MINISTERO DELL'AMBIENTE
E DELLA SICUREZZA ENERGETICA

National Plan
of Adaptation to Climate Change

DECEMBER 2022

1 Summary

Attachments

INTRODUCTION AND OBJECTIVES OF THE NATIONAL CLIMATE CHANGE ADAPTATION PLAN

Climate change represents and will represent in the future one of the most relevant challenges to face globally and also in Italy. Italy is located in the so-called "Mediterranean hot spot", an area identified as particularly vulnerable to climate change (IPCC, ARC.6; IPCC ARC.5; EEA 2012). The national territory is also notoriously subject to natural risks (disaster phenomena, floods, coastal erosion, water shortage) and it is already evident today that the increase in temperatures and the intensification of extreme events connected to climate change (droughts, waves of heat, winds, intense rain, etc.) amplify these risks whose economic, social and environmental impacts are destined to increase in the coming decades.

The importance of implementing adaptation actions in the territory to deal with the risks caused by climate change is therefore evident. Since the topic is highly transversal, the planning of adequate actions requires: - a knowledge base of the phenomena that is systematized;

- an optimal organizational context;
- multilevel and multisectoral governance.

The first steps at national level were taken in 2015, when the National Strategy for Adaptation to Climate Change (SNAC) was adopted, which analyzed the state of scientific knowledge on the impacts and vulnerability to climate change for the main environmental and socio-economic and presented a set of proposals and criteria for action to address the consequences of these changes and reduce their impacts. The general objective of adaptation has been broken down in the SNAC into specific objectives to be pursued, indicating as elements of primary importance for implementing an effective adaptation strategy:

• the activation of infrastructures for the exchange of data and analysis on adaptation, as well as the implementation of activities aimed at promoting participation and increasing stakeholders' awareness of the actions;

• the cost/benefit evaluation of adaptation measures;
• the development and implementation of adaptation strategies and plans at different levels;
• the integration of adaptation criteria into sectoral plans and programs (so-called climate mainstreaming) in order to contain the vulnerabilities of natural, social and economic systems to the impacts of climate change;

• regular monitoring and evaluation of progress made at national, sectoral and territorial.

Important directions aimed at pursuing further development and greater effectiveness of national strategies and plans can be found in international and EU documents that deal with the topic of adaptation.

On the occasion of COP-21 in 2015, the Paris Agreement was presented, which entered into force the following year and, in art. 7, establishes the global adaptation objective and provides, in order to achieve it, that each Party engages in adaptation planning processes and the implementation of measures which consist in particular in the development or strengthening of the relevant plans, policies and/or contributions, which may include: (a) the implementation of adaptation measures, programs and/or efforts; (b) the process of formulating and implementing national adaptation plans (art. 7, par. 9).

In 2021 the European Commission presented the new Adaptation Strategy (COM(2021) 82 final of 25 February 2021, Shaping a climate-resilient Europe – The new EU Strategy for adaptation to climate change) which replaces the previous 2013 Strategy. The new Strategy, announced in the European Green Deal, aims to achieve the transformation of Europe into a Union resilient to climate change by 2050 and It is based on four priorities: smarter, more systemic and integrated, faster adaptation, as well as an intensification of international action.

To make adaptation more systemic and integrated, the Commission, reiterating the importance of national adaptation strategies and plans, urges States to make them effective and develop them further, and for its part undertakes to support their development and implementation for all the levels of governance by articulating the approach around three transversal priorities: integration of adaptation into macro-financial policy, nature-based adaptation solutions and local adaptation actions (para. 2.2. of the Strategy). The objectives outlined in the European Strategy are strengthened by the so-called. European climate law (Reg. (EU) 2021/1119 of 30 June 2021) which, by integrating the Paris Agreement and the United Nations 2030 Agenda into EU law, provides that member states adopt and implement strategies and national adaptation plans, taking into account the EU Adaptation Strategy (art. 5, par. 9 of Reg. (EU) 2021/1119).

The Ministry of Ecological Transition (now Ministry of Environment and Energy Security - MASE) has implemented the guidelines contained in the aforementioned international and EU documents and, consistently with them, as well as with the provisions of the SNAC, has undertaken significant initiatives on the topic of adaptation, consisting, in particular, in both the launch of the Platform national plan on adaptation, and in continuing the efforts undertaken since 2017 to achieve the adoption of a national plan on adaptation.

Firstly, in October 2022 the Ministry of Ecological Transition (now the Ministry of the Environment and Energy Security - MASE), in collaboration with the Higher Institute for Environmental Protection and Research (ISPRA), published the Platform national on adaptation to climate change, a portal aimed at informing and raising awareness among citizens and stakeholders on the topic of adaptation and at making data and tools available useful for supporting the Public Administration in decision-making processes. The Platform will be periodically updated and enriched with data and information from different sources and will be updated periodically.

In line with the indications of the European Adaptation Strategy, which aim to achieve smarter adaptation, the National Platform on Adaptation to Climate Change aims to bring together data, information and operational tools and make them easily available to increase knowledge and ability to plan and implement adaptation actions on the national territory.

Secondly, in implementing the guidelines contained in the aforementioned international and EU documents which occurred following the adoption of the SNAC, a specific working group was established in 2022 with the aim of accelerating the activities aimed at approving the Adaptation plan, with the aim of arriving at an instrument with which Italy will provide its contribution to the achievement of the global objective of adaptation to climate change defined by the 2015 Paris Agreement, consisting of: improving adaptation capacity , strengthen resilience and reduce vulnerability to climate change as part of sustainable development and the objective of limiting the rise in global average temperatures.

The main objective of the PNACC is to provide a national framework for the implementation of actions aimed at minimizing the risks deriving from climate change, improving the adaptive capacity of natural, social and economic systems as well as taking advantage of any opportunities that they will be able to present themselves with the new climatic conditions.

PNACC path

The path that the Ministry has decided to undertake to equip itself with a National Adaptation Plan consists of two complementary and consecutive phases: a first phase, which will end, following the SEA procedure, with the approval of the PNACC and, a second phase, which will materialize with the definition of sectoral and inter-sectoral methods and tools for the implementation of the PNACC measures at the different levels of government.

The first phase is characterized by a complex *process* that was started in 2017, as foreseen by SNAC. In 2018, following the sharing of the Plan documents with the State-Regions Conference, the Ministry considered that the drafting of the Plan should take place as part of a structured participatory process, such as that included in the Strategic Environmental Assessment procedure. We therefore proceeded with the verification of eligibility for SEA in 2020 and the *scoping* phase

in 2021, which ended with the communication from the competent Authority, on 3 June 2021, which transmitted the opinion of the Technical Commission for Environmental Impact Verification - EIA and SEA, n. 13 of 3 May 2021.

In 2022, following the reorganization of the ministerial offices and taking into account the results of the process carried out, the Ministry established a specific working group with directorial decree no. 96 of 12 July 2022, for the necessary technical support for the re-development of the Plan, in light of the observations formulated by the Technical Commission for Environmental Impact Verification - EIA and SEA, in the aforementioned opinion no. 13 of 3 May 2021 and the subsequent European legislation.

The adoption, in the first phase, of the text of the PNACC thus reworked responds to a dual need: that of fully implementing the first and necessary systemic action of adaptation, which is represented by the establishment of a specific national governance structure; and that of producing a policy document, aimed at laying the foundations for short and long-term planning for adaptation to climate change, through the definition of specific measures aimed both at strengthening adaptation capacity at national level, through the increase and systematization of knowledge, and the development of an optimal organizational context, which are basic requirements for the definition of effective actions in the territory.

Following the approval of the PNACC, the second phase of the process will open, aimed at guaranteeing the immediate operation of the Plan through the launch of the actions. This phase, which will be managed by the *governance structure,* is aimed at planning and implementing adaptation actions in the different sectors through the definition of priorities, roles, responsibilities and sources/instruments of adaptation financing and, finally, the removal of both obstacles to adaptation constituted by

failure to access to solutions practicable, obstacles is of the Of character legislative/regulatory/procedural.
The results of this activity will converge in sectoral or intersectoral plans, in which the interventions to be implemented will be outlined.

Structure of the PNACC

The management of processes linked to the impacts of climate change, the construction of adaptation methods and the implementation of operational strategies constitute a complex planning activity that requires the sharing of objectives and methods and the preparation of specific governance models. For this reason, the construction of the 2018 Plan document took place following a *bottom-up approach.* The development phase was accompanied by an initial public consultation via questionnaire, aimed at investigating the perception of the various bearers of interest in the topic of adaptation to climate change, contribute to evaluating the possible actions to be undertaken to encourage it and the most effective governance models to achieve it. A second consultation was implemented through the publication of the first draft of the Plan in 2018, in order to collect observations and suggestions from all interested parties. This method completed the further consultation moments dedicated to specific categories of stakeholders, such as the Regions, Research Institutions, Ministries and environmental associations. The various sharing phases made it possible to integrate the Plan and, where appropriate, to modify its contents based on the indications received.

Subsequently, two fundamental needs guided the work for the preparation of the Plan within the SEA procedure: the urgency of responding to the climatic criticalities found in Italy and the impacts already underway in our territory; the need to take into account the observations and indications provided by the Competent Subjects in environmental matters during the SEA procedure.

The PNACC contains a set of actions aimed at developing an optimal organizational context at a national level, as well as strengthening adaptive capacity, essential prerequisites for correct planning of effective actions. Furthermore, it contains a set of sectoral actions, presented through a Database, which will be applied in the sectoral and intersectoral plans, in the ways that will be identified by the *governance structure.*

PNACC sectors

Sectors
Cryosphere and mountains
Water resources
Desertification and land degradation
Geological, hydrological and hydraulic instability
Biodiversity, ecosystems and ecosystem services
- terrestrials
- marine
- internal and transitional waters
Health
Forests
Agriculture and food production
Sea fishing
Aquaculture
Power
Coastal areas
Tourism
Urban settlements
Cultural heritage
Transport and infrastructure
Dangerous industries and infrastructures

The structure of the PNACC is structured as follows:

1. The legal framework of reference
2. The national climate framework
3. Impacts of climate change in Italy and sectoral vulnerabilities
4. Adaptation measures and actions
5. Adaptation governance.

This Plan is also accompanied by two guidance documents for the definition of regional and local strategies/plans for adaptation to climate change: the *"Methodologies for the definition of regional strategies and plans for adaptation to climate change"* and the *"Methodologies for the definition of local strategies and plans for adaptation to climate change".* These documents, based on international and European experiences and the methodological tools available at regional and local level, outline an organic framework of reference for adaptation by outlining: possible governance frameworks and intervention models at regional and local scale; guidelines for defining impacts and vulnerabilities to climate change; methods of identifying territorial priorities, defining and implementing adaptation actions also starting from ordinary and sectoral planning tools as well as through the financing tools of community and regional programming; elements to support the Covenant of Mayors initiative for climate and energy at a local level.

The aforementioned guidance documents derive from the activities carried out, with the coordination of the Ministry of the Environment and Energy Security, within the CReIAMO PA Project (PON Governance and Institutional Capacity 2014-2020) and produced by Line 5 of the project dedicated to *" Strengthening administrative capacity for adaptation to climate change",* published in 2020 and updated in 2022. They are also the result of extensive comparison and sharing of experiences developed with the various Regions and Local Authorities that have widely participated in the activities line.

1 THE LEGAL FRAMEWORK OF REFERENCE

1.1 The application of rules and principles developed in environmental matters and for the purposes of safeguarding human rights to the issue of climate change

The topic of the current and expected impacts of climate change on natural systems, on humans and on socio-economic sectors, and of adaptation measures to climate change, falls largely, although not exclusively, within environmental matters.
From a legal point of view, the topic of climate change must be framed mainly within the context of environmental law, but also has connections with other branches of law including, in particular, energy law.

The rules and principles that inform environmental matters in general are applicable, to the extent relevant, also to the topic of climate change. These are, in particular, the prohibition on causing damage on the territories of neighboring states, the obligations of emergency information, the obligation - in some cases - to carry out an environmental impact assessment, the principles of prevention , of precaution, "the polluter pays", of common but differentiated responsibilities and respective capacities, of intergenerational and intragenerational equity, of sustainable development, of non-regression, and of some principles that are applied mostly in the context of the European Union, such as the principles of integration, solidarity, the prohibition of causing significant damage to the environment (DNSH).
Equally relevant are the rules that provide for the so-called individual rights of a procedural nature, such as the right of access to environmental information, the right to participate in decision-making processes and the right of access to justice.
In addition to the rules and principles formed within the framework of environmental law, the rules and principles established to safeguard human rights must be considered applicable to the issue of climate change, where relevant: climate change, in fact, can have repercussions on the rights of man (e.g. to health, to life, to private and family life, to property), as can be seen from the large number of proceedings brought before national and international judges (e.g. before the Court European Human Rights Council) concerning the impact of climate change on human rights.

1.2 The acts adopted at international level that specifically concern the topic of adaptation to climate change

The United Nations Framework Convention on Climate Change (UNFCCC)
The first fundamental agreement adopted by the international community to address the issue of climate change is the United Nations Framework Convention on Climate Change (UNFCCC) opened for signature at the United Nations Conference on Environment and Development, held in Rio de Janeiro from 3 to 14 June 1992, and entered into force on 21 March 1994, which was ratified by 198 Parties including Italy, which did so with law. 15 January 1994, n. 65 (in the Official Journal of 29 January 1994, n. 23), and the European Union, which formally approved it in 1994.
The UNFCCC pursues the objective of stabilizing climate-changing gas emissions and at the same time requires States to adopt adaptation measures: it provides, programmatically, that States implement and update national and, where appropriate, regional programs, to implement adaptation to climate change (articles 3.3; 4.1 letter b; 4.1 letter e; 4.4).

The Kyoto Protocol and the Doha Amendment
The Kyoto Protocol to the United Nations Framework Convention on Climate Change was opened for signature on 11 December 1997, entered into force on 16 February 2005, and was ratified by

192 Parties including Italy, which provided for this with law. 1 June 2002, n. 120 (in the Official Gazette of 19 June 2002, no. 142), and the European Union, which formally approved it on 31 May 2002. The deadline for the effectiveness of the Kyoto Protocol was set at 13 December 2012 (first period of commitment of the Kyoto Protocol).

In addition to having introduced legally binding objectives for the reduction of climate-changing emissions for the most developed countries and other aspects relating to mitigation, the Kyoto Protocol also contains provisions on adaptation: in particular, referring to the content of the UNFCCC, it establishes that the States are called upon to implement national and regional adaptation programs (articles 10.1 letter b; 10.1 letter b (i); 10.1 letter b (ii); 12.8).

With the Doha Amendment to the Kyoto Protocol adopted on 8 December 2012, which entered into force on 31 December 2020 and ratified by 148 Parties including Italy, which did so with law. 3 May 2016, n. 79 (in the Official Gazette of 25 May 2016, no. 121), and the European Union, which formally approved it on 21 December 2017, the effectiveness of the Kyoto Protocol was extended until 31 December 2020, with some related changes – among other things – to the forecasting of different reduction objectives (second period of
commitment of the Kyoto Protocol). Even before the entry into force of the Doha Amendment, some States decided to proceed with the provisional application of this instrument.

The Paris Agreement

The Paris Agreement linked to the UNFCCC was adopted in Paris on 12 December 2015 at COP-21, opened for signature on 22 April 2016, entered into force on 4 November 2016, and ratified by 194 Parties, including the Italy, which provided for this with law. 4 November 2016, n. 204 (in the Official Gazette of 10 November 2016, n. 263), and the European Union, which formally approved it on 5 October 2016
The Paris Agreement is a universal international treaty that establishes the global legal framework to address the causes and impacts of climate change for the post-2020 period.
It constitutes the main instrument with which the subject of climate change is currently regulated on an international level.

The heart of the Paris Agreement are the *Nationally Determined Contributions (NDCs),* which represent the commitments undertaken by the States Parties to reduce emissions and adapt to climate change and communicated by them periodically to the UNFCCC. With their communications, States indicate how they intend to contribute to achieving the general objective set by the Paris Agreement of limiting the increase in average global temperature to within 2°C, supporting every effort to contain it to within 1.5°C, compared to pre-industrial levels. The Parties shall also periodically submit to the UNFCCC a communication relating to adaptation, which may be included in other communications or documents.

The overall objective of adaptation is specifically established in the art. 7, in turn divided into 14 paragraphs in which multiple aspects of adaptation to climate change are addressed, from being a global objective for the States parties, to its nature as a global challenge within the context of multilevel governance in a local dimension , subnational, national, regional and international to give a long-term response to the problem of protecting populations, the living environment and the ecosystem. It is also envisaged that all Parties shall, where appropriate, implement national adaptation planning processes.

The 2030 Agenda and the Sustainable Development Goals

The 2030 Agenda with the annexed 17 Sustainable Development Goals is a global action program for people, the planet, prosperity, peace and partnership (so-called 5P) approved with Resolution of

25 September 2015 unanimously adopted by the United Nations General Assembly *(Transforming Our World: the 2030 Agenda for Sustainable Development* – UN Doc. A/RES/70/1).
The 2030 Agenda defines 17 Sustainable Development Goals (SDGs), divided into 169 *targets,* to be achieved by 2030 and constitutes a strategic platform suitable for orienting public policies and horizontal and inter-sectoral sustainability actions, integrated into the environmental, economic and social: the 2030 Agenda and the 17 SDGs have thus become an international framework of reference for sustainable development, understood in its three dimensions of economic growth, protection of social rights and environmental protection.

The 2030 Agenda, expressly recognizing the role of the UNFCCC as the main international and intergovernmental forum for negotiating the global response to climate change, addresses this issue both extensively within Objective 13 *(Promote action, at all levels , to fight climate change)* in turn divided into 5 *targets,* with regard to mitigation and adaptation actions; both in the context of other Objectives among which, in terms of adaptation, Objective 11 *(Make cities and human settlements inclusive, safe, durable and sustainable) takes on particular importance,* which aims at greater resilience of cities compared to climate changes.

The Sendai Framework for Disaster Risk Reduction
The Sendai Framework for Disaster Risk Reduction 2015-2030 adopted in Sendai on 18 March 2015 at the Third United Nations World Conference on Disaster Risk Reduction (WCDRR), *Sendai Framework for Disaster Risk Reduction* 2015 -2030), and approved by the United Nations General Assembly on 25 June 2015 (UN Doc. A/RES/69/284), provides a significant contribution to the discipline relating to disaster risk - both natural and man-made – and at the same time intersects adaptation in many ways, integrating with it.

It expressly provides that States must adopt all necessary measures to prevent and reduce the risk of disasters and that, in this regard, States and other *stakeholders* must promote and protect human rights.

1.3 The acts adopted at European Union level which specifically concern the topic of adaptation to climate change

The legal basis for climate action at European level
The legal basis for EU intervention in environmental and climate matters is constituted by art. 192 TFEU which, for the achievement of the objectives set out in these matters by art. 191 TFEU, provides that the European Parliament and the Council decide according to the ordinary or special legislative procedure. The art.
193 TFEU, then, is without prejudice to the higher levels of protection, compared to those of the EU, possibly provided for in the member states, provided that the measures adopted at national level are compatible with the Treaties.

Main acts and initiatives of the European Union The
European Union presents itself as the leading body and main advocate of climate action at a global level. In addition to having promoted the adoption of important multilateral instruments and having formally approved the main ones, it has undertaken numerous internal initiatives and has issued, within the scope of the competences attributed to it, a large number of acts, partly binding, in part without binding effect, through which it aims to address the causes and impacts of climate change.

Here we briefly recall the main acts that concern, specifically or in part, aspects related to adaptation to climate change, following a chronological order:

- in 2000 the European Climate Change Program (ECCP) was launched; • in 2003, the adoption of Directive 2003/87 which established the EU ETS was implemented, with which the EU policy on climate change was concretely implemented; • in 2008 the European Commission officially established the Covenant of Mayors and in 2014 launched the "Mayors Adapt" initiative as a key action of the EU Climate Change Adaptation Strategy in force at the time, to involve and support the authorities local authorities in actions relating to mitigation and adaptation to climate change. This initiative entered its current phase in 2016 with the name of the Covenant of Mayors for Climate and Energy, subsequently further revised in light of the combined targets of reduction of polluting emissions for 2030 and 2050, climate adaptation and resilience, fight to energy poverty envisaged by the EU 2021 Strategy, the commitments of the Paris Agreement and the European Green Deal;

- in 2012, under a partnership between the European Commission and the European Environment Agency, the Climate-ADAPT Platform was launched (https://climate-adapt.eea.europa.eu), aimed at supporting the EU in adaptation, by supporting users in accessing and sharing climate data and information;

- in 2013 the Commission adopted the first European Strategy specifically focused on adaptation (EU Strategy for Adaptation to Climate Change, COM(2013) 216 final of 16 April 2013), subsequently replaced by the new 2021 Strategy;
- in 2018, Regulation (EU) 2018/1999 on the governance of the Energy Union and climate action was issued, which, although mainly focused on mitigation, contains some provisions relevant to adaptation;

- with Communication from the European Commission COM(2019) 640 of 11 December 2019, the "European Green Deal: Climate-neutral, fair and prosperous EU growth strategy" was adopted, through which the EU aims to to become a fair, healthy, sustainable and prosperous society and to heal the way in which we interact with nature, ensuring - with regard to climate change - that the result of net zero emissions is achieved by 2050 and reaffirms its commitment to the topic of adaptation (par. 2.1.1);

- Regulation (EU) 852/2020 of the European Parliament and of the Council of 18 June 2020 established a framework that promotes sustainable investments (so-called "Taxonomy Regulation") which contemplates six environmental objectives, among which adaptation is included to climate change. The Regulation establishes the principle which provides for the prohibition of causing significant damage to the environment (Do No Significant Harm - DNSH) or significant damage to the six objectives in question, including, therefore, adaptation;

- with Communication COM(2020) 788 final of 9 December 2020, the Commission launched the European Climate Pact, an initiative that - focusing on raising awareness and supporting action - aims to engage different stakeholders and civil society to commit to climate action and more sustainable behaviour;

- with Communication COM(2021) 82 final of 24 February 2021, the Commission approved the new Adaptation Strategy "Shaping a Europe resilient to climate change - The new EU strategy for adaptation to climate change" which replaces the previous Strategy of 2013.

  The new Strategy sets out how the European Union can adapt to the inevitable impacts of climate change and become climate resilient by 2050. It sets 4 objectives

  adaptation principals to be achieved through actions aimed at improving knowledge and manage uncertainties: 1. Smarter and more intelligent adaptation: push the knowledge of adaptation. Improve the quality and quantity of data collected on climate-related risks and losses, making it available to all. Strengthen and expand the Climate-Adapt Platform, which will be supported by an Observatory to improve understanding of climate-related health risks; 2. Systemic and integrated adaptation: in macro-fiscal policy, nature-based solutions, local adaptation actions; 3. Faster adaptation; 4. intensify international action on adaptation to climate change;

• Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 which establishes the framework for achieving climate neutrality (so-called "European Climate Law"), in implementing the objectives set out in the European Green Deal , established the binding objective of climate neutrality in the Union by 2050 and established a

framework to progress in pursuit of the global adaptation goal, thus integrating the content of the Paris Agreement and Agenda 2030 (in particular Goal 13) into the legal framework of the European Union. In the art. 5, entitled "Adaptation to climate change", outlines the role played by the EU institutions and Member States in ensuring continued progress in improving adaptive capacity, strengthening resilience and reducing vulnerability to climate change in

compliance with the art. 7 of the Paris Agreement. The progress made by the States is subject to evaluation by the Commission, pursuant to the following articles. 6 and 7, which, where it judges the progress achieved to be insufficient or the measures introduced by the States to be inconsistent, can adopt the necessary measures in accordance with the treaties, in particular it can formulate recommendations;

• on 14 July 2021 the European Commission presented the package of proposals "Ready for 55%" (known as the "Green Package") aimed at achieving the objectives of reducing emissions by 55% compared to 1990 levels by 2030, indicated in the Green Deal and made binding by the European Climate Law, and also contains relevant elements for adaptation.

Other acts: programming of European funds and climate "tagging" in the EU budget As the EU 2021 Adaptation Strategy itself reports, "in its long-term budget for the period 2021-2027, the EU has increased the spending target for of climate action by 30%, with adaptation as a key component" (p. 14), thus aiming to make a fundamental contribution to the fight against climate change.

According to the Commission's most updated estimates, in the 2014-2020 period the EU budget has already allocated 220.9 billion euros (20.60%) to the fight against climate change, while for the 2021-2027 cycle the EU budget The EU, including NextGenerationEU, is expected to allocate €557 billion, or 32%, to climate spending[1] . This means that in the overall long-term EU budgetary forecast (MFF), each EU Member State must allocate a set share of the funds allocated to it to projects that contribute to achieving the EU's climate (and digital) objectives. were assigned overall.

Precisely the following can be highlighted:

A) «Tagging» in the Funds foreseen in the 2021-2027 programming cycle.

Reg. (EU) 2021/1060 which contains common provisions on ESI funds for the period 2021-2027, in art. 6 "Climate objectives and climate adjustment mechanism", provides that *"...The ERDF and the Cohesion Fund contribute respectively to 30% and 37% of the Union's contribution to the expenditure incurred for the achievement of the climate objectives set for the Union budget".*

1 https://commission.europa.eu/strategy-and-policy/eu-budget/performance-and-reporting/mainstreaming_it

The preliminary financial allocation of the ERDF for Italy, equal to 26.34 billion euros, is therefore allocated 30%, equal to 7.9 billion euros, to the achievement of climate objectives.

B) «Tagging» in the Funds provided for by Next Generation EU within the RFF (and PNRR).

The Recovery and Resilience Device, which is the fulcrum of the Next Generation EU, states in art. 18, par. 4, letter. e) and f), the principle of contribution to the climate and digital objective (so-called tagging).

RFF makes resources available to Italy amounting to 191.5 billion euros, to be used in the period 2021-2026 in investment and reform projects planned on the basis of the PNRR.

37.5% of resources, equal to 71.7 billion euros, must be used to support climate objectives. 15% of this amount, in turn, is allocated to climate change adaptation measures.

1.4 The acts adopted at national level that specifically concern the topic of adaptation to climate change

Environmental protection in the fundamental principles of the Constitution

Following the changes introduced with constitutional law 11 February 2022, n. 1, environmental protection is expressly included among the fundamental principles of the Italian Constitution: art. 9, paragraph III, of the Constitution establishes that «The Republic [...] Protects the environment, biodiversity and ecosystems, also in the interests of future generations».

Acts that specifically address the topic of adaptation

The National Strategy for Adaptation to Climate Change (SNAC) is the act expressly aimed at addressing the issue of adaptation at a national level. It was adopted in Italy with Directorial Decree of 16 June 2015, n. 86, issued by the Director General of the former DG Climate and Energy of the Ministry of the Environment and Protection of Land and Sea (now the Ministry of Ecological Transition).

The SNAC:

identifies the main impacts of climate change on environmental resources and on a set of socio-economic sectors relevant at a national level;

provides a national strategic vision indicating for each of them the first proposals for adaptation actions to these impacts.

In the SNAC the general objective of adaptation is broken down into four specific objectives which concern:

1. the containment of the vulnerability of natural, social and economic systems to the impacts of climate changes
2. the increase in their ability to adapt
3. improving the exploitation of any opportunities
4. coordination of actions at different levels

It constitutes a tool for integrating adaptation actions into planning activities at national, regional and local levels.

The long-term Italian strategy on the reduction of greenhouse gas emissions adopted in January 2021 (Ministry of the Environment and Protection of Land and Sea, Ministry of Economic Development, Ministry of Infrastructure and Transport, Ministry of Agricultural Policies, Food and Forestry), developed within the commitments of the Paris Agreement which invites the countries signatories to communicate their "Long-term development strategies with low greenhouse gas emissions" to 2050 by 2020, and is based on three fundamental guidelines: 1. Reduction in energy demand, thanks above all to the decline in private mobility and consumption in the civil sector; 2. Decisive acceleration of renewables and hydrogen production; 3. Strengthening and improving green surfaces, to increase the CO_2 absorption capacity. It contains numerous references to adaptation and a chapter dedicated specifically to “Adaptation policies and measures”;

The Plan for the Ecological Transition (PTE) approved by the Interministerial Committee for the Ecological Transition (CITE), with resolution 1/2022 of 8 March 2022, which integrates with the PNRR, constitutes a coordination and updating tool for a series of environmental policies, including those relating to mitigation and adaptation to climate change. The PTE includes adaptation to climate change among the five environmental policy macro-objectives shared at European level.

Further acts that are relevant in terms of adaptation

Significant aspects for the topic of adaptation can be found, among others, in the framework of various acts that have a transversal or sectoral character, such as the TU Environment (Legislative Decree 3 April 2006, n. 152); the National Strategy for Sustainable Development (presented to the Council of Ministers on 2 October 2017 and adopted with CIPE Resolution 22 December 2017, no. 108, being revised in 2022); the Protect Italy Plan for the three-year period 2019-2021 (National plan against hydrogeological instability, for the safety of the territory and for risk prevention works, 27 February 2019); the Climate Decree (DL 14 October 2019, n. 111) which introduced provisions aimed, mainly, at the definition of a national strategic policy to combat climate change and improve air quality; the National Integrated Plan for Energy and Climate (PNIEC) prepared pursuant to Regulation (EU) 2018/1999 on the governance of the Energy Union and presented in December 2019, on which the European Commission expressed its opinion on 14 October 2020 (SWD(2020)911 final); the National Recovery and Resilience Plan (PNRR), presented on the basis of the Recovery and Resilience Device (in the framework of the Next Generation EU) and definitively approved on 13 July 2021 with Implementing Decision no. 10160/21 of the ECOFIN Council.

1.5 The regional and local dimension of adaptation to climate change

1.5.1 The regional level

At a regional level, numerous types of acts can contribute to achieving the objectives of adaptation to climate change:

a) Acts specifically dedicated to climate issues: for example regional Strategies, Plans and Action Documents specifically aimed at adaptation or joint ones for mitigation and adaptation to climate change.

b) Territorial or sector planning documents that directly address the adaptation issue or define interventions and measures that influence adaptation processes: e.g.
Regional energy plans, Regional forestry plans, Regional water protection plans, Coastal plans, Regional Air Quality Plans, Civil protection and multi-risk prevention plans, Social and health plans, Regional strategies for the fight against desertification.

c) Integration of adaptation into regional sustainable development strategies. Pursuant to art. 34 of the TU Environment: *«the Regions ensure unity in planning activity... they ensure the dissociation between economic growth and its impact on the environment... the satisfaction of the social requirements connected to the development of individual potential as necessary prerequisites for the growth of competitiveness and employment".*

d) Acts of economic-financial planning and use of regionally managed funds (e.g. POR, DEFR) for the funding of initiatives for the localization of adaptation actions in specific areas of the regional context and for particular climate problems;
e) Regional guidelines and other initiatives such as the adoption of guidelines for the integration of adaptation criteria in the EIA/SEA and generally in climate coherence assessments of plans and projects at a regional and local scale.

This list of instruments must obviously include conventions and collaborative agreements of different nature between several regions of the same geographical area (cross-border areas, Apennine and Alpine regions) as well as intervention and planning programs for interconnected areas such as river basins, areas wetlands and internal bodies of water, protected areas, etc.

1.5.2 The local level

At a local level there are various tools that can make a contribution to the process of adapting to climate change, some of a voluntary nature such as municipal adaptation plans, sustainability and climate resilience plans or strategies, urban agenda programmes, Action Plan for Sustainable Energy and Climate (SECAP-SECAP) adopted in the framework of the new Covenant of Mayors. Added to these are tools that can be developed in an "adaptive" key deriving from specific territorial governance skills and planning of activities on a local scale, such as the Urban Plans for Sustainable Mobility (PUMS) at municipal and large area levels, the urban green spaces, municipal emergency plans, *«climate proof» building regulations,* general urban plans, strategic plans and metropolitan territorial plans.

The initiatives taken within the networks of cities and municipalities are also relevant for achieving the adaptation objectives, such as, for example:

- those concerning the Budoia Charter for adaptation in the Alps (2017) which sees the participation of the municipalities belonging to 7 states of the Alpine arc;
- those concerning the Charter of the Apennines (2018) presented in Camerino, which sees the participation of the Municipalities of the Apennines;
- those concerning the Bologna Charter, signed by all metropolitan mayors in June 2017, and further developed on the initiative of the Ministry of the Environment as part of the CReIAMO PA project which, starting from 2019, has started a path of collaboration and support for metropolitan cities for the drafting of Metropolitan Agendas for Development Sustainable;
- those of the international network ICLEI – Local Governments for Sustainability;
- the transversal ones carried out within the framework of the «Making Cities Resilient 2030» (MCR2030) initiative by the UNDRR (United Nations Office for Disaster Risk Reduction);
- those concerning initiatives supported by the EU Commission (EIT Climate-KIC) or promoted within European project networks (Horizon Europe, LIFE, Interreg, UIA, ESPON, ELENA).

It should also be remembered that adaptation paths and intervention approaches can concern experiences of negotiated planning (river and lake contracts) and planning of services in interconnected areas intended to host natural assets, civil and productive infrastructures strategic for the economy and life of multiple territories and local communities (integrated management and coastal protection plans, port and airport development plans, park management plans, socio-health district plans, etc.).

2 THE NATIONAL CLIMATE FRAMEWORK

This chapter updates what was reported in the previous version of the document by accepting the observations received from the SEA Subcommission (but also taking into account the specific observations of the SCAs) for the part relating to the current state of the climate and future climate projections.

Specifically, in order to support the mapping of environmental critical issues and the specificities of the context at a regional and local scale with a greater number of information, 27 climate indicators were considered (previously the analysis was based on 10 indicators) put into relationship with certain dangers (see **Table XX** of the reference indicators for details). Furthermore, in relation to the observations received regarding the inadequacy of the macro-regional analysis, it was deemed appropriate to update the climate analysis which does not provide for any type of grouping into homogeneous areas. For future projections, a climate framework was developed based on an ensemble of different climate models produced by the international scientific community which also made it possible to include in the document an assessment of the uncertainty for the different climate indicators considered.

As regards the data on the Mediterranean, the projections presented are based on a single model and are therefore not accompanied, at this stage, by an estimate of uncertainty. For completeness of information, reference can be made to the work recently published by ENEA (Sannino et al., 2022)2 which illustrates the evolution of sea level in the Mediterranean through a new model.

The national climate framework reports the climate analysis on the reference period 1981-2010 and the expected climate variations over the thirty-year period centered on the year 2050 (2036-2065), compared to the same period 1981-2010, considering the three IPCC scenarios: RCP8.5 “Business as usual”, RCP4.5 “Strong mitigation”, RCP2.6 “Aggressive mitigation”. For the climate over the reference period, the gridded dataset of E-OBS observations (Cornes et al., 20183 ; Haylock et al., 20084) version 255 at a resolution of approximately 12 km was used. while the expected climate variations were obtained starting from an *ensemble* of climate models available within the EURO-CORDEX program (Hennemuth et al., 20176 ; Jacob et al., 20207 at the highest resolution available (about 12 km)8 . As a reference, the period 1981-2010 was used as the simulations relating to the IPCC "historical experiment" scenario are available until 2005. To estimate future variations, the reference period was therefore obtained using the "historical experiment" simulations for the period 1981-2005, and data based on the IPCC RCP4.5 scenario for the period 2006-2010. Therefore, the period 1981-2010 was also considered for the analysis of the observed climate for the most recent period 1991-2020, please refer to the ISPRA reports, described in detail in paragraph 2.1.

---

[2] Sannino, G., Carillo, A., Iacono, R. et al. Modeling present and future climate in the Mediterranean Sea: a focus on sea-level change. Clim Dyn 59, 357–391 (2022). https://doi.org/10.1007/s00382-021-06132-w

[3] Cornes, R.; van der Schrier, G.; van den Besselaar, EJM; Jones, P. D. An ensemble version of the E-OBS temperature and precipitation datasets. J. Geophys. Atmos. Res. 2018, 123, 9391–9409, doi:10.1029/2017JD028200

[4] Haylock, M.R.; Hofstra, N.; Klein Tank, AMG; Klok, E.J.; Jones, P.D.; New, M. A European daily highÿresolution gridded data set of surface temperature and precipitation for 1950–2006. J. Geophys. Atm. Res. 2008, 113, doi: 10.1029/2008jd010201

5 The version 25 used is the one currently available on the Copernicus C3S platform (https:// cds.climate.copernicus.eu/cdsapp#!/dataset/insitu-gridded-observations-europe?tab=overview)

6 Hennemuth, Tamás Illy, et al. “Guidance for EURO-CORDEX climate projections data use.” Version1. 0-2017.08. Retrieved on 6 (2017): 2019.

