interest

Depending on the user's expertise, it is possible to change the default settings to get closer to a more local reality

The fourth and final step allows the user to view the results of his query (see Figure 11).

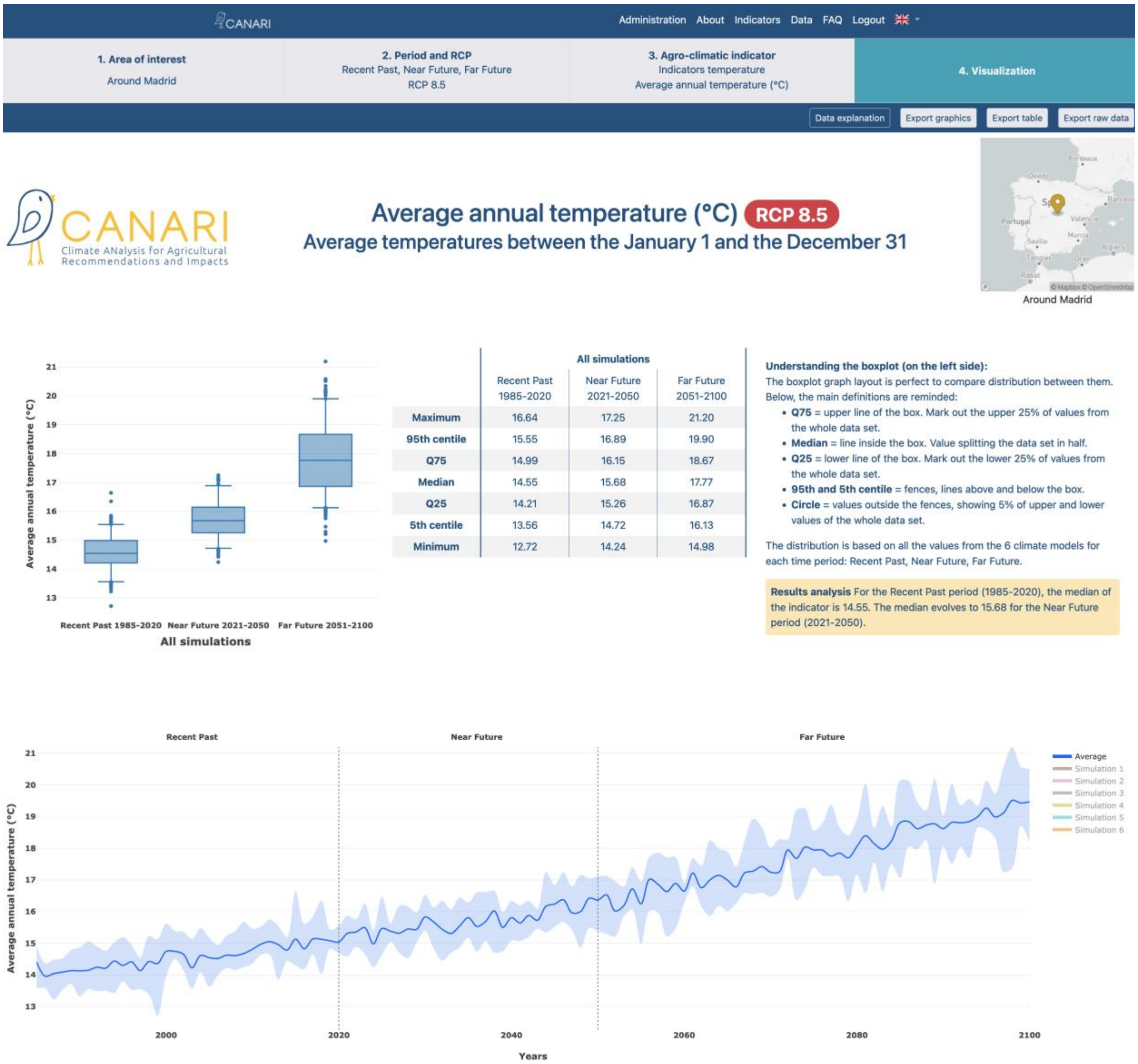


Figure 11 : Fourth step of the process to display an indicator

The visualization of the results is proposed through additional graphs and tables:

- On the left, a boxplot graphic intitled “All the simulations”, represents the results of the 6 sets of simulations, allowing the comparison of distinct periods of time (recent past, near future, far future).
- At the middle of the screen, a dashboard summarizes the main results of the 6 climate simulations of the boxplot by time period. The minimum, maximum and median values are detailed there. On the right of the screen, a short explanation of how to read a boxplot is available as well as a short sentence to analyse the evolution of the indicator from recent past to near and/or far future.
- Finally, a graph in the form of a continuous chronological frieze allowing to visualize the progression of the trend evolution of the indicator until the horizon of the near future (or far according to the configuration carried out). The dark blue line corresponds to the average of the 6 climate simulations. The light blue area that frames the dark blue line corresponds to the variability of the 6 climate simulations. The user can click on the legend to the right of the timeline to display/disappear the 6 climate simulations at their convenience.

