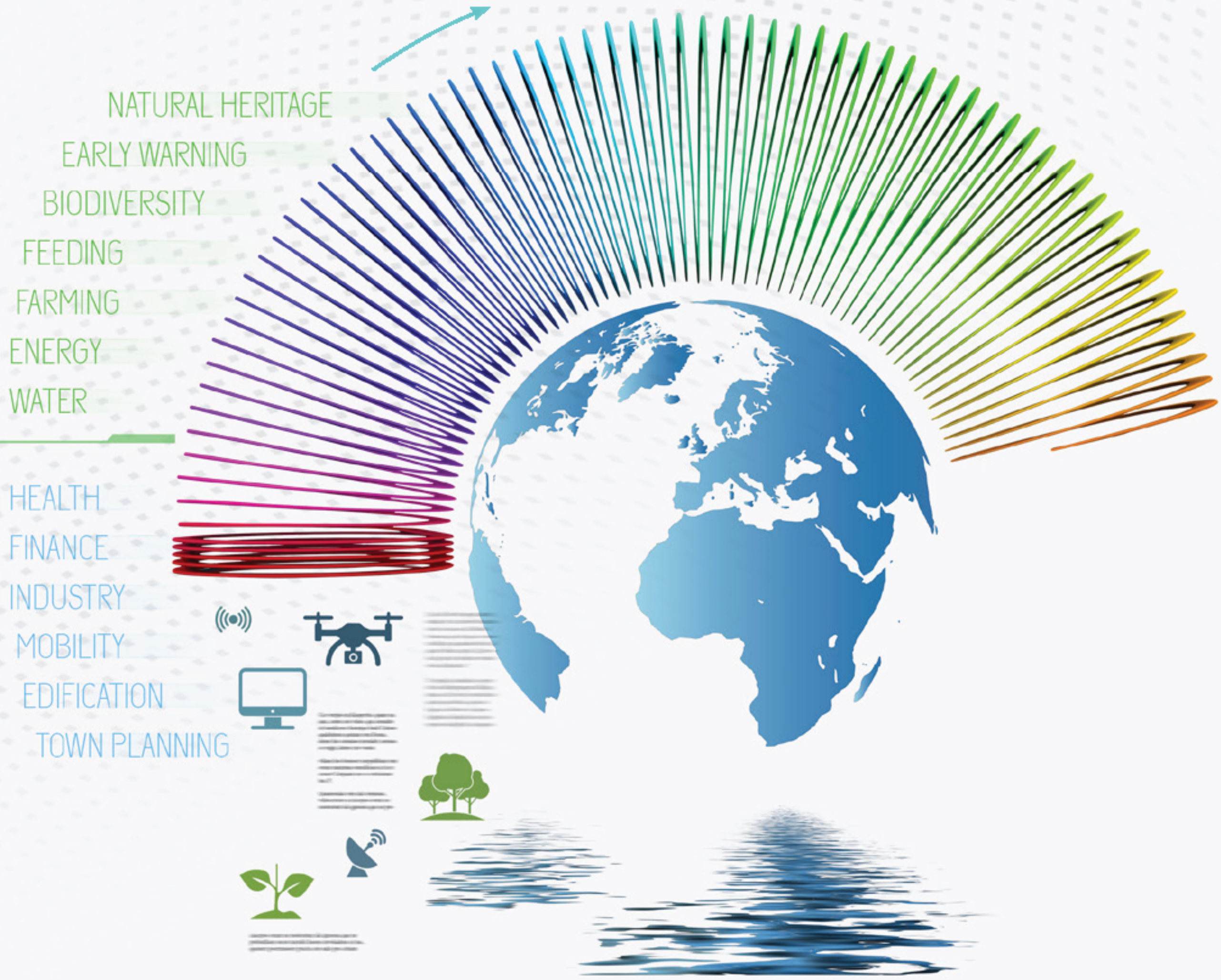
UN WATER
22 MARCH
WORLD WATER DAY



Identifying innovative climate change adaptation technologies and solutions

ENVIRONMENTAL STUDY | 2022

Canal de Isabel II

FUNDACIÓN CANAL
Canal de Isabel II

1 Executive summary

With the aim of disseminating knowledge that promotes and facilitates adaptation to climate change, the Eurecat Foundation, commissioned and supervised by Fundación Canal and with the additional supervision of the R&D&I sub-directorate of Canal de Isabel II, has collected, selected and characterized a set of innovative climate change adaptation solutions for multisectoral application and relevant for the Madrid region.

After a thorough review of different databases of national and international initiatives for adaptation to climate change and related scientific literature and sectoral reports, 127 innovative and relevant solutions in the context of adaptation to climate change have been identified. The inventory of 127 solutions covers all the sectors studied: water, agriculture and livestock, health, urban planning and buildings, early warning, biodiversity and natural heritage, industry and services, transport and mobility, finance and insurance, tourism and cultural heritage.

Regarding the type of solutions, in this inventory, the following have been established or considered:

i) Nature based solutions (NBS)[1], such as rain gardens or plant walls.

ii) Information technologies, such as early warning systems for flooding or the spread of arboviral diseases.

iii) Technological solutions, such as agrivoltaics or the use of drones for the early detection of the risk of landslides.

iv) Specific technologies, such as the biosolar leaf or drones for fire prevention.

v) Management strategies, such as the use of prevention funds to mitigate the effect of flooding.

This set of solutions is a sign of the diversity of resources available to meet the challenge of adaptation to climate change in virtually all sectors. Most of the solutions identified contribute to adaptation to the effects produced by rising temperatures, increased intensity and frequency of floods and increased water stress. These are three of the main risks to which the Spanish peninsular interior is subjected. In this way, we must highlight the role of water, and the associated economic sector, as the main affected by climate change and the backbone of a large part of adaptation solutions. Many of the solutions applicable to the water sector, such as the construction of artificial wetlands, the installation of urban drainage systems or the reuse of water for street cleaning, have a direct effect not only on water saving, but also on urban planning, biodiversity in urban areas and even the insurance sector. Similarly, more than half of the solutions identified for adaptation to climate change in other sectors are related to water or involve better water management. Once again, the intersectoral role of water sector in the adaptation to climate change area is confirmed.

Of the 127 solutions identified, 54 have been selected for their relevance in an intersectoral context of adaptation to climate change, and many of them applicable to the Madrid region. This selection has been possible thanks to the application of an indicator of relevance for adaptation to climate change, fed with the criteria of an external group of experts, and the own criteria of the experts of Fundación Canal and Canal de Isabel II. This indicator has considered factors such as the potential for adaptation, its applicability in multiple sectors and the levels of innovation and maturity of each solution. From each of the 54 outstanding solutions, a technical sheet has been generated to extend the information provided, help the

[1] Nature-based solutions are those that are inspired and supported by nature, that are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more and more diverse nature and natural features and processes to cities, land and seascapes, through locally adapted, resource-efficient and systemic interventions. (European Commission).

reader to evaluate the solution for a possible implementation and guide him to sources where to expand knowledge about it. Each sheet includes a description of the solution and its operation, an evaluation of the applicability of the solution, an estimate of an order of magnitude of the associated costs, and provides examples of its application in real cases.

Some of the featured solutions are:

- In the field of early warning, systems for the detection of floods, extreme rainfall or landslides stand out, whose implementation is essential to prevent potential human or infrastructure losses due to the increase in extreme weather events. Also, infectious disease detection systems.
- In the water sector, the use of regenerated water for compatible uses (street washing, industrial use, irrigation of green areas) stands out, as well as nature-based solutions designed to improve water management in urban areas, such as rain gardens or artificial wetlands for the treatment of excess runoff.
- Regarding the health sector, the use of models and monitoring systems for the prediction of conditions derived from climate change that may affect health, such as extreme temperatures, high pollution or arbovirus outbreaks, stands out.
- In the agricultural sector, the technification of the sector stands out, with the compatibility of agricultural land use with energy production, as is the case of agrovoltaic systems, or smart agriculture, which combines sensors, data processing and decision support systems to increase crop productivity.
- In the urban and building sector, water management solutions stand out, such as the implementation of draining pavements and the generation of floodable urban spaces, as well as the adaptation of buildings to the increase in temperatures, with the implementation of insulating panels made of mycelium or the installation of passive cooling systems such as wind collection towers.

In general, solutions that value traditional strategies stand out, especially in the field of building, agriculture and the conservation of natural heritage; the use of information technologies and predictive models, especially in the context of early warning and improved decision-making; as well as the implementation of new technologies that are increasingly accessible, such as the use of drones or low-cost sensors.

With this publication, Fundación Canal provides a document of dissemination and consultation for local and regional administrations, water operators and other entities linked to the integral water cycle, and, in general, for companies and individuals interested in discovering innovative solutions for adaptation to climate change.

It is not the purpose of this document to give an exhaustive vision of the proposed solutions, but rather an overview of the multiple options already available in the market and provide the necessary information so that the reader can delve into those of greatest interest according to their needs, facilitating the reader to take part in the challenge of adapting to the inevitable effects that climate change poses for our society.