7 Jacob, D., Teichmann, C., Sobolowski, S. et al. Regional climate downscaling over Europe: perspectives from the EURO-CORDEX community. Reg Environ Change 20, 51 (2020). https://doi.org/10.1007/s10113-020-01606-9

8 Among the different models available in the EURO-CORDEX program at 12 km resolution, those currently available for consultation on the Copernicus C3S platform have been selected (https://cds.climate.copernicus.eu/cdsapp#!/ dataset/projections -cordex-domains-single-levels?tab=overview)

Climate change, as reported by the extensive IPCC literature, induces complex variations in climate characteristics on different spatial and temporal scales. In fact, it influences both the frequency, intensity, spatial extension and duration of extreme meteorological events, as well as phenomena such as sea level rise, which affect larger space-time scales[9] . When these variations in the different characteristics of the climate assume such an extent that they can cause negative impacts on environmental and socioeconomic systems, they are typically defined as "climate dangers".

Therefore, climate danger constitutes a fundamental element for the study and assessment of climate risk. In particular, understanding the characteristics of the climate danger (which can be counterintuitive and complex) is fundamental for a correct and adequate definition of adaptation strategies[10] .

Specifically, to characterize the spatial and temporal evolution of the climate danger, climate indicators are usually used which describe specific aspects of the climate (both in terms of average values and in terms of extremes) considered relevant for the study of the impacts of interest for the National territory. However, it is important to note that climate indicators can have a different information content depending on the dynamics of interest but they remain a method

expeditious which cannot replace the analysis of impacts through the adoption of physically based models (EEA 2009[11]; EEA 2018[12]; EEA 2019[13]).

The evaluation of the 27 climate indicators considered (two of which relating to the marine-coastal area) represents a first step to identify priorities and intervention strategies at the level of national geographical areas. The set of indicators analyzed is reported in greater detail in **Table XX.**
For each indicator the following information was reported:

- the definition of the climate indicator;
- the atmospheric variables on which it is based;
- the units of measurement of the indicator and its variation;
- the time scale on which the indicator is evaluated (seasonal/annual);
- the bibliographical references from which the definition of the indicator was derived;
- the climate danger to which the indicator is correlated (based on what has been elaborated by similar studies available in the literature);
- the sector mainly and potentially affected by the aforementioned climate danger.

These indicators were calculated both in absolute terms, as average values over the reference period (paragraph 2.1), and in terms of variation between the selected future period and the reference one, using different concentration scenarios and multiple climate models (paragraph 2.3) .

In paragraph 2.3, however, the description of the present and expected climatic conditions in the marine/coastal areas is reported, considering two primary variables to describe the impact of the evolution of the climate on the Italian seas: the surface temperature of the water and the sea level .

9 ~~https://www.ipcc.ch/site/assets/uploads/2018/03/SREX-Chap3_FINAL-1.pdf~~

10 ~~https://www.ipcc.ch/report/managing-the-risks-of-extreme-events-and-disasters-to-advance-climate-change-adaptation/~~

11 European Environmental Agency (EEA): Regional Climate Change and Adaptation: The Alps Facing the Challenge of Changing Water Resources. https://www.eea.europa.eu/publications/alps-climate-change-and-adaptation-2009, 2009

12 European Environment Agency (EEA): National climate change vulnerability and risk assessments in Europe, EEA Report No 1/2018. https://www.eea.europa.eu/publications/national-climate-change-vulnerability-2018, 2018

13 European Environment Agency (EEA): Spatial distribution of extreme temperature indicators across Europe, 2019

2.1 Analysis of the climate over the reference period

The climate analysis over the reference period 1981-2010 was carried out using the E-OBS gridded observational dataset. This dataset provides daily precipitation, temperature and humidity data on a regular grid with a horizontal resolution of approximately 12 km (0.1° x 0.1°) over the entire national territory. Although this dataset is widely used for the study of climate characteristics and is constantly updated and improved14 in the European area, it is important to underline that it presents some limitations due to the accuracy of the data interpolation, which, in particular, is reduced as the of the density of the number of stations, as happens in southern Italy and in areas with complex orography. This dataset was selected as it is the one that currently makes the greatest number of observed variables available,

spatialized over the entire national territory, however, also in this case it was possible to evaluate only 22 of the 25 climate indicators analyzed for the land part, selected for the carrying out. It is however important to report that at a national level, of the current work and reported in **Table** XX15 .
There are also other sources of data that can be used for regional/local studies.
For example, the national system for collecting, processing and disseminating climate data, SCIA (www.scia.isprambiente.it), created by the Higher Institute for Environmental Protection and Research (ISPRA) and powered in collaboration and with data from the National Environmental Protection System (SNPA) and the main monitoring networks distributed throughout the national territory, responds to the need to harmonize and standardize processing methods and to make available data, indices and indicators useful for representing and evaluating the state, variations and trends of the climate in Italy. Based on time series of observations from different monitoring networks, ten-year, monthly and annual statistics are calculated and represented. Furthermore, the climate data series are subjected to validity checks with homogeneous methodologies, according to the guidelines of the World Meteorological Organization (WMO).

Figure 1 shows the average seasonal values, in the thirty-year period 1981-2010, of total precipitation and average temperature. In terms of total precipitation in the Italian peninsula, the highest values are recorded during the autumn season, especially in Liguria and Friuli Venezia Giulia; the geographical areas of Southern Italy and the Islands, however, are the least rainy, particularly in the summer season. In terms of average temperature, the lowest values are recorded in all seasons along the mountain ranges of the Alps and the Apennines. The strong orographic difference is highlighted perfectly in the summer season by the distribution of average temperature values.

In addition to the average values of cumulative precipitation and average temperature, the average annual/seasonal values of various climate indicators useful for understanding the evolution of specific climate dangers were calculated over the reference period 1981-2010 (for more details on the indicators see see **Table** XX). For this purpose, Figure 2 shows the spatial distribution, relative to the reference period 1981-2010, for the indicators considered most relevant16 also in relation to their representativeness of the expected climate dangers. On the peninsula, the maximum values of the drought indices (in terms of percentage occurrence of the extreme drought class) are recorded in the areas north-

14 Description of the improvements made in the configuration used in this document compared to previous versions https://surfobs.climate.copernicus.eu/dataaccess/access_eobs.php
15 In particular, the quantity of surface snow and the intensity of the maximum daily wind are not available in this dataset.
16 For a more complete view of the data, refer to the platform http://climadat.isprambiente.it/pnacc/dati-indicatori-mappe-pnacc/

west of the nation and values tend to decrease moving south. The maximum values of daily precipitation was recorded in Liguria, on the border between Emilia-Romagna and Tuscany, and in Friuli-Venezia Giulia on the border with Slovenia; these areas, together with the Piedmont Alps, are also those which on average in the reference period recorded the greatest number of days with rainfall exceeding 20 mm.

The north-east of Italy presents, in the reference period, the highest values of the heat period duration index.

Finally, Table 1 and 2 show respectively the average annual values of the average temperature and cumulative precipitation and the seasonal values of the calculated indicators, divided by geographical area in order to evaluate the main impacts of interest. Furthermore, in the “+/-SD” columns, the standard deviation is reported, as an estimate of the spatial variability of the selected indicators within the geographical area. Table 1, for cumulative precipitation, highlights that autumn is the season with the highest precipitation accumulations in the three geographical areas (North East, North West and Centre), while winter is the rainiest for the South and the islands; the standard deviation, on the other hand, clearly shows the orographic complexity of the areas.

Table 2 shows how the areas of Central and Northern Italy are those where the precipitation values, both in terms of accumulations and intense events, are greater, as opposed to temperatures which follow the opposite trend. Despite the higher values of total average annual precipitation, the geographical areas of the North-East and North-West are those which have recorded the highest percentages of drought, with an areal dispersion of a few percentage points.

All figures and tables were created by the CMCC Foundation.

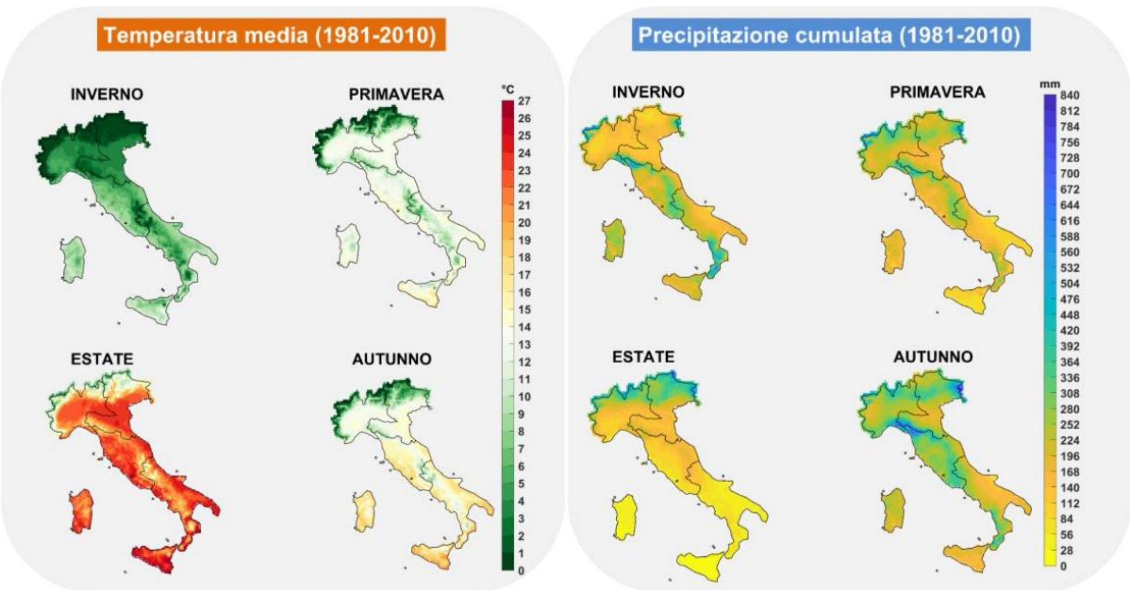


Figure 1: Seasonal average values of average temperatures and cumulative precipitation over the reference period 1981-2010 starting from the E-OBS v25 gridded dataset.

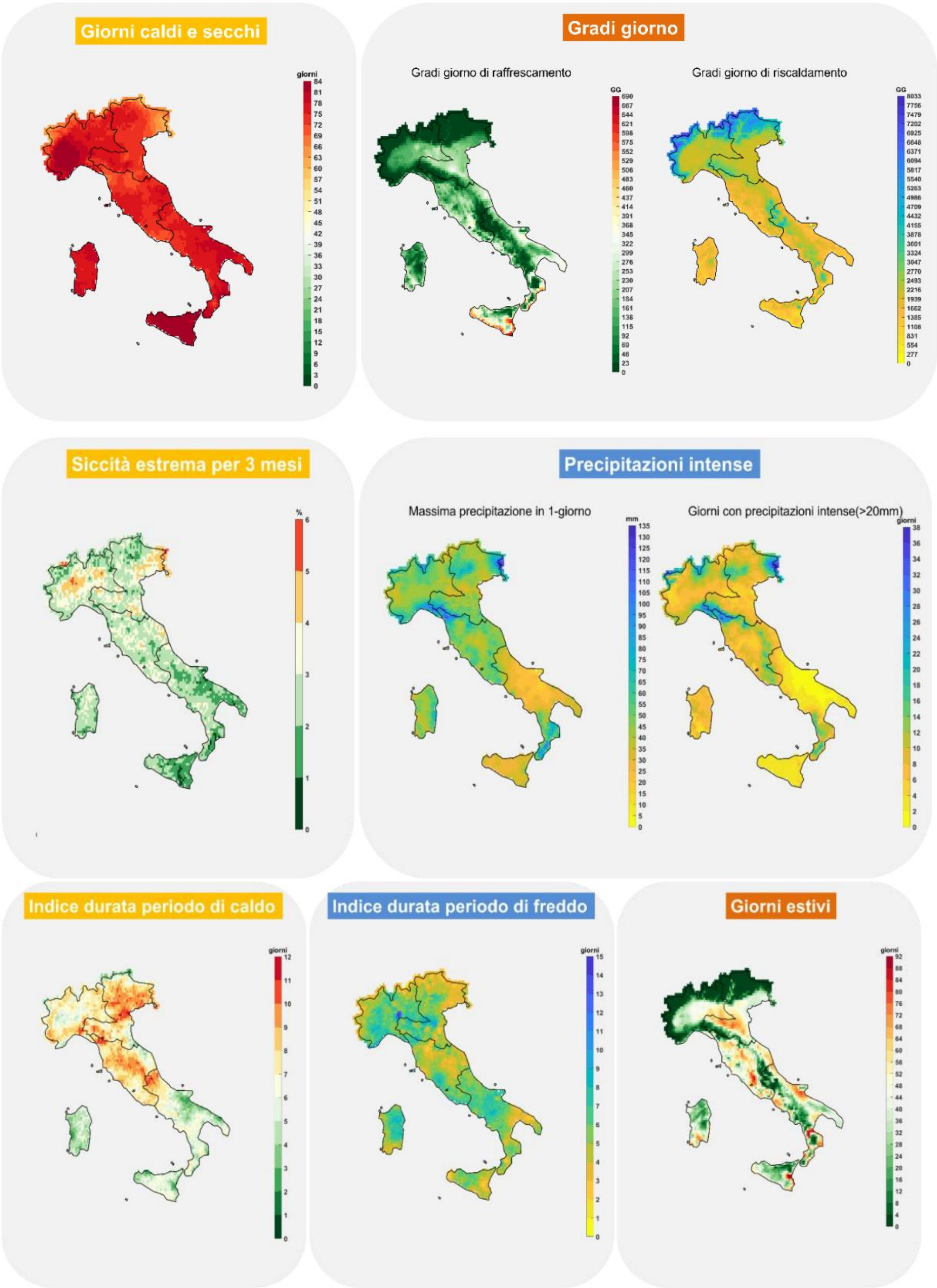


Figure 2: Maps of some of the climate indicators analyzed over the reference period 1981-2010 starting from the E-OBS v25 gridded dataset.

	Valori medi stagionali 1981-2010								
	DJF	±DS	MAM	±DS	JJA	±DS	SON	±DS	
Nord- Ovest	1,6	3,6	9,2	5,0	18,6	5,1	10,4	4,2	Temperatura media (°C)
	170	83	249	70	205	94	289	81	Precipitazione cumulata (mm)
Nord-Est	1,1	3,2	9,4	4,5	19,1	4,8	10,6	4,0	Temperatura media (°C)
	160	69	228	64	242	101	293	104	Precipitazione cumulata (mm)
Centro	6,3	2,0	12,4	1,9	22,1	1,9	14,8	2,1	Temperatura media (°C)
	247	75	217	61	118	41	314	87	Precipitazione cumulata (mm)
Sud	6,7	2,5	11,8	2,5	21,9	2,5	15,1	2,5	Temperatura media (°C)
	228	92	157	59	64	31	216	66	Precipitazione cumulata (mm)
Isole	9,2	1,5	13,4	1,8	23,1	1,9	17,3	1,7	Temperatura media (°C)
	216	36	129	46	23	11	194	33	Precipitazione cumulata (mm)

Table 1: Average seasonal values for geographical areas of average temperature and precipitation starting from the E-OBS observation dataset (version 25) for the period 1981-2010; the +/-SD column instead reports, for each seasonal value, an estimate of the variability on an areal scale (through the calculation of the standard deviation).

	Nord-ovest		Nord-est		Centro		Sud		Isole	
	Valore medio	±DS	Valore medio	±DS	Valore medio	±DS	Valore medio	±DS	Valore medio	±DS
TG (°C)	10,0	4,5	10,1	4,1	13,9	2,0	13,9	2,5	15,8	1,7
WD (giorni)	77	5	73	4	74	2	77	2	80	2
WW (giorni)	55	20	52	16	52	10	62	12	62	7
HDDS (GG)	3180	1448	3171	1293	1934	535	1925	669	1384	390
CDDS (GG)	78	81	97	97	157	91	164	128	225	155
PRCPTOT (mm)	912	277	922	288	897	246	667	227	561	121
R20 (giorni)	10	5	11	6	10	5	5	4	5	2
RX1DAY(mm)	50	12	51	15	51	13	35	16	39	10
SDII(mm)	10	2	10	2	10	2	8	2	8	1
PR99PRCTILE(mm)	46	11	46	12	46	11	34	13	39	8
CDD(giorni)	35	7	33	4	37	8	50	11	81	12
SPI3 classe siccità severa (%)	5	1	5	1	5	1	4	1	4	1
SPI3 classe siccità estrema (%)	3	1	3	1	3	1	2	1	2	1
SPI6 classe siccità severa (%)	4	1	5	1	5	1	4	1	5	1
SPI6 classe siccità estrema (%)	2	1	2	1	3	1	2	1	2	1
SPI12 classe siccità severa (%)	5	1	4	1	4	1	3	2	5	2
SPI12 classe siccità estrema (%)	2	1	2	1	3	1	2	1	2	1
SPI24 classe siccità severa (%)	6	2	4	2	4	1	3	2	4	2
SPI24 classe siccità estrema (%)	2	2	2	2	3	2	1	1	1	1
PET(mm)	650	138	658	130	757	68	750	88	806	72
CSDI(giorni)	6	2	5	2	5	1	6	1	5	1
FD(giorni)	93	63	98	56	34	22	23	26	3	7
WSDI(giorni)	7	1	8	2	8	1	6	2	5	1
HUMIDEX(giorni)	4	6	7	9	13	9	9	9	6	8
SU95P(giorni)	23	21	28	24	43	18	37	21	34	17
TR(giorni)	8	8	9	12	9	11	24	21	36	19

Table 2: Annual average values by geographical areas of the indicators calculated from the E-OBS observation dataset (version 25) for the period 1981-2010; the +/-SD column instead reports an estimate of the variability on an areal scale (through the calculation of the standard deviation).

A description of the average temperature and precipitation values and of some climatic indices, updated to the most recent thirty years, drawn up on the basis of a set of stations of the SCIA system and integrated with data from further sources, is available in the ISPRA report "Climatic normals 1991-2020 of temperature and precipitation in Italy"17. The calculations of a large group of stations are available on the web app valori-climatici-normali.isprambiente.it.

The state of the climate and the updated estimate of current trends are reported in the ISPRA report "Climate indicators in Italy", published annually. As emerges from the latest report, which reached its 17th edition in 202118, the signs of climate change are evident in Italy. The average temperature shows a marked increasing trend, with a rate of change from 1981 to 2021

17 Fioravanti G., Fraschetti P., Lena F., Perconti W., Piervitali E., "The 1991-2020 climate normals of temperature and precipitation in Italy", ISPRA Report / State of the Environment, 99/2022

18 Fioravanti G., Fraschetti P., Lena F., Perconti W., Piervitali E., Pavan V., "Climate indicators in Italy", ISPRA Report / State of the Environment, 98/2022

of (+0.37± 0.04) °C / 10 years and 2022, from preliminary calculations, seems to rank first among the warmest years since 1961; the analysis of extremes shows an increase in indices linked to heat extremes (such as hot days and nights, summer days, tropical nights) and a reduction in those representative of cold extremes (such as cold days and nights, days with frost). As regards precipitation, no significant trends emerge on a national scale. In recent years there have been numerous significant weather-climatic events, a brief summary of which is presented in the following paragraph.

2.1.1 Summary of significant weather and climate events in recent years

With reference to 2022, the precipitation recorded since the beginning of the year was well below the climatological average, especially during winter and spring in central-northern Italy, with precipitation anomalies exceeding -40% compared to the period 1991- 2020; several areas of Northern Italy have experienced conditions of considerable drought. A very long period of consecutive dry days, which caused damage to agriculture and livestock, was recorded for example at the Turin meteorological station in the period of February/March.

The summer was characterized by intense and prolonged heat; a heat wave hit the central-northern regions at the end of June, with maximum temperatures exceeding 38°C in several measuring stations.

On July 3, the enormous collapse that occurred in the Marmolada glacier caused an avalanche of snow, ice and rocks that caused numerous victims. The accident, which occurred due to a series of conditions whose relative weight is not easy to determine, is also linked to the increase in temperatures which influenced the state of the ice.[19]

Around mid-August, intense rain, hail and strong winds, with maximum speeds of up to 110 km/h, hit parts of northern and central Italy, causing landslides, falling trees, damage to buildings and the interruption of roads.

Between 15 and 16 September a violent wave of bad weather that hit the Marche, between the provinces of Ancona and Pesaro and Urbino had a disastrous outcome, causing flooding and flooding of several waterways and the consequent loss of human lives. The event had cumulative rainfall that locally exceeded 400 mm.

On 26 November the island of Ischia was hit by intense rain, the effects of which, amplified by the fragility of the territory, caused a landslide, extensive damage and here too the loss of human lives.

Among the significant events that occurred in 2021 we remember the intense heat wave which at the end of July recorded temperatures above 40°C in vast areas of eastern Sicily, with a thermal maximum of 44.8°C detected in the Syracuse station on 30 July (European record currently being verified by the World Meteorological Organization).

In 2020, intense rains hit northwestern Italy between 2 and 3 October; in particular in Piedmont, 24-hour precipitation values have reached historic highs, with cumulative amounts exceeding 500 mm in several stations and a maximum of 619.6 mm, causing exceptional flood waves on the waterways of the main and secondary network of the region . In Liguria, on the western coast, heavy rainfall caused floods, landslides, landslides, extensive damage to infrastructure, collapses and damaged roads and bridges.

---

19 https://www.unipr.it/notizie/il-crollo-della-marmolada-il-parere-dei-ricercatori-che-da-ventanni-studiano-il-ghiaiuto (Glaciological-geophysical working group for research on the Marmolada: Italian Glaciological Committee, University of Parma, University of Padua, National Institute of Oceanography and Experimental Geophysics)

It is possible to find information relating to the main extreme events that have occurred in Italy on the page http://mappaestremi.isprambiente.it/ (otherwise available from the home page of the ISPRA SCIA system www.isprambiente.it). This information is extracted from the ISPRA annual report "Climate indicators in Italy" with the contribution of various institutions/bodies and is therefore available at the same time as the publication of the report in July of each year in relation to the previous year.

2.2 **Evaluation of future climate projections**

This section reports the climate variations of the indicators previously identified for the future period 2036-2065 (centered on the year 2050), compared to the reference period 1981-2010.

As already indicated, some of the EURO-CORDEX program simulations available in C3S were used; in particular, for each scenario, 14 possible climate simulations were used, in accordance with what is currently available on the Copernicus platform. This dataset, widely used for the regional-scale assessment of climate change in Europe (Jacob et al; 2020), includes data from different models, time frequencies and periods calculated according to the CORDEX20 experiment protocol. In general, these experiments consist of simulations with regional models representing different future socio-economic scenarios (Jacob et al., 201421; Giorgi and Gutowski, 201522). The use of this set of climate models made it possible to evaluate not only the average value (called "ensemble mean" and considered the most reliable value in the literature), obtained starting from the values of the individual models representing the ensemble but also the dispersion of the individual models around this average value (uncertainty). Knowing this dispersion is very important for evaluating the agreement between the models in the evaluation of the indicator and therefore estimating the uncertainty that originates from the climate signal. In the following, the dispersion will be quantified through the calculation of the standard deviation: in other words, for each point of the domain, the lower the standard deviation value, the higher the degree of agreement between the climate models of the EURO- CORDEX, and vice versa (Von Trentini et al., 201923). For each indicator analysed, therefore, the average variations expected in the future were calculated, accompanied by information relating to uncertainty, for each emission scenario considered. In particular, the IPCC scenarios considered in this analysis are:

RCP8.5 (“Business-as-usual”) – emissions growth at current rates. It assumes, by 2100, atmospheric concentrations of CO2 tripled or quadrupled (840-1120 ppm) compared to pre-industrial levels (280 ppm). The RCP 8.5 scenario is characterized by the occurrence of an intensive consumption of fossil fuels and the failure to adopt any mitigation policy with a consequent increase in global temperature equal to +4-5°C compared to pre-industrial levels expected for the end of the century.

20 https://www.euro-cordex.net/060378/index.php.en
21 Jacob, D.; Petersen, J.; Eggert, B.; Alias, A.; Christensen, O.B.; Bouwer, L.M.; Braun, A.; Colette, A.; Deque, M.; Georgievski, G.; et al. EURO-CORDEX: new high-resolution climate change projections for European impact research. Reg. Environ. Change. 2014, 14, 563–578, doi:10.1007/s10113-013-0499-2
[22] Giorgi, F.; Gutowski, WJ Regional dynamical downscaling and the CORDEX initiative. Ann. Rev. Environ. Resour. 2015, 40, 467–490, doi:10.1146/annurev-environ-102014-021217
23 Von Trentini, F., Leduc, M., and Ludwig, R.: Assessing natural variability in RCM signals: comparison of a multi model EURO-CORDEX ensemble with a 50-member single model large ensemble, Climate Dynamics, doi:10.1007 /s00382- 019-04755-8, 2019

RCP4.5 ("Strong mitigation") – assume the implementation of some initiatives to control the emissions. Stabilization scenarios are considered: by 2070 CO2 emissions will fall to below current levels (400 ppm) and atmospheric concentration stabilizes, by the end of the century, at approximately double pre-industrial levels. In RCP6.0, CO2 emissions continue to grow until approximately 2080; concentrations take longer to stabilize and are approximately 25% higher than to the values of RCP4.5.

RCP2.6 ("Aggressive Mitigation") – emissions halved by 2050. Assumes 'aggressive' mitigation strategies whereby greenhouse gas emissions begin to decline after about a decade and approach zero within more or less 60 years from from now. According to this scenario, it is unlikely that the average global temperature increase will exceed 2°C compared to pre-industrial levels.

The temperature increase consistent with this scenario is around 3 degrees at the end of the century (compared to pre-industrial levels, around 2°C compared to today).

The temperature increases reported above and associated with the RCP 2.6, RCP 4.5 and RCP8.5 scenarios represent average increase values at a global level, while at an Italian level they are expected to be slightly higher, as can be seen from the calculations proposed in Figure 3 (which take the period 1976-2005 as reference). As regards the average temperature, by 2100 a growth is expected on average in the Italian area with values between 1°C, according to the RCP2.6 scenario, and 5°C, according to the RCP8.5 scenario. In Figure 3, the Mann-Kendall test (Kendall,1975)24 was used, with a confidence level of 95% to evaluate the statistical significance of the growth trend of the temperature anomaly calculated from the EURO-CORDEX models . The trends are statistically significant for all three IPCC scenarios considered (in Figure 3 statistically significant trends are identified by an asterisk).

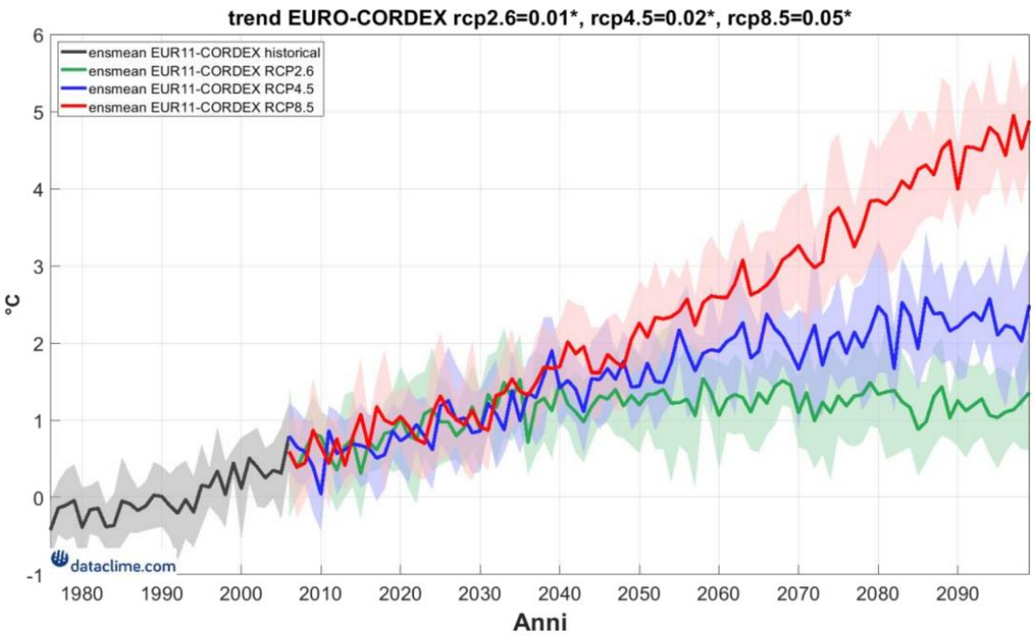


Figure 3: Annual average temperature anomalies (°C) on a national scale obtained from the EURO-CORDEX models, considering the historical period (in grey) and the RCP8.5 (in red), RCP4.5 (in blue) scenarios and RCP2.6 (in green). The annual anomalies are calculated with respect to the average value of the period

24 Kendall, M. G. (1975) Rank Correlation Methods. 4th Edition, Charles Griffin, London

reference 1976-2005. The thick dark line indicates the average climate projection (ensemble mean), calculated by averaging the annual values of all the simulations considered for each concentration scenario; the shaded areas represent the range obtained by adding and subtracting the standard deviation of the values simulated by the models from the ensemble mean and provide a measurement of the uncertainty of the projections.

Figure 4 reports the annual variations for total precipitation and mean temperature at the annual scale, along with the uncertainty estimate. This analysis highlights a general increase in temperatures for all scenarios considered (RCP 2.6, RCP 4.5, RCP8.5), more pronounced considering the RCP 8.5 scenario, with increases exceeding 2°C.

As regards precipitation, however, the projections indicate a decrease in overall annual precipitation for southern Italy, in particular for the RCP8.5 scenario. Specifically, the RCP 8.5 scenario projects a general reduction in southern Italy and Sardinia (up to 20% in 2050s25) and an increase in the North-West and North-East geographical areas (Figure 4). The RCP 2.6 scenario, however, projects a significant increase in precipitation in northern Italy and a slight reduction in the south. In general, the estimate of precipitation variations, both in a spatial and temporal sense, is more uncertain than that of temperature variations as precipitation is already subject to strong natural variations (MATTM, SNACC, Report on the state of knowledge, 2014). As shown in Figure 4, a greater dispersion (expressed in terms of standard deviation) is observed around the average values for variations in precipitation compared to those in temperature. These uncertainties appear particularly pronounced in northern Italy, according to the RCP 2.6 scenario.

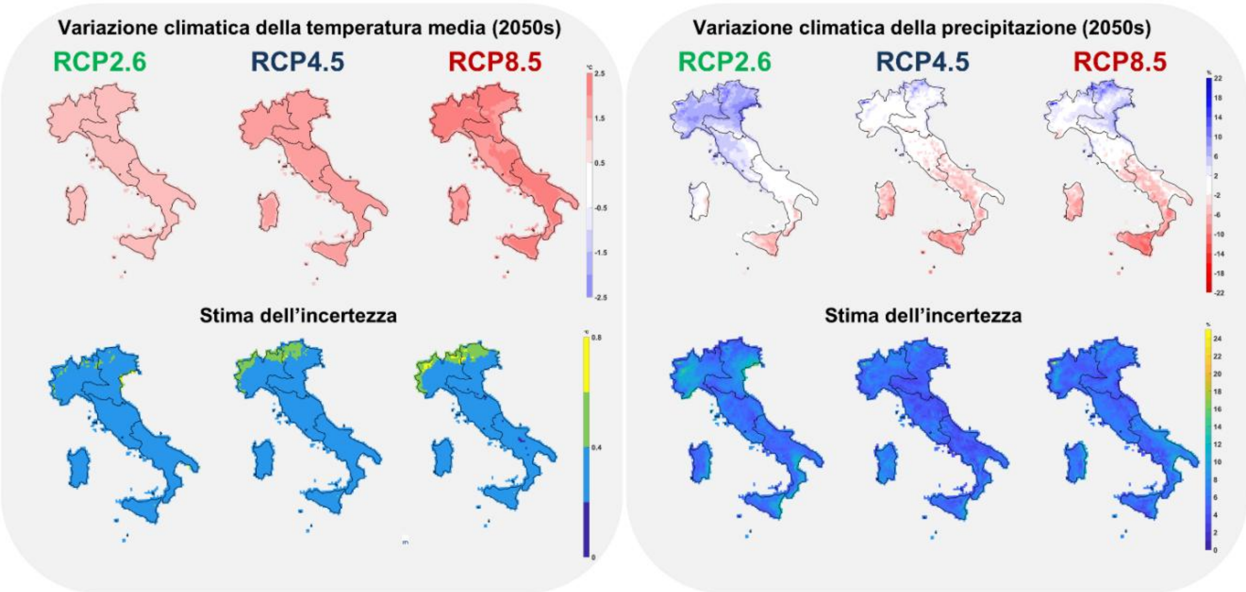


Figure 5: Annual climate variations in mean temperatures and mean cumulative precipitation for the period 2036-2065 (2050s), compared to the reference period 1981-2010, for the RCP 2.6, RCP 4.5 and RCP8.5 scenarios. The values are expressed in terms of mean (ensemble mean) and standard deviation (dispersion around the mean value) calculated on the set of regional climate model projections available within the Euro-Cordex programme.

25 The term 2050s means, in abbreviated form, to indicate the thirty-year period centered around 2050 or 2036-2065 on which the analysis was performed

Variazione della temperatura media (°C)

	RCP2.6				RCP4.5				RCP8.5				
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	
Nord- Ovest	1,2	0,9	1,1	1,5	1,8	1,2	1,9	1,8	2,3	1,7	2,3	2,5	Variazione climatica (2050s)
	0,3	0,4	0,3	0,8	0,5	0,4	0,3	0,8	0,4	0,5	0,4	0,9	Stima dell'incertezza (2050s)
Nord-Est	1,2	0,9	1,1	1,4	1,7	1,2	1,9	1,7	2,2	1,7	2,2	2,4	Variazione climatica (2050s)
	0,3	0,4	0,3	0,7	0,4	0,4	0,3	0,7	0,3	0,5	0,4	0,8	Stima dell'incertezza (2050s)
Centro	1,0	0,9	1,2	1,3	1,5	1,1	2,0	1,7	1,9	1,5	2,3	2,3	Variazione climatica (2050s)
	0,3	0,4	0,4	0,7	0,3	0,4	0,3	0,7	0,3	0,4	0,3	0,8	Stima dell'incertezza (2050s)
Sud	1,0	0,9	1,3	1,3	1,5	1,1	2,0	1,6	1,8	1,6	2,3	2,2	Variazione climatica (2050s)
	0,4	0,4	0,4	0,7	0,4	0,4	0,3	0,6	0,3	0,4	0,3	0,7	Stima dell'incertezza (2050s)
Isole	1,0	0,9	1,2	1,3	1,3	1,1	1,9	1,6	1,7	1,6	2,2	2,2	Variazione climatica (2050s)
	0,3	0,3	0,4	0,7	0,3	0,3	0,3	0,6	0,3	0,4	0,3	0,7	Stima dell'incertezza (2050s)

Variazione della precipitazione cumulata (%)

	RCP2.6				RCP4.5				RCP8.5				
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	
Nord- Ovest	12,3	3,2	5,9	5,1	14,3	-0,3	-4,8	-2,3	2,5	3,3	-0,9	2,4	Variazione climatica (2050s)
	15	5	7	13	10	4	8	11	12	10	11	9	Stima dell'incertezza (2050s)
Nord-Est	12	4	6	5	10	1	-6	2	5	3	0	6	Variazione climatica (2050s)
	16	5	9	11	8	4	11	10	9	7	12	12	Stima dell'incertezza (2050s)
Centro	9	-1	3	3	5	-2	-14	1	0	-3	-6	4	Variazione climatica (2050s)
	13	4	12	11	7	4	13	10	7	6	12	15	Stima dell'incertezza (2050s)
Sud	3	-2	0	1	0	-3	-15	2	-2	-5	-12	1	Variazione climatica (2050s)
	9	7	16	12	6	5	14	10	9	7	13	9	Stima dell'incertezza (2050s)
Isole	3	-6	7	-1	-2	-7	-14	-3	-7	-8	-13	-2	Variazione climatica (2050s)
	8	7	25	11	5	8	14	9	7	7	16	10	Stima dell'incertezza (2050s)

Table 3: Variations in average temperature and cumulative precipitation (ensemble mean) for the period centered on 2050 (2036-2065) compared to the reference period 1981-2010, on a seasonal scale (DJF: winter; MAM: spring; JJA: summer; SON: autumn) for the different macro-areas; in the second line an estimate of the uncertainty is reported (through the calculation of the standard deviation) for the average temperature and cumulative precipitation reported in the first line. The colors in the table are to be understood in a qualitative way: for variation in precipitation the color from light blue indicates low variations with a positive sign up to intense blue which indicates greater variations with a positive sign. For the average temperature variation, pink indicates minor variations while red indicates those of greater intensity. For uncertainty, yellow quantitatively indicates the degree of uncertainty.