At the very top right of the step 4 results display screen (see

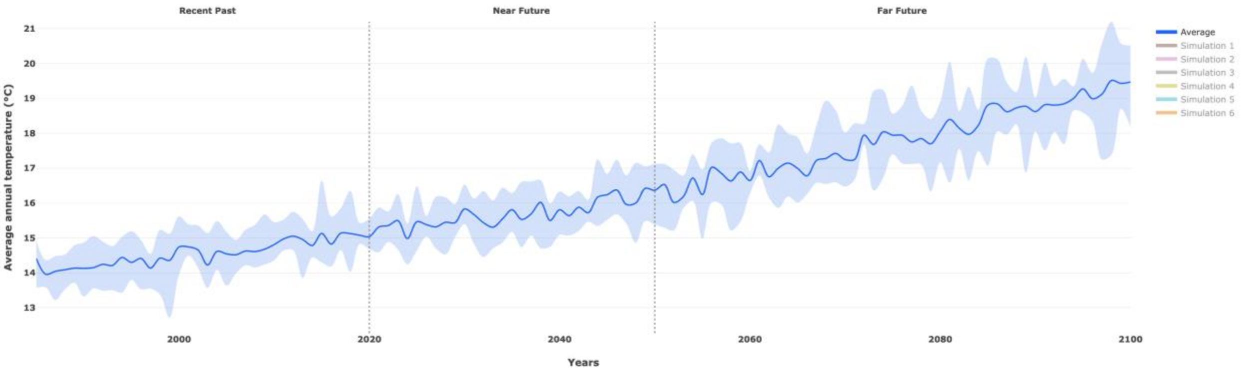


Figure 11), export buttons are available to the user:

- Export graphics: the entire CANARI result page is exported as an image file (png). The user can then save this file at their convenience.
- Export table: the values gathered in the simulation dashboard are exported in the form of a file in csv format, allowing additional use via a data processing tool (Open Office, Excel, etc.).
- Export raw data: the detail of the annual values of the indicator for each of the 6 climate simulations (csv format) is exported in the form of a file in csv format, allowing additional use via a data processing tool (Open Office Excel, etc).

Finally, it is also possible for users to save or share their indicator calculation results by simply copying/pasting from the address bar when they are in step 4 of CANARI.

Step 4 :

Hovering over the graphs with the cursor makes it possible to display the median, min, max, etc. values.

If the display of the result page is problematic (overlay of graphics, absence of legend, etc.), then it is necessary to check that the browser window is in full screen. The page can be refreshed by clicking in the address bar, then on the Validate button on the keyboard

Once the course of the 4 stages of visualization of an indicator carried out by the user, this one has the possibility of:

- Carry out another calculation for the same selected grid point, by clicking on the banner at the top of the screen: possible return to step 3 (change of indicator) or to step 2 (new choice of period and/or RCP scenario).
- Change grid point: possible return to step 1 by clicking on the banner at the top of the screen.
- Return to the CANARI home page: the user must then click on “CANARI” in the black banner located at the top left of the screen.

5 AGRO-CLIMATE INDICATORS

5.1 What is ACI

In order to illustrate the new climatic conditions in which plants and animals will have to evolve locally, the climatic variables are reworked in such a way as to target potential constraints (detrimental to physiological functioning), or conversely new climatic opportunities. We then speak of agro-climatic indicators, revealing the evolution of "climate pressure" by comparison between a reference period and a future period.

- Example of a constraint: high temperatures, characterized by a number of days when the maximum temperature is above 25°C at the end of the development cycle of straw cereals (common wheat in particular), cause a growth defect in the grains and therefore limit the final yield.
- Example of opportunity: the trend increase in the average temperature makes it possible to exploit a higher thermal potential, allowing for example to envisage the success of a catch crop between two main crops.

5.2 ACI available in CANARI

In order to simplify the ACI approach by crop, it can be estimated that the following four major climatic events are likely to affect the yield of the main crops (annual, perennial): water deficit, excess water, high temperatures and low temperatures. Similarly, the intervention of extreme and occasional climatic phenomena (hail, late frost, storm, etc.) will cause yield losses. Each culture corresponds to periods of interest during which stress can have an impact. Knowledge of the physiology of crops and the associated climatic stresses will make it possible to determine the AICs of interest by crop (see example in Figure 12).