2 Introduction

The effects of climate change are increasingly evident, and its trend is increasing even in the most optimistic scenarios of emission reductions. The Intergovernmental Panel on Climate Change (IPCC) estimates that the global increase scenarios of 1.5ºC and 2ºC will be exceeded during the twenty-first century, unless there are deep reductions in CO_2 emissions and other greenhouse gas emissions, this increase being generally greater in continental areas[2]. This seemingly small increase in global temperature is generating, among others, an increase on a planetary scale in the frequency and magnitude of extreme weather events such as heat waves, droughts and torrential rains; sea level rise of between 0.28 and 0.76 m over the twenty-first century; and the reduction of biodiversity, among many others.

In Spain the increase in maximum temperatures is expected to be even greater, between 2ºC and 6.4ºC, this increase being greater in the interior and lower in the north and northwest of the peninsula[3]. This will result in an increase in the frequency and duration of heat waves. In addition, rainfall is expected to decrease across the board. The increase in temperatures and decreased rainfall will result in an increase in the frequency and duration of droughts, a decrease in the recharge of aquifers and the flow of rivers, which will directly affect the availability of water resources. Water is the vector of transmission of a whole cascade of impacts that affect every area of human and natural systems[4].

The report of the Ministry for the Ecological Transition and the Demographic Challenge of 2021 on "Impacts and risks derived from climate change in Spain" analyses the most important impacts that the environment, society and practically all sectors of our economy will suffer.

Regarding the impact of climate change on nature, in terrestrial ecosystems tree species will see their cycles of leaf fall and flowering altered, and their spatial distribution will change to adapt to the new conditions of temperature and availability of water resources. On the other hand, the increase in forest fires will also reduce the extent of forests and expose the soil to further erosion. In marine ecosystems, on the other hand, changes in the distribution of species of marine fauna and flora are already observed, and a decrease in fishing potential.

The different sectors of the economy in our country will also be affected. On the one hand, the agricultural sector will suffer first-hand changes in rainfall and temperature patterns. There will be a decline in agricultural production, especially rainfed, herbaceous and woody. The energy sector will also suffer the effects of climate change, especially the production of hydroelectric energy that will be limited by the lower water supply of rivers. Torrential rainfall, which generates a higher incidence of landslides, will directly impact transport infrastructure. On the other hand, tourism can also be affected. In coastal areas, sea level rise will affect coastal populations, where flooding will increase in frequency and intensity. In addition, the increase in heat waves in the southern peninsular area can change the preferences of tourists regarding the destination or the season. On the other hand, in the winter sports sector, the increase in snow levels will affect ski resorts, which will see the management of the ski area compromised by the lower rainfall in the form of snow and the difficulty of its maintenance.

Climate change also poses a risk to public health. In Spain, high temperatures and floods are the risks derived from climate change that put our health at risk the most. Another emerging risk is the rise of vector-borne diseases such as ticks and mosquitoes.

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[2] IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. In Press.

[3] MITECO (2021). *Impactos y riesgos derivados del cambio climático en España*.

[4] United Nations. (2010). Climate Change Adaptation: The Pivotal Role of Water. *Ginebra, Suiza*, *01*, 18.

The set and complexity of negative effects derived from climate change, as well as its negative trend even in the best scenarios, makes adaptation to these inescapable risks necessary to prevent the deterioration of our society, environment and productive systems during the coming decades. This is contemplated by the "National Plan for Adaptation to Climate Change 2021 – 2030" (PNACC)[5], which defines adaptation to climate change as "the need to adjust to the current or expected climate and its effects". According to the PNACC, adaptation should include a set of strategies aimed at avoiding or reducing the potential impacts of climate change, as well as promoting better preparedness for recovery after damage.

Adaptation to climate change is not only a great necessity, but also a great challenge. On the part of the institutions, the prioritization in the types of actions to minimize costs guaranteeing the maximum effectiveness of the measures implemented, is not an easy task to address. Information and studies are needed to assess the costs of actions and synergies between sectors and adaptation actions. In addition to the need to implement coordinated strategies by institutions, adaptation must also be addressed by citizens. This requires awareness-raising, dissemination and knowledge transfer on adaptation measures.

Adaptation to climate change requires innovative and effective solutions. In the last 20 years, the number of technological patents related to adaptation to climate change has increased steadily. However, almost 50% of this development is concentrated in the United States, Japan and Germany[6]. For this reason, it is necessary in Spain a work of dissemination and transfer of innovative technologies for adaptation.

Fundación Canal´s mission is to improve opportunities for access to knowledge related to the environment and innovation, one of its main objectives being the dissemination of solutions to climate change, considering water its central axis. One of the tools that Fundación Canal must facilitate the dissemination and transfer of knowledge is the generation of scientific-technical publications.

In this context, the Fundación Canal published in February 2021 a tender for the contracting of "Identification Services of innovative technologies and solutions for adaptation to climate change", with the aim of "pushing for action" in terms of adaptation to climate change. The tender emphasizes the need to optimize the investment that will be necessary to adapt to the inescapable effects of climate change. To invest resources optimally and maximize adaptation, it is necessary to have up-to-date and contrasted information on the available climate change adaptation solutions, their effectiveness and applicability.

Thus, the main objective of this publication is the dissemination of knowledge that facilitates better adaptation to the inevitable impacts of climate change, promoting a more climate-resilient society. To this end, this document contains a compilation and characterization of innovative climate change adaptation solutions applicable to different sectors:

- Water
- Agriculture and livestock
- Health
- Urban planning and building
- Early warning
- Biodiversity and natural heritage
- Industry and services

[5] MITECO. (2021). Plan nacional de adaptación al cambio climático 2021 - 2030.

[6] Echezleprêtre, A., Fankhauser, S., J, M. G., & Simon, S. (2020). Invention and Global Diffusion of Technologies for Climate Change Adaptation: A Patent Analysis. *International Bank for Reconstruction and Development / The World Bank*.

- Transport and mobility
- Finance and insurance
- Tourism and cultural heritage

The study that has resulted in this compilation has been divided into two phases, also reflected in the structure of the document.

- The first phase consisted of the exhaustive identification of innovative, immediate, and systemic climate change adaptation solutions. The result of this first phase is an inventory of climate change adaptation solutions, which offers a global and multisectoral vision of the state of innovation in adaptation to climate change, and the typology of solutions available.
- In a second phase, and with the help of experts in each of the sectors, all the identified solutions have been evaluated, selecting those that, due to their level of technological maturity, effectiveness and level of impact, have been considered of great relevance for adaptation to climate change in the context of the Madrid region. For each of the selected solutions, technical sheets have been generated with relevant information for their knowledge and implementation.

3 Diagnostic

3.1 Methodology

The first phase of the study consisted of the comprehensive identification of climate change adaptation solutions by a multidisciplinary group of experts. This group of experts is made up of 11 researchers with high competence (a brief biography of each one is included in the Annex 5.2) in research and dissemination of projects in the field of adaptation and mitigation of climate change:

- Aitor Corchero Rodríguez
- Dr. Carles Ibáñez Martí
- Dr. Carmen Torres Costa
- Eloy Hernández Busto
- Irene Ràfols Ribas
- Dr. Laura del Val Alonso
- Mireia Pla Castellana
- Nil Álvarez Segura
- Dr. Queralt Plana Puig
- Prof. Xavier Rodo
- Dr. Xavier Martínez Lladó

Likewise, the Canal de Isabel II and Fundación Canal teams have provided technical advice both in the identification phase of innovative solutions and in the subsequent development of them and carried out editing work until obtaining this report.

During the study, data sources of different nature were consulted: databases of R&D projects, sectoral reports, scientific literature and generalist publications, considering only the solutions that met a series of pre-established requirements.

Hereinunder are some of the sources of information consulted that collect solutions and technologies for adaptation to climate change under the framework of different international initiatives.