Figure 5 shows, by way of example, some of the most relevant maps (in terms of expected variations) for the indicators considered in this section, while Figure 6 summarizes the expected variations (average values and estimated uncertainties) for the different geographical areas into which Italy has been divided and for all the selected indicators, used to provide information on the climate dangers of interest (further details are given in **Table** XX).

As regards the impacts on energy demand, there is a general reduction, particularly in mountain areas, in heating degree days (HDDs) and a general increase in cooling degree days (CDDs) for flat and coastal areas. These variations, more marked considering the RCP8.5 scenario, could lead to a reduced need for energy necessary for heating the rooms and an increase in the demand for energy for their cooling, particularly in the summer season. This trend is also influenced by the increase in the frequency and intensity of heat waves. In fact, a general increase in the danger linked to heat waves is to be expected while, contrary to a general reduction in cold wave phenomena across the entire national territory, especially in the RCP 8.5 scenario. For the same scenario, a significant increase in fire danger is also expected, up to 20% in particular in the Apennines and Alps.

As regards geo-hydrological disruption, various characteristics of intense precipitation were evaluated and the analyzes show a general increase in both daily cumulations and the intensity and frequency of extreme precipitation events, especially for the RCP 8.5 scenario, and especially for the central-northern areas. This aspect denotes a potential increase in danger due to weather-induced landslides and floods which, however, needs to be studied in greater local detail thanks to impact models coupled with hazard models.

As regards the drought phenomenon, it was evaluated using the SPI index (McKee et al. 1993[26]) considering different time windows for precipitation accumulations (3 months, 6 months, 9 months, 12 months and 24 months). This index, depending on the time period considered, can provide indications on immediate, medium and long-term impacts. The table considers only the two classes of severe and extreme drought (in terms of variation in occurrence with respect to the climatological period), which, over a duration of 3-6 months have predominantly agronomic impacts, while over a duration of 12-24 months they have mainly hydrological and socioeconomic impacts. For all time scales considered, an increase in the number of drought episodes is to be expected, in particular for the RCP8.5 scenario in southern Italy (including the islands). For the evaluation of the other climatic dangers analyzed, please refer to the tables by geographical areas shown in Figure 6.

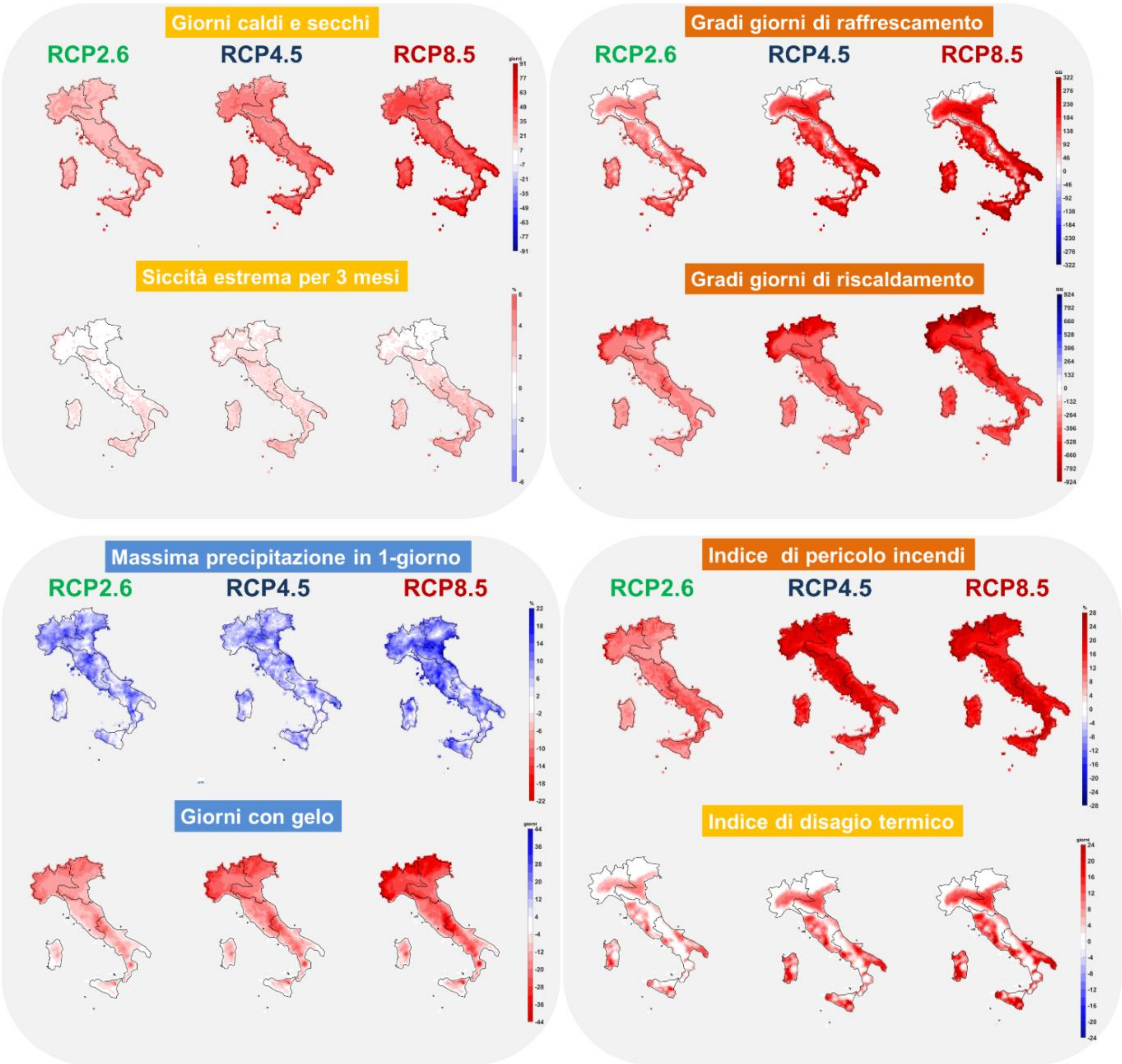


Figure 5: Annual climate variations (ensemble mean) for some of the climate indicators analyzed for the period 2036-2065 (2050s), compared to the reference period 1981-2010, for the RCP 2.6, RCP 4.5 and RCP8.5 scenarios

[26] McKee, Thomas B., Nolan J. Doesken, and John Kleist. "The relationship of drought frequency and duration to time scales." Proceedings of the 8th Conference on Applied Climatology. Vol. 17. No. 22. 1993.

	Nord-ovest					
	RCP2.6	±SD RCP2.6	RCP4.5	±SD RCP4.5	RCP8.5	±SD RCP8.5
TG (°C)	1,2	0,3	1,7	0,3	2,2	0,3
WD (giorni)	20	9	30	13	39	15
WW (giorni)	15	5	20	4	25	4
HDDS (GG)	-349	73	-474	87	-627	90
CDDS (GG)	44	29	76	37	95	50
PRCPTOT (%)	6	6	1	5	2	4
R20 (giorni)	1	1	0	1	1	1
RX1DAY(%)	8	5	6	4	9	4
SDII(%)	5	4	4	2	5	2
PR99PRCTILE(%)	7	4	6	3	9	4
CDD(giorni)	0	1	0	2	-1	1
SPI3 classe siccità severa (%)	0	1	0	1	0	1
SPI3 classe siccità estrema (%)	1	1	1	1	1	1
SPI6 classe siccità severa (%)	0	1	0	1	0	1
SPI6 classe siccità estrema (%)	1	1	1	2	1	2
SPI12 classe siccità severa (%)	-1	2	0	2	0	1
SPI12 classe siccità estrema (%	1	2	1	2	1	2
SPI24 classe siccità severa (%)	-1	2	0	2	-1	2
SPI24 classe siccità estrema (%	1	2	1	3	1	2
PET (%)	6	1	9	2	11	2
CSDI(giorni)	-3	2	-4	1	-5	1
FD(giorni)	-16	4	-22	4	-28	5
WSDI(giorni)	19	10	29	12	41	14
HUMIDEX(giorni)	2	2	3	3	4	3
SU95P(giorni)	6	4	10	4	13	6
TR(giorni)	6	4	10	5	13	6
SCD(giorni)	-2	1	-2	1	-4	2
EWS(%)	0	1	0	1	0	1
FWI(%)	9	7	18	4	20	4

	Nord-est					
	RCP2.6	±SD RCP2.6	RCP4.5	±SD RCP4.5	RCP8.5	±SD RCP8.5
TG (°C)	1,1	0,3	1,6	0,3	2,1	0,3
WD (giorni)	19	9	29	11	37	14
WW (giorni)	14	5	18	3	23	3
HDDS (GG)	-334	76	-450	75	-592	79
CDDS (GG)	50	30	86	36	105	51
PRCPTOT (%)	6	6	2	3	4	4
R20 (giorni)	1	1	0	1	1	1
RX1DAY(%)	7	5	7	4	10	5
SDII(%)	5	3	4	2	6	2
PR99PRCTILE(%)	6	3	7	3	10	4
CDD(giorni)	0	1	0	1	0	1
SPI3 classe siccità severa (%)	-1	1	0	1	0	1
SPI3 classe siccità estrema (%)	1	1	1	2	1	1
SPI6 classe siccità severa (%)	-1	1	0	1	-1	1
SPI6 classe siccità estrema (%)	1	2	1	2	1	2
SPI12 classe siccità severa (%)	-1	2	0	2	-1	1
SPI12 classe siccità estrema (%	0	2	1	2	0	2
SPI24 classe siccità severa (%)	-1	2	0	2	-1	2
SPI24 classe siccità estrema (%	0	2	1	3	0	3
PET (%)	6	2	8	2	11	2
CSDI(giorni)	-3	2	-4	1	-5	1
FD(giorni)	-15	4	-20	4	-26	5
WSDI(giorni)	18	9	27	10	39	12
HUMIDEX(giorni)	2	2	4	3	5	4
SU95P(giorni)	7	4	12	4	14	6
TR(giorni)	7	4	11	5	14	7
SCD(giorni)	-1	1	-2	1	-2	1
EWS(%)	0	1	0	1	0	1
FWI(%)	8	6	17	5	18	4

	Centro					
	RCP2.6	±SD RCP2.6	RCP4.5	±SD RCP4.5	RCP8.5	±SD RCP8.5
TG (°C)	1,1	0,3	1,5	0,2	2,0	0,2
WD (giorni)	21	10	32	12	41	15
WW (giorni)	15	6	19	4	24	4
HDDS (GG)	-273	59	-358	51	-475	63
CDDS (GG)	77	50	127	60	157	83
PRCPTOT (%)	3	5	-1	4	0	5
R20 (giorni)	1	1	0	1	1	1
RX1DAY(%)	8	6	7	4	10	6
SDII(%)	4	3	3	2	5	3
PR99PRCTILE(%)	6	4	7	4	10	6
CDD(giorni)	0	2	2	3	1	2
SPI3 classe siccità severa (%)	0	1	0	1	0	1
SPI3 classe siccità estrema (%)	1	1	2	1	2	1
SPI6 classe siccità severa (%)	0	1	0	1	0	1
SPI6 classe siccità estrema (%)	1	2	1	2	2	2
SPI12 classe siccità severa (%)	-1	2	0	2	0	2
SPI12 classe siccità estrema (%	1	2	2	2	2	2
SPI24 classe siccità severa (%)	0	3	2	3	1	2
SPI24 classe siccità estrema (%	2	4	3	3	4	5
PET (%)	6	2	8	2	11	2
CSDI(giorni)	-3	1	-3	1	-4	1
FD(giorni)	-10	4	-14	4	-18	6
WSDI(giorni)	20	12	31	12	44	14
HUMIDEX(giorni)	3	3	5	5	6	6
SU95P(giorni)	11	6	18	6	21	9
TR(giorni)	10	6	15	8	19	10
SCD(giorni)	0	0	0	0	0	0
EWS(%)	0	1	0	1	0	1
FWI(%)	9	7	18	5	19	4

	Sud					
	RCP2.6	±SD RCP2.6	RCP4.5	±SD RCP4.5	RCP8.5	±SD RCP8.5
TG (°C)	1,1	0,3	1,5	0,2	2,0	0,2
WD (giorni)	25	11	37	12	48	15
WW (giorni)	16	7	22	7	28	8
HDDS (GG)	-260	66	-339	47	-449	61
CDDS (GG)	95	51	153	57	192	80
PRCPTOT (%)	0	5	-3	3	-3	5
R20 (giorni)	0	1	0	0	0	0
RX1DAY(%)	6	6	5	4	7	5
SDII(%)	3	2	2	2	4	2
PR99PRCTILE(%)	5	4	6	3	9	4
CDD(giorni)	1	3	3	3	3	3
SPI3 classe siccità severa (%)	0	1	1	1	1	1
SPI3 classe siccità estrema (%)	1	1	2	1	2	1
SPI6 classe siccità severa (%)	1	1	1	1	2	1
SPI6 classe siccità estrema (%)	1	2	2	2	3	2
SPI12 classe siccità severa (%)	0	2	1	1	2	1
SPI12 classe siccità estrema (%	2	2	2	2	4	2
SPI24 classe siccità severa (%)	1	2	2	2	3	2
SPI24 classe siccità estrema (%	2	3	3	3	5	3
PET (%)	6	2	9	2	12	2
CSDI(giorni)	-2	1	-3	1	-4	1
FD(giorni)	-8	3	-10	4	-13	6
WSDI(giorni)	18	11	28	11	40	14
HUMIDEX(giorni)	3	3	6	5	7	6
SU95P(giorni)	12	6	19	6	23	8
TR(giorni)	12	6	19	6	24	8
SCD(giorni)	0	0	0	0	0	0
EWS(%)	0	1	0	1	0	1
FWI(%)	11	7	16	5	19	4

	Isole					
	RCP2.6	±SD RCP2.6	RCP4.5	±SD RCP4.5	RCP8.5	±SD RCP8.5
TG (°C)	1,1	0,3	1,5	0,2	1,9	0,2
WD (giorni)	29	13	42	15	54	18
WW (giorni)	20	9	26	10	34	12
HDDS (GG)	-230	57	-295	37	-395	47
CDDS (GG)	117	62	179	66	226	87
PRCPTOT (%)	-1	5	-5	4	-6	4
R20 (giorni)	0	0	0	0	0	0
RX1DAY(%)	4	6	5	5	7	6
SDII(%)	2	3	2	2	3	2
PR99PRCTILE(%)	5	4	7	4	10	5
CDD(giorni)	1	5	5	4	4	4
SPI3 classe siccità severa (%)	0	1	1	1	1	1
SPI3 classe siccità estrema (%)	1	1	2	1	3	1
SPI6 classe siccità severa (%)	1	1	2	1	2	1
SPI6 classe siccità estrema (%)	2	2	3	2	3	2
SPI12 classe siccità severa (%)	1	2	2	1	3	1
SPI12 classe siccità estrema (%	2	2	3	2	4	2
SPI24 classe siccità severa (%)	1	3	3	2	3	2
SPI24 classe siccità estrema (%	3	3	5	3	7	4
PET (%)	6	2	9	2	12	3
CSDI(giorni)	-2	1	-3	1	-3	1
FD(giorni)	-3	2	-4	2	-6	3
WSDI(giorni)	20	13	30	13	45	16
HUMIDEX(giorni)	4	3	7	6	9	7
SU95P(giorni)	12	6	19	6	23	8
TR(giorni)	16	7	23	8	29	9
SCD(giorni)	0	0	0	0	0	0
EWS(%)	0	1	-1	1	-1	1
FWI(%)	9	7	14	4	16	4

*Figure 6. Annual climate variations (ensemble mean) by geographical areas, considering all the climate indicators reported in **Table XX,** for the period 2036-2065 (2050s), compared to the reference period 1981-2010,*

for RCP2.6, RCP4.5 and RCP8.5 scenarios. The second column of each table instead reports an estimate of the uncertainty (through the calculation of the standard deviation) for the indicators reported in the first column. The colors in the table are to be interpreted in a qualitative way: more intense colors indicate greater variations while pale colors indicate variations of lesser intensity.

2.3 **Marine areas**

Based on the scientific literature and the availability of observed and modeling data, two primary variables have been identified to describe the impact of climate evolution on the Italian seas: water surface temperature and sea level.

The sea level produced by the forced model and reanalyses must be appropriately treated to include not only the evolution of the free sea surface, referred to as the mass component of the oceans, but also the effect of expansion and contraction of the volume due to changes temperature and salinity of ocean masses. The sea level presented in this document takes into account the cumulative effect of these three components.

*2.3.1 **Analysis of the reference climatic condition***

For the evaluation of the current climatic condition in the marine/coastal areas, the products of the marine reanalyses of the Mediterranean Sea were used (Simoncelli et al. 201927) which are part of the marine services made available by the European CMEMS service (Copernicus Marine Environment Monitoring Service) (http://marine.copernicus.eu), identified here with the acronym REAN. These reanalyses are obtained through the integration of numerical models and the assimilation of multiplatform observations and represent the state of the art for the characterization of sea weather and climate conditions. The data available for the Mediterranean Sea refer to the period 1987-
2010 and have a horizontal resolution of approximately 7 km. Maps of the climatology of the indicators Sea Surface Temperature (SST) and Sea Level SSH are shown in Figure 7.

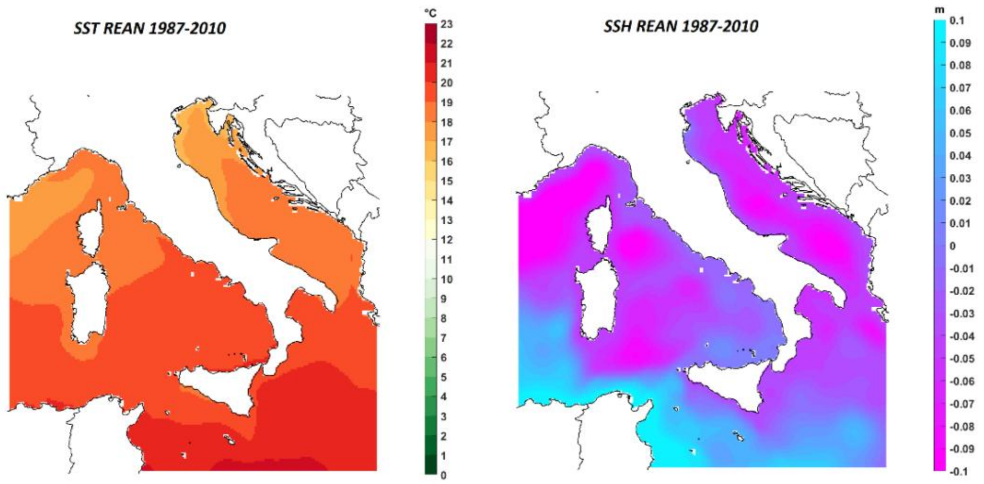


Figure 7: Climatological values of the SST and SSH indicators over the central Mediterranean obtained from the REAN dataset for the period 1987-2010.

27 Simoncelli, S., Fratianni, C., Pinardi, N., Grandi, A., Drudi, M., Oddo, P., & Dobricic, S. (2019). Mediterranean Sea Physical Reanalysis (CMEMS MED-Physics) (Version 1) [Data set]. Copernicus Monitoring Environment Marine Service (CMEMS). https://doi.org/10.25423/MEDSEA_REANALYSIS_PHYS_006_004

2.3.2 ***Future climate projections***

In order to study the climatic anomalies expected during the mid-21st century with regard to temperature and sea level, data from climate simulations for the period 1981-2100 obtained via the NEMO ocean model (Madec 2008[28]) applied to the Mediterranean Sea (7 km resolution) and forced with atmospheric and hydrological data from the CMCC-CM climate model at ~80 km horizontal resolution (Scoccimarro et al. 2011[29]). The model configuration used in these simulations, identified as MEDSEA, was developed by the CMCC Foundation and describes the evolution of the system for the RCP8.5 climate scenario (Lovato et al. 2013[30]; Galli et al. 2017[31]; Reale et al. 2022[32]). The data produced with this modeling system are distributed publicly via the web portal dds.cmcc.it (https://dds.cmcc.it/#/dataset/medsea-cmip5-projections-physics).

In general, the RCP8.5 scenario represents the most precautionary condition as it describes the evolution of the climate for a “business as usual” emissions scenario.

A first analysis was conducted with the aim of validating the spatio-temporal consistency between the REAN dataset and the current climate reproduced in the MEDSEA dataset (used for the analysis of expected climate anomalies).

In particular, the difference in the spatial distribution and the seasonal variability of the primary physical variables over the period 1987-2010 were considered. In general, this analysis revealed that both the surface temperature and the sea level of the MEDSEA dataset present very limited differences compared to the reanalysis data and allow the state of the seas in the reference climate period to be described with a good degree of realism. .

An anomaly analysis was then conducted for the primary physical variables between the periods 2036–2065 and 1981–2010. Below is a summary of the main results for surface temperature and sea level, in order to characterize the climate projections of the MEDSEA dataset at the basin scale and along the Italian coastal areas.

2.3.3 ***Analysis of the marine areas of the coastal strip***

This section contains a detailed analysis of future climate projections for the marine areas of the coastal strip. The Italian seas are divided into three macro-regions on the basis of the Framework Directive on the Strategy for the Marine Environment (MSFD 2008/56/EC implemented in Italy with Legislative Decree 190/2010): Western Mediterranean Sea, Adriatic Sea, Ionian Sea and Central Mediterranean.
In order to provide greater detail for the framework of the changes in the Italian seas, in this analysis the main macro-regions have been further divided into eight sub-units as

---

28 Madec, G. (2008) NEMO Ocean Engine. Note du Pole de modélisation, Institut Pierre-Simon Laplace (IPSL), France
29 Scoccimarro E, Gualdi S, Bellucci A, et al (2011) Effects of Tropical Cyclones on Ocean Heat Transport in a High-Resolution Coupled General Circulation Model. J Clim 24:4368-4384. doi: 10.1175/2011jcli4104.1
30 Lovato T, Vichi M, Oddo P (2013) High-Resolution Simulations of Mediterranean Sea Physical Oceanography Under Current and Scenario Climate Conditions: Model Description, Assessment and Scenario Analysis. C Res Pap No 207
31Galli, G., Solidoro, C., & Lovato, T. (2017). Marine heat waves hazard 3D maps and the risk for low motility organisms in a warming Mediterranean Sea. Frontiers in Marine Science, 4, 136. https://doi.org/10.3389/fmars.2017.00136
32 Reale, M., Cossarini, G., Lazzari, P., Lovato, T., Bolzon, G., Masina, S., ... & Salon, S. (2022). Acidification, deoxygenation, and nutrient and biomass declines in a warming Mediterranean Sea. Biogeosciences, 19(17), 4035-4065. https://doi.org/10.5194/bg-19-4035-2022

illustrated in Figure 8. The coastal strip has been identified as the area within the limit of twelve nautical miles from the coast and corresponds to territorial waters.

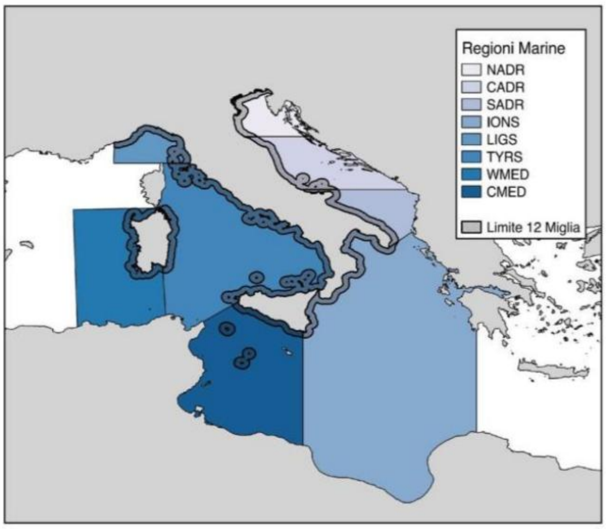


Figure 8: Division of the Italian seas into specific marine sub-regions (Fratianni et al. 201633). The shaded area indicates the 12 mile limit from the coastline. The marine regions are identified using the following acronyms: NADR: Northern Adriatic, CADR: Central Adriatic, SADR: Southern Adriatic, IONS: Ionian Sea and Central Mediterranean, LIGS: Ligurian Sea, TYRS: Tyrrhenian Sea, WMED: Western Mediterranean Sea, CMED : Central Mediterranean Sea.

Table 4 shows annual anomalies for surface water temperature (SSTA) and sea level rise (SSHA), respectively, calculated using MEDSEA data for the current climate (1981-2010) and scenario (2036-2065), averaged within the coastal areas within the 12 nautical miles defined in Figure 8.

The surface temperature anomaly shows that all Italian coastal areas will be characterized by an increase in temperature compared to the reference period 1981-2010. This increase varies from a minimum of 1.9 °C in the Central and Western Mediterranean areas and in the Sea

Ligurian at a maximum of 2.3 °C in the northern and central Adriatic. The increase is almost constant throughout the year, thus maintaining the seasonality of each area unchanged.

Similar to surface water temperature, sea level rise during the period 2036-2065 for the RCP8.5 scenario characterizes all coastal areas. Compared to the reference period 1981-2010, the values range from a minimum of +16 cm for the three subregions of the Adriatic basin, up to a maximum of 19 cm in the Tyrrhenian and Ligurian seas and in the western Mediterranean.

33 Fratianni C, Pinardi N, Lalli F, et al (2016) Operational oceanography for the Marine Strategy Framework Directive: the case of the mixing indicator. J Oper Oceanogr 9:s223----s233 . doi: 10.1080/1755876x.2015.1115634

Table 4: Mean surface temperature anomaly (SSTA) and sea level anomaly (SSHA), calculated as the difference between the period 2036-2065 and 1981-2010 using the MEDSEA dataset.

Coastal Area	SSTA [°C]	SSHA [cm]
NADR	+2.26	+16
CADR	+2.26	+16
SADR	+2.14	+16
IONS	+2.03	+17
CMED	+1.92	+18
LIGS	+1.90	+19
TYRS	+1.91	+19
WMED	+1.93	+19

2.3.4 ***Analysis at a national scale***

The analyzes conducted in this paragraph aim to evaluate climate anomalies for surface temperature and sea level at a national level.

The spatial distributions for SSTA and SSHA between the periods 2036-2065 and 1981-2010 on an annual basis obtained considering the RCP8.5 future scenario are illustrated in Figure 9. Sea surface temperature anomalies indicate a general increase on an annual basis that varies from around 1.9°C in the Tyrrhenian Sea to around 2.3°C in the Adriatic. The Adriatic Sea presents the most significant change in average temperature of approximately +2.3°C, with variations in the winter and spring periods that could reach +2.6°C.

As regards, however, the changes in sea level expected for the period 2036-2065, they are equal to approximately 16 cm in the Adriatic, Tyrrhenian and Ligurian Seas and 17 cm in the Ionian Sea and the Sicilian Channel, while in the western Mediterranean they reach 19 cm.

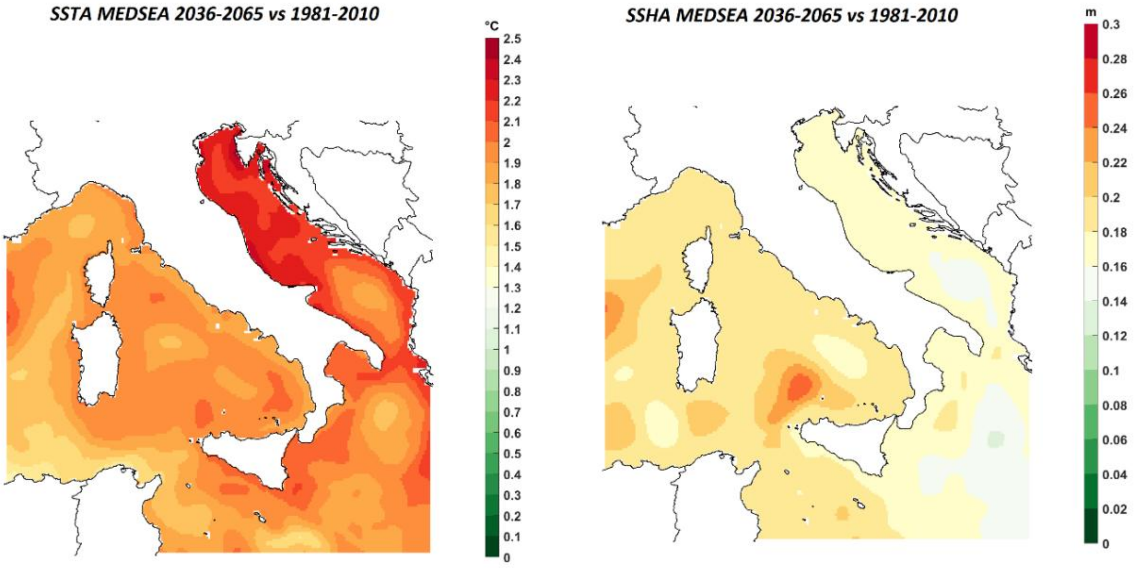


Figure 9: Climate anomalies of the SSTA and SSHA indicators over the central Mediterranean obtained from the MEDSEA RCP8.5 dataset for the period 2036-2065 vs 1981-2010

Table XX – Reference indicators for the PNACC Climate Framework

Acronym, definition of climate indicator	Variables fundamentals	Unit of measure of the indicator	Unit of measurement of variation climate (scenario)	Stairs storm	Reference	Climate Hazard/Proxy	Sector
Average Temperature (TG): Average of the average daily temperature.	**T**	°C	+ - °C	seasonal/ annual		Increase in temperatures	
WD: *Hot - dry days* - Number of days with average daily temperature greater than the 75th percentile of the average daily temperature and with daily precipitation less than the 25th percentile of daily precipitation.	**T - Prev**	days	+ - days	annual	ECAD-EU, Beniston 2009	Examples of expected impacts for which the indicator can represent a proxy	**Health, agriculture**
WW: *Hot - rainy days* **-** Number of days with average daily temperature greater than the 75th percentile of the average daily temperature and with daily precipitation greater than the 75th percentile of daily precipitation.	**T - Prev**	days	+ - days	annual			
HDDs: *Heating Degree Days* - Sum of 18°C minus the average daily temperature if the average daily temperature is less than 15°C.	**T**	DD	DD or %	annual	https://www.isprambiente.gov.it/files2018/publications/rapporti/R_277_17_Allega_RelazionidelsottogroupHDD_CDD.pdf	Impacts on energy demand for heating and cooling	**Power**
CDDs: *Cooling degree days* - sum of the average daily temperature minus 21°C if the average daily temperature is greater than 24°C.	**T**	DD	DD or %	annual			
PRCPTOT: Cumulative precipitation on rainy days (mm) - Cumulative (sum) of precipitation for days with precipitation greater than/equal to 1 mm.	**Prev**	mm	%	seasonal/ annual	ETCCD	Geo-hydrological instability	**NOTE:** it was considered it is advisable not to assign a sector to geo-hydrological instability

Acronym, definition of climate indicator	Variables fundamentals	Unit of measure of the indicator	Unit of measurement of variation climate (scenario)	Stairs storm	Reference	Climate Hazard/Proxy	Sector
R20: *Heavy precipitation days* - Number of days with precipitation greater than 20 mm.	**Prev**	days	+ - days	annual	ETCCD		in itself. It constitutes a danger that affects most sectors, each with a different degree of exposure.
RX1DAY: Maximum value of daily precipitation	**Prev**	mm	%	annual	ETCCD		
SDII: Daily precipitation intensity index - Average daily precipitation on days with precipitation greater than or equal to 1mm.	**Prev**	mm	%	annual	ETCCD		
PR99prctile: 99th percentile of daily precipitation on days with precipitation greater than/equal to 1 mm.	**Prev**	mm	%	annual	Kumar et al, 2020		
CDD: Dry consecutive days - Maximum number of consecutive days with less daily precipitation to 1 mm.	**Prev**	days	+ - days	annual	ETCCD	Drought	**Agricultural production, Water resources ed Terrestrial ecosystems**
SPI3: Standardized precipitation index for 3-month periods - Percentage of class occurrence (severely dry, extremely dry) in the SPI3 index calculated for a short accumulation period (3 months).	**Prev**	-	%	annual	McKee et al. (1993)	Drought This index provides indications on immediate impacts, such as those relating to the reduction of soil moisture, snow cover and flow in small streams.	
SPI6: Standardized Precipitation Index for 6-month periods - Percentage of class occurrence (severely dry, extremely dry) in the SPI6 index calculated for an average accumulation period (6 months).	**Prev**	-	%	annual	McKee et al. (1993)	Drought This index provides indications on the reduction river flows and reservoir capacities.	

Acronym, definition of climate indicator	Variables fundamentals	Unit of measure of the indicator	Unit of measurement of variation climate (scenario)	Stairs storm	Reference	Climate Hazard/Proxy	Sector
SPI12: Standardized Precipitation Index for 12-month periods - Percentage of class occurrence (severely dry, extremely dry) in the SPI12 index calculated for an average accumulation period (12 months).	**Prev**	-	%	annual	McKee et al. (1993)	Drought This index provides indications on the reduction river flows and reservoir capacities.	
SPI24: Standardized Precipitation Index for 24-month periods - Percentage of class occurrence (severely dry, extremely dry) in the SPI24 index calculated for a long accumulation period (24 months).	**Prev**	-	%	annual	McKee et al. (1993)	Drought This index provides indications on the reduction recharge of the reservoirs and on the availability of water in the aquifers.	
PET: Potential Evapotranspiration (with method Thornwaite)	**Tmin, Tmax, Tmean**	mm	%	annual	Thornwaite (1948)	Drought and desertification. It provides, as part of the estimate of the available or potential water resource, an evaluation of the maximum quantity of water that would pass into the atmosphere, through the processes of evaporation and transpiration, if the quantity of water in the land is not a limiting factor. Potential evapotranspiration is used to calculate climate indices such as, for example, the "aridity index" (UNEP, United Nations Environment Programme) adopted as the official index within the Convention on United Nations for the fight against drought and desertification, which summarizes qualitatively the climatic characteristics of the area. The aridity index is defined as the ratio between annual precipitation and potential evapotranspiration: Ia = P / Etp Potential evapotranspiration is the basis of models for evapotranspiration estimation real.	