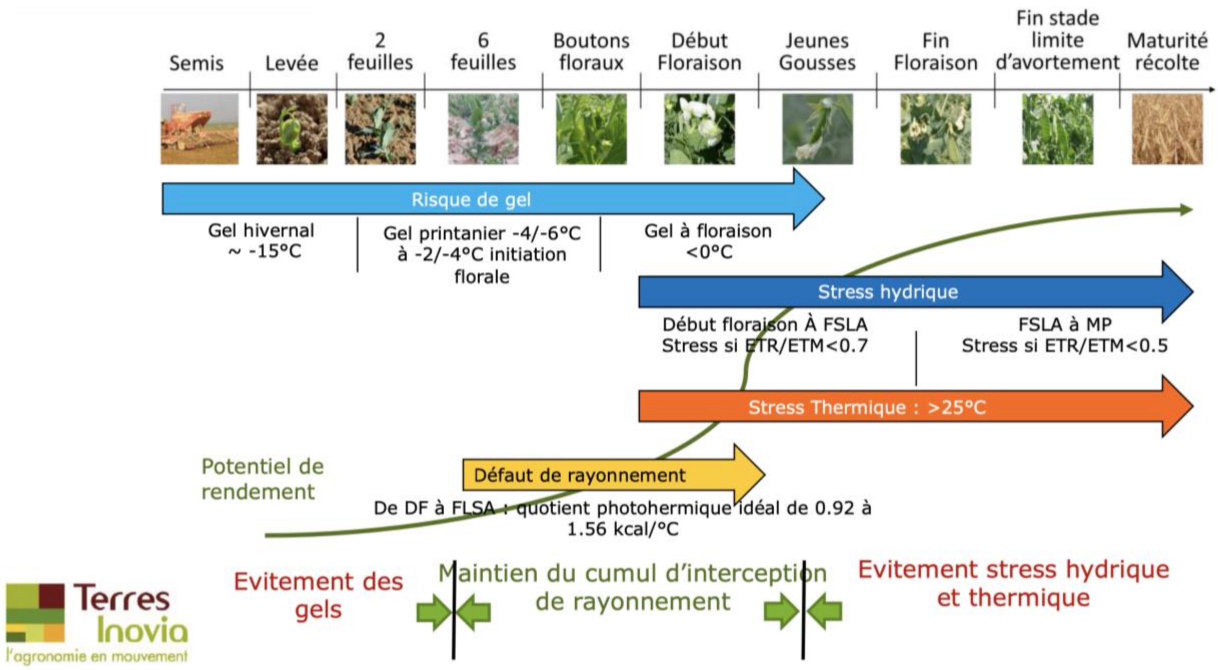


Figure 12 : Illustration of yields limiting factors for high pea crop

Multiple ACI calculations are therefore possible depending on the production orientations of each farm. Most of the time, the ACIs will seek to illustrate similar changes, for example the stress linked to the increase in the number of hot days. However, the periods of interest and/or the temperature thresholds may need to be adjusted according to the productions in which one is interested or even the geographical area considered.

CANARI users less experienced with ACIs wishing to explore additional information can refer to the AgriAdapt farming adaptation training pack : this allows you to learn about ACI relating to soft wheat, grain corn, rapeseed, meadows, protein peas, vines, and livestock buildings.

To help users identify computational possibilities for ACI, CANARI offers (see Figure 13):

1. General indicators not specific to a crop or sector, corresponding to the first three categories proposed: "Temperature", "Rainfall, ETP, water deficit", "Other variables"
2. Agro-Climate Indicators (ACI), specific indicators of a crop or sector: "winter cereals", "corn, sunflower, beets", etc.

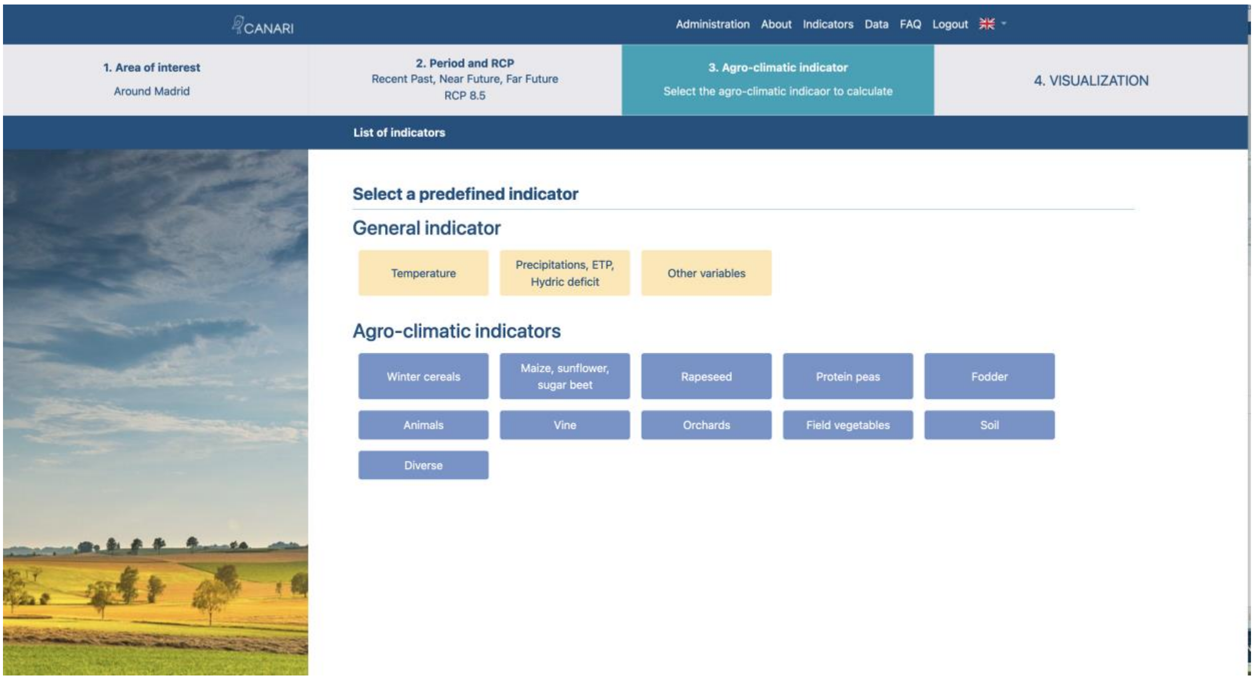


Figure 13 : Organization of indicators in CANARI tool

5.3 General indicators

The general indicators are organized into 3 different headings (see Table 3):

- Temperature: average/maximum/minimum temperature, thermal amplitude, temperature sum, number of hot/cold days, etc.
- Rainfall, ETP, water deficit: cumulative rainfall, number of days of intense rain, cumulative water deficit, etc.
- Other variables: accumulation of radiation, average wind speed, etc.