Responsible organization	**Initiative**	**Description**
EEA - European Environment Agency	[Climate-ADAPT - European Climate Adaptation Platform]()	Climate-ADAPT is a database on projects, agents, initiatives, organizations, publications and tools related to adaptation to climate change.
EPA – Environmental Protection Agency	[Centro de Recursos para la Adaptación (ARC-X)]()	EPA's Adaptation Resource Center (ARC-X) is an interactive resource to help local governments deliver services effectively under the effects of climate change. Decision makers can create an integrated

Responsible organization	Initiative	Description
		package of information tailored specifically to their needs.
United Nations Environmental Programme. United Nations Industrial Development Organization.	*UN Climate Technology Centre & Network*	The CTCN, hosted by the United Nations Environment Programme and the United Nations Industrial Development Organization (UNIDO), is the centre promoting the accelerated transfer of technologies for low-carbon and climate-resilient development at the request of developing countries.
Adaptation Fund	*Adaptation Fund projects database*	The Adaptation Fund finances projects and programmes that help vulnerable communities in developing countries adapt to climate change. On its website, it provides an inventory of adaptation projects and initiatives funded by the fund around the world.
GCF - Green Climate Fund	*Inventory of climate change adaptation projects*	The GCF is the world's largest fund dedicated to helping combat climate change. In its project database, fund-funded adaptation initiatives can be found around the world.
GEF - Global Environmental Facility	*GeF Project Inventory*	The Global Environment Facility was created on the eve of the Rio Earth Summit (1992) to address our planet's most pressing environmental problems. Since then, it has provided more than $21.7 billion in grants and mobilized another $119 billion in co-financing for more than 5,000 projects and programs.
German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety	*IKI – International Climate Initiative*	The IKI project map provides access to all climate change adaptation projects funded by this initiative in the world.
German International Cooperation Agency (GIZ) International Union for Conservation of Nature (IUCN)	*PANORAMA - Ecosystem-based adaptation solutions database*	PANORAMA - Solutions for a Healthy Planet is a collaborative initiative to document and promote examples of inspiring and reproducible solutions on a range of conservation and sustainable development issues, enabling cross-sectoral learning and inspiration. Through its database you can find initiatives and projects to adapt to climate change.
European Commission	*OPPLA - EU Repository of Nature-Based Solutions*	Oppla is the European repository of nature-based solutions. More than 60 universities, research institutes, organizations and companies contribute to Oppla within the framework of a joint activity of the OPERAs and OpenNESS projects, funded by the FP7 Program of the European Commission.
CDP - Disclosure Insight Action	Database of states, private companies and cities implementing climate change adaptation actions	CDP is a non-profit charity that manages a global disclosure system on climate change adaptation actions, for investors, businesses, cities, states and regions to manage their environmental impact.

Responsible organization	Initiative	Description
Naturvation - NATure-based URban innoVATION	*Urban Nature Atlas*	Inventory with more than 1,000 nature-based solutions from European cities and other countries.
Oxford University	*Nature based solutions Initiative - case studies*	The Nature-Based Solutions Initiative is comprised of an international, interdisciplinary team of natural and social scientists, seeking to apply impactful research to shape the policy and practice of nature-based solutions through research, teaching, and engagement with policymakers and practitioners. The case study inventory offers examples of climate change adaptation solutions in different parts of the world.
Columbia University	Urban Climate Change Research Network - UCCRN Case Study Database	The Urban Climate Change Research Network (UCCRN) is a global consortium of more than 1,000 people from more than 150 cities dedicated to the analysis of climate change mitigation and adaptation from an urban perspective. The database of case studies shows evidence of what many cities around the world are doing to mitigate and adapt to climate change.
Ministry for the Ecological Transition and the Demographic Challenge (MITECO)	AdapteCCa - Climate Change Adaptation Platform in Spain	Inventory of practical cases of adaptation to climate change in Spain.
Madrid City Council	Proposed solutions for adaptation to climate change	Database of solutions proposed by the Madrid City Council for adaptation to climate change.
AEAS - Spanish Association of Water Supply and Sanitation	Online Archive	The Spanish Association of Water Supply and Sanitation (AEAS) is the professional association of reference in the urban water sector in Spain. On its website you can find industry reports and inventory of innovative solutions in the field of water supply and sanitation, many of them in line with adaptation to climate change.

During the review of the different sources of information, a series of criteria have been used to decide if a solution/technology was relevant to the study, and therefore to be considered in the inventory of identified solutions. The criteria are as follows:

- The solutions/technologies for adaptation to climate change considered must have a high level of technological development that allows their implementation as immediately as possible.
- Solutions/technologies must be innovative.
- The solutions/technologies must be, as far as possible, applicable and relevant in the context of the Madrid region.

In addition to the criteria for the selection of each solution individually, the inventory resulting from this review work must meet two other requirements:

- The resulting inventory should be representative of the main sets of climate change adaptation solutions for each of the sectors.
- The inventory should consider different types of solutions for each sector. Thus, we have defined five types of solutions: Nature-based solutions, technological solutions, concrete technologies, IT solutions and governance strategies or solutions.

The set of identified solutions has been compiled in an inventory in which basic information about each of them has been included. This information includes:

- Sectors for which the solution is relevant.
- Typology of the solution.
- Effects of climate change that it would help us adapt to.
- Country or countries where it has been developed or tested.
- Basic description of its operation.
- Estimate of order of magnitude of costs.
- Relevance with respect to adaptation to climate change.
- Description of its level of innovation.
- Sources consulted.

3.2 Technologies and solutions

As a result of the review of databases and literature, 127 climate change adaptation solutions have been identified (Annex 5.1).

Each of the solutions has been associated with a major sector or area of knowledge, however, most of them are applicable to several. Given that priority has been given to the identification of solutions applicable to the water, agriculture and livestock, early warning, health, and urban planning and building sectors, 75% of the solutions identified belong to these sectors.

Another important fact, to understand the multisectoral characteristics of the solutions, are the sectors that have been identified as secondary for each solution. These are sectors that are affected (positively) or involved in the implementation of the solution, directly or indirectly. The secondary sectors that are most repeated are, firstly, water and secondly that of urban planning and building. This implies that most of the adaptation solutions identified are applicable to or involve water management. The same goes for the urban and building sector. Both sectors are strategic for cross-sectoral adaptation to climate change.

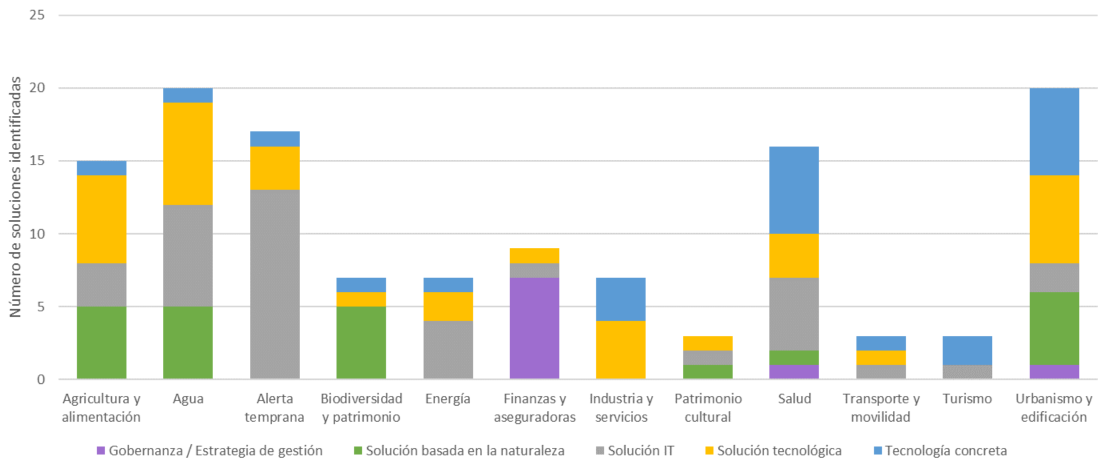

Figure 1. Number of climate change adaptation solutions identified by sector and typology. (Source: own elaboration).

The identified solutions have also been classified according to their typology (Figure 1). In this way, five types of solutions have been identified:

- Nature-based solutions: are those that are inspired and supported by nature, generating and / or improving the environmental services provided by the ecosystem, being both profitable and simultaneously providing environmental, social and economic benefits, helping to create resilience.
- IT Solutions: These are those that apply Information Technology (IT) and communication to store, retrieve, transmit and manipulate data.
- Technological solutions: set of technologies that in a combined way favour the adaptation to climate change of some activity. Thus, while each technology individually does not offer any benefit or innovation, in a combined way it does.
- Specific technologies: system, product or instrument, which is marketed individually, usually associated with a patent.
- Governance solutions or management strategies: these are methodologies for management and decision-making.

Nature-based solutions dominate in the water, agriculture and food, biodiversity and natural heritage, and urban and building sectors. IT-type solutions dominate in the area of early warning and are also very present in the water and health sectors, especially associated with early warning tools and decision support in both sectors. In the finance and insurance sector, most of the solutions are based on governance, as many are risk management or decision-making strategies to allocate investments or funds. Technological solutions or specific technologies are present in all sectors.

On the other hand, each of the identified solutions serves for adaptation to different effects of climate change. The main risks arising from climate change are described in the Technical Annex to the European Commission (EC) report entitled "Financing a sustainable European economy". The climate change effect that is the most frequently addressed by the adaptation solutions identified in the inventory is the changing temperatures, followed by flooding and water stress. These three climate change effects are the ones that have the greatest incidence in the centre of Spain. Specifically, floods are the risk derived from climate change that cause more human[7] and economic[8] losses in our country.

A large part of the solutions identified have been developed or tested in Spain. However, the inventory includes solutions from 31 countries. Of all of them, the USA, the Netherlands, Italy, Germany and the United Kingdom are countries most present in the development or testing of the identified solutions.