Acronym, definition of climate indicator	Variables fundamentals	Unit of measure of the indicator	Unit of measurement of variation climate (scenario)	Stairs storm	Reference	Climate Hazard/Proxy	Sector
CSDI: *Cold Period Duration Index* - Total number of days in which the daily minimum temperature is below the 10th percentile* of the daily minimum temperature for at least 6 consecutive days.	**T**	days	+ - days	annual	ETCCD	Cold waves	**Health, Energy**
FD: Days with frost - Number of days with minimum daily temperature below 0°C.	**T**	days	+ - days	annual	ETCCD		
WSDI: *Hot Period Duration Index* - Total number of days in which the daily maximum temperature is above the 90th percentile* of the daily maximum temperature for at least 6 consecutive days.	**T**	days	+ - days	annual	ETCCD	Heat waves	**Health, Energy**
FWI: Fire Danger Index (based on maximum wind speed, relative humidity, cumulative precipitation, temperature). This index involves the calculation of 5 sub-indexes: three primary sub-indexes (FFMC, DMC, DC) which represent the humidity of the fuel; two intermediate sub-indexes (ISI, BUI) which represent the dispersion rate and consumption of available fuel.	**T - Prev - UR - V**	-	%	annual	Van Wagner, 1987	Fires	**Forests, terrestrial ecosystems, Settlements**
EWS: 98th percentile of maximum daily wind speed.	**V**	m/s	%	annual/ seasonal	EEA, 2017	Wind storms	**Settlements, Forests**
SCD: *Snow cover duration* - Number of days in the snow season (from November 1st of a given year to March 31st of the following year) with daily surface snow quantity exceeding 300 mm.	**Hn**	days	+ - days	November- March	Durand et al. 2009, Marcolini et al. 2017	decrease/absence of snowfall	**Winter tourism**

Acronym, definition of climate indicator	Variables fundamentals	Unit of measure of the indicator	Unit of measurement of variation climate (scenario)	Stairs storm	Reference	Climate Hazard/Proxy	Sector
Humidex5 (days): *Thermal discomfort index* - Measurement of the perceived heat resulting from the combined effect of humidity and temperature - Category 5: number of days per year in which the humidex index is greater than 45°C.	**T - UR**	days	+ - days	annual	Masterson and Richardson 1979	Thermal discomfort	**Health**
SU95p: *Summer days* - Number of days with maximum daily temperature greater than 29.2°C. This indicator was defined for the Italian territory (PNACC 2018).	**T**	days	+ - days	annual	PNACC 2018	Thermal discomfort	**Health**
TR (days): *Tropical nights* - Number of days with daily minimum temperature above 20°C.	**T**	days	+ - days	annual	ETCCD	Thermal discomfort	**Health**
SST: Water surface temperature	T	°C	°C			Impacts on biocoenoses	
SSH: Sea level	W	m	m				**Marine ecosystems, Summer tourism, Infrastructure (ports)**

3 IMPACTS OF CLIMATE CHANGE IN ITALY AND SECTORAL VULNERABILITIES

This Plan includes a summary framework relating to the most relevant aspects regarding the impacts of climate change and sectoral vulnerabilities that characterize the Italian territory. The sectors covered they are those already included within the National Strategy for Adaptation to Climate Change (MATTM, 2015), which correspond to the environmental systems and socio-economic sectors most vulnerable to climate change in our country.

To this end, the results of the climate projections for Italy were taken into consideration and some of the most consolidated impact indicators at national level were selected. Finally, some of the most recent and significant phenomena that have occurred on Italian territory following extreme meteorological events are recalled, by way of example of the possible repercussions that climate change could have on the environment, society and Italian economy and to support the identification of possible options of adaptation. For a more in-depth discussion of these topics, please refer to Annex III.

The framework of knowledge on the impacts of climate change in Italy, contained in Annex III and produced over the years 2017-2018 by a large community of experts, despite not being updated to the most recent years, is nevertheless efficient in anticipating the repercussions on the sectors of government, economic and environmental policy.

This Plan, however, contains updated elements of knowledge for some sectors, where it was possible to find information quickly, without prejudice to the fact that a complete update of the impact and vulnerability assessment is foreseen among the *soft* actions identified.

3.1 Cryosphere and mountains

The cryosphere, the combination of snow, glaciers and permafrost, is strongly impacted by climate change: in recent decades the duration and thickness of the snow have significantly reduced, as has the snow water stock that accumulates every year at the end of winter. Glaciers have already lost 30 to 40 percent of their volume. Figure This indicator represents the algebraic sum between the accumulated mass, deriving from winter and spring snowfall, and the mass of ice lost in the melting period (ablation). Although the availability of data, with adequate temporal coverage, is related to a limited number of glacial bodies, the mass balance measurement is relevant information on the effects of climate on glaciers.

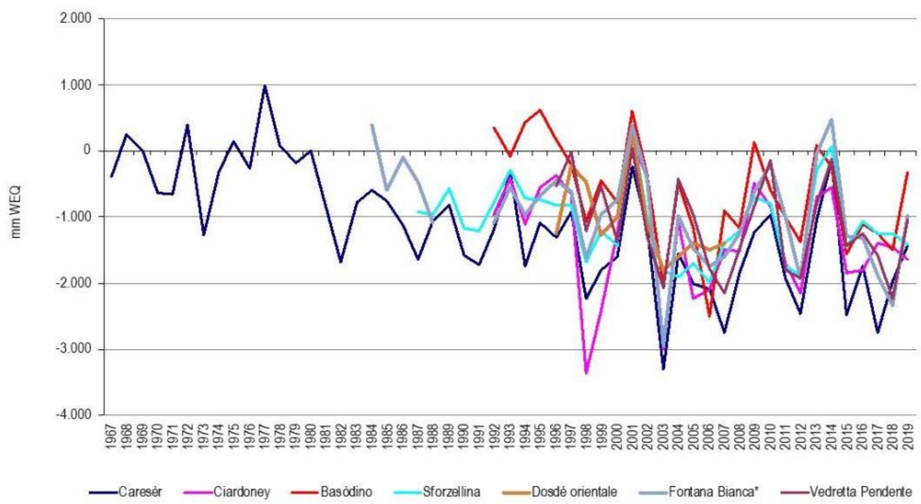


Fig. X – Net mass balance of some Italian glaciers (Source: SNPA, 21/2021)

For the seven glacial bodies considered, there is a general tendency towards deglaciation and melting, albeit with a discontinuous trend. The decidedly more significant balance sheet trend is that expressed by the long historical series of Caresèr (Trentino-Alto Adige): it is a glacier of larger dimensions than the others, although it is significantly reducing its area. From the point of view of correlation with climatic trends, although the annual budget information has a high intrinsic value, the response of the glacier to the main climatic factors (temperature and precipitation) is not always linear as the characteristics of the individual basin glacial periods can affect the annual budget in different ways. Overall, a very complex picture emerges, where the melting of glaciers represents the result of the thermal factor combined with the variations in the distribution of precipitation over the course of the year and the peculiar climatic conditions.

The so-called "peak water", the phenomenon of temporary increase in the flow of mountain streams caused by the increase in glacial melting which ends when the glacier dies out or retreats to such high altitudes that it can no longer melt, has already been reached in most Italian glacial basins. The temperature of the permafrost is increasing significantly in all Alpine measurement sites as is the thickness of the layer of soil or rock that is thawed annually. These trends will continue in the coming decades depending on the intensity of the increase in global temperatures. The duration of snow cover in the valley bottoms and on the southern slopes up to 2,000 m will be reduced by 4/5 weeks and by 2/3 weeks at 2,500 m. Glacier retreat will continue to accelerate as will permafrost degradation.

It is above all due to the presence of snow and ice that the mountains are considered "water towers" capable of supplying water to the downstream territories and the plains, compensating for the reduction in summer precipitation typical of Italian climates. The contribution of melting snow and ice to the total runoff of Italian rivers can vary from 5% in the southern regions to 50-60% in the Po basin. The reduction of snow and the disappearance of glaciers will compromise this fundamental buffer role, increasing summer water crises. In fact, it is in the summer months that the peak demand for water for civil use occurs, sensitive to the enormous fluctuations in presence in tourist, irrigation and industrial destinations, triggering multi-scale (local, regional and national) and inter-sectoral (primary, secondary and tertiary).

The mountains are an area particularly sensitive to natural dangers essentially linked to the intensification of the water cycle and changes in the cryosphere, both important factors in controlling the stability of walls and slopes. Compared to other mountain areas, the Alpine regions are particularly vulnerable due to the high population density, the significant tourist attendance and the large extent of the surface affected by glaciers and permafrost. The degradation of permafrost can reduce the stability of slopes and affect the stability of high mountain infrastructures (cableways, shelters, buildings, pylons). Ice avalanches, the fall of seracs and the sudden emptying of glacial pockets of water are processes linked to the interaction between global warming and the natural evolution of glaciers.

The collapse of the Marmolada serac occurred in July 2022. From a glaciological point of view, it is necessary to underline how collapses of this type are only partially affected by the temperatures recorded on a daily basis, since the inertia of the glaciers to changes in temperatures and the responses in terms of phenomena of this type require time long and persistent unfavorable conditions, conditions that have been occurring for years now. Given this from an analysis of the station's meteorological data

automatic machine of Punta Rocca of the ARPAV, it appears that in May and June, in which the glacier melting processes, the average daily temperatures were significantly higher than the historical average, with a difference of +3.2°C in the two months (ARPA Veneto, 2022).

While there is strong agreement that the collapse of hanging glacier fronts will be exacerbated by rising glacier basal temperatures, it remains difficult to deterministically link such processes to climate factors and develop predictive warning systems. It is important to underline the role of local specificities and the substantial impossibility of generalization.

It should also be highlighted that the types of risks presented can act in synergy and cumulatively, with cascade effects. It follows that all risk adaptation strategies will have to, taking into account these possibilities of interaction between hazards, act at different levels in order to allow local communities to take charge of effective governance of the issue of natural risks associated with

mountain.

Finally, it is essential to underline how climate changes are modifying mountaineering activities. Many itineraries have been modified and revised. Consistent with the recent Directives of the National Civil Protection Department, the action of the responsible authorities must be aimed exclusively at anthropized areas and infrastructures, while mountaineering activity must be left to the assessments of the individual mountaineer and mountain professionals such as Alpine Guides .

Compared to targeted and localized closures of itineraries, priority must be given to the rules of risk awareness and self-responsibility and to the self-regulation initiatives of the Alpine Guide Societies, especially considering the greater value and impact on other mountaineers.

3.2 Water resources

Most of the impacts of climate change are attributable to changes in the hydrological cycle and the consequent increase in risks resulting from it. Water resources are fundamental for equitable and sustainable development and water security is a fundamental requirement for economic development, food production, social balance, business competitiveness and protection of the natural environment.

With reference to the thirty-year period 1991-2020, in Italy an estimated rainwater input of approximately 285 billion m3 , corresponding to an average annual precipitation height of approximately 943 mm. 53% of precipitation (about 498 mm) returned to the atmosphere through evapotranspiration; the remaining 47%, remaining on the ground, is divided between subsoil infiltration (21%) and surface runoff (26%) (ISTAT, 2022).

In 2020, there was a decrease in precipitation compared to the 1971-2000 climate period (CLINO: Reference Climatological Normal). In particular, there was a total annual precipitation of 661 mm corresponding to a decrease in precipitation of -132 mm (ISTAT, 2022). The total annual rainfall, in reference to the CLINO for the various Italian regions, shows significant distribution anomalies on the territory in line with the forecasts highlighted in the latest IPCC 2022 report, which are determining, both on a global and national scale, anomalies critical meteorological and

extreme.

The quantity of renewable water resources in Italy corresponds to approximately 116 billion m3 . Recent data on the volumes of water that can actually be used are not available, estimated by SNAC (Castellari et al. 2014a) at around 52 billion m3 · The main user sectors of the resource are agriculture (around 20 billion m3), drinking water (9.5 billion m3) and the manufacturing industry (5.5 billion m3). Use in energy production does not lead to greater water consumption compared to current availability. However, it should be noted that the cooling of thermoelectric plants uses approximately 18.4 billion m3, of which only 11.5% comes from internal water. From this picture emerges a use of over 30% of renewable resources

available in our country, well above the 20% threshold indicated by the objective of a Europe efficient in the use of resources (EC 2011a, b). As a result, the Organization for Economic Co-operation and Development (OECD) has classified Italy as a country subject to medium-high water stress.
Furthermore, the distribution of availability and demand for water resources is characterized by strong heterogeneity at the subnational level. The water structure includes over 9,000 natural bodies - defined as significant pursuant to the Environmental Code - and artificial, made up of drainage and irrigation canals, over 180,000 km long. Large reservoirs can regulate a volume of resources corresponding to approximately 13 billion m3

, distributed in 367 operational dams, of which 37 have limited reservoir, 93 are considered experimental reservoir and 11 are under construction. The prevalent use, positioning and authorized volumes are indicated in Fig. X (ISPRA, 2020).

UTILIZZO PREVALENTE	n.	Volume autorizzato (10^6 m^3)	Superficie dei bacini idrografici sottesi (km^2)
IDROELETTRICO	306	4.371	86.328
IRRIGUO	126	8.264	37.789
POTABILE	34	409	1.120
INDUSTRIALE	13	192	953
LAMINAZIONE	10	135	4.569
MISTO	8	25	298
Totale	497	13.396	131.057

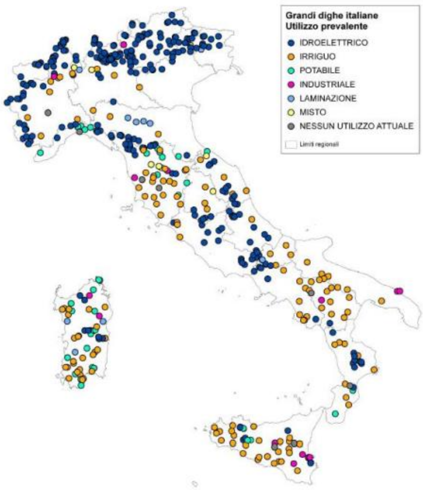


Fig. X: Reservoirs (Volumes, Uses and Location (Source: ISPRA, 2020)

Climate change could act more or less directly on the quality of water resources by altering both physical parameters (e.g. temperature, pH, turbidity, thermal stratification) and chemical parameters (e.g. concentration of nutrients, organic matter, dissolved oxygen, heavy metals) with cascading consequences on biological and ecological characteristics (e.g. phytoplankton concentration, community composition and structure, habitat loss due to changed salinity conditions). However, the evaluation of these impacts is particularly complex as it must take into consideration not only the processes linked to the effects of climate change on the hydrological cycle, but also the numerous interactions with the anthropogenic component (Carvalho and Kirika 2003; Greig et al. 2011). In particular, it is problematic to determine whether the impacts and alterations observed can be directly attributable to climate change or other anthropic disturbances affecting water bodies both from a qualitative point of view (e.g. excessive nutrient ratio due to agricultural or civil waste) and quantitative (e.g. the withdrawal from underground and surface water reserves for irrigation purposes). Despite this difficulty, the determination of the impact of climate change on the qualitative and ecological state of water bodies constitutes a fundamental aspect in the definition of the environmental quality requirements of waters defined by national and European legislation (Directive 2000/60/EU or Water Framework Directive - DQA, European Commission, 2000; In the future, the quality objectives defined by member states may be inadequate considering the possible variation of the reference conditions of water bodies induced by climate forcing (Kernan 2015).

3.3 Marine environments: biodiversity, functioning and ecosystem services

The Mediterranean Sea is one of the most exploited seas in the world, put to the test by enormous pressures such as pollution, coastal development, fish overexploitation, anthropic activities, etc. to which climate change is added: the latter, interacting with the effects of other anthropogenic disturbances, tend to exacerbate the effects, with consequences that are not predictable and difficult to manage (Claudet and Fraschetti, 2010). The Mediterranean region is one of the most vulnerable areas to global climate change due to its geographical location between the temperate climate of Central Europe and the arid climate of Northern Africa. Due to its modest extension and the characteristic of being a semi-enclosed sea, the changes induced by global warming can cause faster biological responses than those found in other systems on a global scale. For example, changes in temperature and rainfall intensity have caused important consequences in the Mediterranean biota (Bianchi, 2007; Boero et al., 2008; Lejeusne et al., 2010). On a regional scale, the Mediterranean Sea plays a role as a sentinel (hotspot) of global warming as it responds to climate change.

This trend of increasing surface and deep temperatures of Mediterranean waters began as early as the mid-1980s and according to current climate scenarios the increase is likely to continue in the near future. Trend analysis provides an increase of 0.041 ± 0.006 ÿC / year over the entire Mediterranean. The trend has an irregular spatial trend, with values increasing from 0.036 ± 0.006 ÿC/year in the western basin to 0.048 ± 0.006 ÿC/year in the Levantine-Aegean basin (Pisano et al. 2020 and cited bibliography).

Over the past 20 years, Marine Heat Waves *have* globally doubled in frequency and become longer lasting, more intense and more extensive (Collins et al., 2019), increasing mass mortality events worldwide (Garrabou et al., 2009; Hughes et al., 2017; Thomson et al., 2015; Wernberg et al., 2016) as well as in the Mediterranean Sea (Cramer et al., 2018; Marbà et al., 2015; Rivetti et al., 2014). Most studies on mass mortality events in the Mediterranean have focused on habitat-forming species such as, for example, gorgonians and algae (Chimienti et al., 2021; Garrabou et al., 2019; Verdura et al. , 2021) and, in the populations studied, some species have shown mortality rates of up to 80% (Cerrano et al., 2000; Garrabou et al., 2009) with important consequences for the structure and functioning of benthic ecosystems (Gómez -Gras et al., 2021; A recent study (Garrabou et al., 2022) highlighted that the Mediterranean Sea is also experiencing an acceleration of ecological impacts due to marine heat waves: an unprecedented threat to the health and functioning of its ecosystems. Overall, the models developed for the Mediterranean Sea indicate that climate change could lead to ecological extinctions of species at local, regional or even pan-Mediterranean levels and to widespread structural and compositional changes of ecological communities up to potential changes in the functioning of ecosystems, especially in cases where the lost species were functionally unique (Bellwood et al., 2004; Bianchi et al., 2014; Harvey et al., 2022; Loya et al., 2001; Moullec et al., 2019) . Possible socio-economic implications could concern the loss of species

fishing targets, erosion of essential ecosystem services, and mass mortality of ecologically important species (Smith et al., 2021).
Furthermore, with the increase in temperature over the last 50 years, there has been an increase in non-indigenous species which, thanks to the opening of the Suez Canal, aquaculture and ship transport, have entered and established themselves in the Mediterranean basin influencing indigenous species (CIESM 2002).
In addition to the constant warming of the waters, the Mediterranean is undergoing a progressive increase in salinity, which affects all three layers (the superficial layer, the one between the surface and 200 m, and the depth layer with a notable increase in the phenomenon in the last two decades). The causes of this phenomenon are to be found in the increase in evaporation in the Mediterranean basin and in the decrease in precipitation.
Furthermore, the exponential increase in carbon dioxide concentrations in the atmosphere, caused by anthropogenic activities, such as the combustion of fossil fuels, deforestation, cement production and large-scale land use changes, has led to a significant decrease in the pH in water in marine-coastal environments (Touratier and Goyet, 2009). The consequences of this decrease in pH are very serious, affecting the structure and functioning of marine ecosystems (Fauville et al. 2008; Gattuso and Hansson, 2011; Riebesell et al., 2013; IPCC, 2021).

The Mediterranean thus risks becoming increasingly warmer and undergoing profound changes both in terms of composition (biodiversity, alien species, community composition) and in functional terms (alteration of biogeochemical cycles, change in food networks) with an increase in vulnerability and extinction rates of its components. The loss of natural capital will also lead to a reduction in the goods and wealth (ecosystem services) that ecosystems guarantee to humans, with consequent social and economic implications.

3.4 Ecosystems and biodiversity of inland and transitional waters

Wetlands and coastal lagoons are valuable environments and important reserves of biodiversity and their importance has been widely recognized internationally, particularly under the Wetlands Convention (Ramsar, Iran, 1971) and the Convention on Biological Diversity (CBD) signed at the United Nations Conference on Environment and Development (UNCED) (Rio de Janeiro, Brazil, 1992). According to the national inventory of wetlands in Italy there are 1,511 wetlands.
The total extension amounts to 771,125 ha. 48% are lakes and rivers, 32% are marine and coastal environments and 20% are artificial wetlands. Among these sites, 57 are recognized as being of international importance under the Ramsar Convention34. Of the 57 Ramsar sites, 33 are coastal lagoon environments. Coastal lagoons listed as Ramsar sites amount to 73,982 ha out of the total 167,575 ha of Italian coastal lagoons, or 44% of the country's total lagoon area.
Climate change affects these environments by altering their ecological state. Some types of ecosystems, such as those that refer to open transition environments, have a high resilience typical of systems adapted to high environmental variations. Other types, such as lake ecosystems and groundwater ecosystems, are much more vulnerable and difficult to manage.
In detail, the increase in temperatures, the reduction in snow cover and the high seasonal variability of precipitation alter the hydrological cycle, also threatening the ecological state of rivers.
The Alpine rivers will see a decrease in the supply from the glaciers while the rest of the waterways will suffer from a greater frequency and duration of low and dry periods. This will lead to an alternation, in the Po Valley rivers, of winter floods and summer eutrophication, while more generally there will be a

[34] https://www.mite.gov.it/pagina/zone-umide-di- importance-internazionale-ai-sensi-della-convenzione-di-ramsar#1

worsening of water quality with consequent loss of biodiversity. Similar to rivers, lentic systems are also affected by climate change in a differentiated manner compared to climatic areas. Alpine lakes, for example, will suffer a loss of species and colonization by species normally established at lower altitudes. The deep lakes of Northern Italy will be negatively affected by the increase in temperatures which will lead to an increase in microalgal and cyanobacterial blooms with consequent damage to macrophytic vegetation and coastal animal communities. The lakes in the center and south will see a substantial decrease in water levels (with the risk of drying out for the shallower lakes) and a serious loss of biodiversity.

Climate change will also have impacts on the ecosystems of river mouths and lagoons. The high variability of precipitation will produce a winter increase in nutrients and pollutants in the lagoons of Northern Italy. The increase in the frequency of floods could destroy the banks and aggravate the phenomenon of erosion, leading to losses of biodiversity. Likewise, the increase in summer drought events could create problems relating to the intrusion of the salt wedge, with drying up and microdesertification. These lagoons will be subject to the spread of non-indigenous species. In the lagoon ecosystems of the center and south of the country, the increase in temperatures will have an impact on the evaporation of water and may lead to hypo-anoxic crises with consequent threat to

biodiversity.

Finally, groundwater will be subject both to alternating drought and flood phenomena and to the probable increase in groundwater withdrawals. This will impact the vertical connection between surface water and groundwater.

3.5 Coastal areas

Changes in sea level (Chap. 2), although slow and not directly appreciable to the human eye, are the subject of attention and monitoring also due to the potential consequences they could have on Italian coastal areas in the medium to long term. In Italy, where the strong anthropization of coastal areas has caused a strong growth in the number of people and activities over the years, exposure to coastal risk has been increasing: this is particularly true in areas characterized by delicate balances between land and sea , underlying the sea level, or low elevation, with a high density of resident population or high urbanization such as, for example, the Northern Adriatic coastal arc, including its lagoons and the Po Delta. In a peculiar and unique territory such as this, in addition to the rise in the absolute mean sea level due to climatic factors, is also added locally to the loss of altitude due to the compaction of the clay and sandy layers of the subsoil (subsidence). It is, in fact, the vertical movement of the ground that locally exacerbates the global phenomenon due to climate change (SNPA, 2021). These systems, located at mean sea level or below (e.g. lagoons, coastlines, rivers, plains, inhabited centers and related infrastructures and cultural assets), are exposed to the risk of flooding, both from sea and land, of loss of habitat and reduction of water quality.

Furthermore, an increase in the frequency and intensity of extreme storm surges could significantly exacerbate the impacts of climate change on the coast. Indeed, although it is possible that the frequency of storm surges will not increase significantly, it is likely that the predicted sea level rise will lead to much more severe impacts, increasing both the severity of storm surge effects and the likelihood that they will generate an impact negative on the coasts (e.g. impacts on habitats, on the use of the coastal strip, on the population).

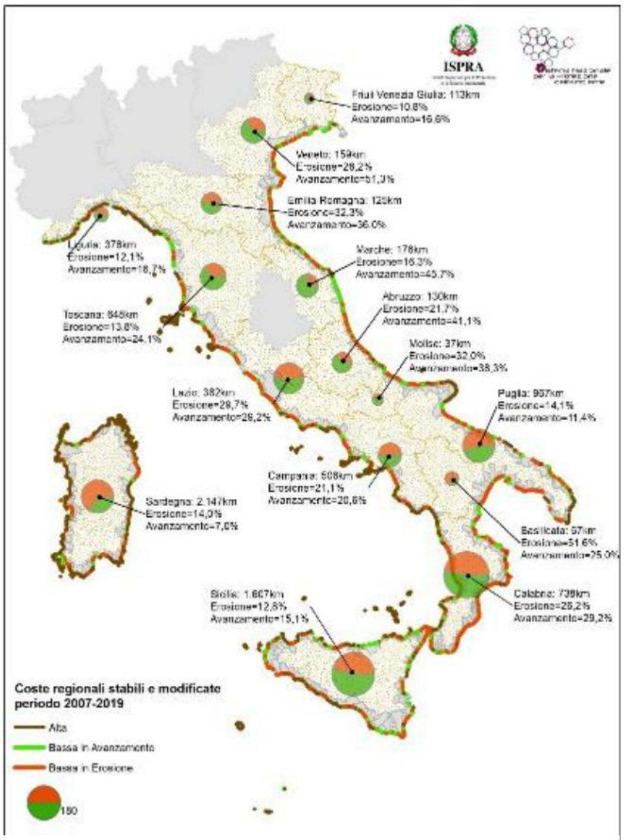


Fig. X – **Regional coast and percentage of variations in the period 2007-2019 due to erosion and advancement** (ISPRA, 2021)

Sea level rise and increase of the frequency of extreme events are the two main factors impacting the physical coastal system: coastal erosion and flooding temporary wind due to storms are quite common along the Italian coasts, particularly in areas with low beaches (CMCC, 2021).

In the period between 2007 and 2019, 37.6% of the coastlines underwent variations of more than 5 metres.

In many coastal regions there is a general trend towards a worsening of the stability of the coasts, in other words many coastal areas of the country are burdened by important erosion processes although 16% of the Italian coasts, equal to 1,291 km, are protected with defense works . Between 2007 and 2019, new works were carried out to protect a further 180 km of coastline but the effect of the numerous efforts made over the years to mitigate coastal instability is only visible in some areas of the country (ISPRA, 2021). Calabria, Sicily, Sardinia and Puglia are the regions with the greatest number of kilometers of receding coastline (Fig. X).

In a medium emissions scenario, an estimate made by the CMCC to 2050 indicates an average regression of the coasts characterized by beaches of approximately 17 meters (CMCC, 2021).

The effect of climate change on salt intrusion can be explained on the basis of two potential impacts: 1) the expected rise in sea level may naturally cause greater salt intrusion towards land; 2) the alteration of the rainfall regime, which according to climate models would lead to drier summers almost everywhere in Italy, could favor a decrease in low-water river flows, which will be less and less able to effectively counteract the salt rise from the sea. The measurements carried out on the Po demonstrate that in the 1950s and 1960s the phenomenon was felt no more than 2-3 km from the mouth; in the 70s and 80s it went about 10 km inland, reaching up to 25 km from the mouth in the 2000s. A similar progression is also found in the Adige, where it went from 5-

7 km of uplift in the 1970s to 10-12 km in the 2000s (Kurdistani et al, 2022).

Moving closer to the present, during the summer of 2022 the Po at Pontelagoscuro reached the historical minimum flow rate of around 100 m³/s with a monthly average of around 160 m³/s in July, when the salt wedge reached up to 40 km from the mouth (National Association of Land and Irrigation Water Management and Protection Consortia).

A significant figure if compared with the rise of the wedge in ordinary low water conditions (650 m³/s) provided by the Po River District Basin Authority. This led to the total interruption of the water supplies for irrigation purposes, various forms of rationing and rotations in many areas of the delta.

In light of the data available for the current state, the phenomenon now seems to be taking on characteristics close to irreversibility. Relative to the specific Po Delta system, in the hypothesis of the RCP8.5 emission scenario (high emissions) there could be an 80% increase in the intrusion of the wedge and a 100% increase in the persistence of the phenomenon, with important consequences on the availability of water resources for the entire area. Furthermore, in these conditions, the factor linked to the reduction of the river flow is more impactful and decisive than the increase in sea level (Kurdistani et al, 2022). Another study, limited to the Po di Goro, using the same scenario, shows that in the period 2021-2050 the intrusion will increase by 15% on an annual basis (up to 50% in summer) with an annual increase in salinity of 9% (up to 35% in summer). Furthermore, extreme upwelling events that today occur with a return time of 10 years will occur twice as frequently in the future (Kurdistani et al, 2022).

Finally, it should be mentioned the phenomenon of proliferation of algal species in marine-coastal waters *(Harmful Algal Blooms)* which in recent decades seem to have intensified both in terms of temporal frequency and greater geographical diffusion in most areas of the world (Anderson et al., 2012; Zingone, 2010). The surveillance activity of planktonic microalgae of health interest has been carried out for some years along the Italian coasts, reporting episodes of blooms of *Alexandrium* spp., *Dinophysis* spp., *Pseudo-nitzschia* spp., *Fibrocapsa japonica,* etc. Only since 2005 has greater attention been paid to potentially toxic benthic microalgae, and in particular to *O.* cf. *ovata, Prorocentrum lima, P. emarginatum, Amphidinium* spp. Among these, only *Ostreopsis ovata* has shown a relationship between exposure during bathing activities and health effects: it is a potentially toxic benthic species, typical of tropical and subtropical areas, found in recent years also in temperate zones and in many Mediterranean countries. The origin of *Ostreopsis* in the Mediterranean Sea is, however, still to be clarified.

3.6 Soil and territory

3.6.1 Geological, hydrological and hydraulic instability

The phenomena of geological, hydrological and hydraulic instability (e.g. floods, landslides, erosion and sinking) are widespread and frequent in Italy where they have already caused victims and serious damage to the environment, movable and immovable assets, infrastructures, services and the economic and productive fabric with huge economic consequences (more than two billion euros per year). Although the natural peculiarities of the Italian territory (geological, geomorphological, meteorological and climatic characteristics) play a fundamental role in the origin of these phenomena, various anthropic factors contribute significantly to the triggering or exacerbation of their consequences. From this perspective, the potential increases induced by climate change in the frequency and intensity of some types of atmospheric events (for example, short-term and high intensity rains), which regulate the occurrence of instability phenomena, could represent a substantial increase in the current risk conditions; at the same time, other phenomena could occur less frequently due to variations in the opposite sign or effect (for example, the increase in losses due to evaporation and transpiration). Currently, considerable and diverse sources of uncertainty (among others, the quantity and quality of the historical series of observations, shortcomings of the current climate simulation modeling chains, contemporary variations in land use and cover and levels of anthropization) make it complex and the estimate of the variation in occurrence and magnitude of instability phenomena due to climate change is uncertain.

The high vulnerability of our country is well represented by the data of the latest ISPRA Report on *"Hydrogeological instability in Italy: danger and risk indicators":* almost 94% of Italian municipalities are at risk from landslides, floods and/or coastal erosion and over 8 million people live in highly dangerous areas. In 2021, over 540 thousand families and 1,300,000 inhabitants live in landslide risk areas while around 3 million families and almost 7 million inhabitants live in flood risk areas. The regions with the highest values of population living in areas at risk of landslides and floods are, in order, Emilia-Romagna, Tuscany, Campania, Veneto, Lombardy and Liguria (ISPRA, 2021). Since these assessments refer to the current scenario, and are not already calibrated with respect to future climate scenarios, the possibility that the increase in extreme meteorological events, expected for the next decades due to climate change, could determine a modification of the dangerous areas.

Without prejudice to the fact that the phenomena of geological, hydrological and hydraulic instability originate from various factors (e.g. geological and morphological characteristics of the slopes and/or hydrographic basins, urbanisation, vegetation cover, etc.), in many cases a decisive role is played from rainfall: among the countless events that have occurred on Italian territory, mention is made, in this regard, of those that most recently hit Trentino-Alto Adige (August 2022), Senigallia (September 2022), Maratea (October 2022) and Ischia (November 2022) with loss of human lives, damage to movable and immovable property, cultural heritage, infrastructure and services, energy blackouts. Many of the recent examples cited have involved the soil, i.e. the most superficial layer made up of mineral components, organic matter, water, air and living organisms. Since experimental data and an adequate monitoring network to evaluate soil loss due to water erosion are practically absent, models that use factors linked to soil characteristics, climate, vegetation, land use and shape of the landscape. The extent of soil loss estimated at European level using the RUSLE model (Panagos et al. 2015) highlights average values of 2.46 tonnes/hectare * year in the Member States, equal to 970 million tonnes of soil lost annually. Italy, with an average of 8.77 tonnes/hectare *, presents the highest values, particularly concentrated in hilly agricultural areas and in areas with low vegetation cover (Fig. X).

year

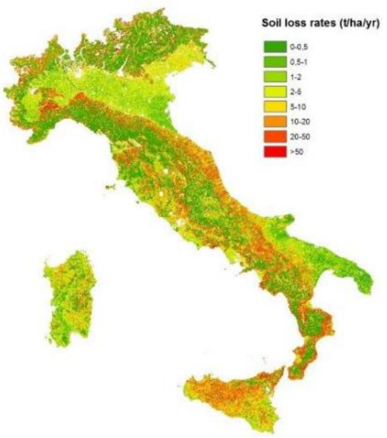


Fig. X - Estimate of soil loss due to water erosion expressed in tonnes/hectare*year (Source: JRC-IES)

Since the impact of climate change on geological, hydrological and hydraulic risk is expressed mainly through changes in temperatures and precipitation regimes, which occur in ways that are highly variable in space and time, and are influenced by natural conditions and local anthropic influences, this will lead to a variation in the frequency of hydraulic instability phenomena in smaller basins, of superficial and deep landslide phenomena in terrain characterized by coulters of reduced thickness and/or high permeability. The degradation of the permafrost may manifest itself differently depending on the substrates involved, the morphological conditions of the slopes and rock walls and possible interference with anthropic infrastructures. An increase in instability phenomena related to rock collapses/overturns, debris flows and other surface phenomena is expected, as well as variations in the hydrogeological characteristics of high altitude slopes, with sometimes significant impacts on the quantitative and qualitative characteristics of surface waters. The frequency of river floods will be more impacted in catchments with reduced permeability that respond more

quickly to meteorological stresses and have reduced attenuating effect against
rainfall of short duration and strong intensity. Urbanization and land use can have a negative impact, contributing to the worsening of instability phenomena.

3.6.2 Land degradation

Soil degradation is a reduction in the biological productive capacity of the soil resource. Often, this process is inextricably linked to the loss of biodiversity and the impacts of climate change. The United Nations Statistical Commission has defined indicator 15.3.1 for monitoring target 15.3 of the SDGs as "percentage of degraded areas of the national territory", based on the methodology used by the United Nations Convention against Desertification (UNCCD), a international reference regarding the target 15.3. Although the best approach is still the subject of scientific debate, the UNCCD (2021) recommends for this purpose the combined use of three sub-indicators: land cover and its changes over time, soil productivity, soil content organic carbon *(Soil Organic Carbon,* SOC), leaving the possibility of integrating other specific sub-indicators at the individual country level.

The degradation is assessed by analyzing the change in the sub-indicators considering a baseline (2000-2015) and a reporting period (2016-2019) as a time reference. The assessments carried out at the Italian level follow the methodology proposed at the international level, trying to use and enhance national and community databases to replace less detailed global datasets.

The final indicator summarizes the information relating to the baseline and the reporting period according to the methodology proposed by the UNCCD for the calculation of SDG 15.3.1. For Italy, the final calculation for 2019, considering the contribution of the baseline degradation (2000-2015) and the reporting period (2016-2019) combined, estimates the degradation for the national level at 17.0%. Limiting ourselves to the deteriorated part alone, the different condition of the islands and the center compared to the other areas is evident. Sardinia and Lazio are the regions with the majority of their territory in degraded conditions (29.9% and 29.4% respectively), while Sicily is the region with the greatest degraded surface area in absolute terms with 1, 87 million hectares, slightly higher than the degraded territory in Piedmont (1.82 million hectares). Sardinia, according to the SDG indicator, is the one with the highest percentage (28.1%) followed by Emilia-Romagna (23.5%) and Campania (20.8%) (Fig. In the reporting period, other degradation factors were added (in addition to the standard ones: land cover, productivity and organic carbon content) partly linked to land consumption (loss of habitat quality, fragmentation, areas of potential impact, density of artificial covers, increase in natural spaces smaller than 1,000 m2 and areas affected by fires), a particularly relevant phenomenon in the Italian context.

Fig .