Table 3 : List of indicators for each heading of the general indicators

Category	Indicator	Unit
Temperature	Average annual temperature (°C)	°C
	Maximum annual temperature (°C)	°C
	Minimum annual temperature (°C)	°C
	Annual thermal amplitude (°C)	°C
	Average winter temperature (°C)	°C
	Average spring temperature (°C)	°C
	Average summer temperature (°C)	°C
	Average temperature in autumn (°C)	°C
	Sum of temperatures (degree days)	Degree days
	Number of hot (or summer) days	Nb days
	Number of very hot days	Nb days
	First hot day	Date
	Last hot day	Date
	Heat wave (consecutive days)	Nb days
	Number of frost days	Nb days
	Number of very cold days	Nb days
	First day of frost	Date
	Last day of frost	Date
	Cold wave (consecutive days)	Nb days
Rainfall, ETP, hydric deficit	Cumulative annual rainfall (mm)	mm
	Number of rainy days per year	Nb days
	Number of intense rainy days per year	Nb days
	Annual potential evapotranspiration (mm)	mm
	Potential evapotranspiration (mm) in spring	mm
	Potential evapotranspiration (mm) in summer	mm
	Potential evapotranspiration (mm) in autumn	mm
	Annual number of days for which ETP > a threshold (mm)	mm
	EPT wave (consecutive days)	Nb days
	Annual water deficit (mm)	mm
	Spring water deficit (mm)	mm
	Summer water deficit (mm)	mm
	Autumn water deficit (mm)	mm
Other	Total annual radiation (kJ/m2)	kj/m^2
	Average annual radiation (kJ/m2)	kj/m^2
	Radiation (kJ/m2) above a threshold	Nb days
	Radiation (kJ/m2) below a threshold	Nb days
	Radiation (kJ/m2): number of consecutive days > threshold	Nb days
	Radiation (kJ/m2): number of consecutive days < threshold	Nb days
	Average annual wind speed (m/s)	km/h
	Annual number of windy days > threshold (km/h)	Nb days

	Wind wave (consecutive days)	Nb days

Each of the ACI proposed in CANARI remains adjustable by the user, whether for the period or the calculation threshold.

5.4 Sector-specific indicators

Winter cereals: indicators specific to straw cereals (wheat, barley, triticale, etc.) targeting in particular the risks associated with high temperatures, frost and water deficit.

Table 4 : List of indicators for winter cereals category

Category	Indicator	Unit
Winter cereals	Precipitation during a phase of the development cycle (mm)	mm
	Risk of excess post-sowing water (mm)	mm
	Frost stress beginning of bolting	Nb days
	Late frost during bolting	Nb days
	Risk of early scalding (number of days)	Nb days
	Heat stress heading - flowering (number of days)	Nb days
	Heat waves (consecutive days)	Nb days
	Water deficit during heading (mm)	mm
	Water deficit heading - seed filling (mm)	mm
	Accessibility during harvest (consecutive days without rain)	Nb days

Maize, sunflower, sugar beet: indicators specific to crops with a summer cycle (e.g. corn or sunflower) targeting in particular the risks associated with high heat, cold, water deficit and simulation of harvest dates.

Table 5 : List of indicators for the maize, sunflower, sugar beet category

Category	Indicator	Unit
Maize, sunflower, sugar beet	Precipitation during a phase of the development cycle (mm)	mm
	Intense precipitation at sowing (number of days)	Nb days
	Low temperatures in spring (number of days)	Nb days
	Very low temperatures in spring (number of days)	Nb days
	Summer heat stress (number of very hot days)	Nb days
	Risk of scalding during flowering	Nb days
	Heat wave (consecutive days)	Nb days
	Water deficit (mm) from May to August	mm
	Number of days without rain	Nb days
	Date of first significant frost in fall	Date
	European corn borer flight: start of activity	Date
	European corn borer flight: high activity	Date
	Early sunflower: harvest date simulation	Date

	Mid-early sunflower: harvest date simulation	Date
	Very early maize (G0): simulation of the harvest date	Date
	Mid-early to mid-late maize (G3): simulation of the harvest date	Date
	Very late maize (G6): simulation of the harvest date	Date

Rapeseed: indicators targeting in particular possible difficulties during sowing (low rainfall) and autumn weather conditions (days of frost, water deficit).

Table 6 : List of indicators for the rapeseed category

Category	Indicator	Unit
Rapeseed	Rainfall at rapeseed planting (mm)	mm
	Number of consecutive days without rain following implementation	Nb days
	Fall water deficit (mm)	mm
	Fall frost (number of days)	Nb days
	Scalding at end of cycle (number of days)	Nb days
	Water deficit at the end of the cycle (mm)	mm

Pea crop: indicators adapted to pulses and targeting the risks associated with high temperatures, the risk of frost and water deficit.