3.3 External reviewers

With the aim of ensuring the relevance, degree of innovation and representativeness of the set of identified solutions, the inventory (Annex 5.1) has been evaluated by an independent committee of experts. Each of the experts involved is a benchmark in their sector in the context of adaptation to climate change. The evaluation of the solutions included in the inventory by the external reviewers has been based on the criteria used to feed the indicator of relevance for adaptation to climate change, which we explain below in this document.

External expert	Affiliation	Area of expertise
Christos Makropoulos	Professor at the School of Civil Engineering of the National Technical University of Athens (NTUA).	• Early warning • Water
Robert Savé	Emeritus Researcher at the Institute of Agri-food Research and Technology (IRTA).	• Agriculture and food
Raquel Iglesias	Director of the biofuels and biochemicals unit at the Centre for Environmental and Technological Energy Research in Madrid (CIEMAT).	• Water • Energy
Madalen González	Professor of the Department of Urbanism and Territorial Planning at the Polytechnic University of Catalonia.	• Urban planning and building
José Maria Ordoñez	General Directorate of Public Health, Ministry of Health. Madrid region. Professor of Public Health at the Francisco de Vitoria University.	• Health
Marcello Notarianni	International expert in hospitality and sustainable tourism and associate member of SMA Tourism.	• Tourism • Cultural heritage
Xavier Bellés	Research Professor at the CSIC and director of the Institute of Evolutionary Biology (CSIC-UPF).	• Biodiversity and natural heritage
Diego Iribarren	Senior researcher at the IMDEA Energy Foundation (Madrid Institute of Advanced Studies).	• Energy • Transport and mobility
Francisco Espejo	Deputy Director of Studies and International Relations of the Insurance Compensation Consortium.	• Finances and insurance
Cristina Rivero	Director of the Department of Industry, Energy, Environment and Climate at the Spanish Confederation of Business Organizations (CEOE).	• Industry and services

[7] MITECO, 2020. El Perfile Ambiental de España 2020. Ministerio para la Transición Ecológica y el Reto Demográfico de España.

[8] Hidalgo Pérez, A.I. 2020: Impactos, vulnerabilidad y adaptación al cambio climático en la actividad aseguradora. Oficina Española de Cambio Climático. Ministerio para la Transición Ecológica y el Reto Demográfico, Madrid

4 Characterization

4.1 Methodology

One of the objectives of this study is to provide practical information to encourage and facilitate multisectoral adaptation to climate change. Technical data sheets have been generated for the 54 most relevant solutions of the identified in the inventory for climate change adaptation.

The selection of 54 adaptation solutions has been made using an indicator designed to assess the relevance of each of the solutions with respect to adaptation to climate change in each of the sectors. This indicator considers multisectoral scope, short-term implementation potential, level of innovation, expected social acceptance and provenance.

To ensure the impartiality of the indicator, the group of external experts that has evaluated the inventory of identified solutions have been responsible for assessing each of these criteria based on the relevance indicator is calculated.:

$$R = \sum_{i=1}^{5} p_i \cdot c_i$$

where, R is the value of the indicator, c_i is the value given to each of the evaluated criteria (from 1 to 3), p_i is the value of the weight given to each criterion (whose values range from 0 to 1) and n is the number of criteria (in this case 5).

The selection of the 50 most relevant solutions for adaptation to climate change arises from the combination of expert criteria and the result of this indicator.

<table>
<tr><th rowspan="2">Criteria</th><th rowspan="2">Weight</th><th colspan="3">Indicator value</th></tr>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><td>Potential reach</td><td>0.3</td><td>Very specific solution. Applicable in one or two cases in the region and in a specific sector.</td><td>Intermediate scope solution.</td><td>Very versatile solution. Easy to implement, applicable in many cases, different situations and sectors.</td></tr>
<tr><td>Short-term application potential</td><td>0.15</td><td>Unfeasible</td><td><4 years</td><td>Immediate</td></tr>
<tr><td rowspan="2">Social acceptance</td><td rowspan="2">0.15</td><td>Low acceptance.</td><td>Average acceptance.</td><td>High acceptance.</td></tr>
<tr><td>Technology or solution that would generate confrontation with a social agent.</td><td>There are no social agents positioned now neither for nor against.</td><td>Technology for which there is demand from social agents and / or provides social benefits beyond adaptation to climate change.</td></tr>
<tr><td>Spanish origin</td><td>0.10</td><td>Foreigner</td><td>-</td><td>Spanish</td></tr>
<tr><td>Technological maturity</td><td>0.3</td><td>Validated in relevant environment.</td><td>Pilot or prototype.</td><td>Complete or real operating system.</td></tr>
</table>

4.2 Selected technologies and solutions

A total of 54 solutions have been selected as the most relevant of all those identified with respect to intersectoral adaptation to climate change. A large part of the solutions considered very relevant are part of the early warning, water, and urban planning and building sector.

At the time of generating the technical sheets, some of the solutions initially identified and selected have been grouped, due to their similarity in the problems addressed and the typology and approach of the solution. Similarly, some solutions have become widespread to offer more useful information and provide different case studies or examples. Thus, the total number of chips generated is 48.

	Solution	Sector	R
1	Agrovoltaic energy	Agriculture and food	1.8
2	Development of new varieties of cultivated plants	Agriculture and food	1.9
3	Smart agriculture	Agriculture and food	2.1
4	Methods of managing desertified areas to adapt to climate change	Agriculture and food	2.3
5	Project LIFE AgriAdapt	Agriculture and food	2.7
6	ADAPTaRES	Water	1.0
7	Evaluation of the performance of reservoirs in the face of the effects of climate change	Water	2.0
8	Natural water retention measures for the renaturalization of wetlands	Water	2.0
9	Floating photovoltaic systems to reduce evaporation	Water	2.1
10	Artificial wetlands	Water	2.5
11	Rain Gardens	Water	2.6
12	Improve the accuracy of landslide early warning systems using "*machine learning*"	Early warning	1.8
13	Analysis based on the geomorphology of critical flood zones in small mountain basins	Early warning	1.8
14	Design of a real-time early warning system for storm flooding	Early warning	1.8
15	Planning and deployment of dynamic infrastructures in real time for disaster early warning systems	Early warning	1.9
16	Improvement of an extreme rainfall detection system with data GPM IMERG	Early warning	2.1
17	Territorial systems for early warning of landslides caused by rains	Early warning	2.2
18	Landslide prediction with satellite rainfall data	Early warning	2.2
19	Analysis of the potential of IT system support in early warning systems for flood risk mitigation	Early warning	2.5
20	MIDAS: *A New Integrated Flood Early Warning System for the Miño River*	Early warning	2.7
21	Envira IOT	Early warning	2.9
22	ARANTEC	Early warning	3.0
23	GEONICA	Early warning	3.0
24	Combating desertification, the case of Alvelal	Biodiversity and natural heritage	0.0
25	*WILD HOPPER*	Biodiversity and natural heritage	2.3
26	Urban green infrastructure strategy of Vitoria-Gasteiz	Biodiversity and natural heritage	2.3
27	C3S Energy	Energy	2.3
28	Energy adaptation map	Energy	2.3
29	Ground-to-air heat exchanger	Energy	2.5

	Solution	Sector	R
30	Dynamic Line Rating	Energy	2.5
31	Map of financial stress derived from the CC	Finances and insurances	1.0
32	Pilot projects for the adaptation to the risk of flooding of infrastructures and buildings	Finances and insurances	2.4
33	InVEST	Finances and insurances	2.7
34	Grants for flood risk adaptation of existing buildings	Finances and insurances	2.8
35	*Fonds de Prévention des Risques Naturels Majeurs* (FPRNM)	Finances and insurances	2.8
36	Supply Chain Digitalization	Industry and services	2.4
37	Circular water use systems in industrial estates	Industry and services	2.4
38	LIFE ALGAECAN	Industry and services	2.5
39	*iSCAPE living labs*	Health	1.5
40	SMARTCITIZEN	Health	1.6
41	UrbClim	Health	1.7
42	Calculation *Wet Bulb Globe Temperature* map	Health	2.1
43	ARBOCAT	Health	2.4
44	Plant walls	Health	2.5
45	PANOPTIS	Transport and mobility	2.4
46	RESIST	Transport and mobility	2.6
47	BIOHM	Urban planning and building	2.3
48	RESILENCE BY RENOVATION	Urban planning and building	2.4
49	PHUSICOS	Urban planning and building	2.4
50	*Ebroresilience*	Urban planning and building	2.5
51	*Water Square*	Urban planning and building	2.5
52	THERMAFY	Urban planning and building	2.5
53	Wind catchment towers	Urban planning and building	2.5
54	RESILIO	Urban planning and building	2.7

4.3 Characterization of the selected technologies and solutions

4.3.1 Early warning

4.3.1.1 Early warning systems for the detection of flood events

(Authors: Aitor Corchero Rodríguez and Eloy Hernández Busto)

Areas or sectors where it applies:

- Early warning
- Water

Type of solution: IT "Information Technology" Solution[9]

Solution / Technology

Flood Early Warning Systems (FEWS) correspond to digital systems that use prediction techniques (decision trees, neural networks, support vector machines, linear regressions, etc.) and systems of applied rules on information from multiple sources (e.g. weather stations, hydrological stations, etc.) of the river and drainage network, to determine flood alert states and assist in the development of actions to improve water storage and distribution and mitigate vulnerability and risks in exposed areas.