SDG 15.3.1

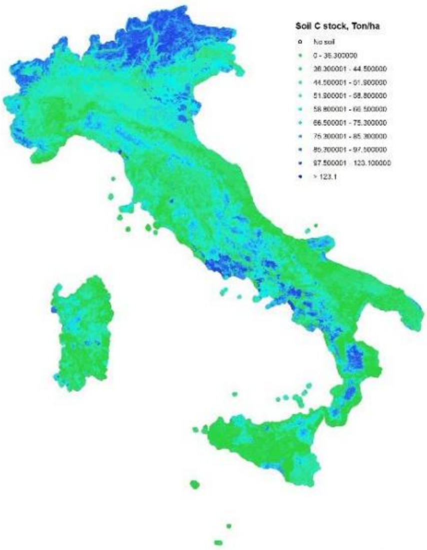


Fig. Y – Organic carbon content in the most superficial levels of Italian soils (0-30 cm). Source: CREA, CNR, University of Foggia; Mediterranean University of Reggio Calabria, ARPAV, ARSSA Calabria, Lamma Consortium, Tuscany Region, ERSA-FVG, ERSAF Lombardia, IPLA, ISPRA, Campania Region, Emilia-Romagna Region, Liguria Region, Marche Region, Puglia Region, Region Sicilian.

The decrease in the content of Organic Carbon in the Soil (Soil Organic Carbon, SOC) is one of the main threats to the soil now recognized in all official documents at European level (7th Environmental Action Programme, New Green Deal, thematic strategy for soil, biodiversity strategy, etc.). The national processing carried out within the activities of the Global Soil Partnership (FAO, 2018) shows an overall accumulation of organic carbon in the first 30 cm of soil equal to 1.67 Pg; Sicily, Sardinia, Valle d'Aosta and Puglia are the regions where the poorest soils in carbon are present on average, with agricultural areas (vineyards, orchards and olive groves) the most penalized from a stored carbon point of view, contrary to wooded areas characterized by the highest contents (Fig. Y).

The risk of salinization and the accumulation of excess sodium is considered one of the major threats to Italian agricultural soils (Dazzi, 2008). The phenomenon is mainly due to waters rich in salts or brackish used for irrigation and is particularly evident along the coastal strips (Dazzi & Lo Papa, 2013). In these areas the excessive exploitation of the aquifers, due to withdrawals of quantities of water exceeding the inputs of fresh water, causes the intrusion of the salt wedge with effects that can be found for kilometers inland on the river plains as in the case of the southern Sardinia (Castrignanò et al., 2008). Around the Po Delta and further north, up to the areas bordering the Venice lagoon, vast areas have been reclaimed for agricultural purposes in the last century. The water level is strictly regulated here by canals and pumping stations (Vittori Antisari et al., 2020; Buscaroli and Zannoni, 2010; Teatini et al., 2007) and the intrusion of sea water along rivers, canals and in aquifers is aggravated by subsidence phenomena (Teatini et al., 2005). Salinization problems are also well known in Sicily (Dazzi and Fierotti, 1994), both in inland and coastal areas. Here the salinity of the soil is also linked to the geological nature of the substrate characterized by the chalky-sulphuric formation which

it contributes to enriching the water used in the irrigation of agricultural areas in salts (Dazzi and Lo Papa, 2013, Selvaggi et al., 2010). Other lithologies capable of increasing the salinity of the soil are the Plio-Pleistocene marine deposits widely spread both in Sicily and in the rest of the peninsula.
Climate changes will have a profound effect on the structure and functions of agro-forestry and pastoral ecosystems, influencing their composition, productivity, ability to regulate biophysical and biochemical cycles and soil characteristics. Increases in aridity and extreme meteorological phenomena such as drought and intense rainfall will influence ecosystems by modifying the competition relationships between organisms, with possible loss of biodiversity, and reflecting on the other properties of the ecosystems and the services provided. Climate changes could exacerbate degradation processes through complex and unprecedented feedback mechanisms of the soil-vegetation-water system. The organic substance in agricultural and forestry soils may undergo a reduction due to the alteration of the thermal and rainfall regime. Alterations in the organic substance content could contribute, together with other factors, to the abandonment of hilly and mountain areas together with phenomena of over-exploitation of soil and water in flat areas could increase the risk of desertification and degradation. The progressive abandonment of agricultural activities in hilly and mountainous areas, the consequent expansion of shrubby vegetation, the decrease in soil fertility and the increase in fire risk, especially when associated with the increase in the frequency of drought events, are concomitant phenomena that strongly contribute to determine situations of extreme degradation.

In parallel with the abandonment of hilly and mountainous areas, it will be possible to intensify the use and urbanization of flat areas with consequent waterproofing of soils. Finally, in the lowland areas resulting from drainage reclamation, the fertility of organic soils will be threatened by the mineralization of organic C due to the unprecedented state of oxidation, which will lead to a reduction in resilience capacity as well as massive CO_2 emissions .

3.7 Terrestrial ecosystems

Climate is the environmental factor that has the greatest influence on natural systems, determining their dynamics, structure, composition and productivity. By virtue of this role, climate change contributes massively to the current biodiversity crisis.

As regards terrestrial fauna, numerous impacts due to climate change have been documented, the consequences of which could determine a general decline of some populations, variations in phenological cycles, modification of distribution areas (with thermophilic species expanding towards the north and towards higher altitudes). high; while species in cold habitats may suffer a contraction), alterations in the normal ecological interactions between species, with a possible expansion of pathogen-vector species and with invasions of alien species that could find ideal environments in the changed climatic conditions. Furthermore, the functioning of ecosystems is compromised by the phase shift in the biological cycles of interconnected species and by changes in the composition of communities.

Italy has a great wealth in terms of animal species, with a high incidence of endemic species: the Italian fauna is estimated at over 58,000 species, of which approximately 55,000 are invertebrates and 1,812 protozoans, which together represent approximately 98% of the total species richness, as well as 1,258 vertebrate species, representing 2%. If the subspecies are also considered, the total number reaches around 60,000 taxa. The richest phylum is that of arthropods, with over 46,000 species, mostly belonging to the insect class.

The main effects of climate change on fauna are linked to:

- changes in physiology, productivity and abundance: the analysis of time series, together with targeted observations in recent years, highlight that several species may see their physiology, reproductive success and consistency altered by climate change. A contrasting trend can be detected in which some changes are positive, and others negative, but overall the scenarios proposed by the various authors are negative. For some high altitude species, for example, there may be positive effects regarding survival in the winter period or reproductive success thanks to the early thawing of snow in spring, and negative effects due to the increase in precipitation in the summer period and the delayed onset of autumn snowfalls which have an impact on survival, with an overall negative balance which translates into population decline (Imperio et al., 2013, Viterbi et al. 2015).

  The increase in temperature has effects on the physiology of some amphibious species, especially for those species that are more vulnerable to climate changes and could represent a selective element for intraspecific variability which could therefore influence their outcomes.
- changes in the life cycle: the life cycle of numerous animal species is linked to the climate. The increase in temperatures, the bringing forward of the spring season, the shortening of winter, the presence of prolonged periods of drought and the increase in extreme events can modify the rhythms of the life cycle. In particular, various activities (reproduction, egg hatching, reproductive success) are regulated by these events which can in turn lead to negative impacts. One of the most evident effects is the advance in the timing of spring migration of birds, which is important to reach their destination at the moment of maximum availability of resources (Jonzén et al. 2006).
  This adaptive response has not been adopted in the same way by all migratory bird species, and it has been shown that failure to anticipate migration translates into a low resilience of populations to climate change with negative effects on their conservation status (Møller et to 2008).

- changes in the distribution of species: several studies have confirmed that the shift in the distribution of species (including many taxa present in Europe) is consistent with the changes expected from climate change (Parmesan & Yohe, 2003; Hickling et al., 2006).
  Thomas (2010) concludes that for more than half (perhaps two thirds of the terrestrial fauna species considered) a change in the boundaries of their ranges has already been highlighted, attributable to global warming of anthropic origin which occurred between 1970 and 2000. These shifts are directed towards areas with more favorable climatic conditions, i.e., mainly towards higher altitudes and latitudes. Parmesan & Yohe (2003) estimated an average shift of 6.1 km northwards (or 6.1 m towards higher altitudes) every ten years, globally. Species linked to colder climates or habitats may observe a contraction of their ranges. Not infrequently a joint and contrasting effect is observed, as for example in the case of the red partridge *(Alectoris rufa),* which is modifying its range, expanding in western Monferrato, but shrinking in the Langhe and along the Alpine margin; the authors attribute this dynamism of the range due to changes in the climate at a local scale (Tizzani et al., 2013). Habitat modifications and anthropic activities can negatively contribute to climate change, leading to a reduction in the distribution ranges of species (Chamberlain et al. 2016, Brambilla et al. 2016).

The Italian territory is characterized by a high degree of plant biodiversity, thanks to its extension both latitudinal (with three different biogeographical regions: alpine, continental, Mediterranean) and altitudinal (from the basal to the nival horizon). Among the Italian biogeographical regions, the impacts of

Recent climate changes have so far been more evident mainly in the Alpine region and in a less accentuated (but also less documented) manner in the Mediterranean region: the two extremes of the Italian climatic and altitudinal gradient.

The Italian flora is among the richest in Europe with 3,913 entities of non-vascular plants, of which 302 Liverworts and Anthocerotes, 907 Mosses (Aleffi et al., 2020) and 2,704 Lichens (Nimis and Martellos, 2017), and with 8,237 entities of vascular plants (Bartolucci et al., 2021)

The main effects of climate change are linked to:

- changes in physiology, productivity and abundance: the increasing increase in the frequency of extreme events has a direct effect on the increase in the variability of climatic conditions which, much more than average climate conditions, seems to influence the physiological and phenological response of plants at of species (Reyer et al. 2013). In the Alpine biogeographical region, the impacts of climate change on the physiology and productivity of ecosystems can be observed to a greater extent. They are evident in particularly sensitive environments such as snow valleys, which are very vulnerable due to the expected decrease in the amount and persistence of snowfall. In fact, in these extreme habitats, species richness, density and primary production vary according to snow conditions (Carbognani et al., 2012). In the Mediterranean area, environmental warming influences plant growth by inducing changes in photosynthesis rates, respiratory losses of CO_2 and increased photorespiration.

- modifications to the life cycle: one of the most widespread and evident impacts of climate change on the life cycle of plants concerns the bringing forward of certain phenophases, such as flowering, which characterize both the birth rate of plant species populations, and the risk to human health, for example exposure to allergens (Ugolotti et al. 2015). Some climatic variables representing the thermal, hydrothermal and hydrogeological regime would, in fact, be able to directly influence physiological processes and key phenological events such as the time at which flowering begins, the winter hardening of the tissues, the resistance to late frosts and summer drought .

changes in the distribution of species: among the main observed impacts of climate change on the distribution of species in the Alpine biogeographical region are: the migration of alpine species and shrub species towards higher altitudes (Pauli et al., 2012; Cannone et al., 2007), the rise of tree species with consequent raising of the limits of tree vegetation (Leonelli et al., 2011), the variation of the floristic composition, the extension of the spatial distribution patterns (patterns) of the plant communities (Erschbamer et al., 2011) and finally the acceleration of the impacts of climate change on the dynamism and colonization processes of species (Cannone et al., 2008). Such changes, in combination with projected climate change trends, may result in an increasing loss of biodiversity and an increased risk of extinction for many species in the near future.

3.8 Alien species

Invasive alien species today represent one of the main threats to biodiversity and the number of species introduced on all continents is still growing without there being any signs of saturation (Seebens et al., 2017); a recent study estimates that in Europe there will be a 64% increase in the number of alien species by 2050 (Seebens et al., 2020). Italy today has the highest number of alien species in Europe with almost 3500 species present on the national territory, an introduction rate of

approximately 13 species/year in the past decade and an increase of over 500% in new alien species introduced in the last 120 years (ISPRA, 2022).
The scientific community agrees in the assessment that climate change will aggravate the negative impact of invasive alien species, with effects on multiple areas (e.g. biodiversity, human and animal health), and production sectors (e.g. agriculture and forestry, forestry, fishing commercial, aquaculture, transport) of crucial importance also for our country (Hulme, 2017).

A first global assessment of the potential future impacts of biological invasions on biodiversity (Essl et al., 2020) highlights how climate change, trade and socio-economic development represent the 3 major *drivers* of future biological invasions in all contexts. In particular, in developed nations with temperate climates, *climate change* represents the second most relevant *driver* . The implications of climate change for biological invasions are multiple and act through three main mechanisms (Robinson et al., 2020): modifying the nature of the introduction vectors (for example, opening new access routes), altering the abiotic nature of the environment recipient (making it more vulnerable) and modifying biotic interactions in the receiving communities. While the first of these mechanisms acts on the transport and introduction phases, the second two act simultaneously on the establishment and diffusion phases.

As regards new introduction routes, over 90% of world trade is now enlivened by maritime transport (IMO 2019). This carrier is expected to be affected by the melting of the Arctic ice cap, a process that will open up new shipping routes. Mediterranean marine environments are particularly exposed to the impacts due to the spread of alien species following climate change, as the progressive warming of the waters, in addition to favoring the arrival and expansion of Lessespsian species, increases the stabilization potential of alien species which arrive from warmer seas through naval traffic, both commercial and recreational, and are introduced into the natural environment with ballast water and hull encrustations (biofouling). These effects have recently been highlighted also for the national marine context (Azzurro et al., 2022; Ferrario et al., 2017),

As regards the stabilization and spread of invasive alien species, most of the literature indicates that invasive alien species, thanks to their ecological plasticity and tolerance to a wide range of temperatures, will be favored or at least not negatively influenced by climate change, while native species will be disadvantaged (Vilà et al. 2007; Hellmann et al. 2008; Thuiller et al. 2008) also due to the stress induced by climatic conditions on the latter which often do not seem to be able to respond with the necessary speed to climate change (Corlett and Westcott, 2013). In this regard, recent work at a national level has highlighted how climate change is able to favor the expansion dynamics of Robinia pseudoacacia to the detriment of native tree species, with indirect effects also on the distribution of native epiphytic species which contracts due to the loss of suitable substrate (Nascimbene et al., 2020).

A further important effect of climate change is the increase in the frequency and intensity of extreme events such as droughts, floods, storms and heat waves, capable of transporting invasive alien species to new areas. The arrival and possible establishment of new invasive alien species reduce the resilience of natural habitats, making them more vulnerable to the impacts of climate change: for example, the presence of some invasive alien plant species (trees and shrubs) can significantly alter fire regimes, especially in areas that are becoming hotter and drier, increasing the frequency and severity of fires (IUCN 2021).

Even the effects of climate change on the spread of alien species capable of carrying infectious diseases (Gould and Higgs, 2009) find an alarming example in Italy relating to mosquitoes of the genus

Aedes, currently present with three species *(A. albopictus, A. koreicus, A. japonicus)* which show worrying expansion dynamics and settlement capacity even in areas that would once have been been climatically inhospitable (Negri et al., 2021).

3.9 Forests

Italy is particularly rich in forests: over a third of the national surface is covered by woods. Since the Second World War, the Italian forest surface has had a gradual and continuous expansion: from 8,675,100 ha in 1985 it went to 10,982,013 ha in 2015, with an increase equal to 27% in total, which however corresponds to a surface area that has tripled in the last sixty years, mainly following the progressive depopulation of mountain areas and the abandonment of agro-silvo-pastoral practices.

The response of forest ecosystems to climate change is resulting, and increasingly in the future, in an alteration of growth rates and productivity (Sabaté et al. 2002; Rodolfi et al. 2007; Giuggiola et al. 2010; Lindner et al. 2010; changes in the distribution of species and altitudinal shifts (Parolo and Rossi 2008) of forest habitats, often also influenced by land use, resulting risk of fire and damage from insects and other pathogens, alteration of the water and carbon cycle.

One of the main threats for the European forestry sector and, in particular, for southern Europe is that of forest fires, indirectly related to climate change: in Italy the areas that have historically suffered the most significant damage in terms of burned surface area are located mainly in the southern part of the peninsula, in the major islands and in the Ligurian and Tuscan coastal strip (Bacciu et al. 2014; State Forestry Corps 2015; Schmuck et al. 2015). The phenomenon of forest fires in Italy, which among other things contribute to the emission of non-negligible quantities of carbon dioxide into the atmosphere, presents a fluctuating trend over time: a critical period is observed in the mid-eighties, which was followed by years of where the level of the phenomenon remained high overall. Over the last four decades, an average value of land area covered by fire of 107,289 ha has been recorded. The year 2017 was the most critical of the last decade and among those with the most serious damage since 1980, for a total surface area affected by fire of over 160,000 ha, with approximately 8,000 events (Fig. X).

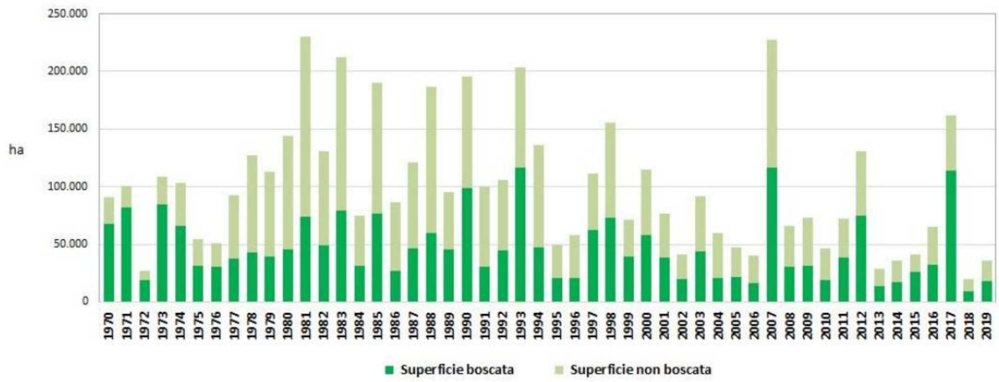


Fig .

The improvements observed in some years could also be attributable to greater prevention and better control of the territory, as well as greater timeliness in intervention operations in the event of an emergency. The data relating to the causes confirm the voluntary origin of the majority of fires, being over half of the total ones recorded, even exceeding 60% in some years.

The combination of climate change and the abandonment of rural and forestry areas, if not addressed correctly, could exacerbate the problem of fires and cause increasingly intense and significant events, capable of causing huge economic, environmental and social losses. In terms of threats to the forestry sector deriving from climate change, it is necessary to remember the extreme meteorological event called "Storm Vaia" which affected the north-east of Italy (mountain area of the Dolomites and the Venetian Pre-Alps) between 26 and 30 October 2018. Despite being called a "storm", the event involved winds that reached hurricane speed (100-200 km/h), causing the fall of tens of millions of trees (a figure never recorded in Italy in recent times).) and the destruction of tens of thousands of hectares of Alpine coniferous forests: a true natural disaster with devastating environmental, social and economic consequences (estimated damages for the most affected region, Veneto, equal to almost 2 billion euros) .

3.10 Agriculture and food production

Italian agriculture, like that of all countries in the Mediterranean area, is one of the most vulnerable to the effects of climate change at a European level. Although climate adaptation is an intrinsic characteristic of the primary sector, the extent, uncertainty and speed of ongoing and expected climate changes make it necessary to increase its adaptive capacity, to reduce its impacts, but also to seize the opportunities offered by changed climatic conditions.

As regards ongoing impacts, there are currently no useful indicators available for the agricultural sector, at a national scale, to evaluate the impacts of climate change on agriculture. At a regional level, for example, Emilia Romagna has developed an indicator aimed at quantifying the impact of climate change relating to increased drought on agricultural systems: the transpiration deficit indicator[35], calculated as the difference between maximum transpiration and actual transpiration (SNPA, 2021).

It has been applied to some agricultural crops representative of Emilia-Romagna such as alfalfa, corn and vines. In the last 60 years (1961-2020) there has been a statistically significant increase in the maximum annual value of this index, cumulative over the last 60 years: this indicates an increase in agricultural drought, in the short (30 days) and medium term (90 days) . The highest increase in the maximum cumulative deficit is observed for corn which for the 30 days presents a trend of 8 mm/decade, compared to alfalfa and grapevine (5 mm/decade), and for the 90 days a trend of 20 mm/decade, compared to 18 mm/decade for alfalfa and vines.

Significant negative economic impacts can arise from the effects of climate change on yields and agricultural production (Ronchi, 2019). The literature (EEA, 2016; Dominguez & Fellman, 2018; MATTM, 2017; Boere et al., 2019; Hristov et al., 2020) highlights a high variability in yield projections due both to the different characterization of precipitation in climate models than to the responses of agrological models to climate forcing. However, there are clear indications of a deterioration of agro-climatic conditions in terms of both increased water stress and shortened growing season in Central and Southern Europe (Trnka Olesen et al., 2011; Hristov et al., 2020) .

35 http://climadat.isprambiente.it/

Specifically, agrosystems will be subject to variations in terms of duration of the phenological cycle, productivity and potential movement of typical cultivation areas (towards the north and higher altitudes), with different responses in intensity and signal depending on the species and geographical areas reference (Moriondo et al. 2013a, Moriondo et al. 2013b). In general, crops will be affected by the increase in temperature by reducing the length of the growth cycle resulting in less biomass accumulation and therefore reduction in yield (Lobell and Field 2007; Lobell et al. 2011). The greatest yield reductions are expected for spring-summer cycle crops (corn, sunflower, soybean), especially non-irrigated ones such as sunflower. However, crops classified as C3, such as wheat, rice, barley, will be able to partially compensate for the negative impacts of the changed climatic conditions as they are capable of responding more efficiently to the direct effects of the increase in the atmospheric concentration of CO_2
compared to C4 species (e.g. maize, sorghum, millet, etc.) (Qian et al. 2010). For tree crops, such as vines and olives, the variation in the rainfall regime and the increase in temperature could lead to a qualitative and quantitative reduction in production in the areas of southern Italy and potential shifts of the cultivation areas towards more northern or higher altitudes.
The expected reductions in yields are estimated to lead to a reduction in the value of aggregate production of 12.5 billion euros in 2050 in a scenario compatible with RCP 2.6 which could increase up to 30 billion in RCP 8.5 (McCallum et al., 2013). The damage, especially to valuable products, could also lead to a progressive loss of land value of agricultural land. Estimates vary between a depreciation of 1–11% in RCP 4.5, to 4–16% in RCP 8.5 at the end of the century (Bozzola et al.
2018). Van Passel et al. (2017) report even more pessimistic estimates of a 10% loss in value of land values per degree of temperature increase (MIMS, 2022).
Climate change also represents a risk factor for farmed livestock, with consequences that may concern welfare and productivity (Notenbaert et al. 2017). High temperatures, which already characterize Italian summers and which future climate scenarios predict will increase, have a direct negative impact on the animal's physiological and behavioral processes such as thermoregulation, food ingestion and immune response. Added to these direct effects are the indirect effects that climate change can have, for example, on foods (contamination by mycotoxins, food quality and availability) and on the ecological and biological dynamics of pathogens and their vectors (Kipling et al. 2016). Further indirect impacts can be distinguished between impacts on extensive livestock farming (mainly associated with the availability of forage and the quality of food due to probable reductions and modifications of the species present on the surfaces intended for grazing following phenomena of desertification, salinisation of the groundwater or advancement of forest scrub in meadow and pasture areas) or intensive (associated with factors that can put at risk entrepreneurial activities of high added value to which agricultural businesses are particularly exposed from a financial point of view; for example impacts of events such as floods on buildings and equipment).

Although in some areas and for some crops there may also be potentially positive repercussions, the agricultural sector and, consequently, the agri-food sector will be subject to a general decline in production capacity, accompanied by a probable decrease in the qualitative characteristics of the products.

3.11 Sea fishing

Overall, the national fishing sector employs approximately 73,400 operators (including related industries) and contributes to 2.3 billion in gross added value, representing one of the most important sectors of the *blue economy* at an Italian level (EC, 2022). Fisheries in particular employs around 23,000 direct operators

It possesses, in addition to a high socio-economic importance, considerable importance in terms of history, culture and management of the marine environment.
Fishing, depending on the productivity of ecosystems and the consistency and distribution of exploited resources, is subject to the effects that climate changes have directly and indirectly on the biological component. The effects on the resources exploited by fishing and the relative vulnerability of the fishing sector are exacerbated by the state of overexploitation of the stocks. In fact, around 70% of national fish stocks are overexploited (ISPRA, 2022a in press), with an average harvest rate exceeding double the maximum sustainable yield (ISPRA, 2022b, in press). These alarming data are in line with recent assessments of the state of resources conducted for the entire Mediterranean by the General Fisheries Commission for the Mediterranean (FAO, 2022). Data relating to the Italian fishing sector have also demonstrated the severe effects of the COVID-19 pandemic on commercial fish production, which fell from around 180,000 tonnes in 2018 to around 120,000 in 2020 (FAO, 2022).

Recently, in accordance with the objectives defined by the EU for its Common Fisheries Policy (PCP, EU Reg. no. 1380/2013) a further push to reduce fishing effort on the basis of community rules and multi-annual management plans is determining a significant reduction in the withdrawal.
As described in the paragraph on “Marine environments: biodiversity, functioning and ecosystem services” ocean warming is currently considered one of the main forcings causing changes in the structure of marine communities (Portner and Peck 2010). Climate change affects marine species in terms of geographical and bathymetric distribution, growth rates, reproductive period, maturity size, recruitment and mortality (Pecl et al., 2014). Therefore, such changes affect ecosystem services provided by the sea, such as fisheries (Gamito et al., 2015).

Also due to ocean warming, a geographical shift of the marine species most sensitive to temperature is resulting (Cheung et al., 2010). Cold-blooded marine species are in fact characterized by a preferential temperature of the environment in which they live linked to their physiological characteristics. Each species therefore has a geographical distribution compatible with its own thermal needs. In temperate zones, such as the Mediterranean, warming waters mainly translate into a northward expansion of warm-affinity species. Fish communities are affected by the so-called "southernization" (Azzurro et al., 2011) and "tropicalization" (Bianchi, 2007), i.e. an increase in species from warmer waters compared to those from colder waters, and the increase in thermophilic non-indigenous species, respectively. The composition of fisheries catches therefore changes (Tsikliras et al., 2014), and this can lead to changes in the intensity and spatial distribution of fishing effort (Haynie and Pfeiffer, 2012).

This phenomenon is described by an indicator known in the scientific literature as *“Mean Temperature of the Catch (MTC)”* (Cheung et al., 2013), which represents the average thermal affinity of commercial fishing catches. This indicator allows us to describe over time the relative increase of warm-affinity species compared to cold-affinity species in the composition of the catch, as a consequence of sea warming. The indicator highlights how commercial fishing catches are changing globally in terms of specific composition (Cheung et al., 2013). This is a phenomenon also observed for the catches of the Italian fishing fleets between 1972 and 2012 (Fortibuoni et al., 2015).

In 2021, the MTC indicator was included in the Environmental Data Yearbook (ISPRA, 2022), and presents a significantly positive trend in all three FAO divisions into which the Italian seas are divided. In the Sardinian and Ionian Seas, there was an increase in the average catch temperature of almost 2 °C from the beginning (1987-1996) to the end (2009-2018) of the historical series, at a rate of approximately 0.07 °C per year. In the Adriatic Sea, the increase from the first period of the time series to today was 1 °C, with an annual increase of 0.046

°C. A process of southernization of commercial fishing catches is therefore underway in Italian seas (Fig. X).

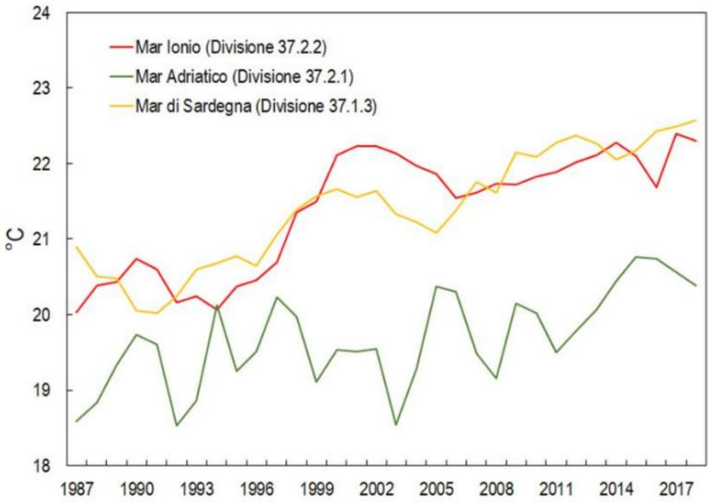


Fig . (Source: FAO-GFCM. 2021. Fishery and Aquaculture Statistics. GFCM capture production 1970-2018 (FishStatJ). In: FAO Fisheries and Aquaculture Division [online]. Rome. Updated 2021. www.fao.org/fishery/statistics/ software/fishstatj/en. Cheung WWL, Watson R, Pauly D (2013) Signature of ocean warming in global fisheries catch. Nature 497: 365–369.

It is highlighted that the annual increase in MTC in the Adriatic is almost half compared to the other two areas.
This smaller increase could be determined by the fact that the Adriatic is the northernmost and coldest basin of the Mediterranean, and within certain limits of sea temperature increase it is hypothesized that it could act as a refuge for cold-affinity species (Ben Rais Lasram et al., 2010). This hypothesis, according to which by 2050 the Adriatic could act as a "cul-de-sac" for cold-affinity species (Ben Rais Lasram et al., 2010), can only be validated with a temporal extension of the series

of data and further analysis.

In addition to sea warming, other factors related to climate change may have a significant impact on fisheries, in particular the increase in the frequency and intensity of extreme weather events and changes in the vertical stratification of the water column (Hidalgo et al., 2022). The major impacts of increased temperatures on marine biota do not concern surface temperatures so much as the thermal stratification of the water column. The heated layer becomes increasingly wider, the thermocline deepens and this can cause mass deaths of organisms that cannot tolerate high summer temperatures and that have developed populations adapted to living below the average depth of the summer thermocline (Rivetti et al., 2014). Furthermore, the greater stratification of marine waters determines a slowdown in the flow from the lower layers of nutrients, in particular phosphates and nitrates, which are necessary for primary production (Patti et al., 2022). The lower influx of nutrients into the photic zone leads to an increase in microbial activities and a trophic chain characterized by smaller sized planktonic organisms (Lazzari et al., 2014), with possible cascade effects on the food web (Garzke et al., 2014) . In the coastal areas close to the mouths of large rivers, which, in the Mediterranean area, are the most suitable for fishing due to the contributions in terms of nutrients and suspended organic substance (eg, Darnaude at al., 2004), there is a contraction in primary productivity due to the decline in precipitation and therefore in river flow (Gualdi et al.,

2009). Furthermore, a shift in the seasonal peak of precipitation involves the arrival of nutrients in seasons in which high or low temperatures can be a limiting factor for phytoplankton organisms, causing a further decrease in primary productivity (Cossarini et al., 2008) .
In addition to fish stocks, climate change will have local impacts, even very diversified ones, with effects both on the productivity of resources and on fishing operations. Added to this is the fact that fishermen will have to adapt fishing tactics more frequently, which will necessarily have to differ, at least in part, from those of the past and, therefore, the knowledge handed down or learned from experience will become less useful.

Finally, it is worth considering the scarcity of economic resources dedicated to interventions to mitigate the impacts of climate change or to adapt to them, also due to the now chronic low profitability of national sea fishing, linked to the competition of aquaculture products or those coming from fishing in extra-Mediterranean areas (as well as, to a modest extent, from extra-national areas within the Mediterranean).

3.12 Aquaculture

Aquaculture has close relationships with inland, transitional and marine environments and ecosystems and is considered among the socio-economic sectors most vulnerable to climate change (Collins, 2020; Falconer et al., 2022; WGII AR5 of IPCC). The assessment of the impacts of climate change is made complex by the diversification of production systems, the technologies adopted, the species, the geographical location, the environmental characteristics of the territory, and the possible combination of multiple impact factors. Other socio-economic, demographic, technological and governance factors can interact with climate factors and contribute to determining impacts on the environment and the sustainability of aquaculture (Castellari et al., 2014).
The current environmental strategies and regulations at community and national level in the context of adaptation to climate change, maritime spatial planning, green transition and blue economy, promote the development of aquaculture in the Mediterranean area and a careful evaluation of effects that climate change may have on the development of the sector. In 2020, Italian aquaculture represented 50% of the national fishing sector, with a production volume of 122,760 tonnes, of which 74,990 tonnes of molluscs (61%) and 47,770 tonnes of fish (39%), for a total value of 392 million euros (Donadelli & Chiesa, 2022). Fish and shellfish farming activities in Italy are deeply rooted in territories and tradition and in some regions represent an important source of employment and income for coastal and rural communities (Marino et al., 2020). Five regions (Veneto, Emilia-Romagna, Friuli-Venezia Giulia, Puglia, Sardinia) host 71% of aquaculture plants; Emilia-Romagna, Veneto and Friuli are the main production hubs and together with Marche and Tuscany they cover 69% of national production (Donadelli & Chiesa, 2022).

From the sectoral analysis, shellfish farming appears to be the most vulnerable sector as it is subjected to a greater number of pressures and impacts. This criticality is linked to the fact that the majority of shellfish farming activities (number of plants and production volumes) are concentrated, due to the natural vocation of the territory, along the coastal and lagoon areas of the Adriatic Sea (e.g. Emilia Romagna and Veneto), areas particularly exposed to climate change.
The impacts of climate change on Italian shellfish farming may concern various aspects, such as: i) the reduction in the performance of farmed species; ii) changes in the reproductive cycle of species, resulting in a reduction in natural recruitment and seed availability; iii) stress conditions, onset of diseases, mortality events due to changed and/or unfavorable environmental conditions;

iv) episodes of contamination linked to water quality; v) damage to infrastructure and loss of biological material linked to extreme weather and marine events.
In addition to shellfish farming, extensive fish farming is also a sector vulnerable to climate change. This form of traditional farming is in fact conducted in valley and lagoon environments, particularly exposed to rising sea levels, heat or cold waves and conditions of water stress. For marine fish farming, particularly if located in offshore areas, the greatest impact will be determined by the increase in the frequency of extreme marine weather events.
Freshwater fish farming, in particular trout farming, developed especially in the North-East (Veneto and Friuli-Venezia Giulia) is an important production sector (33,774 tonnes), subject to significant impacts of climate change, due to the rise in temperature , the reduction in the quantity and quality of water available for breeding facilities, with consequences on production performance and the health of the farmed species.

Furthermore, compared to other food production systems, aquaculture is the one characterized by the best ecological footprint and with less relevance in greenhouse gas emissions, linked to the production of feed and the consumption of electricity. Shellfish farming in particular provides numerous control and regulation ecosystem services, including the sequestration of carbon from the environment with consequent mitigation of the impacts of emissions.
Although the available knowledge regarding the impacts of climate change on aquaculture activities allows us to make some predictions and assessments on the possible effects on the physiology of farmed species, on the availability of suitable farming sites, on the risks to animal and public health and economic sustainability of the sector, implementing knowledge relating to the vulnerability of aquaculture to climate change is a priority. It is necessary to acquire more precise and
detailed knowledge of the effects of climate change on the various farmed species (biology, ecology, genetics and health), through experimental tests, development of predictive models and specific indicators; on the possibility of selecting species/strains tolerant to the conditions induced by climate change; and develop methods (risk analysis) for analyzing the vulnerability of the various production systems present on the national territory. Furthermore, it is necessary to implement monitoring systems also through the use of satellite data and data collection systems relating to the physical-chemical and biological characteristics of water bodies.
Fig.