Table 7 : List of indicators for pea crop category

Category	Indicator	Unit
Pea crop	Winter frost (number of days)	Nb days
	Risk of scalding in May (number of days > 25°C)	Nb days
	Risk of scalding in June (number of days > 25°C)	Nb days
	Water deficit at the end of the cycle (mm)	Nb days

Fodder: indicator concerning grassland forage areas, and targeting recovery dates (grassing, mowing) and the risks of water stress at different seasons.

Table 8 : List of indicators for the fodder category

Category	Indicator	Unit
Fodder	Restart of grass growth (date)	Date
	Date for 1st grazing	Date
	Early mowing date (silage, wrapping)	Date
	Intermediate mowing date (hay)	Date
	Late mowing date (hay)	Date
	Fall precipitation (mm)	mm
	Spring precipitation (mm)	mm

	Spring water deficit (mm)	mm
	Water deficit in summer (mm)	mm
	Autumn water deficit (mm)	mm
	Number of consecutive days without rain in spring	Nb days

Cattle: indicators targeting the sensitivity of cattle to heat waves, as well as the ventilation needs of closed livestock buildings (pigs, poultry).

Table 9 : List of indicators for cattle category

Category	Indicator	Unit
Cattle	Number of hot days per year	Nb days
	Temperature-Humidity Index (THI)	Nb days
	Air conditioning requirement (degree days)	Degree days

Vineyard: indicators targeting the evolution of thermal availability (link with the choice of grape varieties), the evolution of the coolness of pre-harvest nights (link with wine quality), or the risks of late frost and water stress on the development cycle.

Table 10 : List of indicators for the vineyards category

Category	Indicator	Unit
Vineyard	Huglin's heliothermal index (HI)	IH
	Winckler Index (IW)	IW
	Risk of late frost (number of days)	Nb days
	Last day of spring frost	Nb days
	Cold night index	IF
	Water deficit over the crop cycle (mm)	mm
	Evolution of global radiation (kJ/m2)	kj/m^2
	Intense rains (number of days)	Nb days
	Difficulty of mechanical interventions (number of days)	Nb days
	Hot days during the harvest	Nb days
	Feasibility of phytosanitary treatments	Nb days

Orchards: indicators targeting risks related to cold or heat and water stress during the development cycle.

Table 11 : List of indicators for the orchards category

Category	Indicator	Unit
Orchards	Risk of late frost (number of days)	Nb days
	Last day of spring frost	Date
	Intense rains (number of days)	Nb days
	Number of hot days	Nb days

	Number of hot days in summer	Nb days
	Water deficit over the crop cycle (mm)	mm

Soil: indicator targeting the emptying level of a water resource.

Table 12 : Indicator for the soil category

Category	Indicator	Unit
Soil	Water resource: drain (mm)	mm

Diverse: indicator targeting the feasibility of an intermediate culture and simulation of crop stages for lentils as well as bruchid pressure on lentils.

Tableau 13 : List of indicators for the diverse category

Category	Indicator	Unit
Diverse	Cover crop: feasibility	Degree days
	Lentils: mid bloom date	Date
	Lentils: harvest date	Date
	Bruchid arrival date	Date

Vegetables: indicator targeting green bean, green pea and carrot vulnerability.

Tableau 14 : List of indicators for the field vegetable category

Category	Indicator	Unit
Field vegetables	Green bean - Intense precipitation at sowing (> 25 mm)	Mm
	Green bean - Cumulative water deficit (mm)	Mm
	Green pea - Number of consecutive days of frost	Nb days
	Green pea - Number of consecutive very hot days	Nb days
	Carrot - Number of consecutive days of intense precipitation at sowing	Nb days

	Carrot - Carrot Fly	Date
	Spinach - Heat wave (consecutive days > 25°C)	Nb days

5.5 How to add a new indicator?

In its current version, CANARI offers users 121 indicators, knowing that all are adjustable by the user, whether for the period or the proposed calculation threshold.

It is not technically possible for a user to directly add an indicator on CANARI. However, users can send by email (canari@solagro.asso.fr) any additional proposal for an indicator that meets their needs.

A major effort has been made to provide users with a fairly exhaustive list of general purpose indicators through the first 3 headings offered in CANARI: "Temperature", "Rainfall, ETP, water deficit", "Other variables".

There are nearly 40 indicators that allow you to freely manipulate the different climatic variables offered in the application (rainfall, evapotranspiration, temperature, radiation, wind, etc.). Since the calculation thresholds and periods of interest are fully configurable by the users, there are therefore many exploration possibilities for carrying out analyses of local climate projections.

6 ADAPTATION MEASURES

Many adaptation measures are possible at the farm level (see Figure 15). Users who want to know more about this can refer to the resources described below, produced as part of the Life AgriAdapt project.