Basic description

In many regions of Europe, global warming is expected to lead to higher rainfall intensity, coupled with longer dry spells. This situation becomes more prominent in the Mediterranean area, for which these events are expected to have progressively greater consequences.[10,11]

Considering that floods cannot be avoided, minimizing their impacts (known as 'flood protection') simply seeks to protect and reduce impacts on people and material goods. In this regard, numerous digital tools for flood prediction and early warning systems have been designed and put into operation.

Today, these flood prediction systems and early warning systems are composed of a monitoring layer that uses *Internet of Things* (IoT) systems[12]. IoT systems will capture on-site information that, in turn, will be transferred to a control centre (based on a cloud system). Within this control centre, an analysis of the information is carried out to determine the alert states and flood predictions. To do this, the captured in-situ information is combined with satellite information. On this basis, risk patterns are established at the geographical level and, therefore, decision-making based on specific information.

[9] Information Technology. IT solutions are those that apply Computers and telecommunication to store, retrieve, transmit and manipulate data.

[10] Heavy precipitation in Europe

[11] https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap23_FINAL.pdf

[12] Technological system that allows objects to connect to the Internet and each other, being able to measure parameters of the environment, generate associated data and transmit them through a communications network.

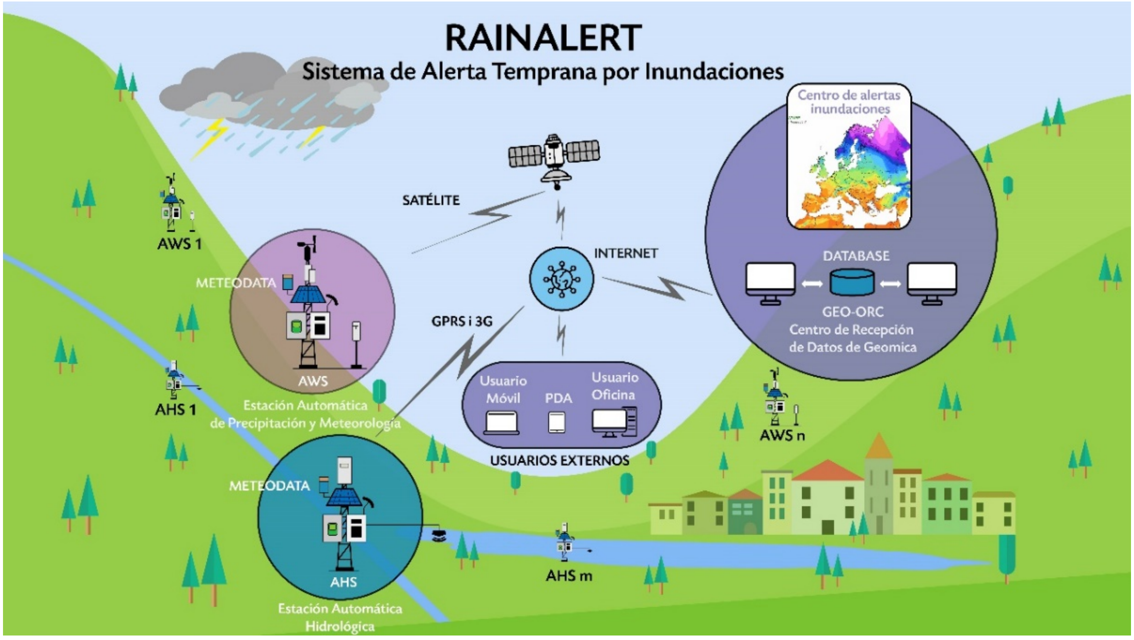

Figure 2. Flood early warning system. It shows the layer of data acquisition by automatic weather stations (AWS) and automatic hydrological stations (AHS), and its subsequent sending to data analysis centres through communications systems and their communication with users or interested parties. (Source: Geónica)

As shown in Figure 2, data collection can be performed by different types of sensors (temperature, atmospheric pressure, relative humidity, anemometers, and rain gauges). In this way, one of the challenges of these systems lies in the understanding and interconnection of information, due to the coexistence of different standards. This makes interoperability between digital systems a key point. Finally, and from the point of view of data analytics models, these systems need, first, the capacity for self-adaptation towards the constant changes in the patterns of the ecosystems of the basin. The last challenge is in the level of detail of the information and the ability to predict in the face of climate uncertainties.

That is why these systems have evolved towards greater scalability in their ability to sample and capture information. To do this, little by little, these architectures have been nourished by Internet of Things systems, to give greater precision and detail to the information. Thanks to the interconnection of systems and the integration of information in the cloud, basin managers can have a greater global vision for decision making. Finally, these systems have advanced to adapt to the constant ecosystem changes, adding a layer of event prediction and interrelation of variables by combining parametric models and data-driven systems.

Implementation potential

Advantages	Disadvantages
• Decision support to develop flood protection plans. • Scalable system, with the ability to add more sensors in the data collection layer. • The cost-benefit ratio of these solutions is positive.[13] • Support systems in watershed management and resource management.	• It needs a maintenance of the sensors to maintain the quality of the monitored information. • It needs a calibration of the models to adapt to the dynamic changes of the ecosystems. • Potential lack of collaboration between institutions to combine biodiversity indicators, impacts on society and other values of the nexus to deepen the generation of protection plans.

[13]https://ec.europa.eu/environment/integration/research/newsalert/pdf/large_scale_early_flood_warning_systems_provide_high_returns_on_investment_425na5_en.pdf

Advantages	Disadvantages
	• The lack of collaboration and coordination in terms of access to data by different entities, agencies and administrations can cause a reduction in the performance of statistical and mathematical models, in addition to data-based ones.[14][15] • Interoperability influences the performance of these systems.

Potential barriers to implementation

The main barriers (or requirements) for the implementation of these systems are classified into the following blocks:

- Technological. It requires a high knowledge of the sensors to be used for their installation and calibration, as well as the underlying models for the correct functioning of the solution.
- Institutional. Close collaboration and coordination between institutions is needed since the different competences of the institutions need to be interrelated in real time in case of pluvial floods.

Level of innovation today TRL = 9

Currently, there are different commercial initiatives and prediction systems. The RAINALERT tool [16] offers a combination of IoT systems through different weather stations (water flow sensors, wind speed and direction, soil moisture, water level sensors, precipitation systems) that, combined with cameras (imaging systems) allows remote and real-time monitoring of the basins. The alert detection system is based on a system of rules about the information collected.

Another relevant flood early warning system[17] is EnviraIoT[18]. This system is formed by a set of autonomous stations (*"dataloggers"*) that are responsible for capturing information related to temperature, humidity, turbidity, and water speed among others. The novelty of this system lies in its data communication, based on 3G and LoRa (*Long Range*)[19]. In addition, this product uses *machine learning* technology [20] for the detection of flood alerts.

Finally, early warning systems have also been combined to interrelate information from *IoT* systems along with information from social networks. In this sense, the approach is to interrelate measurements provided by sensors together with measures provided by users under a concept called "user as sensor". In this way, sensor measurements can be validated and associated with flood events.

[14] Of Wrachien, D., Mambretti, S., & Sole, A. (2010). Mathematical models in flood management: Overview and challenges. WIT Transactions on Ecology and the Environment, 133, 61–72.

[15] Han, H., & Morrison, R. R. (2021). Data-driven approaches for runoff prediction using distributed data. Stochastic Environmental Research and Risk Assessment.

[16] http://www.geonica.com/fil/Model/DocumentLibrary/1/9992-0058-rainalert-sistema-alerta-temprana.pdf

[17] Acosta-Coll, M., Ballester-Merelo, F., Martinez-Peiró, M., & de la Hoz-Franco, E. (2018). Real-time early warning system design for pluvial flash floods—a review. In Sensors (Switzerland) (Vol. 18, Issue 7). IPR AG.

[18] ENVIRA IoT

[19] Broad spectrum modulation technology. This allows it to tolerate noise, multiple signal paths and the Doppler effect, while keeping power consumption very low. The cost of achieving this is bandwidth, which is very low compared to other wireless technologies.

[20] Machine learning. Machine learning is a branch of artificial intelligence that aims to develop techniques that allow computers to learn. An agent is said to learn when their performance improves with experience and through the use of data.

Expected or desirable advances in the coming years

One of the challenges of these systems is their ability to integrate different sources of information in a reliable and secure way. In order to respond to this challenge, over the next few years, these systems will evolve towards the use and adoption of *Distributed Ledger Technologies*[21]. That is, technologies to manage information in a decentralized and immutable way. The second evolution of these systems will tend to the adoption of so-called *Continuum Computing*[22] as technologies that combine the generation, processing, and computation of data in real time.