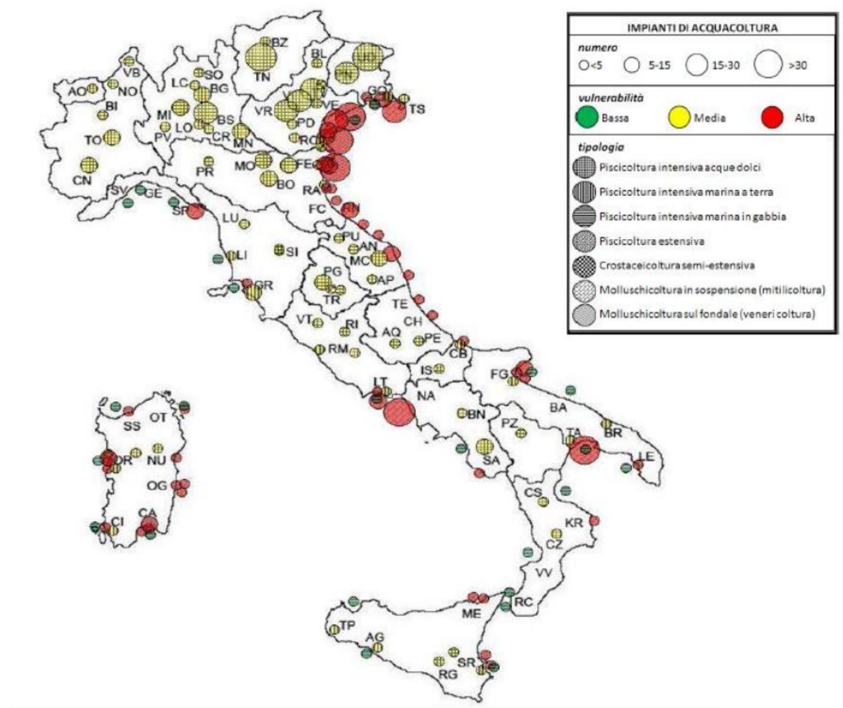


Fig. X - Vulnerability of Italian aquaculture production systems to climate change

3.13 Tourism

Italy represents one of the favorite destinations for international tourism. Seaside tourism generates the majority of presences: according to the recent classification of municipalities based on tourist density, the municipalities with a maritime vocation and with a cultural, historical, artistic and landscape vocation welcome around 20% of tourist presences, followed by both the large cities typical of multidimensional tourism which welcome 19.7% of tourist presences and municipalities with a purely maritime vocation (19.6%).

The recovery of the tourism sector in our country began in 2021, after the exceptional contraction of the 2020 "pandemic", when the sector's impact on total value added at current prices had fallen to 4.5 percent, from 6. 2 in 2019. Tourism revenue in Italy was 1.2% of GDP in 2021, just below the EU average (Bank of Italy, ISTAT).

This situation, however, is destined to change as a result of climate change since the tourism sector is particularly sensitive to meteorological characteristics and climate comfort, especially in the case of seaside and mountain tourism.
The main impacts of climate change on tourism in Italy can be linked to a possible loss of attractiveness of the Mediterranean climate which would become "too hot" or unstable (heat waves, extreme events), to the reduction of days of snow cover in typical tourism destinations winter, coastal erosion and extreme meteorological events that put seaside and non-seaside tourist infrastructures at risk (Ronchi, 2019).

Direct and indirect effects are therefore expected. As regards the former, a shift in travel destinations towards higher latitudes and altitudes is expected, while tourists coming from more temperate climates will spend more and more time in their countries of origin. Furthermore, a shift is also likely to occur at a seasonal level, with an increase in the influx of tourists towards the coasts in the months in which the air and water temperatures are not too hot, therefore from the hot summer months, towards the spring and autumn months. More and more foreign tourists will choose less hot destinations than ours,

while more and more Italian tourists will stay in Italy instead of taking holidays in even warmer places. The balance will be negative, also because part of the Italian tourists will contribute to the flow of international tourism towards less hot countries. At the Italian provincial level, however, the phenomenon will not be uniform, but will vary depending on the different international popularity of the various localities and will occur in particular in the coastal provinces.
McCallum et al (2013) report some estimates of possible variations in tourist flows based on the simple variation of thermal comfort conditions associated with future temperatures. In a 2°C temperature increase scenario, a 15% reduction in international arrivals is estimated, and by 21.6% in a 4°C increase scenario. Also taking into account the behavior of national tourists, the net impact on total Italian demand still results in a contraction of 6.6% and 8.9% with direct losses for the sector estimated at 17 and 52 billion euros in the two climate scenarios, respectively. The winter tourist segment deserves a separate discussion. According to the OECD (Abegg et al, 2007), even in the case of a moderate variation in temperatures (+1°C), none of the ski resorts in Friuli Venezia-Giulia would have sufficient natural snow cover to guarantee the season. The same would happen to 33%, 32% and 26% of the stations in Lombardy, Trentino and Piedmont, respectively. With an increase of 4°C, only 18% of all stations operating in the entire Italian Alpine arc would have natural snow cover suitable to guarantee the winter season (Spano et al, 2020).

As regards indirect impacts, anthropic pressure will increase the vulnerability of the Italian coasts to the impacts of climate change, in terms of sea level rise and the incidence of extreme events, reducing the natural resilience capacity of coastal environments. The expected indirect impacts concern the worsening of erosion phenomena, and the consequent disappearance of coastal areas and infrastructures relevant for tourist activities, desertification/decrease in water resources (and greater risk of fires), the growing competition between energy uses alternatives (with consequent higher costs for tourist services), the demographic explosion of organisms such as algae and jellyfish, which are difficult to reconcile with tourism, and the increase in the incidence of extreme events.
For Alpine summer tourism, both negative impacts (landscape changes, water scarcity, increase in natural risks, algal blooms in lakes and reduction of their navigability) and positive impacts (greater attractiveness in spring and summer) are expected.

3.14 Urban settlements

Urban settlements are crucial in terms of climate change: if, on the one hand, they are among the main responsible for greenhouse gas emissions, contributing substantially to the causes of the problem, on the other hand cities are particularly vulnerable and exposed to the effects of a changing climate (e.g. intense precipitation events, extreme temperature events, reduction in precipitation, rising sea levels). Furthermore, these effects are accentuated by a high inter- and intra-specific heterogeneity, determined by topographic, morphological, demographic and socioeconomic characteristics. It is important, however, to underline how the climatic element represents, in the majority of cases, a factor exasperating previous critical issues (CMCC, 2020).

In terms of water management, in Italian cities, the chronic inefficiency of the water infrastructure is characterized by total losses in the distribution network in some municipalities which are even very serious with values that in 2018 exceeded 50% in Catanzaro (57.8%), Campobasso (56.8%) and Cagliari (54.7%), among the regional capitals. In general, the lack of investment in the water network increases inefficiencies with increasing drinking water withdrawals, even in the face of decreasing demand, accentuating the pressure of demand on supply and the conflict between alternative uses (SNPA, 2022).

The urbanization processes which have often occurred in a poorly controlled manner over the last century, the systematic waterproofing of the soil and the artificialisation of watercourses, associated in many cases with inadequate drainage systems, have contributed to increasing the risk of hydrogeological instability in urban areas: in the period 2015-

In 2020, Rome recorded by far the highest overall value of waterproofing of natural and semi-natural areas (around 96 ha), followed by Venice and Bari, the only regional capitals, in addition to the capital, to exceed 20 ha in the five-year period. Even the scarcity of vegetation, in addition to the abundance of surfaces that retain heat, the density and height of buildings, intensify the vulnerability to temperature increases and consequently the negative impacts on health: in the 2016-2020 period they are still very limited the percentages of vegetated surface on the urbanized surface in Turin (29%), Naples (34%), Milan and Cagliari (36%) (SNPA, 2022).

Figura 1 – Numero di eventi alluvionali e di allagamento in area urbana, catalogati nel periodo 2000-2018.

Fig. X – Number of flood events and flooding in urban areas (2000-2018).
(Source: SNPA, 2022)

In terms of the occurrence of flood phenomena and

flooding (Fig. of the outflow sections of some watercourses that cross it, such as the Lambro and the Seveso. The city of Genoa (10 events) highlights problems of hydrogeological structure, enhanced by the particular characteristics of the geomorphological structure of its main basins, but also heavily influenced by the works to modify the naturalness of the riverbeds (e.g. graves and manhole covers) and by narrowing and/or o waterproofing of the flow sections of the streams, as well as the insufficiency of some spans of the bridges located near the most vulnerable inhabited areas. Messina (3 events), Catania (5 events) and the Apuan area with Carrara (3 events) show a high hydrogeological hazard, connected both to the local peculiar characteristics of the geomorphological and hydraulic structure, and to the characteristics of the urbanized area, often built at critical points of natural dynamics. The city of Rome (5 events) reveals a high hydrogeological danger resulting from many problems induced in the urban structure (e.g. high presence of waterproofed surfaces) in recent decades (Berti and Lucarini, 2021).

Because of the “urban heat island effect,” people living in cities are at higher risk of death when temperatures and humidity are high than those living in suburban or rural areas. Exposure to conditions of thermal discomfort is in fact generally greater in urban agglomerations, as a consequence of the characteristics of the materials used (Sanchez Martinez et al., 2016). Studies on mortality linked to heat waves have widely demonstrated that the most vulnerable categories of people are the elderly (Conti et al., 2005). Added to these are children and patients with existing pathologies, but also people with low per capita income, who live in disadvantaged economic conditions, and workers who carry out their activities outdoors and are therefore exposed to high temperatures for prolonged periods. . The high temperatures and heat waves that affected our country in June 2022 and in the first 2 weeks of July 2022 were associated with an increase in mortality, especially in the central-south regions most affected due to the intensity and duration of the phenomenon . In the month of June, overall, the increase in mortality occurred in the 33 cities observed estimated is 9%, while in the first 2 weeks of July the increase was 21% (+733 deaths in total) (Ministry of Health and DEP Lazio, 2022).

Finally, on the issue of sea level rise, the case of Venice is mentioned here, which has already been mentioned both in Chapter 2 and in the paragraph "Coastal areas" of Chapter 3. As is known, the average sea level at Venice has been on the rise since the beginning of the surveys (1872). Over the entire period, however, the curve did not always show a constant slope, with phases characterized by relative stability or even countertrend (approximately between 1915 and 1925 and between 1965 and 1995) and others instead characterized by a steep slope (between the 30s/60s and the period from the mid-90s to today). If in the long term (1872-2021) the rate of rise of the mean sea averages around 2.5 mm/year, it is considered appropriate to highlight the almost doubled rate in the last period.

From 1993 to 2021, the rise in average sea level has in fact stood at 4.7 mm/year. The rate of growth has undergone a further strong acceleration in the last decade such that since 2009 the maximum annual mean sea level values have been recorded since the beginning of systematic recordings of the
tide in Venice (SNPA, 2021 and subsequent updates and ISPRA analysis on ISPRA validated tide gauge data). 2019 will long be remembered for the extraordinary number of exceptional meteorological and marine events that occurred between November and December: in Venice the peak reached on 12 November (189 cm) represents the second highest level since 1872 and in just one week (12-17 November) the tide exceeded the level of 140 cm 4 times, thus recording levels that enter the top 20 of the last 150 years. Throughout 2019, the sea level exceeded 110 cm 28 times, a level at which 12% of the city of Venice floods, with a total stay of around 50 hours in the month of November alone.

Numbers that greatly exceed the maximum values reached in the previous 150 years, equal to 18 events in one year (2010) and a total of 24 hours spent (2012) above 110 cm. In more recent times the MOSE was put into operation, which consists of 4 barriers made up of 78 independent mobile gates capable of temporarily separating the lagoon from the sea and defending Venice both from exceptional and destructive tidal events and from more frequent. This work will be able to protect Venice and the lagoon from tides up to 3 meters high and from a rise in sea levels of up to 60 cm over the next century (Consorzio Venezia Nuova, 2022).

3.15 Transport and infrastructure

Mobility constitutes a key system within society, the Italian territory and its economy, on which the level of industrial productivity, the exchange of goods, the quality of life of the inhabitants, the connective tissue capable of creating added value depends . The close correlation of the transport and infrastructure sector with most other sectors is inevitable: among all hydrogeological instability, air, the water system, urban settlements, industry, tourism, energy. Building a unitary analysis of the vulnerability of the mobility system is necessary but not easy. The infrastructure

physics is made up of arcs and nodes, it is expressed throughout the territory widely and with different densities, often correlated with different uses (in densely urbanized territory with shorter and more frequent journeys, in low-density areas in the form of long journeys). The type of infrastructure varies based on the modes of transport, the orography and connection needs.

For the transport sector it is estimated that the current direct economic impact associated with extreme climate events (0.15 billion euros per year) could increase by approximately 1900% by 2040-2070 (MIMS, 2022).

3.15.1 Land Transportation

Land transport infrastructure includes road and railway works.
The transport system certainly benefits from an expected reduction in days with frost and snowfall, widespread throughout the territory, but significant in the Alpine passes, in the Ligurian and Tuscan-Emilian Apennines: the risk of damage to infrastructures is reduced, the cost of snow removal interventions, and safety in the movement of all vehicles is increased. The risk is represented by the fragility of the territory, which - in passing from snow to rain -
sees an increased possibility of hydrogeological disruption.
The increase in summer temperatures is expected in particular in the Po Valley area and in the extended agglomeration of the capital as well as in the far south. The presence of large urban agglomerations risks emphasizing heat waves, triggering urban heat island effects. Severe heat waves contract non-motorised mobility (pedestrians and cyclists), put vehicles with thermal engines to the test as well as increasing energy consumption due to multiple cooling actions (cars, public transport, stations, airports). Other impacts attributable to the increase in temperatures are the excessive overheating of signaling and telecommunications components which could reduce their reliability and generate malfunctions (Ferranti et al., 2016). The road surfaces, or the asphalted parts (shunting yards in ports and freight villages, airport runways), are subjected to overheating cycles that degrade their technical and functional characteristics. Railways (tramways and railways) risk expansion, albeit marginal, sufficient to modify the layout of the tracks with consequent risk of derailments or more easily slowdowns. The increase in summer temperatures associated with water scarcity could affect the Po Valley navigable system.

Floods/inundations and flooding generate significant impacts on land transport infrastructure. In particular, we can distinguish two main impact phenomena: a) river erosion which can lead to structural damage due, for example, to the increase in thrust on geotechnical works and on the abutments of bridges, b) undermining of the foundations of geotechnical works and bridge piers. Floods and intense rainfall can also cause temporary flooding of road and railway sites and/or their damage due to water flow and the malfunction/collapse of drainage systems (Nemry & Demirel, 2012; UNECE, 2020). Furthermore, intense rainfall localized over small basins can generate significant impacts on transport infrastructures due to the high level of solid transport that can obstruct road and railway systems.

The spread of fires near land infrastructures generally causes temporary closures of roads and railways. In the presence of particularly severe events, the heat released by a fire can compromise parts of the infrastructure involved (e.g. material damage to road and railway bridges) and cause failures in control and monitoring systems or damage road signs, increasing costs maintenance necessary for the restoration/replacement/reconstruction of the affected infrastructural components (Fraser et al., 2020).

3.15.2 Air transport

Heat waves tend to alter the properties of the materials constituting the pavements of runways. In particular, a high temperature makes the asphalt less rigid and more viscous, increasing the rolling resistance during the take-off and landing run of aircraft (Puempel & Williams, 2016; Burbidge, 2016). This variation translates into greater fuel consumption. Furthermore, the increase in temperature reduces the density of the air, and consequently also the lift, i.e. the force that supports the aircraft in the air (Puempel & Williams, 2016; Burbidge, 2016).

For this reason, existing runways could become insufficient for the take-off and landing of fully loaded aircraft. The presence of ice on pavements as a result of cold waves reduces grip during aborted take-off and landing phases (ENAC, 2014). This is particularly dangerous because the aircraft may not have enough room to brake safely.

Furthermore, the formation of ice on aircraft wings modifies the surface of the wings themselves, decreasing lift.

3.15.3 Naval transport and ports

Along the coasts of the Italian peninsula (over 7,500 km) there are 282 ports and 1988 moorings (data updated as of 12/31/2015 - Ministry of Infrastructure and Transport 2015), including commercial and tourist ports. Coastal flooding phenomena can cause significant damage to maritime transport infrastructures, including: damage to external works (outbreaks) and internal port works (quays and embankments), siltation of ports, damage to maritime vessels located in ports, out of service of port infrastructures which, in the event that damage or significant siltation phenomena occur, can be prolonged over time, until the damaged works are restored, damage in general to interconnected infrastructures, such as urban centers and communication routes, mainly due to erosion coastal. The phenomenon of ocean acidification could lead to a decrease in the integrity of port infrastructures with an increase in the phenomenon of corrosion of metal reinforcements. As already mentioned, heat waves tend to modify the characteristics of the constituent materials

paving in bituminous conglomerate which, in the case of ports, concerns maritime terminals and in particular the areas where the movement and storage of goods and the intermodal exchange of transport takes place. (Ligteringen, 1999). A persistent increase in average air temperature can influence the fuel consumption of ships, due to the reduction in efficiency of the cooling systems of the propulsion equipment and the energy consumption of the cargo refrigeration systems on board the ships and in the areas of storage such as, for example, refrigerated containers. Furthermore, in ports, river flooding phenomena can cause a series of impacts such as the temporary out of service of embankments and maritime terminals, damage to systems, floors, goods handling vehicles, buildings and warehouses, and the siltation of port basins.

3.16 Hazardous industries and infrastructures

The activity of the industrial sector can be negatively impacted by climate change through direct or indirect infrastructural stress induced by extreme events, by the increase in temperature through the negative effects on labor productivity, by the scarcity and variability in the availability of water resources, fundamental in many production processes, and subject to constant demand competition from other sectors. With regard to the effects relating to impacts on industrial infrastructures, particular attention is required for activities that use processes and substances classified as "dangerous" (as in some chemical sectors), which, in the event of damage following extreme events, could cause significant negative impacts on health and the environment.

The increase in the frequency and intensity of extreme meteorological events, with their accompanying lightning strikes, floods and landslides, expected in the thirty-year period 2021-2050 (in particular in the RCP8.5 scenario) in some of the areas of the country (Po Valley, Tyrrhenian regions, Sardinia), could directly produce effects on the industrial activities and infrastructures located there that use dangerous processes and chemical substances, as well as on the operations carried out there.

NaTech is defined as events in which a natural disaster triggers one or more technological disasters. While NaTech events have been relatively rare events in the past, there is growing evidence that they are increasing.

The natural events that have affected our country in recent years have caused dozens of victims, including many workers, highlighting the high vulnerability of production activities and the territory in general towards natural risks. It therefore becomes unavoidable to evaluate the safety of the workplace in relation to natural risks and identify precise prevention and protection interventions that could reduce the impact of a NaTech event on health and the environment (INAIL website, 2022).

3.17 Cultural heritage

Knowledge of the impact of climate change on cultural heritage in Italy is based, first of all, on the identification of the priority climatic parameters that determine its degradation both in the external environment (mainly architectural, archaeological heritage, etc.) and in the internal environment (museums , churches, hypogea, etc.).

The assessment of the vulnerability and risks to which cultural heritage is subject, the study of the different materials that constitute the assets spread across the territory and the forms of degradation that affect them - in relation to environmental particularities, landscape characteristics, anthropic impact - constitute the priority theme in the development of protection, control and damage prevention strategies for the conservation of the cultural heritage itself.

Based on available knowledge, the predominant role of water emerges as a factor of direct and indirect degradation of the materials constituting cultural heritage. Extreme events, increasingly frequent such as intense rainfall up to floods and storms, are also responsible for structural damage in historic buildings, in particular with regard to ornamental elements (spires, pinnacles, sculptures, finishes, etc.).

Prediction models indicate that during the 21st century the chemical dissolution of carbonate stone materials will be mainly due to precipitation and increasing CO_2 concentrations atmospheric, determining in Italy a maximum increase in surface recession equal to 30% compared to the reference period 1961-1999 and corresponding to average values of 30 ÿm/year.
The data demonstrate that the Mediterranean regions and especially the major islands, particularly rich in monuments and archaeological sites made of stone material, will continue to experience a high level of risk from thermal stress, with values sometimes exceeding 200 events per year at the end of century.
The decohesion of porous building materials is expected to increase due to the increase in salt crystallization/solubilization cycles throughout Europe, including Italy. Instead, there will be a general reduction in the damage caused by freezing and thawing cycles.

Furthermore, as regards the landscape, its vulnerability linked to the evolution of cultural and socio-economic factors is aggravated by the presence of natural risks, connected to the physical reality of its environment, among which both geomorphological characteristics and environmental factors play a significant role. climate of the territorial context. With direct reference to climate risks, it is useful to mention thermal overheating which is creating problems of landscape transformation with the shift in altitude of the altitudinal limits of vegetation belts, while, again by way of example, the vulnerability of the landscapes of the Mediterranean area , by its warmer and drier nature, appears to be among the most critical for the ongoing desertification processes, in addition to the recorded trend of increasing the frequency of extreme events which leads to an increased risk of damage and irreversible loss of landscapes and buildings historians.

With reference to the exposure of cultural heritage to the risk of landslide, an estimate was carried out by intersecting the dangerous areas with the Italian architectural, monumental and archaeological cultural heritage of the VIR System - Network Constraints of the MiC (ISPRA, 2021). According to this estimate, the overall Cultural Heritage at risk of landslides in Italy is equal to 17.9% of the total (VIR database as of 7 June 2021) and compared to the high danger classes P3 and very high P4, the Cultural Heritage exposed is equal to 5.9%. The highest number of cultural assets at risk of landslides in P3 and P4 hazard areas is recorded in Campania, Tuscany, Marche, Emilia-Romagna and Lazio. In relation to flood danger, if we consider the cultural assets falling within the perimeter of the risk areas, the calculations provided by ISPRA identify that the percentage of assets falling in high danger areas (HPH) reaches 7.8% of the total national (6.8% in 2017); those exposed to medium danger (MPH) are 16.5% (15.3% in 2017) and finally the cultural assets that fall into low danger areas (LPH) are 24.3% (19.4% in 2017) of the national total (ISPRA, 2021).

The cultural heritage located on the Italian coasts is and will be subject to the increase in the incidence of extreme events, the rise in sea levels and coastal erosion phenomena with the probable loss of archaeological sites and coastal monumental complexes. The increase in extreme events could cause flooding, especially of underground sites and historic centres. The main critical issues related to climate events with direct effects on cultural heritage can be summarized as follows:

- increase in extreme rainfall events and temperatures which, with the alternation of wetting and drying of the soil, increase the risk of land subsidence and accelerate the degradation of wall structures;
- intense and frequent rainfall which causes greater erosion of archaeological sites and harmful floods with direct effects on historical settlements;
- changes in the hydrological and hydrogeological regime which put the archaeological heritage at risk buried and historic settlements;
- changes in vegetation patterns and related proliferation of invasive species that threaten the integrity of archaeological remains and historic landscapes;
- increase in temperatures which makes some plantations of historically native tree species difficult to conserve;
- climate changes with effects on the proliferation of parasites that threaten the integrity of historical and landscape heritage, particularly in the agricultural sector;
- reduction of snow cover, retreat of glaciers which cause instability and degradation of the landscape;
- rising sea levels and increased storms which seriously endanger historic landscapes, structures, buildings and archaeological areas in coastal areas;
- effects linked to maladaptation, i.e. the implementation of particular solutions that bring benefits in one sector, while at the same time producing negative effects on other areas. An emblematic case is represented by the construction of new dams to resist the rise in sea level which determines irreversible alterations to the historical-landscape profile of the area coastal.

3.18 Energy

The main relationship between climate change and energy is inherent to the increase in cooling demand which determines an increase in electricity consumption in the summer period, directly linked to the rise in average temperatures. The same phenomenon will determine a lower demand for energy to satisfy the heating demand in the winter period.

In relation to the production of electricity, the tendency to increase in the intensity and frequency of extreme precipitation events, if accompanied by a reduction in cumulative precipitation, can directly impact hydroelectric production. In this sense, a factor of enormous importance is the variability of rainfall and the increase in the frequency of dry periods with consequent problems from a management point of view, especially if some reservoirs were to be closed due to the lack of economic conditions for their exploitation. This impact is directly related to the ongoing melting of glaciers and the consequent change in the regime of the waterways fed by them. In fig. X shows the historical trend of the production of hydroelectric energy and the relative installed power, developed by ISPRA (SNPA, 2021). In the period 1935-1963, installed capacity showed a constant increase and hydroelectric production followed a parallel trend. For the following years, the volatility of production in relation to meteorological events and in particular rainfall was evident. Furthermore, the ratio between production and installed power appears to be decreasing.

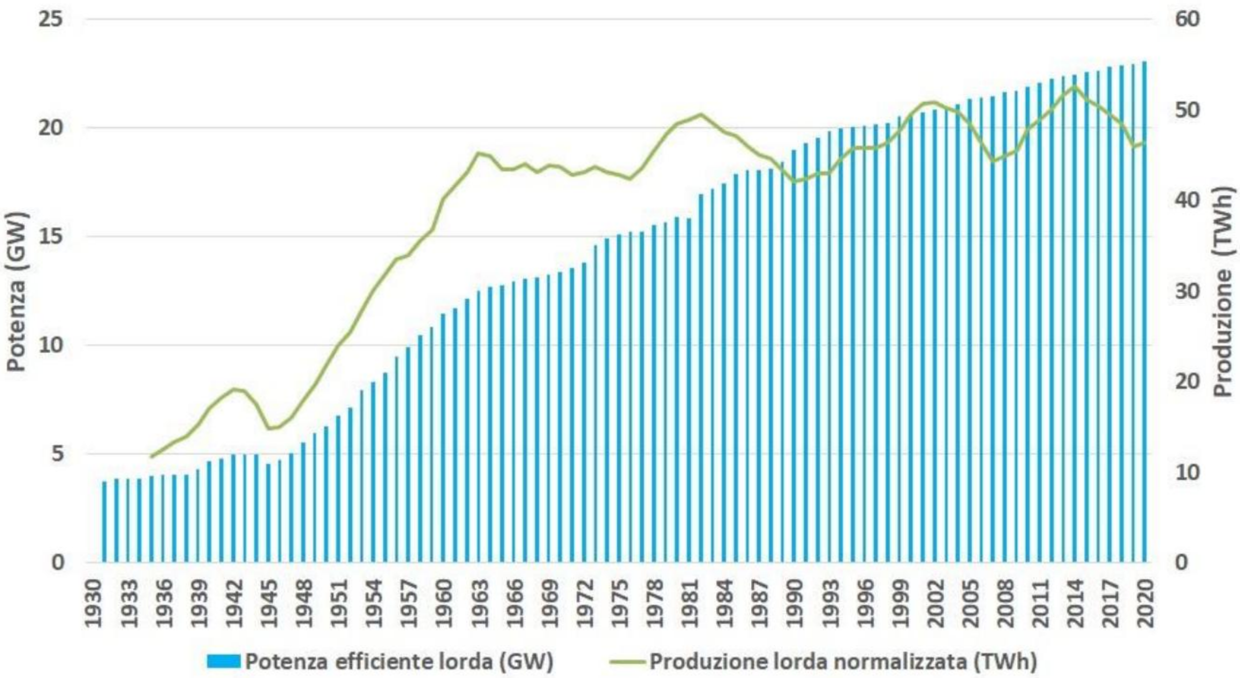


Fig. X – Hydroelectric energy production and installed capacity in Italy (Source: SNPA, 2021)

2022 is proving to be a particularly dry year and the TERNA data updated to October 2022 sees a progressive annual reduction in hydroelectric production equal to -37.6% compared to 2021.

The increase in temperature will impact the thermoelectric production sector also in relation to the sector's water needs for cooling the plants. Furthermore, *"the climatic variations expected in our territory may increase, depending on the particular geographical position, the temperature of the cooling water entering the plants, whether of marine or river origin. Should a scenario of this type arise, the plants would need a greater quantity of water to guarantee both their operation and compliance with current legislation"*

(Annex III). The ongoing drought in 2022 has highlighted how water shortages are also impacting the thermoelectric sector. Some production plants on the Po river were forced to shut down due to lack of water necessary for their cooling. The withdrawal of water for the thermoelectric production combined with the increase in the frequency of dry periods poses a problem of considerable importance.

A further impact on electrical transmission and distribution due to the increase in temperature is the expected increase in cable resistance, and therefore network losses, and more difficult heat dissipation. Also worth highlighting is the risk of interruption of energy transmission due to extreme weather events.

3.19 Health

Climate change is one of the main global threats to human health in the 21st century (Watts et al, 2021): due to the increase in the frequency and intensity of extreme meteorological events, it can cause direct effects (e.g. death, injuries, diseases, due to heat, landslides, floods, fires, etc.) and indirect (e.g. diseases linked to vectors such as *Chikungunya, West Nile, Dengue, Zika,* malaria; effects on ecosystems, food chains, critical infrastructures, etc.).

In Italy, due to the high percentage of the population over the age of 65 (approximately 23% in 2020, ISTAT), extreme temperatures and heat waves represent a strong critical issue. In June this year (2022) the Ministry of Health recorded an overall mortality rate of 9% higher than expected in the Italian cities monitored by the Daily Mortality Surveillance System; in the first half of July 2022, a significant increase in mortality of +21% was observed overall with increases in several cities where the heat wave occurred (Ministry of Health and DEP Lazio, 2022). In addition to the elderly, children and patients with chronic pathologies, people in socioeconomic conditions and workers who carry out outdoor activities are also particularly vulnerable.

The National Warning System for the prevention of the effects of heat waves on health (HHWWS) has been active since 2004, managed centrally by the Lazio DEP in collaboration with the Ministry of Health and the Department of Civil Protection. The System, operational in 34 Italian cities distributed across all regions and with a coverage of 93% of the national urban population over 65 years of age (WHO, 2018), allows the identification of weather-climatic conditions that can have a significant impact on health of vulnerable subjects, and issue alert bulletins accordingly. Based on the literature available to date, episodes of mortality linked to extreme heat appear to have been decreasing, especially in cities that have activated the warning and prevention protocol envisaged by the plan (WHO, 2018).

However, Italy remains one of the countries in Europe with the highest mortality rates both for high temperatures and, more specifically, for summer temperatures (WHO, 2018, Martínez-Solanas et al., 2021). The cost of heat stress mortality as a proportion of Gross National Product increased from 0.64% in 2000 to 1.03% in 2017 (Watts et al., 2020). Although only indirectly connected to climate change, Italy also has the highest cost in Europe from health impacts from air pollution.

Following the increase in average and extreme temperatures, heat stress on the population is expected to increase significantly. According to Naumann et al. (2020) the number of people exposed to episodes of particularly intense heat (heat waves with a return period of 50 years) in the peninsula would increase, compared to the current situation, by 10 to 15 times in an RCP 2.6 scenario and from 15 to 20 times in a CPR 4.5 scenario. This in turn would lead to increased associated morbidity and mortality. In the RCP 4.5 scenario, an increase in mortality of between 86% and 137% is estimated with an impact on GDP that would rise from approximately 1% currently to 2%.

Forzieri et al. (2017) estimate that in Italy the number of deaths associated with extreme climate phenomena (especially heat waves) could grow up to 60 times compared to the present by the end of the century in a scenario similar to RCP 6.0/ RCP 4.5. This increase would lead the premature mortality rate caused by extreme climate events to exceed that due to air pollution (Lelieveld et al., 2015) and become the largest environmental risk for Italy (Lim et al., 2012).

As regards further direct impacts, the damage and risks associated with landslides and floods must be considered. The data referring to the period 1972-2021 of the Periodic Report on the Risk posed to the Italian population by landslides and floods (CNR-IRPI, 2022) account for the extent of the problem (Tab.

	Dead	**Dispersed**	**Wounded**	**Evacuees and homeless**
for Landslide	1,071	10	1,423	145,548
for Flood	539	32	452	160,313
Totals	**1,610**	**42**	**1,875**	**305.861**

Tab .

Given the average high exposure to these types of phenomena in Italy, there is a risk that climate change could negatively influence the number of deaths and damage to health produced by extreme meteorological events and their consequences.

In addition to extreme heat, Italy is facing growing water crisis problems, with negative impacts on water quality, and therefore on health. Water scarcity mainly affects the southern and inland regions, with particular peaks in the summer season. However, it also affects the central and northern regions, thanks to the progressive disappearance of Alpine glaciers. Climate models suggest that drought and water scarcity will increase in several regions, generating serious problems in access to drinking water, similar to what happened in the summer of 2017, when 6 Italian regions found themselves having to declare State of Emergency (WHO, 2018).

3.20 The socio-economic impacts of climate change

One of the main purposes of the national strategy and plan on adaptation to climate change is to prevent the negative socio-economic effects resulting from climate impacts from creating or increasing social and economic inequality, creating disparities in terms of access to resources, work, and more, in general, to the prospect of a dignified life. A recent study predicts the loss of 410,000 jobs by 2050 if adaptation measures are not taken.36

The concept of social equity and prevention of the exacerbation of social inequalities is expressed on several levels: *geographical,* through the identification of the communities most at risk based on their location or dependence on a specific production sector (e.g. coastal communities, mountain communities , etc, *individual*
through the identification and support of the weakest sections of the population and *generation,* guaranteeing the younger and future generations a dignified life, also through the choice of adaptation policies whose burdens fall equally between the present and future population.
The impacts of climate change are divided between those caused by extreme climatic events, such as floods, landslides and tropical cyclones, and the so-called *slow onset ones,* such as the rise in temperature, the rise in sea levels and water temperature, the reduction of available water resources, both capable of causing losses and damage.

[36] (Triple E consulting (2014), Assessing the implications of climate change adaptation on employment in the EU)

While for slow-onset impacts it is possible to quantify in advance the intensity of the effects and the socioeconomic repercussions on local communities and the most vulnerable population groups, the impacts deriving from extreme climatic events cause unpredictable social and economic repercussions.
From 1981 to today, as reported by the 2020 CMCC study37, the probability of extreme atmospheric events in Italy has increased by 9%. Forest fires, floods, landslides, in one of the most vulnerable territories in Europe from the point of view of hydrogeological risk38, cause enormous damage to housing structures and private assets, as well as to production sectors and local economies, with notable consequences on social and economic situation of the communities directly and indirectly affected. Among the countries of the European Union, Italy holds the sad record of the economic value of the losses suffered, between 74 and 90 billion euros in the last 40 years, and between 1500 and 2000 per capita.39

Extreme phenomena, as mentioned, are accompanied by long-term impacts. Italy, also in this case, thanks to its peculiar and very differentiated physical and morphological characteristics, with a territory rich in biodiversity, with around 8000 km of coastline, risks paying a very high price in terms of production capacity, loss of GDP and of jobs.

The loss of wealth and jobs takes on an even more dramatic dimension when it affects citizens of already fragile communities, with high unemployment rates and low GDP/capita, where it is not possible to imagine, often also due to the high age average, autonomous professional retraining or migratory possibilities.

In addition to the segments of the population with the lowest income and those with the least education, and therefore with fewer tools to cope with the increase in the cost of living and the need for professional retraining, there are also social categories that risk being more affected and to pay a higher price than others. Such as women, for example, due to employment and salary disparities, individuals with disabilities, the elderly, and finally the younger and new generations, who are burdened on the one hand by the awareness of a difficult and uncertain future and on the other the weight of the economic and financial burdens of the actions necessary to mitigate the effects of climate change for which they were not responsible.

Systemic actions are needed which, through the allocation of resources in a structured way, mitigate the negative impacts on communities that suffer extreme and long-term climatic events, causing repercussions in terms of production capacity and loss of jobs with consequent need for retraining professional. Greater incentives, including fiscal ones, for innovative, sustainable and reduced climate-changing impact production systems.

As described in the Italian action plan40, the Bioeconomy is a response to contemporary environmental challenges, capable of mitigating the effects of climate change and reducing the use of fossil fuels.

The bioeconomy is one of the fundamental pillars of the Italian economy, generating approximately 11% of national turnover and employment. With an annual turnover of 345 billion and two million employees (2018 data),
it is the third bioeconomy in Europe. Italy boasts long experience in the field of the circular bioeconomy, i.e. that component of the circular economy itself that uses the biological resources of the land and sea as raw materials for the production of food and animal feed as well as chemical compounds, biobased materials and energy.

[37] Spano D., Mereu V., Bacciu V., Marras S., Trabucco A., Adinolf M., Barbato G., Bosello F., Breil M., Chiriacò MV, Coppini G., Essenfelder A., Galluccio G., Lovato T., Marzi S., Masina S., Mercogliano P., Mysiak J., Noce S., Pal J., Reder A., Rianna G. , Rizzo A., Santini M., Sini E., Staccione A., Villani V., Zavatarelli M., 2020. “Risk analysis. Climate change in Italy". DOI: 10.25424/CMCC/ANALISI_DEL_RISCHIO

38 Michalis I. Vousdoukas, Lorenzo Mentaschi, Jochen Hinkel, Philip J. Ward, Ignazio Mongelli, Juan-Carlos Ciscar & Luc Feyen. JRC 2020

39 Economic losses from climate-related extremes in Europe, EEA 2022

[40] Action plan (2020-2025) for the implementation of the Italian strategy for the bioeconomy (BIT II)

Furthermore, the promotion of reuse, and more generally of the circular economy, cannot fail to be considered synergistic with actions to reduce the negative effects of climate change. In this sense, coordination with the actions already foreseen by the National Strategy for the circular economy is necessary.
Furthermore, professional retraining takes on a central and strategic role in the policies to be adopted to mitigate the socio-economic effects resulting from climate change.
In an increasingly dynamic job market, in fact, guaranteeing the possibility of updating and being competitive and updating professionalism in accordance with the new standards of the so-called "green jobs" is essential to allow companies to be in compliance with the requirements national, European and international regulations.
Therefore not only the promotion of degree and master's courses dedicated to environmental and sustainable economics, but also refresher programs in synergy with local authorities, companies, trade unions and the actors most involved.