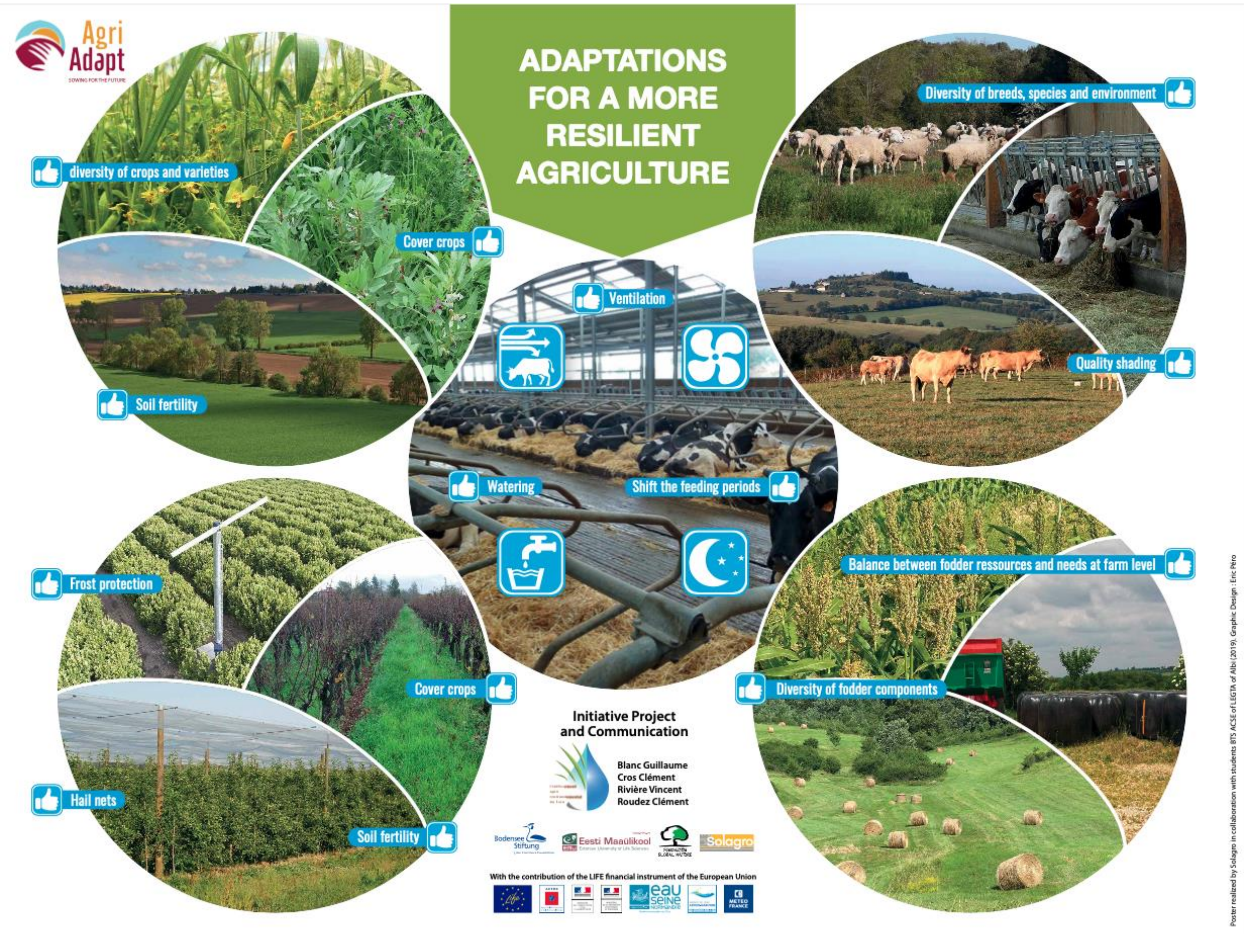


Figure 14 : Illustrations of possible adaptations for more resilient agriculture (AgriAdapt)

6.1 AWA platform

The AWA platform (AgriAdapt Wetool for Adaptation), allow user to view within a module dedicated to adaptation measures (see Figure 16), sustainable adaptation measures according to the climatic zone, the agricultural system (field crops, livestock and permanent crops) and classified by farm vulnerability components (4 components).