At the level of data analytics, the models currently used are based on mathematical models, parametric or data-based models. Independently, these models must model the behaviour of ecosystems, their interrelationship and the uncertainties attached to them. That is why over the next few years it is expected that they will appear[23]:

- Systems for quantifying the impacts and consequences on ecosystems and biodiversity.
- Systems for measuring impacts on society beyond the direct effects of a flood episode.

Expected results

The potential results and added value of the adoption of this type of technology have been quantified based on the following elements[24]:

Benefit	Measure
Reduction of losses due to damages to companies	Reduction between 50-75% of losses caused by floods.
Harm reduction	Reduction by 30% in people affected and 60% of those directly or indirectly affected.
Cost-benefit ratio of this type of solutions	25% reduction in the expected costs of flooding.

Installation costs

The installation costs of this type of solutions are highly dependent on the installations to be carried out based on the type and number of sensors, weather stations and analytical modules. On average, based on available studies[25] (located in Nepal), these systems are estimated, in terms of order of magnitude, a cost of € 12.75M considering the large-scale installation of hydrological stations (€ 750k), professional weather stations (between € 500 and € 1,500 per unit), climate change prediction systems (€ 6M), climatological, precipitation and early warning models (€ 3.5M). [26]

[21] Duminda, et al. (2022) Challenges and Technical Advances in Flood Early Warning Systems (FEWSs)

[22] Beckman, P., Dongarra, J., Ferrier, N., Fox, G., Moore, T., Reed, D., & Beck, M. (2019). *Harnessing the Computing Continuum for Programming Our World.*

[23] Kundzewicz, Z. W., Beven, K., Hall, J., Krasovskaya, I., Penning-Rowsell, E., & They, B. S. (2013). Emerging lessons from ecosystems | Floods: lessons about early warning systems Late lessons from early warnings: science, precaution, innovation 347 Emerging lessons from ecosystems | Floods: lessons about early warning systems 15 Floods: lessons about early warning systems (1) The author gratefully acknowledges valuable comments from five reviewers.

[24] Thielen-of Well, J., Thiemig, V., Pappenberger, F., Revilla-Romero, B., Salamon, P., of Groeve, T., Hirpa, F., & European Commission. Joint Research Centre. (2015). *The benefit of continental flood early warning systems to reduce the impact of flood disasters.* Publications *Office.*

[25] Rai, R. K., van den Homberg, M. J.C., Ghimire, G. P., & McQuistan, C. (2020). Cost-benefit analysis of flood early warning system in the Karnali River Basin of Nepal. International Journal of Disaster Risk Reduction, 47.

[26] Taiko Meteorology

Operating costs

As for the operating costs, these are quantified at around € 131-152k per year considering annual maintenance of the monitoring systems and algorithms (€ 100k), maintenance of the cloud system (between € 1,300 and € 2,500 per year)[27] and personnel costs for the analysis and processing of the recorded data (between € 30,000 and € 50,000 gross annual salary) [28].

Social acceptance

It is evident that the social acceptance of the measures at the institutional level is high because an improvement in prediction and early warning systems helps to reduce the impact of these events on populations, especially those nearby in risk regions.

Although these technologies and their use go unnoticed by society, they have an impact on the management and restoration of ecosystems and minimize the risk of flooding in cities. Both the management and restoration and mitigation of flood damage are of general interest, due to the impacts of climate change on cities and towns near risk areas.

Recipients

- Public administrations
- Hydrographic confederations
- Environment agencies at regional level
- Farms

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Floods
- Heavy rainfall
- Cyclones, hurricanes, and typhoons

Conceptual fit within climate change adaptation

The solution presented helps to minimize the impacts caused by floods in the different risk regions. At the state level, the most vulnerable regions to this type of extreme event are coastal areas as well as nearby areas of rivers or reservoirs. In addition, these tools will help in the selection of specific technology for climate change adaptation that will help minimize flood risks.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Balkans	JRC	2014	Combination of climate projections (COPERNICUS) with flood prediction systems. This helped displace 140,000 people before the floods.
Duero Hydrographic Demarcation	ADASA	2015	Implementation of 280 meteorological and hydrological stations under the Delft-FEWS system.
Marbella	PEARL	2014	Combining NWP models[29] with on-site data for alert detection.
Colombia	Corporación Universidad de la Costa	2018	Installation of an early warning system that combines IoT systems with information from social networks to determine alerts.

[27] Jones, E. (2021) Cloud Market Share – A Look at the Cloud Ecosystem in 2022.

[28] Universidad Europea (2022) How much a computer engineer earns.

[29] Numerical Weather Prediction

Location	Responsible	Year	Description
La Vega Baja (Alicante)	AGBAR/SUEZ	2021	Use of simulations, AI, and real-time information to analyse infrastructure and mitigate the effects of floods and assess underlying impacts.
Andorra	Government of Andorra (Envira IoT)	2018	Permanent monitoring of river waters that allows to measure the flow, detect possible floods, and warn of flood risk.
Madrid, Spain.	Canal de Isabel II	2018	Real-time monitoring system composed of three radars with a range of 65km, some laser rain gauges and several traditional rain gauges covering the entire basin.

Main stakeholders (organizations, companies, institutions, etc.)

- Watershed managers.
- Companies providing digital and physical technology.
- Water-related research organizations.

4.3.1.2 Hydrological and hydraulic models applied to Early Warning Systems

(Authors: Aitor Corchero Rodríguez and Eloy Hernández Busto)

Areas or sectors where it applies:

- Early warning
- Water

Type of solution: IT "Information Technology" Solution[9]

Solution / Technology

As part of an early warning system for river floods, hydrological[30] and hydraulic[31] prediction models are included in many cases. These models offer predictions and/or simulations on the evolution of the hydraulic regime in the channels (variations in flow, draft, and speed) as a result of heavy rainfall and environmental conditions. The information offered by the models integrated within an EWS (Early Warning System), provides useful help in decision-making to mitigate the effects of a flood accurately and effectively. These models complement the information provided by detailed maps of areas where greater and lesser danger is estimated. (see Fernandez-Novoa et al, 2020).

It should be noted that as a basis on which these hydrological and hydraulic models are applied are the digital elevation models, which correspond to the so-called DTM (*Digital Terrain* Model) and DSM (Digital *Surface Model*) created through LIDAR (*Laser Imaging Detection and Ranging*), and whose difference is the incorporation of the elevation of artificial and natural elements (Figure 3). LIDAR technology is based on the use of a device that allows to determine the distance from a laser emitter to an object or surface using a beam of light. The distance to the object is determined by measuring the delay time between the emission of the pulse and its detection through the reflected signal.

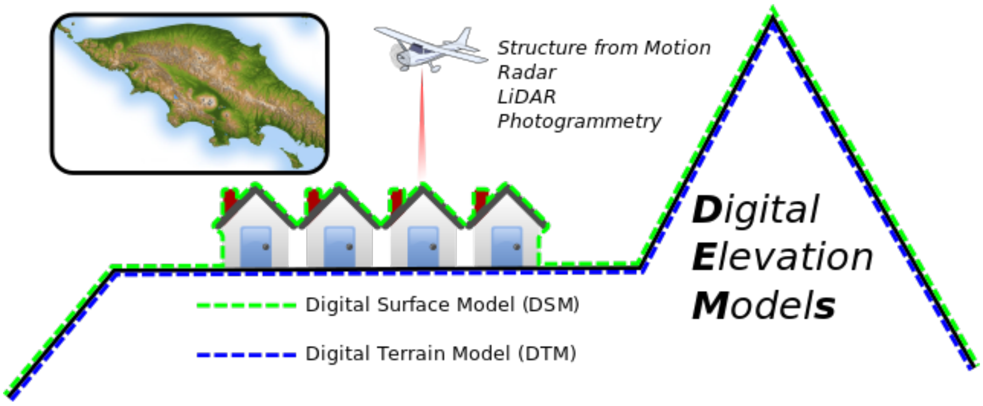

Figure 3. The difference between the digital surface model (DSM) and the digital terrain model (DTM)(Source:https://commons.wikimedia.org/wiki/File:The_difference_between_Digital_Surface_Model_(DSM)_and_Digital_Terrain_Models_(DTM)_when_talking_about_Digital_Elevation_models_(DEM).svg).

Basic description

These types of solutions take as a starting point the information related to avenue flow scenarios provided by hydrological models from precipitation predictions. Based on this information, on the digital model of the terrain elaborated, this flow is circulated through the channel represented in the digital model of the terrain, to evaluate its hydraulic regime and determine the areas of flooding and possible affection to personal and material property. There

[30] Model that provides information on the probable evolution of the flows of the river network.