4 ADAPTATION MEASURES AND ACTIONS

Adaptation means anticipating the adverse effects of climate change and taking appropriate measures to prevent or minimize the damage they may cause or take advantage of opportunities that may arise. Examples of adaptation measures are large-scale infrastructure changes, such as building defenses to protect people or structures from rising sea levels, and behavioral changes, such as reducing food waste by individuals. In essence, adaptation can be understood as the process of adjusting to the current and future effects of climate change can be achieved through different types of measures.

Soft measures: include policy, legal, social, managerial and financial measures, which can change behavior and lifestyles, helping to improve adaptive capacity and increase awareness on climate change issues.

Green measures: involve nature/ecosystem-based actions, which employ the multiple services provided by natural ecosystems to improve resilience and adaptive capacity.
Infrastructural/technological measures: physical interventions and/or constructive measures useful to make buildings, infrastructures, networks, territories more resilient to climate change.

This Plan is aimed at laying the foundations for short and long-term planning for adaptation to climate change, through the definition of specific measures aimed both at strengthening adaptation capacity, through the improvement and systematisation of cognitive framework, and the development of an optimal organizational context, which are preparatory and indispensable for the planning and implementation of adaptation actions at a national level. The latter have been identified and presented in the PNACC Action Database and will be implemented through the definition of sectoral and inter-sectoral methods and tools at the different levels of government.

The general objective of the PNACC is expressed through four specific objectives:

- define a national *governance* for adaptation, explaining the coordination needs between the different levels of territorial government and the different sectors of intervention;
- improve and systematize the framework of knowledge on the impacts of climate change on the impacts of climate change, vulnerability and risks in Italy;
- define the methods of inclusion of the principles, actions and measures of adaptation to climate change in the national, regional and local Plans and Programs for the action sectors identified in the PNACC, enhancing the synergies with the other national Plans;
- define sectoral and inter-sectoral methods and tools for implementing the actions of the PNACC ai different levels of government.

4.1 Soft measures and actions

This Plan identifies 4 *soft* actions aimed at administrative and technical strengthening for adaptation to climate change. The aforementioned actions fall within the *governance* and information categories.

The following summary table shows the list of *soft* measures and actions identified.

Table XXX - Summary of PNACC *soft* measures and actions

N	Measurement	Action	Objective	Progress indicator (measuring method)	Target	Implementation times	Subjects involved
1	Administrative strengthening for adaptation at the national level *(Governance)*	Establishment *of the "National Observatory for adaptation to climate change"*	Establishment of the National Observatory and establishment of the Technical Secretariat within three months of the ministerial approval decree of the PNACC	Issuance of the ministerial decree (Protocol)	Three months from the ministerial decree of approval of PNACC	Three months from the ministerial decree of approval of PNACC	BUT IF
2	Administrative strengthening for adaptation at the national level *(Governance)*	Identification of the methods, tools and competent subjects for the introduction of principles, measures and actions for adaptation to climate change in National, regional and local plans and programs	*Mainstreaming* of adaptation in planning at all levels of territorial government	Number of plans and programs for which methods, tools and competent subjects for *mainstreaming* have been identified / Number of programs and/or plans evaluated	100%	Six months from the approval decree of PNACC	Observatory
3	Strengthening administrative for adaptation at the national level *(Governance)*	Definition of modality e sectoral tools e intersectoral implementation of PNACC measures at different levels of government	Approval of the act defining the modalities e of the tools for implementing the measures of PNACC within twelve months of taking office of the Observatory	Approval of the act defining the modalities e of the tools for implementing the measures of PNACC (Protocol)	Twelve months after taking office of the Observatory	Twelve months from the settlement of the Observatory	Observatory
4	Strengthening technical skills for adaptation to national level *(Information)*	Development of a research program to improve the knowledge framework on the impacts of climate change, on vulnerability and risks in Italy	Activation of the Agreement/Convention within twelve months of the decree approving the PNACC	Agreement/Convention (Protocol)	Twelve months from decree approving the PNACC	Twelve months from decree approving the PNACC	BUT IF

4.2 Sectoral measures and actions

This Plan reports a set of sectoral actions, identified by the experts who collaborated in the development of the 2018 Plan document by virtue of their specific skills, starting from the information contained in the National Adaptation Strategy, from the analyzes on expected impacts and vulnerability of resources, environmental processes and selected socio-economic sectors, taking into consideration the current and future climate condition, as well as existing sector regulations and *best practices.*

A set of 361 sectoral adaptation actions was thus identified to which an evaluation methodology was applied which led to the attribution, to each individual action, of a value judgment (low, medium, medium-high and high) compared to some criteria selected from the available literature (efficiency, effectiveness, second-order effects, performance in the presence of uncertainty, policy implementation).

The set of 361 actions can be consulted via a database structured in such a way as to allow multiple interpretations of the available information, through appropriate filters that allow the data present to be selected and grouped in various ways.
The information contained in the database offers a reference framework for the construction of packages of integrated actions through the merging of actions that affect the same environmental component.

4.3 Characterization of actions

The set of 361 sectoral adaptation actions identified by the experts were subjected to an evaluation process in order to obtain an overall value judgment with respect to some criteria selected from the available literature.

Due to the purely "local" and "specific" nature of the adaptation, the scale of value of the shares is not established absolutely but varies, sometimes considerably, based on the geographical and socio-economic context of reference, as well as depending on the different climate scenarios and risks taken into consideration. Furthermore, due to the nature of many actions, the actual availability of data and the type of objectives to be achieved, the evaluation is often based on the application of qualitative criteria, following the informed opinion of experts, rather than on a rigorous quantitative analysis. This is especially true when defining the cost-benefit or cost-effectiveness ratios of the various actions. If it is possible to have a quantitative basis, the latter is often referred to specific contexts and therefore difficult to generalize or, on the contrary, to "maximum" values that present very high variability.

The methodology proposes an evaluation for "homogeneous macro-categories of intervention" that are more easily classifiable and often recurring in different sectors, and identifies an order of value for the actions, namely high, medium-high, medium, medium-low and low. The proposed evaluation also took into account the results of the public consultation through a questionnaire, addressed to the various stakeholders, aimed at measuring perceptions towards adaptation. In particular, two main segments of analysis were explored in depth in this consultation. The first aimed at identifying the relative importance of the different evaluation criteria proposed, in order to determine whether some of them should be given greater weight than others and therefore whether they should be predominant when evaluating the different actions. The second aimed at acquiring an order of value of the different actions; this proved particularly useful in the presence of ambiguous situations.

The action characterization process in its categorization and evaluation phases is described in detail below.

4.4 Categorization of actions

In order to facilitate the evaluation process, a taxonomy of the 361 actions identified in the Plan was carried out in homogeneous families.
In particular, the 361 actions were assigned to the following 5 macro-categories which identify the project typology: information, organizational and participatory processes, governance, adaptation and improvement of systems and infrastructures, solutions based on ecosystem services, river, coastal and marine, redevelopment of buildings. Each macro-category has also been detailed through specific categories.

Furthermore, the shares have been divided into two main types: type A shares (soft) and type B shares *(not soft - green* or *grey).*
In generic terms, *soft* actions are those that do not require direct structural and material interventions but which are nevertheless preparatory to the implementation of the latter, contributing to the creation of adaptive capacity through greater knowledge or the development of an organisational, institutional and legislative context favorable.
The macro categories of information actions, development of organizational and participatory processes, and governance belong to the *soft* typologies .
Gray and *green* actions , however, both have a component of materiality and structural intervention, however, the latter clearly differ from the former by proposing "nature based" solutions consisting in the use or sustainable management of natural "services", including ecosystem services, in order to reduce the impacts of climate change. Finally, the *gray* actions are those relating to the improvement and adaptation to climate change of plants and infrastructures, which can in turn be divided into actions on plants, materials and technologies, or on infrastructures or networks.
The following table describes the structuring and coding of the actions in the typologies, macro-categories and categories identified.

Table xxx: Categorization of adaptation actions.

Typology	Macro-categories	MacrID	Categories	CatID	Main types of action
	Information I		Search e assessment	R	Not classified
				R	Risk, resilience, vulnerability including components
				R	Impacts and solutions
				R	Scenarios and downscaling
			Monitoring, data, models	M	Climatic, physical, chemical, biological indicators
				M	System and measurement performance indicators
				M	Databases and information portals
				M	Forecasting and early warning systems
				M	DSS and integral IT systems
				M	Harmonization and standardization
			Dissemination, perception, awareness and training	F	Management innovation
				F	Risk, resilience and vulnerability
TO				F	Climate change, impacts and solutions
	Processes organizational and participatory	SSS	Institutions	IS	
			Organization and management	OR	Selections of genotypes and genetic varieties
					Organization of civil protection at local level
					Diversification of business strategies
					Controls and inspections
			Partnership e participation	PP	Intersectoral coordination, tables, committees and networks
					Creation of tables, committees, networks
	GOV Governance		Legislative and regulatory adjustments	L	Other sectoral regulations
					Review of water diversion concession regime
					Adapt SEA/EIA to climate change
					Minimum viable flow
					Health risk prevention

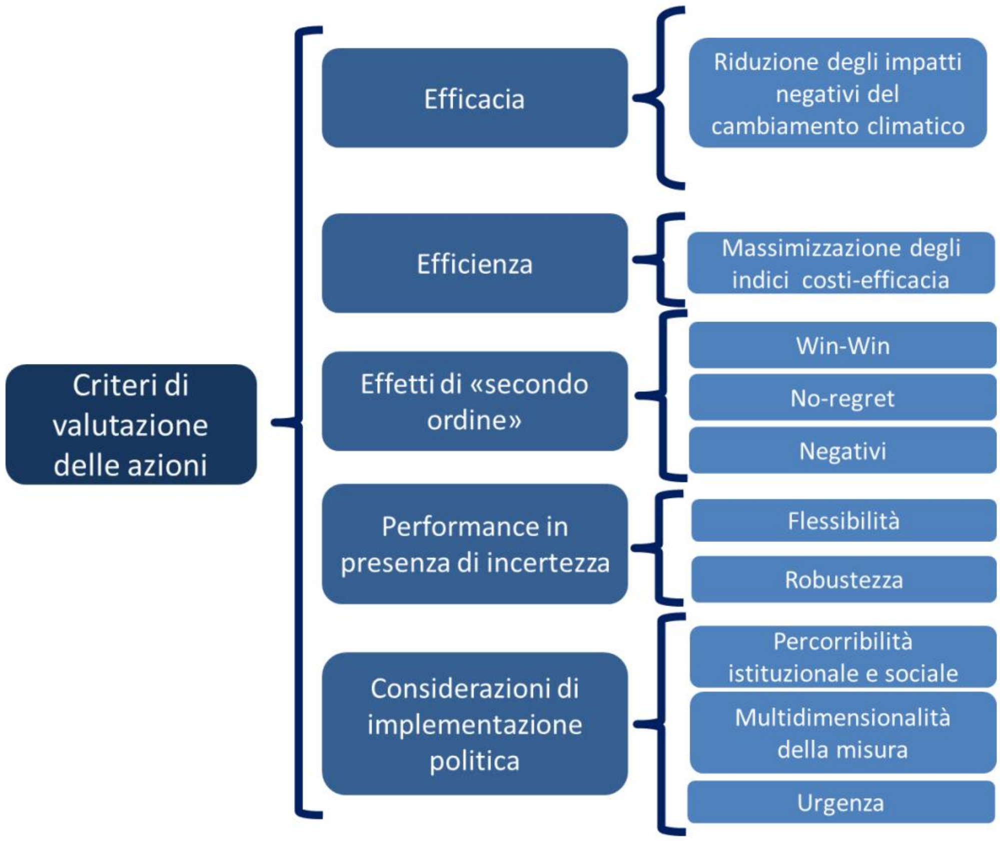
					Protected areas
					Temporary regulations
					Building regulations
					Water quality
					Security parameters
			Plans and strategies	P	Not classified
					Urban and territorial planning
					Emergency and evacuation plans
					Strategies and plans for adaptation to climate change
					Urban mobility and traffic plans
					Transport infrastructure
					Drought management
					Fire risk
					Management of protected areas
					Forest Planning
					Hydrographic District Planning
					Hydrogeological management plan
			Instruments cheap and financial	S	Insurance and other risk transfer instruments
					Economic and financial incentives
					Investment plan
					Compensations
					Environmental certifications
			Address	G	Experimentation and pilot projects
					Good practice
					Guidelines
B	Adaptation And improvement of systems and infrastructures	GR	Systems, materials and technologies	TO	Structures
					Vehicles and machinery
					Materials and technologies//Processes
					Cooling systems
					Electricity generation
					Storage of water resources
			Defense systems, networks, storage, distribution and transmission	B	Conversion of irrigation systems
					Construction of structural defense works
					Accumulation and lamination systems
					Maintenance, improvement and interconnection of networks
					Buriing of networks
					Maintenance and improvement of drainage and irrigation networks
					Flexible transmission systems
					Energy storage
	Solutions based on services ecosystemic	NBS	Solutions integrated	C	Increase in territorial connectivity (green infrastructure)
			Forestry and agro-forestry ecosystems	D	Forest ecosystems
					Silvicultural management for the protection and conservation of biodiversity
					Silvicultural management for the prevention and reduction of risks
					Establishment and maintenance of agroforestry systems
					Biological control for the prevention and fight against plant diseases
					Restoration and restoration of forests damaged by disasters
					Reforestation, afforestation and reforestation
			Ecosystems river, coastal and marine	AND	River redevelopment
					Restoration and management of wetlands
					Buffer strips and vegetated barriers
					Conservation, reconstruction and renaturalization of coastal areas
					Safeguarding coastal biodiversity

					Restoration of the vegetation of aquatic plants and vegetation barriers in Canneto at the mouth of the watercourses
					Promotion of the natural reconstruction of structures corals
					Network of marine protected areas
					Protection and management of marine habitats
			Redevelopment of buildings	F	Residential construction
					Road drainage systems
					Urban greenery

4.5 Evaluation of actions

The 361 categorized sectoral adaptation actions were evaluated against the following 5 criteria (Flörke et al. 2011): effectiveness, economic efficiency, second-order effects, *performance* under uncertainty, and considerations for policy implementation (fig. 4 .x).

The result consisted in the attribution, to each individual action, of a value judgment (high, medium-high, medium, medium-low, low).



The criteria are defined as follows:

- **Effectiveness.** The criterion is aimed at evaluating how well the action is able to achieve the purpose for which it was implemented, that is, in generic terms, to reduce the negative impacts of climate change.

- **Economic efficiency.** The criterion categorizes actions based on their ability to achieve the established objective, i.e. the reduction of the negative impacts of climate change at the lowest costs; in other words the categorization occurs based on the cost/effectiveness ratio of the different actions. Costs are considered, when possible, in an extensive way, also including transaction costs and not just direct "construction/implementation" costs.

- **Second order effects.** This criterion is aimed at evaluating all the effects that derive from the implementation of adaptation actions but which do not constitute their main and explicit aim. Second-order effects can be both positive and negative. In the first case we also talk about ancillary benefits of adaptation actions. Typical examples in the literature are: job creation, advancement in the process of technological innovation, creation of social capital. In turn, positive second-order effects can give rise to actions:

  - ***No-regret.*** In this case the actions produce benefits in different climate change scenarios, do not involve elements of conflict with other public policy objectives and above all are characterized by high benefits and relatively low costs. In practice, the difficulty in identifying no-regret options lies in the concrete identification of the benefits and the related economic evaluation;

  - ***Win-win.*** This concept refers to actions that produce benefits even outside the context of reducing climate impacts.

It is important to underline that both *no-regret* and *win-win* actions are not zero or even negative cost. However, they involve investments, even substantial ones, and this can constitute an obstacle to the adoption of the action in the presence of liquidity constraints on public budgets or other priorities on the part of the political decision maker.

Finally, in the case of negative second-order effects, we speak of "mal-adaptation" *and* this occurs when an action aggravates the vulnerability to climate change by accentuating its impacts in different sectors or in other territories or when it increases the effort required for mitigation (e.g. increasing greenhouse gas emissions).

- **Performance in the presence of uncertainty.** This criterion evaluates how applicable a specific action can be in a variety of possible climatic and socioeconomic conditions. The criterion consists of two specific characteristics:

  - ***Robustness.*** It implies the ability of the action to maintain acceptable effectiveness in contexts different;
  - ***Flexibility.*** It describes actions capable of adapting, at "low costs", to different contexts. The adaptation may consist of transformations of the action or integrations with complementary actions or, in extreme cases, the abandonment of the action itself if it proves unsuitable.

- **Considerations for policy implementation.** The choice of an adaptation action depends not only on the type of action but also on the regulatory, economic and social reference framework within which the action takes place. The following criteria are taken into account (EEA 2007; van Ierland et al. 2007):

  - ***Social institutional viability.*** Assess the existence of barriers that can potentially make implementation of the action difficult. A first category of impediments is related to institutional aspects: the more an action requires the cooperation of different institutions, the more complex the implementation process will be. Furthermore, the complexity increases further in cases where the regulatory/institutional framework is not well determined or in the presence of barriers of a legal nature or relating to the social acceptability of the action;

  - ***Multidimensionality.*** It identifies both actions that, in combination with each other, can increase mutual effectiveness, and those that contribute to alleviating negative consequences relating to multiple impacts or in different sectors;

  - ***Urgency.*** It identifies actions aimed at reducing the impacts judged to be most harmful and therefore those that should be treated first based on the risks posed to the socio-economic system.

The criteria on which the overall judgment of the shares is based are easier to apply to *gray* and *green* shares than to *soft ones.* Applying criteria such as effectiveness, economic efficiency and second-order effects to non-structural actions is extremely complex precisely because of their intrinsic immateriality. On the other hand, the *soft* actions all tend to be robust, flexible and above all urgent, having to precede the *green* and *gray* actions and introduce facilitating elements to create the optimal conditions for territorial governance at the basis of effective planning and subsequent implementation of the actions.

Following the evaluation carried out by the experts, 59% of the shares received an overall high rating, 29% medium-high and 12% medium, medium-low and low. By crossing the three dimensions - typology, temporal orientation and evaluation judgment - a group of non-structural *(soft)* actions emerges distributed across almost all sectors, with a high judgment and achievable in the short term.

The following table shows the distribution of shares by valuation judgment and sector to which they belong.

Adaptation actions by evaluation judgment and sector to which they belong.

	TT	AC	AG	DS	DI	EA	EM	ET	EN	FO	IP	IU	PC	PM	RI	SA	TR	TU	ZC	Total	%
High	13 7		17 10 24 2				21 13		2	8 8 15 11 11 20 16 9 4 2										213 59.0	
Medium-high		1	9		5	3	3	6	12 24 5 1				1		7 4 5			3	15	104	28.8
Average		1	1						13	3	1			8	1			1	9	38	10.5
Medium-low																		2		2	0.6
Low			1						1					1						3	0.8
nd													1							1	0.3

4.6 The Action Database

The database of adaptation actions (Annex IV) offers a summary of the set of proposed sectoral actions and their attributes. It is structured to allow simple and flexible consultation and at the same time rapid extraction of contents.

The Action Database has been revised compared to that of 2018 following the transposition
of the observations of the VIA-SEA Technical Commission (e.g. elimination of macro-regions and homogeneous climate areas) and of the need for updating (e.g. actions by 2020).
For each action the database provides, by way of example, the macro-category and the category within which it falls, the main associated impacts, the type it belongs to *(Soft, Green and Grey)* and the value judgement. Also reported are the regulatory sources to which the individual actions refer, the possible costs, the bodies potentially involved in the implementation, as well as the indicators for monitoring both the progress and effectiveness of the actions.

As regards the type, most of the actions are non-structural *(Soft):* 274 equal to 76% of the total. This is followed by actions based on an ecosystem approach *(Green)* which amount to 46, equal to 13%. Finally, infrastructure and technology stocks *(Grey),* which are 41 or 11% of the total. *Soft* actions are distributed evenly across almost all sectors, while the *green* type prevails in the forestry sector. Infrastructure/grey type actions are more concentrated (proportionately) in the energy sector, while in the coastal zone sector there is a substantial balance between the three types of actions (Table 2.6-1).

Table: Analysis of shares by type and sector.

	TT AC AG DS DI EA EM ET EN FO IP											IU PC PM RI SA TR TU ZC Total %									
Green			1			1	5	2		17	1	5			1		1 2 10			**46**	***13***
Grey		1	4						16	3	2		1		3			2 9		**41**	**11**
Soft	13 8 23			8 29 4 19 17 12 15 11 11 12 20 24 20 13 6 7																**274**	**76**

Regarding the stock evaluation criteria, 59% of the stocks received a high overall rating, 29% medium-high and 12% a medium, medium-low and low overall rating.

Table: Analysis of shares by valuation judgment and sector.

	TT AC AG DS DI EA EM ET EN FO IP IU PC PM RI SA TR TU ZC Total %																				
High	13 7		17 10 24 2				21 13		2	8 8 15 11 11 20 16 9 4 2										**213 59.0**	
Medium-high		1	9		5	3	3	6	12 24 5 1				1		7 4 5			3	15	**104**	**28.8**
Average		1	1						13	3	1			8	1			1	9	**38**	**10.5**
Medium-low																		2		**2**	**0.6**
Low			1						1					1						**3**	**0.8**
nd													1							**1**	**0.3**

By crossing the three dimensions - typology, temporal orientation and value - a group of non-structural *(soft)* actions emerges, distributed across almost all areas of action, with high value and achievable in the short term.

It is underlined that the majority of the actions identified (76.7%) have an inter-sectoral character and are capable of producing effects on multiple sectors simultaneously. In fact, only 23.3% of the actions relating to a specific sector have no relationships or impacts with the other sectors taken into consideration in the Plan (Table 2.6-4).

Table: Analysis of the distribution of shares across multiple sectors.

INTER-SECTORIALITY OF ACTIONS		
Mono-sector	84	23.3
On 2 sectors	58	16.1
On 3 sectors	58	16.1
On 4 sectors	45	12.5
On 5 sectors	25	6.9
> 5 sectors	78	21.6
All sectors	13	3.6
Total	361	100%

From the distribution of mutual relations between the actions it emerges that agriculture, urban settlements, forests and water resources are the most significant nodes of the network since a large number of actions converge on them and branch off from them which also affect other sectors. In particular, the agriculture sector forms a cluster with the desertification, forests, terrestrial ecosystems and water resources sectors; the urban settlements sector with geological, hydrological and hydraulic instability, water resources, transport and coastal areas; finally, the water resources sector forms a grouping with aquaculture, agriculture, energy, dangerous infrastructures and industries, and urban settlements. These anniversaries show a certain importance of water resources, in the role of conjunction between the agriculture, urban settlements and energy sectors.

Sources of financing

As widely shared by economic doctrine, a reorganization of taxation that better promotes the use of environmental fiscal instruments would produce a double benefit: that of reducing the negative impacts on the climate and that of reducing the fiscal impact of other issues, including that on work. .

Net of this consideration, the development of which is left to another forum, various sources of financing related to the theme of adaptation are already active.

Given this, as has been the case for years now, even in Italy, national economic planning is associates with the European one, contributing to the co-financing of the programs with its own resources, but limiting themselves to selecting the spending priorities already defined at European level. For this reason, most part of the financing sources are attributable to European funds or, at least, adopt theirs same financing scheme.

In this context, the Council of the European Union, with the approval in 2021 of the new Strategy for adaptation to climate change, underlined the important role played by strengthening resilience to climate change in the economic recovery from the COVID-19 pandemic . The EU has set a spending target of at least 30% on climate action, including adaptation, under the Multiannual Financial Framework for the period 2021-2027 and at least 37% in the scope of the Recovery and Resilience Facility.

By analyzing European and national funds in this light, many potentially emerge resources for the measures suggested in the PNACC. In particular, three areas would have significant funding at European, national and regional level:

- scientific research and technological innovation for adaptation (e.g. the Horizon 2027 programme, the Research and Development PON and all the PORs);
- the creation and climate-proof adaptation of transport, energy and water infrastructures (e.g. the Connecting Europe Mechanism, the spending chapters on infrastructure of the Cohesion and Development Fund, the Pacts for the South, etc.);
- sustainable and resilient agriculture, forestry and fishing (the CAP, the various regional Rural Development Programmes, the EMFF OP, etc.).

The resources identified with the logic of integration (mainstreaming) would cover the actions of almost everyone the 19 sectors covered by the PNACC. In addition to the aforementioned Transport, Energy, Water Resources, Agriculture, Forestry and Maritime Fisheries, the existing funds could also finance measures in the sectors Aquaculture, Geological, hydrological and hydraulic instability, Inland and transition water ecosystems, Marine ecosystems and Terrestrial ecosystems, urban settlements, cultural heritage, health, tourism and socio-economic impacts.

However, it should be noted that only part of the resources we refer to are in the live broadcasts availability of the Italian system. The European financing scheme mentioned in fact provides for an allocation of funds on a competitive basis and therefore the attribution is uncertain and subject to the condition of a particular effort for the presentation of excellent quality applications.

European Programs

Going into more detail, it is possible to distinguish funding sources on the three levels of government: European, national and regional.

The budget of the LIFE Program for the period 2021-2027 is set at 5.45 billion euros, of which 0.95 billion euros are intended to co-finance actions under the LIFE Sub-programme "Mitigation and Adaptation to climate change" (LIFE CLIMA) and the areas of intervention included in the three priority sectors of this Subprogram: 1. "Mitigation of climate change"; 2. "Adaptation to climate change"; 3. "Governance and information on climate change".

The indicative budget allocated to the LIFE CLIMA Subprogramme for the period 2021-2024 is 505.5 million euros. The majority of this financial allocation will be spent on Standard Action Projects (SAPs, the so-called "traditional" LIFE projects, which support the development of innovative solutions and the application of good practices in the field of environment and climate action) and for Integrated Strategic Projects (SIP). SIPs implement, at regional, multi-regional, national or transnational scale, environmental or climate strategies or action plans developed by Member State authorities and required by specific Union environmental, climate or energy legislation or policy. SIPs also ensure stakeholder involvement and promote the coordination and mobilization of at least one other source of Union, national or private funding.

The Union Civil Protection Mechanism also confirmed, with the 2022 communication, it has adopted conclusions in which it asks to adapt civil protection so that it can deal with extreme weather events caused by climate change.
In addition to these two instruments expressly dedicated to adaptation, all other European programmes they integrated the topic into their normal planning and spending activities.
In this sense, the European Regional Development Fund (ERDF) supports the development of strategies adaptation, networks, exchange of good practices and capacity building activities related to it.
The URBACT 2021-2027 program is also active within the ERDF with an explicit focus on the urban environment. The European Social Fund has a similar role in supporting adaptation, which focuses above all on supporting training activities, dissemination of knowledge and awareness raising.
Urban Innovative Actions (UIA) is an initiative of the European Commission aimed at providing funding to European urban areas to test innovative solutions in addressing their major challenges present and future problems, among which, the recently introduced thematic area, appears precisely adaptation to climate change. The UIA has an allocated budget for the period 2021-2027 of 450 million Euros.
The Horizon Europe program is structured in three pillars, which have specific research programs and themes within them, and in a transversal programme. Within the "Global challenges and European industrial competitiveness" pillar there is the program on "Climate, Energy and Mobility". This program, which has funds of 15 billion euros, provides that the European aspiration to understand the causes of climate change, its evolution, its impacts, the risks and opportunities related to it is closely accompanied by the need to make the more sustainable, intelligent, safe, resilient, inclusive, competitive and efficient energy and mobility systems.

The 2021-2027 CAP is based on 10 key strategic objectives, one of which is "to contribute to climate change mitigation and adaptation, including through the reduction of greenhouse gas emissions and the improvement of carbon sequestration, as well as promoting sustainable energy."
There are also other funds that could potentially be of interest for adaptation actions: the Connecting Europe Facility, dedicated to strategic transport and energy infrastructures for the continent, must necessarily take adaptation into account considering the long life cycle of its investments. Similarly, the Health Action Program could also be a source of funding for some adaptive health and risk prevention actions. Also at European level we find funds from the European Investment Bank (EIB) and the European Investment Fund which are attributable to adaptation. The two institutions, in fact, foresee

financial instruments (such as loans and guarantees) for the infrastructure, energy sectors (of strategic importance for adaptation) and for the environmental sector.

National programs

At the national level, economic planning proceeds hand in hand with the European one. The agreement with the EU provides that the various National Operational Programs (NOPs) take into consideration spending priorities in the field of environment and sustainability, but they are only indirectly linked to adaptation. Nonetheless, from the perspective of the potential integration of the topic into ordinary spending, these funds represent a huge resource for adaptive measures. For example, the National Program (PN) Metro plus and medium-sized cities in the South, intended for urban development in metropolitan cities which dedicates part of the investments to activities that are known to be climate-resilient, as well as properly sustainable.

The program provides for the allocation of approximately 330 million euros for point 2. Environmental sustainability and for point 3, multimodal and sustainable urban mobility.
Similarly, the PON Culture and Development 2014-2020, (270 million euros), currently under development for the period 2021-2027, could be a source of financing for those measures that aim to protect cultural heritage from the risks of climate change.
Similarly, the National Research Plan 2021-2027, intended to finance technological and industrial innovation, could finance those research bodies or companies that begin to develop commercial solutions for adaptation (as foreseen by some PNACC actions).
Alongside these European-based instruments, there are resources directly available to the State such as the Cohesion and Development Fund, the Health Pact and programs such as the Major R&D Projects (financed by the Sustainable Growth Fund) which can be a source for measures adaptation of the PNACC in the fields of infrastructure, health and research.
It is also necessary to highlight the resources of the Cassa Depositi e Prestiti which, similarly to what the equivalent European institutions, supports the creation of a financial market in the infrastructure sector a which those actors interested in implementing the adaptive measures could theoretically draw on transport and energy infrastructure.
The "Experimental program of interventions for adaptation to climate change in the urban context" provides approximately 80 million euros aimed at increasing the resilience of settlement systems subject to the risks generated by climate change, with particular reference to heat waves and climate phenomena. extreme rainfall and drought.

Regional Programs

At the regional level there are essentially three types of financing instruments: Operational Plans Regional (POR), the European cross-border cooperation programs and the various agreements signed between the regional and central administrations. As already mentioned, the ROPs and INTERREG programs of pertaining to Italy, implementing the European guidelines, provide for many expenses in the environmental field and even resources specifically dedicated to adaptation. Many Italian regions have in fact selected, among the various Thematic Objectives defined by the EU, adaptation (intended especially as a work of land arrangement against geological and hydrological instability). And furthermore, always in the logic of integration (mainstreaming) of ordinary spending, all POR and INTERREG offer resources that can be used to finance adaptation measures in the fields of research and innovation, transport infrastructure, energy and efficiency energy, in the protection and adaptation of environmental and cultural resources.

5 GOVERNANCE OF ADAPTATION

The impacts of climate change on society are so pervasive that states' responses must be systemic, as also foreseen in the EU 2021 Climate Change Adaptation Strategy. At the same time, the ways of acting are inevitably different from one state to another. 'other, also in relation to the different governance systems of each of them.

Since climate change has effects on most natural systems, on humans and on socio-economic sectors, which are interconnected, adaptation to climate change is characterized by a strong inter-sectoral and multi-sectoral nature of action. Furthermore, the planning and implementation of adequate adaptation actions, as well as the monitoring of their effectiveness, presupposes a multilevel organization since the topic intercepts many skills at different levels of government, both horizontally and vertically, and requires the active and conscious participation of civil society.

Therefore, it is essential to establish a *governance* structure that can represent the reference body at a national level and that involves, in various capacities and in compliance with their respective roles, Public Administrations, technical bodies and civil society.

The *governance* structure will be fundamental for the definition of sectoral and inter-sectoral methods and tools for implementing the PNACC actions at the different levels of government and for the second phase of the PNACC path which will guarantee the immediate operation of the Plan. The results of this activity will converge in sectoral or intersectoral plans, in which the interventions to be implemented will be outlined.
With a view to guaranteeing the circularity of resources, the PNACC governance structure will have to guarantee close synergy with the Observatory on the implementation of the national circular economy strategy.

5.1 National observatory for adaptation to climate change

Directorial Decree no. 86 of 16 June 2015 adopting the SNAC provides for the establishment:

- of a national observatory made up of representatives of the Regions and local representatives, for the identification of territorial and sectoral priorities and for monitoring the effectiveness of adaptation actions;

- of a permanent Forum, for the promotion of information, training, and decision-making capacity of citizens and stakeholders.

In line with the aforementioned indications, the first action identified in this Plan is represented by the establishment of a permanent governance structure, "The National Observatory for adaptation to climate change" which makes use of a technical-scientific support structure (Technical Secretariat) and a consultative-informative body (Permanent Forum). The National Observatory is configured as a coordination and discussion table for updating intervention priorities over time and for planning and implementing adaptation actions.

5.1.1 National observatory for adaptation to climate change

The national Observatory, to be established at the Ministry of the Environment and Energy Security, is conceived as a structure with broader participation than that envisaged in the decree adopting the SNAC, composed of representatives of the Ministries responsible for each of the sectors of action taken into consideration in the SNAC, the Regions and the autonomous Provinces, the Department of Civil Protection of the Presidency of the Council, the District Basin Authorities. The participation of other Ministries or other Bodies with competence in the sectors of action on the agenda of the Structure's meetings is expected.

Operational support will be guaranteed by the General Directorate responsible for the topic of adaptation to climate change.

The National Observatory has the task of updating the intervention priorities and adaptation actions identified by the PNACC over time; plan the use of funding sources, the timetable of interventions; take care of the monitoring activities of the progress and effectiveness of the interventions identified to pursue the actions of the PNACC, as well as the *reporting* and evaluation activities of approving the intervention proposals presented by the Regions, Local Authorities or other public bodies with the action proposals identified in the PNACC.

5.1.2 Technical secretariat

The technical-scientific support body has the task of:

- analyze and convey to the coordination structure the basic technical information necessary for planning, implementation and monitoring of PNACC actions;
- evaluate the coherence of the intervention proposals presented by the Regions and Local Authorities with the actions of the PNACC.

5.1.3 Permanent forum

The consultative-informative body is structured in the form of a Forum.
The Forum has a Steering Committee made up of members of the coordination structure and the technical-scientific support body, as well as representatives of other regional and local bodies.
The Steering Committee may invite representatives of production categories, national, international and EU bodies, the research sector, civil society and other stakeholders to participate in its initiatives.

The Forum meets once a year. The Steering Committee has the task of organizing the annual meeting, preparing the relevant Program and preparing a report on the outcomes of the aforementioned meeting to be sent to the Coordination Structure also for the purpose of identifying regulatory proposals aimed at implementing the adaptation actions.

Furthermore, the Forum also carries out the following tasks:
- encourage dialogue, discussion, connection and coordination between central authorities and regions, autonomous provinces and local authorities on adaptation; - inform civil society and stakeholders on the topic of adaptation, facilitating e soliciting active participation on adaptation;
- promote the protection of the rights and interests involved: the Forum promotes, in appropriate circumstances and according to the established methods, access to information, participation in decision-making processes and access to justice;
- promote the exchange of information between the bodies responsible for planning in the field of adaptation.

The reference tool for the dissemination of information and the involvement of civil society and stakeholders is the National Platform for Adaptation to Climate Change.
The Platform, developed by ISPRA, was published in October 2022 with the aim of informing, raising awareness and making data and information available from different sources, useful for supporting the bodies involved in the decision-making process on the topic of adaptation.
The Forum provides civil society and stakeholders with information from the National Platform on adaptation to climate change and collects comments, proposals and observations received from them.