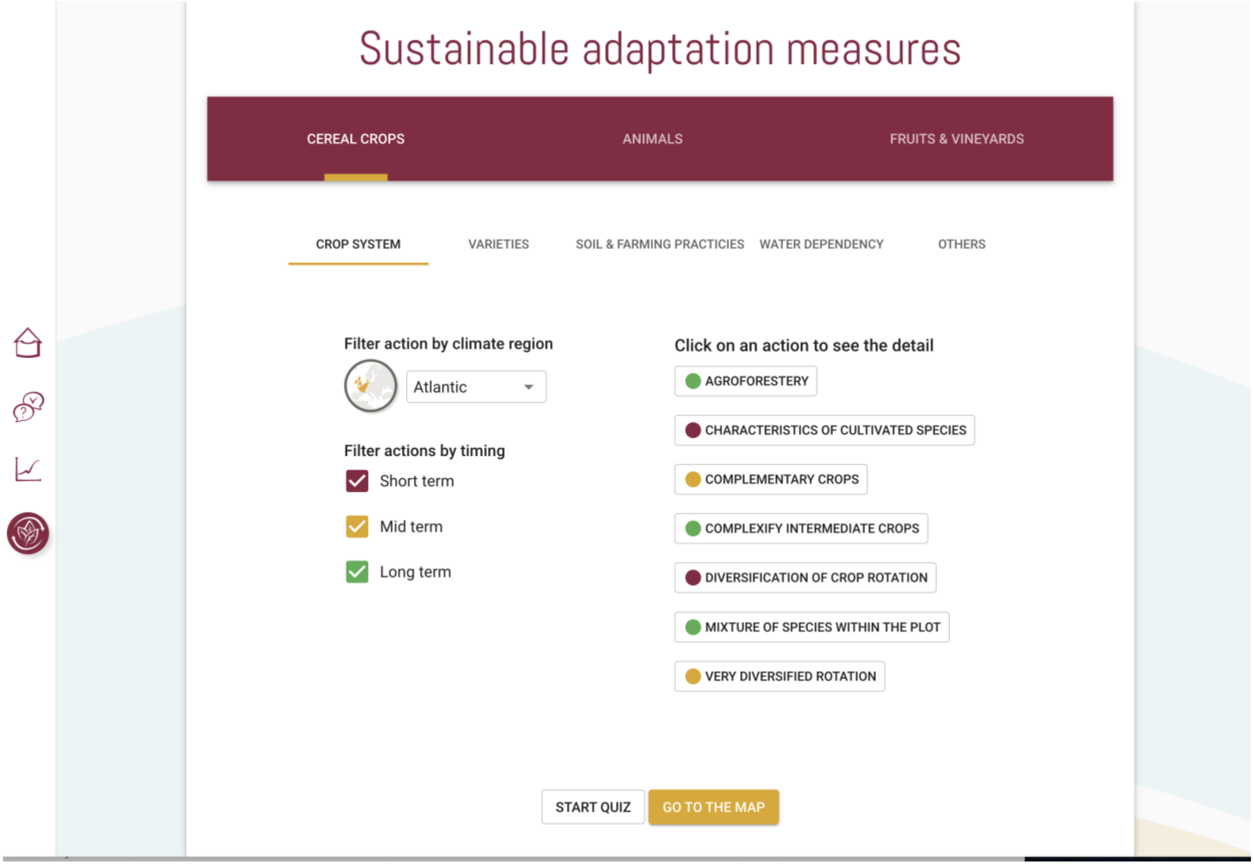


Figure 15 : Sustainable adaptation measures (AWA platform)

A color code makes it possible in particular to distinguish between short, medium and long-term measures. For each measure, it is possible to open a detailed file, making it possible to point out the potential existence of positive, neutral or negative impacts on different components of sustainability: greenhouse gas emissions, air quality, soil, water, biodiversity, etc. In total, nearly a hundred sustainable adaptation measures are to be discovered in this module.

6.2 Videoclips

Climate change: what adaptation levers leviers in agriculture ?
Expert views on the levers of adaptation to climate change, collected on the occasion of the Weather and Climate Day of May 30, 2018.

Adaptation to climate change: testimonial from a polyculture livestock farm
Located in the Tarn, the Bellegarde farm (dairy cattle and irrigated crops) took part in the Life AgriAdapt pilot farm network. The farm manager explains the farm's sensitivity to climate change and the adaptations implemented.

Adaptation to climate change: testimonial of a field crop farm
Located in Aube, the SCEA Arc en Ciel (field crops in chalky champagne) participated in the network of pilot farms Life AgriAdapt. The farm manager explains the farm's sensitivity to climate change and the adaptations implemented.

7 FREQUENTLY ASKED QUESTIONS

7.1 Climate Change

- **What is the observed evolution of the climate in France?**

An increase in average temperatures in France of 1.4°C has been observed since 1900, the cumulative rainfall remains stable across the country but contrasting changes appear depending on the region and the season, the duration of snow cover is decreasing in mountains and the intensity of the droughts is increasing. Since 1980, the increase in warming has been significant, with an average rate of around +0.3°C each decade (source: Climat HD).

- **What is the observed evolution of precipitation in France?**

On the scale of France, annual precipitation has not shown any marked change since 1961. However, it is characterized by a clear disparity with an increase over a large northern half (especially the northeast quarter) and a decrease in the south of the country (source : Climat HD).

- **Is there more soil drought in France?**

The analysis of the annual percentage of the surface affected by soil drought since 1959 makes it possible to identify the years having experienced the most severe events such as 1976, 1989, 2003 and 2011. The evolution of the ten-year average shows the increase of the surface of droughts going from values the order of 5% in the 1960s to more than 10% today (source: Climat HD).

- **Are there more heat waves in France?**

Heat waves recorded since 1947 on a national scale have been significantly more numerous in recent decades. This development is also materialized by the occurrence of longer and more severe events in recent years. Thus, the three longest heat waves and three of the four most severe episodes occurred after 2000. The heat wave observed from August 2 to 17, 2003 was by far the most severe in France. It was also during this episode and during the heat wave from July 21 to 26, 2019 that the hottest days since 1947 were observed (source: Climat HD).

- **How is the number of frost days changing in France?**

The number of frost days observed in France is quite different depending on the region and shows strong variations from one year to the next. Over the period 1961-2010, a decrease is observed in all regions: the decreases are less marked in the coastal areas where the annual number of frost days is low, the strongest decreases are observed in the northeast and the center of the country; in the other regions, the drop is between two and four days per decade (source: Climat HD).

7.2 Climate projections

- **Qu’est-ce qu’une modélisation climatique ?**

Numerical climate models are used to project the possible future course of the climate system as well as to understand the climate system itself. They are built on mathematical descriptions of the governing physical processes of the climate system (eg, momentum, mass and conservation of energy, etc.).