[31] Model that provides information on the balance and movement of water.

are several commercial tools for both the modelling of the avenue flow and the hydraulic simulation of the flow in the channel. Among the first, it is worth mentioning HEC-HMS[32]. Among the latter, there are the most popular tools such as InfoWorks[33] and, at the national level, Iber+[34]. In addition, this system uses the precipitation forecast as input data to elaborate the simulations and, therefore, the predictions of the behaviour of the hydrological system.

Precipitation forecasts can be owned or can also be obtained from agencies and public bodies, which can offer different prediction ranges with different weather windows (days, hours, minutes), and covering areas of different sizes. The results of both models are obtained on an hourly time scale, posing scenarios from hour to hour up to a horizon of 24h.

The system runs automatically through a set of *"scripts"*[35] that can be developed in different programming languages such as, for example, "*Python"*[36]. When any hazard is detected, the system issues an alert, along with detailed flood and hazard maps, to help decision-makers adopt accurate and effective mitigation measures.

Implementation potential

Advantages	Disadvantages
• It allows to make predictions based on the physical behaviour of the area of interest. • Being a system dependent on public bodies for the intake of data ensures the reliability and coherence of these. • It facilitates decision-making based on simulations and potential behaviours of the area of interest. • Flood prediction system in time window depending on the place of its implementation. • Visual detail of affected areas • Validated system with statistical analysis based on historical data. • Free software for use of the models described.	• Requires aerial mapping of the area with LIDAR technology. • Specific solution for each region or area since the maps are specific to each place. • Maintenance of a cartographic database.

Potential barriers to implementation

The main barriers (or requirements) for the implementation of these systems are classified into the following blocks:

- Technological. These types of prediction models need to be fed with high-resolution elevation data from the use of LIDAR, they also require the collection and maintenance of historical flood data.
- Methodological. For the system to be extended and applied to different scenarios, it is necessary that the data that defines the boundary conditions of the prediction models have a standardized format.
- Topographical: The system must have the topographic changes of the land in an updated way, either by extension of urbanized areas or by geographical features.
- Human resources. This type of systems requires for their start-up and operation the involvement of experts in aerial laser scanning and hydraulic modelling, with the

[32] HEC-HMS is a rain-runoff model that is based on structuring the origin basin in sub-basins associated with the channels of the river network.

[33] Mathematical model that fully integrates the basin model, being able to do hydrology, hydraulics of sanitation and drainage networks, as well as fluvial hydraulics.

[34] Iber+ is a free software for hydraulic modeling, composed of a two-dimensional mathematical model, which includes a hydrodynamic module for the simulation of flows of rivers, channels, and natural channels, thus allowing the calculation of floods and floods and the delimitation of flood zones. (González-Cao J., et al. (2020) Iber+ : A New Code to Analyze Dam-Break Floods. In: Fernandes F., Malheiro To. Chaminé H. (eds) Advances in Natural Hazards and Hydrological Risks: Meeting the Challenge. Advances in Science, Technology & Innovation (IEREK Interdisciplinary Series for Sustainable Development). Springer, Cham)

[35] The script is a document that contains instructions, written in programming code.

[36] "Python" is a programming language whose philosophy emphasizes the readability of its code.

necessary knowledge to interpret meteorological and historical flood data. In addition, computer experts are required for the maintenance of cartographic, meteorological, and historical databases. In the case of making use of drones, experts would be required in their driving and handling.

Level of innovation today TRL = 6

The solution and technologies described have been validated in relevant environments, such as the Miño River basin, where historical data was available, and it has been possible to compare conditions and results of the predictions made by the system.

As for innovative features, the combination of both models together results in a quick prediction and in turn response to such phenomena, a situation that occurred slowly in the past since both models worked separately and that meant a calculation time of hours until obtaining an answer.

Expected or desirable advances in the coming years

With the increasing frequency of large-scale flooding around the world, there is an increasing need to provide accurate information on the potential impacts of such floods in the future. Flood modelling and simulation has evolved in recent decades from the simulation of individual river stretches to millions of continental stretches. In the future it is expected that there will be a generalization of two-dimensional modelling thanks to advances in computing capacity and development of computer tools, so predictions will focus on integrating approaches such as atmospheric processes, hydrological and social models.[37]

It should be noted that the growth of technologies in the field of artificial intelligence and machine learning will lead to the more in-depth processing of the laser information points collected by LIDAR.

As for the social approach, it is expected that in the future more and better references can be offered to users or inhabitants of areas at risk of flooding in a way that allows them to better calibrate the risk to which they are exposed [38].

Expected results

The expected results and added value of the adoption of this type of technology can be summarized as:

Benefit	**Measure**
Time range	24 hours.
Prediction resolution	Detailed maps with risk level separated by sections.
Benefit-cost ratio	By making use of free software the costs of use are significantly reduced.
3D cartographic accuracy	• At 100 m the systems have a resolution of a few centimetres. • It allows cartographies under vegetation. • Allows mapping underwater.
Viewing angle	360º.

[37] Singh, V.P. Hydrologic modeling: progress and future directions. *Geosci. Lett.* **5,** 15 (2018).

[38] Jose Adolfo Alvarez, Guilermo Perez Dolset. Conferederation Hydrographic of the Ebro. (2019). *Support system for the decision of the Ebro.*

Installation costs

Since the use of hydraulic and hydrological models suppose a cost 0 for being of free domain, the installation costs would be associated with the necessary equipment to execute the models and the code that makes them execute when detecting an alert (between € 1,000 and € 10,000 per unit, including computers and servers).

Operating costs

As maintenance costs, the expenses required by a computer infrastructure for the execution of hydraulic models and programming codes responsible for the detection of alerts, the working hours of qualified personnel (between € 30,000 and € 50,000 per year as gross salary of a worker), the cost of *"drone"* devices would be taken into account, if they were used for aerial mapping and LIDAR equipment (between € 25,000 and € 30,000)[39], as well as the cost of insurance of the equipment, both *"drones"* and LIDARs (€ 15,000).

Social acceptance

It is evident that the social acceptance of the measures at the institutional level is high because an improvement in prediction and early warning systems helps to reduce the impact of these events on populations, especially those nearby in risk regions. Although these technologies and their use go unnoticed by society, they have an impact on the management and restoration of ecosystems and minimize the risk of flooding in cities. Both the management and restoration and mitigation of flood damage are of general interest, due to the impacts of climate change on cities and towns near risk areas.

Recipients

- Public administrations
- Hydrographic confederations
- Environment agencies at regional level
- Farms

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Floods
- Erosive phenomena
- Dragging solids in channel

Conceptual fit within climate change adaptation

In relation to adaptation to climate change, this tool allows the detection of areas or geographical areas susceptible to flooding according to severity, as well as estimating that they are likely to flood, based on the combination of hydraulic and hydrological models. This type of tool makes it possible to identify these vulnerable areas and to carry out operational and political decision-making focused on these areas.

[39] Hobby Tuxtla. Lidar integration for DJI drones

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Spain Portugal	University of Vigo	2020	Integrated flood early warning system for the Miño River.
Poland	European Regional Development Fund	2019	Project funded by ERDF in Poland, in which exactly the solution described in this sheet is implemented.
Italy	University of Perugia	2019	Integration of 2D and VGI hydraulic models into a data assimilation framework for real-time flood forecasting and mapping. Using LIDAR technology in specific use cases.
Portugal	Polytechnic Institute of Leiria, Polytechnic Institute of Castelo Branco	2021	An interactive Web-GIS river flood warning and forecasting system in operation in Portugal.

Main stakeholders (organizations, companies, organizations, etc.)

- Watershed managers
- Companies providing digital and physical technology
- Water-related research organizations

4.3.1.3 Dynamic Infrastructure Planner

(Authors: Aitor Corchero Rodríguez and Eloy Hernández Busto)

Areas or sectors where it applies:

- Early warning
- Water

Type of solution: IT "Information Technology" Solution[9]

Solution / Technology

Dynamic infrastructure planners are digital tools that are applied in a virtual environment (*cloud* environment). That is, these systems offer to visualize the infrastructure virtually to simulate operational and policy decisions that need to be applied in case of natural disasters to obtain support in decision making and improve resource management.

These systems (Figure 4) are complex tools that typically consist of (i) early warning modules as decision support systems; (ii) planning systems and models in order to optimize the use of resources in case of emergencies; (iii) database systems to manage all information necessary for decision-making; and (iv) visualization systems that automate planning, provision resources and monitor potential alerts over time based on the monitored region.