5.2 Monitoring, reporting and evaluation of the National Adaptation Plan

In recent years, both the awareness that adaptation represents a fundamental and necessary component of the social and institutional response to climate change has increased (Karali and Mattern 2017), and the amount of public spending allocated to the development and implementation of policies and adaptation actions. Consequently, the interest of institutions in keeping track of the use of funds and ensuring that the investments supported are justified, convenient and effective in achieving the expected results has grown (Hammill et al. 2014b; EEA 2015; EEA 2016). For this reason, the development of monitoring, *reporting* and evaluation (MRV) processes is essential.

Monitoring examines progress made in implementing adaptation policies and measures over a given period of time; evaluation focuses on their effectiveness, while *reporting* consists of documenting and communicating the results achieved.

The role of MRV systems is extremely important for various reasons. The data and information produced can help prioritize policies and actions so that adaptation goals are achieved in a cost-effective manner (OECD 2015). Furthermore, these help to identify and address any knowledge gaps in a timely manner, improve learning and clearly define the roles and responsibilities of the policy makers involved (EEA 2016; UNFCCC 2010).

Incorporating MRV activities into the adaptation policy cycle and related processes is of great importance and beneficial in the long term. In particular, a monitoring system constitutes an essential element of the implementation process of a Plan.

The identification of adequate indicators for each of the MRV processes allows us to:
(i) monitor the implementation of adaptation policies, measures and actions; (ii) justify and monitor funding for adaptation programs based on objectives fixed;
(iii) integrate adaptation through linkages between sectors and related indicators; (iv) communicate the adaptation to policy makers and other interested parties *(stakeholders);* (v) compare adaptation results at sub-national scales and across sectors of interest (Harley and van Minnen 2009, p.4).

Collecting data to build national indicators is a very resource-intensive process and requires a shared metric that allows evaluation results to be compared.
The spectrum of indicators is quite broad and their choice reflects the aims and objectives of the MRV system and the reference context (local/national). Indicators must be representative, i.e. able to measure progress on important factors, and be easily available on a continuous basis to ensure monitoring.

The list of indicators suggested for evaluating the progress and effectiveness of the adaptation actions of this Plan was built starting from the indications of the same experts who selected the sectoral actions included in the database. For each adaptation action they proposed, the experts identified indicators of effectiveness and implementation status. The indicators were subsequently revised as a whole and grouped by main types of action, categories and macro-categories, although this attribution is not to be understood in a rigid manner. In fact, each indicator can be relevant for more than one main type of action, category and therefore also macro-category. The list thus constructed was then evaluated by MRV experts on the subject of adaptation to climate change. This processing was carried out with the aim of: (i) harmonizing the list of indicators (eliminating duplications or indicators which had been given different names but with the same metric) as well as (ii) identifying and filling potential gaps in the first list .

The "Progress Indicators" and "Effectiveness Indicators" worksheets of the Database represent a *portfolio* of indicators which must subsequently be refined and adapted to the territorial context, in order to provide valid support to the national MRV system.

The preparation of a system for monitoring the impacts of climate change, through a set of indicators at a national level, is an indispensable preparatory element for the development of an MRV system since it allows us to have a cognitive framework of reference *(baseline)* with respect to which be able to monitor the effectiveness of adaptation actions over time.

In any case, even during the implementation phase of the Plan, the list of indicators must be understood as an "in progress" document, i.e. which needs to be reviewed and updated based on new information available, considering any changes in the overall context Italian.

Reporting

Italy, as a party to the United Nations Framework Convention on Climate Change (UNFCCC), must periodically transmit to the Secretariat a set of information on its respective policies and measures on climate change through the "National Communication". Decision 6/CP. 25 *requires* the Parties to Annex I of the UNFCCC (which contains the list of industrialized countries and countries with economies in transition) to transmit, by 31 December 2022, the eighth National Communication (NC8). *Vulnerability assessment, climate change impacts and adaptation measures"* is carried out by a working group made up of representatives of MASE, ISPRA and the CMCC Foundation.

With regard to *reporting* at the European level, Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018, on the *governance* of the Energy Union and climate action, in Article 19 requires the Member States' obligation to communicate national adaptation actions.

In particular, "By 15 March 2021 and every two years thereafter, Member States shall communicate to the Commission information on their adaptation plans and strategies, outlining the actions implemented and planned to facilitate adaptation to climate change, including set out in Annex VIII Part 1, and in accordance with the reporting obligations agreed under the UNFCCC and the Paris Agreement".

Following the issuance of Commission Implementing Regulation (EU) 2020/1208 of 7 August 2020, concerning the structure, format, transmission procedures and revision of information communicated by Member States pursuant to Regulation (EU) 2018 /1999, the information to be transmitted is contained in Annex I of the aforementioned Regulation.

BIBLIOGRAPHY CHAPTER 3 - Impacts of climate change in Italy and sectoral vulnerabilities

MATTM (2015). *National Strategy for Adaptation to Climate Change.*

SNPA (2021). *Climate Change Impact Indicators Report* – 2021 Edition. SNPA Report 21/2021 – ISBN: 978-88-448-1058-0.

Cryosphere and mountains

SNPA (2021). *Climate Change Impact Indicators Report* – 2021 Edition. SNPA Report 21/2021 – ISBN: 978-88-448-1058-0.

ARPA Veneto (2022). Marmolada collapse, *meteorological, climatic and glaciological analysis.*

Water resources

ISPRA, 2020. *Water resources in the geological context of the Italian territory.* ISPRA Report 323/2020.

Castellari S, Venturini S, Ballarin Denti A, et al (2014a). *Report on the state of scientific knowledge on impacts, vulnerability and adaptation to climate change in Italy.* Ministry of the Environment and Protection of Land and Sea, Rome.

EC (2000). *Directive 2000/60/ EU or Water Framework Directive* - WFD, European Commission, 2000.

EC (2011a). *A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy.* COM(2011) 21.

EC (2011b). *Roadmap to a resource efficient Europe* - COM(2011) 571 final.

ISTAT (2022). *REPORTACQUA - ISTAT statistics on water 2019-2021.*

Kernan M (2015). *Climate change and the impact of invasive species on aquatic ecosystems.* Aquat Ecosyst Heal {&} Manag 4988:321–333 . doi: 10.1080/14634988.2015.1027636.

Marine environments: biodiversity, functioning and ecosystem services

Bianchi, C. N. (2007). *Biodiversity issues for the forthcoming tropical Mediterranean Sea.* Hydrobiologia 580:7–21. doi: 10.1007/s10750-006-0469-5.

Boero, F., Bouillon, J., Gravili, C. et al (2008). *Gelatinous plankton: irregularities rule the world (sometimes).* Mar Ecol Prog Ser 356:299–310. doi: 10.3354/meps07368.

CIESM (2002). *Alien marine organisms introduced by ships in the Mediterranean and Black seas.* Monk.

Claudet, J., Fraschetti, S. (2010). *Human-driven impacts on marine habitats: A regional meta-analysis in the Mediterranean Sea.* Biol Conserv 143:2195–2206. doi: 10.1016/j.biocon.2010.06.004.

Cerrano, C., Bavestrello, G., Bianchi, CN et al (2000). *A catastrophic mass-mortality episode of gorgonians and other organisms in the Ligurian Sea (North-western Mediterranean),* summer 1999. Ecol Lett 3:284–293. doi: 10.1046/j.1461-0248.2000.00152.x.

Fauville, G., Queiroz, ACM, Brown, L.H.B.A., Bailenson, J.N. (2021). *Participatory research on using virtual reality to teach ocean acidification: a study in the marine education community.* Environ. Educ. Res. 27:2, 254–278. doi: 10.1080/13504622.2020.1803797.

Gattuso, J.P., Hansson, L. (2011). *Ocean acidification* (Oxford University Press).

Lejeusne, C., Chevaldonné P., Pergent-Martini C., et al (2010). *Climate change effects on a miniature ocean: the highly diverse, highly impacted Mediterranean Sea.* Trends Ecol {&} Evol 25:250–260. doi: 10.1016/j.tree.2009.10.009.

Pisano, A.; Marullo, S.; Artale, V.; Falcini, F.; Yang, C.; Leonelli, F.E.; Santoleri, R.; Good morning Nardelli, B. (2020). *New Evidence of Mediterranean Climate Change and Variability from Sea Surface Temperature Observations.* Remote Sens. 2020, 12, 132. https://doi.org/10.3390/rs12010132.

SNPA (2021). *Climate Change Impact Indicators Report* – 2021 Edition. SNPA Report 21/2021 – ISBN: 978-88-448-1058-0.

Ecosystems and biodiversity of inland and transitional waters

UNESCO, *Convention on Wetlands of International Importance especially as Waterfowl Habitat,* Ramsar 1971.

UNCED (1992). *Convention on Biological Diversity,* Rio de Janeiro 1992.

Coastal areas

Anderson, D.M., Cembell,a.D., Hallegraeff, G.M. (2012). *Progress in understanding harmful algal blooms: paradigm shifts and new technologies for research, monitoring, and management.* Ann. Rev. Mar. Sci., 4: 143-76.

CMCC (2021). *G20 Climate Atlas,* Italy.

ISPRA (2021). *Hydrogeological instability in Italy: hazards and risk indicators* - 2021 Edition, ISPRA.

Kurdistani, S.M., Verri, G., Pinardi, N., Coppini, G. (2022). *Climate Projections of salt-wedge intrusions in a Po river branch (Northern Adriatic Sea).* Technical Notes Issue TN0291, OPAOcean.

Spano D., Mereu V., Bacciu V., Marras S., Trabucco A., Adinolfi M., Barbato G., Bosello F., Breil M., Chiriacò MV, Coppini G., Essenfelder A., Galluccio G. , Lovato T., Marzi S., Masina S., Mercogliano P., Mysiak J., Noce S., Pal J., Reder A., Rianna G., Rizzo A., Santini M., Sini E., Staccione A., Villani V., Zavatarelli M. (2020). *Risk analysis. Climate changes in Italy.* DOI: 10.25424/ CMCC/ANALISI_DEL_RISCHIO.

SNPA (2021). *Climate Change Impact Indicators Report* – 2021 Edition. SNPA Report 21/2021 – ISBN: 978-88-448-1058-0.

Zingone, A. (2010). *Harmful algal blooms in the Mediterranean Sea: a historical overview.* In: Briand F (Ed.) Phytoplankton responses to Mediterranean environmental changes. Munich: CIESM, 19-24.

Soil and territory

Buscaroli, A. & Zannoni, D. (2010). *Influence of ground water on soil salinity in the San Vitale Pinewood (Ravenna - Italy).* Agrochemistry, 54: 303–320.

Dazzi, C. (2008). *Salinization.* In Di Fabbio A. & Fumanti F., eds. The soil, the root of life, pp. 52–53. APAT, Rome.

Dazzi, C. & Lo Papa, G. (2013). *Soil Threats.* In EAC Costantini & C. Dazzi, eds. The Soils of Italy, pp. 205–245. World Soils Book Series. Dordrecht, Springer Netherlands. https://doi.org/10.1007/978-94-007-5642-7_8

FAO (2018). *Global Soil Organic Carbon Map (GSOCmap).* Technical report.

FAO. 2022. *Halt soil salinization, boost soil productivity – Proceedings of the Global Symposium on Salt-affected Soils.* 20–22 October 2021. Rome. https://doi.org/10.4060/cb9565en

Munafò, M. (ed.), 2022. *Land consumption, territorial dynamics and ecosystem services.* 2022 edition. SNPA Report 32/2022.

Panagos, P., Borrelli, P., Poesen, J. et al. (2015). *The new assessment of soil loss by water erosion in Europe.* Environ Sci {&} Policy 54:438–447. doi: 10.1016/j.envsci.2015.08.012.

Teatini, P., Strozzi, T., Tosi, L., Wegmüller, U., Werner, C. & Carbognin, L. (2007). *Assessing short and long-time displacements in the Venice coastland by synthetic aperture radar interferometric point target analysis.* Journal of Geophysical Research: Earth Surface, 112(F1).

Vittori Antisari, L., Speranza, M., Ferronato, C., De Feudis, M., Vianello, G. & Falsone, G. (2020). *Assessment of Water Quality and Soil Salinity in the Agricultural Coastal Plain (Ravenna, North Italy).* Minerals, 10(4): 369. https://doi.org/10.3390/min10040369.

Terrestrial ecosystems

Aleffi, M., Tacchi, R., Poponessi, S. (2020). *New Checklist of the Bryophytes of Italy.* Cryptogamie, Bryologie 41 (13): 147-195. https://doi.org/10.5252/cryptogamie-bryologie2020v41a13

Bartolucci, F., Galasso, G., Peruzzi, L., Conti, F. (2021). *Report 2020 on plant biodiversity in Italy: native and alien vascular flora.* Natural History Sciences. Atti Soc. it. Nat. skiing Civil museum Stor. nat. Milan, 8 (1): 41-54, 2021. DOI: 10.4081/nhs.2021.520.

Cannone, N., Sgorbati, S., Guglielmin, M. (2007). *Unexpected impacts of climate change on alpine vegetation.* Frontiers in Ecology, 5, 360-364.

Cannone, N., Diolaiuti, G., Guglielmin, M., Smiraglia, C. (2008). *Accelerating climate change impacts on alpine glacier forefield ecosystems in the European Alps.* Ecological Applications, 18, 637-648.

Carbognani, M., Petraglia, A., Tomaselli, M. (2012). *Influence of snowmelt time on species richness, density and production in a late snowbed community.* Acta Oecologica, 43, 113-120.

Erschbamer, B., Unteluggauer, P., Winkler, E., Mallaun, M. (2011). *Changes in plant species diversity revealed by long-term monitoring on mountain summits in the Dolomites (northern Italy).* Preslia, 83, 387-401.

Hickling, R., Roy, D.B., Hill, J.K., Fox, R., Thomas, C.D. (2006). *The distributions of a wide range of taxonomic groups are expanding polewards.* Global Change Biology, 12, 450-455.

ISPRA (2022). *Environmental Data Yearbook 2021.*

Leonelli, G., Pelfini, M., Morra di Cella, U., Garavaglia, V. (2011). *Climate warming and the recent treeline shift in the European Alps: the role of geomorphological factors in high-altitude sites.* Ambio, 40, 264-273.

Parmesan, C., Yohe, G. (2003). *A globally coherent fingerprint of climate change impacts across natural systems.* Nature, 421, 37-42.

Tizzani P., Boano G., Mosso M., Pelazza M., Carolfi S., Ferra M., Marletta N., Pio G., Pellegrino I., Meneguz PG, Silvano F., Negri E., Spanò S. (2013). *Recent distribution of red-legged partridge Alectoris rufa in Piedmont (North Western Italy): signs of recent spreading.* Avocet 37: 83-86 (2013).

Pauli, H., Gottfried, M., Reiter, K., Klettner, C., Grabherr, G. (2007). *Signals of range expansions and contractions of vascular plants in the high Alps: observations (1994-2004) at the GLORIA master site Schrankogel, Tyrol, Austria.* Global Change Biology, 13, 147-156.

Reyer CPO, Leuzinger S, Rammig A, et al (2013). *A plant's perspective of extremes: terrestrial plant responses to changing climatic variability.* Glob Chang Biol 19:75–89. doi: 10.1111/gcb.12023.

Ugolotti M., Pasquarella C., Vitali P. et al (2015). *Characteristics and trends of selected pollen seasons recorded in Parma (Northern Italy) from 1994 to 2011.* Aerobiologia (Bologna) 31:341–352. doi: 10.1007/s10453-015-9368-4.

Alien species

Azzurro, E., Smeraldo, S. & D'Amen, M. (2022). Spatioÿtemporal dynamics of exotic fish species in the Mediterranean Sea: Over a century of invasion reconstructed. *Global Change Biology* 28.21: 6268-6279.

Corlett, R. T. & Westcott D. A. (2013). Will plant movements keep up with climate change? *Trends in Ecology & Evolution* 28.8: 482-488.

Essl, F., Lenzner, B., Bacher, S., Bailey, S., Capinha, C., Daehler, C., ... & RouraÿPascual, N. (2020). Drivers of future alien species impacts: An expertÿbased assessment. Global Change Biology, 26(9), 4880-4893.

Ferrario, J., Caronni, S., Occhipinti-Ambrogi, A. & Marchini, A. (2017). Role of commercial harbors and recreational marinas in the spread of non-indigenous fouling species, Biofouling, 33:8, 651-660, DOI: 10.1080/08927014.2017.1351958

Gould, E. A. & Higgs, S. (2009). Impact of climate change and other factors on emerging arbovirus diseases. *Trans R Soc Trop Med Hyg,* 130(2), 109-121.

Hellmann, J.J., Byers, J.E., Bierwagen, BG & Dukes, J.S. (2008), Five Potential Consequences of Climate Change for Invasive Species. Conservation Biology, 22: 534-543.

Hulme, P. E. (2017). Climate change and biological invasions: evidence, expectations, and response options. *Biological Reviews* 92.3: 1297-1313.

IUCN (2021). Invasive alien species and climate change. Issue Brief IUCN (International Union for Conservation of Nature) https://www.iucn.org/resources/issues-brief/invasive-alien-species-and-climate-change

Nascimbene, J., Benesperi, R., Casazza, G., Chiarucci, A. & Giordani, P. (2020). Range shifts of native and invasive trees exacerbate the impact of climate change on epiphyte distribution: The case of lung lichen and black locust in Italy. Science of The Total Environment, Volume 735, 139537, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2020.139537.

Negri, A., Arnoldi, I., Brilli, M., Bandi, C., Gabrieli, P., & Epis, S. (2021). Evidence for the spread of the alien species *Aedes koreicus* in the Lombardy region, Italy. Parasites & vectors, 14(1), 1-6.

Robinson, T. B., Martin, N., Loureiro, T. G., Matikinca, P., & Robertson, M. P. (2020). Double trouble: the implications of climate change for biological invasions.

Seebens, H., Bacher, S., Blackburn, T. M., Capinha, C., Dawson, W., Dullinger, S., ... & Essl, F. (2020). Projecting the continental accumulation of alien species through to 2050. Global Change Biology, 27(5), 970-982.

Seebens, H., Blackburn, T.M., Dyer, E.E., Genovesi, P., Hulme, P.E., Jeschke, J.M., Pagad, S., Pyšek, P., Winter, M., Arianoutsou, M., Bacher, S. , Blasius, B., Brundu, G., Capinha, C., Celesti-Grapow, L., Dawson, W., Dullinger, S., Fuentes, N., Jäger, H., … & Essl, F. (2017). No saturation in the accumulation of alien species worldwide. Nature Communications, 8, 14435. https://doi.org/10.1038/ncomms14435

Thuiller, W., Richardson, D. M. & Midgley, G. F. (2008). Will climate change promote alien plant invasions? In: Nentwig, W. (eds) Biological Invasions. Ecological Studies, vol 193. Springer, Berlin, Heidelberg, pages 197-211. https://doi.org/10.1007/978-3-540-36920-2_12.

Vilà, M., Corbin, J.D., Dukes, J.S , Pino, J. & Smith, S. D. (2007). Linking plant invasions to global environmental change. In Canadell, J., Pataki, D. & Pitelka L. (eds) Terrestrial ecosystems in a changing world. Springer Verlag, New York. Pages 93–102.

Forests

Bacciu V., Masala F., Spano D., Sirca C. (2014). *Trends and changes of fire danger in Italy and its relationships with fire activity (1985-2008).* In: Advances in forest fire research. Coimbra University Press, pp 1759–1768.

Bertini G., Amoriello T., Fabbio G., Piovosi M. (2011). *Forest growth and climate change: evidence from the ICP-Forests intensive monitoring in Italy.* iForest - Biogeosciences For 4:262–267. doi:

State Forestry Corps (2015). *Forest fires 2015,* summary data.

Jujube A., Kuster TM, Saha S. (2010). *Drought-induced mortality of Scots pines at the southern limits of its distribution in Europe: causes and consequences.* iForest - Biogeosciences For 3:95–97. doi: 10.3832/ ifor0542-003.

Lindner M., Maroschek M., Netherer S. et al (2010). *Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems.* For Ecol Manage 259:698–709. doi: 10.1016/j.foreco.2009.09.023.

Parolo G., Rossi G. (2008). *Upward migration of vascular plants following a climate warming trend in the Alps.* Basic Appl Ecol 9:100–107. doi: 10.1016/j.baae.2007.01.005.

Rodolfi A., Chiesi M., Tagliaferri G. et al (2007). *Assessment of forest GPP variations in central Italy.* Can J For Res Can Rech For 37:1944–1953. doi: Doi 10.1139/X07-010.

Sabaté S., Gracia CA, Sánchez A. (2002). *Similar effects of climate change on growth of Quercus ilex, Pinus halepensis, Pinus pinaster, Pinus sylvestris and Fagus sylvatica forests in the Mediterranean region.* For Ecol Manage 162:23–37. doi: 10.1016/s0378-1127(02)00048-8.

Schmuck G., San-Miguel-Ayanz J., Durrant T. et al (2015). *Forest Fires in Europe, Middle East and North Africa 2014.* Publications Office of the European Union.

Agriculture and food production

Boere, E., Valin, H., Bodirsky, B. Baier, F., Balkovic, J., Batka, M., Folberth, C., Karstens, K., Kindermann, G., Krasovskii, A., Leclere , D., Wang, X., Weindl, I., Havlik, P., Lotze-Campen, H. (2019). *D2.2 Impacts on agriculture including forestry & fishery.* Deliverable of the H2020 COACCH project.

Bozzola, M., Massetti, E., Mendelsohn R., and Capitanio F. (2018). *A Ricardian analysis of the impact of climate change on Italian agriculture.* European Review of Agricultural Economics 45(1): 57-79. https://doi.org/10.1093/erae/jbx023.

Domínguez, I. and Fellmann, T. (2018). *PESETA III: Agro-economic analysis of climate change impacts in Europe Final Report.* 10.2760/179780.

European Environment Agency (EEA) (2016). *Climate change impacts and vulnerability in Europe 2016: An indicator-based report.* Luxemberg. doi: 10.2800/534806.

Foundation for Sustainable Development (2019). *Report on the state of the green economy 2019: focus on the economic impacts of climate change in Italy,* available online from: http:// italyforclimate.org/wp- content/ uploads/2019/12/Relazione_sullo_stato_della_green_economy_2019.pd

Hristov J., Toreti A., Pérez Domínguez I., Dentener F., Fellmann T., Elleby C., Ceglar A., Fumagalli D., Niemeyer S., Cerrani I., Panarello L., Bratu M. (2020). *Analysis of climate change impacts on EU* *agriculture by 2050,* EUR 30078EN, Publications Office of the European Union, Luxembourg. ISBN 978-92-7610617-3, doi:10.2760/121115, JRC119632.

Kipling RP, Bannink A, Bellocchi G, et al (2016). *Modeling European ruminant production systems: Facing the challenges of climate change.* Agric. Syst. 147:24–37.

Lobell DB, Field CB (2007). *Global scale climate-crop yield relationships and the impacts of recent warming.* Environ Res Lett 2: . doi: 10.1088/1748-9326/2/1/014002.

Lobell DB, Schlenker W, Costa-Roberts J (2011). *Climate trends and global crop production since 1980.* Science 333:616–620. doi: 10.1126/science.1204531.

McCallum, S., Dworak, T., Prutsch, A., Kent, N., Mysiak, J., Bosello, F., Klostermann, J., Dlugolecki, A., Williams, E., Konig, M., Leitner, M., Miller, K., Harley, M., Smithers, R., Berglund, M., Glas, N., Romanovska, L., van de Sandt, K., Bachschmidt, R., Voller, S ., Horrocks, L. (2013). *Support to the development of the EU Strategy for Adaptation to Climate Change: Background to the Impact Assessment, Part I - Problem definition, policy context and assessment of policy options.* Environment Agency Austria, Vienna.

MIMS (2022). *Climate change, infrastructure and mobility.*

Moriondo M, Jones G V., Bois B, et al (2013a). *Projected shifts of wine regions in response to climate change.* Clim Change 119:825–839. doi: 10.1007/s10584-013-0739-y.

Moriondo M, Trombi G, Ferrise R, et al (2013b). *Olive trees as bio-indicators of climate evolution in the Mediterranean Basin.* Glob Ecol Biogeogr 22:818–833. doi: 10.1111/geb.12061.

Notenbaert AMO, Cardoso JA, Chirinda N, et al (2017). *Climate change impacts on livestock and implications for adaptation: Climate impacts on land use, food production and productivity session.* Rome.

MATTM (2017). *National Plan for Adaptation to Climate Change,* version for verifying eligibility for SEA. Ministry of the Environment and Protection of Land and Sea.

Qian B, Zhang X, Chen K, et al (2010). *Observed long-term trends for agroclimatic conditions in Canada.* J Appl Meteorol Climatol 49:604–618. doi: 10.1175/2009JAMC2275.1.

Ronchi, E. (ed.) (2019). *Report on the state of the green economy 2019, focus on the impacts of climate change in Italy,* Foundation for Sustainable Development REPORT.

SNPA, 2021. *Climate Change Impact Indicators Report* – 2021 Edition. SNPA Report 21/2021 – ISBN: 978-88-448-1058-0.

Trnka M, Olesen JE, Kersebaum KC, Skjelvåg AO, Eitzinger J, Seguin B, et al. (2011). *Agroclimatic conditions in Europe under climate change.* Globe. Change Biol. 17, pp. 2298-2318.

Van Passel, S., Massetti, E., Mendelsohn R. (2017). *A Ricardian analysis of the impact of climate change on the European agriculture.* Environmental and Resource Economics, 67: 725-760.

Sea fishing

Ben Rais Lasram, F., Guilhaumon, F., Albouy, C., Somot, S., Thuiller, W., & Mouillot, D. (2010). *The Mediterranean Sea as a 'cul-de-sac' for endemic fishes facing climate change.* Global Change Biology, 16(12), 3233–3245. https://doi.org/10.1111/j.1365-2486.2010.02224.x.

Cheung, W. W. L., Lam, V. W. Y., Sarmiento, J. L., Kearney, K., Watson, R., Zeller, D., & Pauly, D. (2010). *Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change.* Global Change Biology, 16(1), 24–35. https://doi.org/10.1111/j.1365-2486.2009.01995.x.

Darnaude, A.M., Salen-Picard, C., Polunin, N.V.C., et al. (2004). *Trophodynamic linkage between river runoff and coastal fishery yield elucidated by stable isotope data in the Gulf of Lions (NW Mediterranean).* Oecologia 138, 325–332 (2004). https://doi.org/10.1007/s00442-003-1457-3.

Hidalgo, M., El-Haweet, AE, Tsikliras, AC, Tirasin, EM, Fortibuoni, T., Ronchi, F., Lauria, V., Ben Abdallah, O., Arneri, E., Ceriola, L., Milone, N., Lelli, S., Hernández, P., Bernal, M., & Vasconcellos, M. (2022). *Risks and adaptation options for the Mediterranean fisheries in the face of multiple climate change drivers and impacts.* ICES Journal of Marine Science, October. https://doi.org/10.1093/icesjms/fsac185.

ISPRA (2022). *Environmental Data Yearbook 2021.*

Patti, B., Fiorentino, F., Fortibuoni, T., Somarakis, S., & García-Lafuente, J. (2022). Editorial: *Impacts of environmental variability related to climate change on biological resources in the Mediterranean.* Frontiers in Marine Science, 9(October), 1–4. https://doi.org/10.3389/fmars.2022.1059424.

Rivetti I, Fraschetti S, Lionello P, et al (2014). *Global Warming and Mass Mortalities of Benthic Invertebrates in the Mediterranean Sea.* PLoS One 9:e115655. doi: 10.1371/journal.pone.0115655.

Tsikliras, A. C., & Stergiou, K. I. (2014). *Mean temperature of the catch increases quickly in the Mediterranean Sea.* Marine Ecology Progress Series, 515, 281–284. https://doi.org/10.3354/meps11005.

Aquaculture

Castellari S, Venturini S, Ballarin Denti A, et al (2014a). *Report on the state of scientific knowledge on impacts, vulnerability and adaptation to climate change in Italy.* Ministry of the Environment and Protection of Land and Sea, Rome.

Falconer, *Impact of climate change on farm-level aquaculture production and carrying capacity.*

IPCC (2014). *Fifth Assessment Report on Climate Change,* Working Group II, Assessment Report V.

Tourism

Abegg B., Agrawala S., Crick F., De Montfalcon A. (2007). *Climate change impacts and adaptations in winter tourism. In: S. Agrawala (ed) Climate change in the European Alps: Adapting winter tourism and natural hazard management.* OECD Publishing, Paris, pp 25–60.

Foundation for Sustainable Development (2019). *Report on the state of the green economy 2019: focus on the economic impacts of climate change in Italy,* available online from: http://italyforclimate.org/wp- content/uploads/2019/12/Relazione_sullo_stato_della_green_economy_2019.pd

McCallum, S., Dworak, T., Prutsch, A., Kent, N., Mysiak, J., Bosello, F., Klostermann, J., Dlugolecki, A., Williams, E., Konig, M., Leitner, M., Miller, K., Harley, M., Smithers, R., Berglund, M., Glas, N., Romanovska, L., van de Sandt, K., Bachschmidt, R., Voller, S ., Horrocks, L. (2013). *Support to the development of the EU Strategy for Adaptation to Climate Change: Background to the Impact Assessment, Part I - Problem definition, policy context and assessment of policy options.* Environment Agency Austria, Vienna.

Ronchi, E. (ed.) (2019). *Report on the state of the green economy 2019, focus on the impacts of climate change in Italy,* Foundation for Sustainable Development REPORT.

Spano D., Mereu V., Bacciu V., Marras S., Trabucco A., Adinolfi M., Barbato G., Bosello F., Breil M., Chiriacò MV, Coppini G., Essenfelder A., Galluccio G. , Lovato T., Marzi S., Masina S., Mercogliano P., Mysiak J., Noce S., Pal J., Reder A., Rianna G., Rizzo A., Santini M., Sini E., Staccione A., Villani V., Zavatarelli M., (2020). *Risk analysis. Climate changes in Italy.* DOI: 10.25424/CMCC/ANALISI_DEL_RISCHIO.

WTCC (2021). *Italy 2021, Annual Research, Key Highlights,* available at: https://wttc.org/Research/Economic-Impact.

Urban settlements

Berti D., Lucarini M. (2021). *Alluvial and inundation events in urban environments: a possible indicator for analyzing the effects of climate change on the ground.* Environmental Geology, n. 3/2021.

Conti S. et al. (2005). *Epidemiological study of mortality during the Summer 2003 heat wave in Italy,* Environmental Research, 98(3), pp. 390–399, doi: 10.1016/j.envres.2004.10.009.

Ministry of Health and DEP Lazio (2022). *Results of the alarm systems (HHWWS), the Daily Mortality Surveillance System (SISMG) and emergency room (ED) accesses* - Report 16 May-15 July 2022.

Sanchez Martinez G. et al. (2016). *Projected heat-related mortality under climate change in the metropolitan area of Skopje.* BMC public health, 16, 407, doi:10.1186/s12889-016-3077-y.

SNPA (2021). *Climate Change Impact Indicators Report* – 2021 Edition. SNPA Report 21/2021 – ISBN: 978-88-448-1058-0.

SNPA (2022). *Cities in transition: Italian capitals towards environmental sustainability.* SNPA Report n. 30/2022 – ISBN 978-88-448-1121-1.

Ministry of Health website, 2022.

Consorzio Venezia Nuova website, 2022.

Transport and infrastructure

Burbidge, R. (2016). *Adapting European Airports to a Changing Climate.* Transp. Res. Procedia 14, 14-23.

ENAC (2014). *Criteria for evaluating the surface conditions of a runway.* ENAC http://www.enac.gov.it/la-normativa/normativa-enac/circolari/serie-apt/apt-10b.

Ferranti, E. et al. (2016). *Heat-Related Failures on Southeast England's Railway Network: Insights and Implications for Heat Risk Management.* Weather Clim. Soc. 8, 177-191.

Fraser, A. M., Chester, M. V., & Underwood, B. S. (2020). *Wildfire risk, post-fire debris flows, and transportation infrastructure vulnerability.* Sustain. Resilient Infrastructure. 0, 1-13.

Ligteringen, H. (1999). *Ports and Terminals.* Lect. Notes CTwa4330.

MIMS (2022). *Climate change, infrastructure and mobility.*

Nemry, F., & Demirel, H. (2012). *Impacts of climate change on transport: a focus on road and rail transport infrastructures.* Publications Office of the European Union, 2012.

Puempel, H., & Williams, P. D. (2016). *The impacts of climate change on aviation: scientific challenges and adaptation pathways.*

UNECE (2020). *Climate Change Impacts and Adaptation for International Transport Networks.*

UNECE website https://unece.org/transport/publications/climate-change-impacts-and-adaptation-international-transport-networks-0

Dangerous industries and infrastructures

MIMS (2022). *Climate change, infrastructure and mobility.*

MATTM (2017). *National Plan for Adaptation to Climate Change,* version for verifying eligibility for SEA. Ministry of the Environment and Protection of Land and Sea.

INAIL website, 2022.

Cultural heritage

ISPRA, 2021. *Report on flood hazard conditions in Italy and associated risk indicators.*
Report 353/2021. ISBN: 978-88-448-1080-1.

ISPRA (2021). *Hydrogeological instability in Italy: hazards and risk indicators* - 2021 Edition.
Report 356/2021. ISBN: 978-88-448-1085-6.

WebGis RAPTOR – geodatabase that lists national archaeological sites www.raptor.beniculturali.it.

Sites of Regional Landscape Plans and Regional Territorial Plans with landscape value; Territorial, Environmental and Landscape Information System – SITAP: http://sitap.beniculturali.it/.

Risk Map – ICR: http://vincoliinrete.beniculturali.it/vir/vir/vir.html.

ISPRA (2022). *Environmental Data Yearbook 2021.*

SICaR – Information System for the documentation and planning of restoration sites http://www.sicar.beniculturali.it.

Italian UNESCO Sites and related Management Plans.

National Strategic Plan of the National Rural Network, https://www.reterurale.it/PAC_2023_27/PianoStrategicoNazionale.

National Register of Historic Rural Landscapes website, https://www.reterurale.it/registropaesaggi.

Power

MATTM, 2015. *National Strategy for Adaptation to Climate Change.*

MIMS (2022). *Climate change, infrastructure and mobility.*

MATTM (2017). *National Plan for Adaptation to Climate Change,* version for verifying eligibility for SEA. Ministry of the Environment and Protection of Land and Sea.

SNPA, 2021. *Climate Change Impact Indicators Report* – 2021 Edition. SNPA Report 21/2021 – ISBN: 978-88-448-1058-0.

TERNA SpA, *Statistical data on electricity in Italy,* various years.

Health

Forzieri, G., Cescatti, A., Silva, F.B., & Feyen, L. *Increasing risk over time of weather-related hazards to the European population: a data-driven prognostic study.* Lancet Planet. Health 1, e200-e208 (2017).

Lelieveld, J., Evans, J. S., Fnais, M., Giannadaki, D. & Pozzer, A. (2015). *The contribution of outdoor air pollution sources to premature mortality on a global scale.* Nature 525, 367–371.

Lim, S.S. et al. (2012). *A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010.* Lancet Lond. Engl. 380, 2224-2260.

Martínez-Solanas, È., Quijal-Zamorano, M., Achebak, H., Petrova, D., Robine, J.M., Herrmann, F.R., ... & Ballester, J. (2021). *Projections of temperature-attributable mortality in Europe: a time series analysis of 147 contiguous regions in 16 countries.* The Lancet Planetary Health, 5(7), e446-e454.

Ministry of Health and DEP Lazio (2022). *Results of the alarm systems (HHWWS), the Daily Mortality Surveillance System (SISMG) and emergency room (ED) accesses* - Report 16 May-15 July 2022.

Naumann G., Russo S.(a), Formetta G.(b), Ibarreta D., Forzieri G., Girardello M., and Feyen L., (2020). *Global warming and human impacts of heat and cold extremes in the EU,* EUR 29959 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92- 76-12954-7, doi:10.2760/47878, JRC118540.

Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Beagley, J., Belesova, K., ... & Costello, A. (2021). *The 2020 report of the Lancet Countdown on health and climate change: responding to converging crises.* The Lancet, 397(10269), 129-170.

WHO (2018). *Climate and health country profile: Italy.* Available at https://apps.who.int/iris/bitstream/handle/10665/260380/WHO-FWC-PHE-EPE-15.52-eng.pdf?sequence=1&isAllowed=y.