- **Why are climate change calculations carried out over periods of 30 years?**

The climate is a synthetic representation of climatic variables characterizing a given region. It is defined by the average values, generally over 30 years (according to the World Meteorological Organization), and the dispersion around the average of climatic quantities (temperature, rainfall, wind, sunshine, etc.) and particular phenomena such as fog, storms, hail. Conversely, the notion of "weather" refers to the meteorological conditions of a given moment or a short period (a day, a week, etc.).

- **What time periods are available in CANARI?**

The user can use 3 different time periods in the application: the Recent Past (1985 to 2020), the Near Future (2021-2050) and finally the Far Future (2051-2100). The principle of CANARI is to compare the representation of an indicator between these different time periods to understand what the evolutions are: Recent Past / Near Future, or Recent Past / Near Future / Distant Future. Initially, it is advisable to promote comparisons of Recent Past / Near Future indicators that are easier to analyze and explain to farmers. It is also often easier for an economic player to limit himself to the next 30 years to structure his adaptation process.

- **Which RCP scenario should I choose for my simulations in CANARI?**

The user can choose two different RCP (for Representative Concentration Pathway) scenarios in CANARI: the RCP 4.5 scenario (or intermediate greenhouse gas emissions reduction target scenario) and the 8.5 scenario (or extreme or pessimistic scenario , absence of a greenhouse gas emission reduction target). Due to climate inertia, the choice of RCP 4.5 or 8.5 will have little impact on the results for the Near Future period (2021-2050). On the other hand, the choice of the RCP 4.5 or 8.5 scenario will be decisive for the calculation of an indicator for the Distant Future period (2051-2100).

- **Why are CANARI indicator calculations offered for multiple climate models?**

CANARI offers the user results for a set of 6 different pairs of simulations. There are two main sources of uncertainty concerning climate projections: the "model" uncertainty linked to the representation of physical processes and the uncertainty associated with greenhouse gas emission scenarios whose effect is significant above beyond 2050. It is therefore recommended to systematically use simulations from several models in order to foresee the possible variability of the results.

- **Does the period of the Recent Past proposed in CANARI correspond to climatic observations?**

The CANARI portal offers the user only climate projections, so there are no climate observations. The values proposed for the Recent Past period in CANARI therefore correspond to climate simulations specific to each of the selected models. However, bias correction methods were applied to the simulations taking into account observations.

7.3 Agricultural impacts

- **What are the observed impacts of climate change on bread wheat yields?**

The last two decades have seen the decline of the upward trend in cereal yield in many European countries, including France. Climate change (heat stress, drought) is one of the major explanatory factors for the stagnation of yields. Recently, the year 2016 completes the list of years where the climate has severely affected yields. Thus, farms must deal with greater interannual variability in yield.

With CANARI, it is possible, for example, to quantify and visualize the evolution of the risk of heat stress (scalding) or water deficit at different periods of the wheat development cycle.

- **What are the observed impacts of climate change in viticulture?**

Since the 1980s, the harvest date has been brought forward by nearly 20 days for most vineyards in France. This progress is due to the average increase in temperatures of about 0.3°C. per decade (i.e. 1.2°C. over a period of 30 years). Thus, the harvest takes place during a warmer period, with consequences on the quality of the wine (degree of alcohol, aromatic profiles, etc.). The higher accumulation of temperatures also results in an earlier start to vegetative growth in the spring, with the consequent exposure to the risk of frost. Finally, the productive potential of the vine is regularly constrained by a growing water deficit, particularly in the southernmost terroirs of France.

With CANARI, it is possible, for example, to quantify and visualize the evolution of the risk of late frost for the vine, the evolution of the water deficit over the crop cycle or even the evolution of the thermal availability in relation to each grape variety.

- **What are the observed impacts of climate change on fodder production?**

Like all cultivated plants, fodder species also benefit from a higher accumulation of degree days with the rise in average temperature in France. This is particularly the case for meadows, the dates for which vegetation resumes, animals are put out to grass, or silage or hay is made tend to advance by several days. The same is true for annual fodder species such as silage corn, the harvest date of which is advancing regularly. In addition, the strengthening of the water deficit over the spring and summer periods causes reductions in the production of fodder to feed the animals.

With CANARI, it is possible, for example, to quantify and visualize the evolution of the dates of recovery of grasslands (grassing, hay, etc.), or even the evolution of the summer water deficit of grasslands or corn silage.

- **What is the risk of thermal discomfort for dairy cows with more intense and more frequent heat waves?**

The cow is poorly adapted to heat since it evacuates it with difficulty by sweating little while it produces a lot itself. Cows show their discomfort in the event of heat stress by visible changes in their behavior: they stay up longer, seek shade and watering points, going so far as to reduce their food metabolism and consequently their level of production. of milk. Thus, a moderate heat wave (5 consecutive days at more than 30°C.) can lead to a drop of 20 to 30% in daily milk production. The issue of heat stress in cows is now a central concern for all breeders.

With CANARI, it is possible, for example, to quantify and visualize the risks of thermal stress according to the time of year, or even to determine the level of thermal discomfort through the different classes of THI (Temperature-Humidity Index).

7.4 A request concerning CANARI?

Users can send all requests concerning CANARI by email: canari@solagro.asso.fr