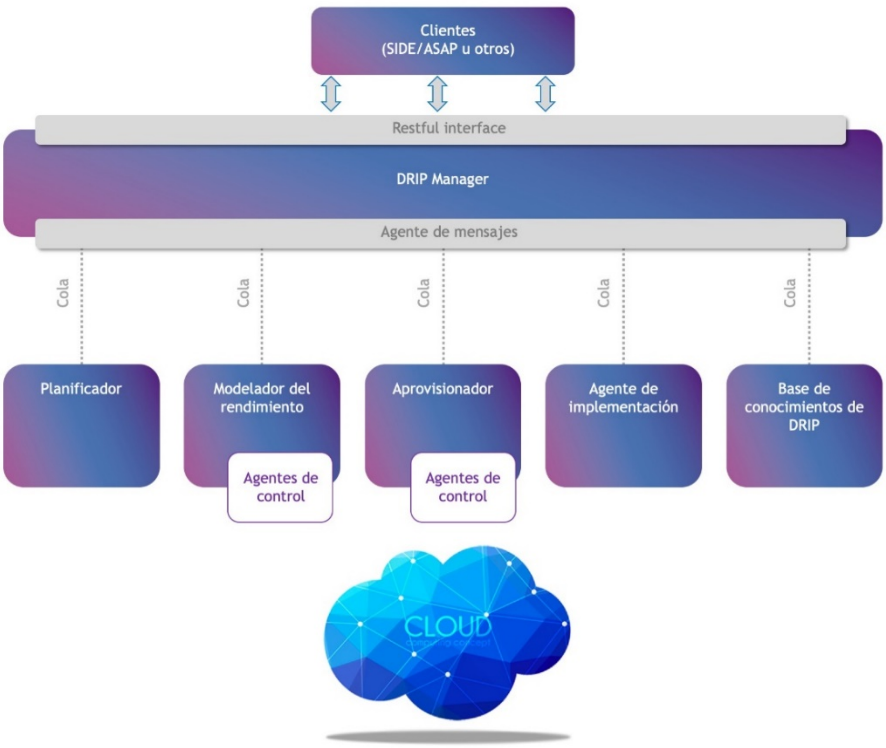

Figure 4. Architecture and schematic of the components and modules of which a Dynamic Realtime Infrastructure Planner (DRIP) is composed.

Basic description

Dynamic infrastructure planners offer different services or virtual infrastructures that are responsible for optimally and efficiently simulating different processes and operational and political decisions. In this way, this type of solutions allows to facilitate the implementation of new measures and strategies in case of natural disasters in an adaptable way to different types of scenarios.

This type of virtual tool makes decisions in an automated way based on the results of the different processes it executes and the information collected in real time. These types of tools are adaptable to different environments and infrastructures by eliminating setbacks in the installation such as device compatibility, responsiveness whatever the number of users to report to and calculation of planning according to resources. In this way, this tool can be defined as "elastic" and "adaptable", thus reducing the implementation time, analysis, and robustness that conventional alert systems entail.

The key features of this tool are modelled as a series of microservices, which are coupled with each other, these services are as follows and are specified according to industry and community standards:

1. The infrastructure planner in charge of designing an efficient infrastructure based on workflows by selecting virtual machines and connecting between them. As standards on which to base and specify this module we can find YAML (*"Yet Another Markup Language"*)[40] in accordance with TOSCA (*"Topology and Orchestration Specification for Cloud Applications"*)[41].

2. The performance modeler allows you to test different cloud resources to provide performance data for use by the infrastructure planner and other components inside and outside of DRIP. As an example of infrastructure that demonstrates the functionality of this module, we find the ExoGENI[42] platform, which is a network infrastructure-as-a-service (NIaaS) platform that uses sophisticated embedding algorithms to take advantage of semantic resource descriptions using NDL-OWL (*" Network Description Language"*)[43].

3. The infrastructure provisioner can break down the description of the infrastructure provided by the planner and provision it in multiple data centres (possibly from different vendors) with a transparent network configuration. Uses the *Open Cloud Computing Interface* (*OCCI*)[44] as the default interface

4. The deployment agent installs the application components on the provisioned infrastructure. The deployment agent can schedule based on network bottlenecks and deployment timelines. You can deploy overlapping *Docker*[45] clusters using *Docker Swarm*[46] or *Kubernetes*[47].

5. Infrastructure control agents are a set of APIs that DRIP provides to applications to control virtual machines and to adapt network flows. They provide access to the underlying programmability provided by virtual infrastructures, for example, scaling out and vertical virtual machines, providing interfaces through which the infrastructure hosting an application can be dynamically manipulated at run time.

6. The DRIP manager is implemented as a web service that allows external clients to invoke DRIP functions as services. Each request is directed to the appropriate component by a manager, who is responsible for coordinating the individual components and scaling them up if necessary. The manager also maintains a database that contains user accounts DRIP.

[40] YAML. Wikipedia [Agreed the 25/2/2022]

[41] Lauwers, C. & Tamburri, D. "OASIS Topology and Orchestration Specification for Cloud Applications (TOSCA) TC", OASIS OPEN.

[42] ExoGENI

[43] SDNL Ontology Specification

[44] Open Cloud Computing Interface (Occi)

[45] Docker docs.

[46] "Swarm mode"

[47] Kubernetes

7. Communication between the manager and the individual components is facilitated by a *"Message Broker",* which communicates using the *Advanced Message Queuing Protocol* (AMQP) and *RabbitMQ* protocols. Message intermediation is an architectural pattern for message validation, transformation, and routing, which helps compose asynchronous and loosely coupled applications by providing transparent communication to independent components.

8. Application resource information, credentials, and workflows are managed internally through a knowledge base. Maintains descriptions of cloud providers, resource types, performance characteristics, and other relevant information. The knowledge base also provides an interface for these agents to search for providers, resources, and runtime state data during the execution of an application.

Potential implementation

Advantages	Disadvantages
• Integration of heterogeneous information for the efficient generation of optimal and political decisions. • Analysis of the information considering temporalities and cost-efficiency of the measures. • Analysis and evaluation of critical scenarios for decision making. • Incorporation of environmental indicators. • Optimization of resources.	• It requires the realization of some simplification of the scenarios. • Involvement of different *stakeholders* to select objectives of operational and policy decisions. • High cost in the characterization of the uncertainty and the corresponding models. • Due to the complexity of the solution, these types of solutions are costly in terms of time and effort.

Potential barriers to implementation

The main barriers (or requirements) for the implementation of these systems are classified into the following blocks:

- Technological. At the technological level, the main barriers to the adoption of this technology lie in the lack of interoperability of the systems, which causes it to be necessary to make a great effort in the harmonization of data models. Another of the most important technological barriers of this type of solutions is in the elaboration of reduced climate models that require mathematical equations and data at a low level.
- Regulatory/Governance. In the field of governance, the main barrier is the alignment of this type of solutions with standard models such as, for example, ISO 31000 (risk assessment) and ISO 27001 (information security). The complexity in its implementation aligned with the complementation with other directives in the sector (directive in the framework of water) makes its adoption complex.
- Institutional. At the institutional level, the main implementation barrier is the time required for the elaboration of the objectives and scope of the solution. This gap is highlighted when different operational and political actors (environmental and water authorities) are involved in the process.
- Environmental. At the environmental level, the main barrier is in the political decision-making part to be modelled. For this, it is necessary to align the potential incentives with the environmental directives or even environmental protections of the area that needs to be monitored.
- Economical. At the economic level, the main implementation barrier lies in the high cost and complexity in the implementation of a complete system. That is why these systems are developed in a gradual and incremental way over time.

Level of innovation today TRL = 6

Currently, the implementation of these systems is partially elaborated, and the technology is in the validation phase in controlled environments. Considering these aspects, one of the dynamic planning systems applied to natural disasters is the so-called DRIP (*"Dynamic Real-*

Time Infrastructure Planning")[48]*.* This system is a digital tool in the cloud where decisions and operations are calculated based on a graph-based planning algorithm. The optimization of these decisions is calculated based on a series of environmental indicators previously identified and defined.

Another of the recently implemented solutions[49] use Bayesian networks on weather predictions (two levels of pattern extraction) for the calculation of these political and operational operations.

Expected or desirable advances in the coming years

This technology is still in a process of continuous evolution and adoption. In this sense, the main challenges of this technology lie in the use of control methods and dynamic planning techniques, also considering aspects of climate change. In relation to this aspect, future lines of research of this technology will tend towards:

- *Refinement of models representing climate processes.* considering the correction of errors in these models and a characterization of uncertainty on a more refined scale.
- *Development of uncertainty classification systems.* This aspect is key with the potential to learn from these uncertainties and analyse the cascading effects of different events.
- *Development of robust systems for policy validation.* There is a need to create robust and unified tests for the realization of political validations. In this sense, it is necessary to carry out datasets that characterize the uncertainties to address these tests.
- *Reduction of computational complexity.* Development of evaluation methods and systems to measure efficiency and effectiveness. In addition, one aspect to take into account is to move from monolithic models to a scalable system (e.g., based on micro-services) in order to expand the use of technology. Finally, these systems will tend towards the use of methods based on lighter data for the characterization of the different problems and their determination.
- *Autonomy in decision-making.* A current trend is the application of optimization for autonomous decision making (based on reinforcement learning techniques) to establish balanced policies (based on beneficial strategies for different relevant actors or domains) at different levels.

Expected results

The expected results and added value in the adoption of this type of technology have been quantified based on the following elements:

Benefit	**Measure**
Reduced policy calculation versus conventional models	Reduction of about 15%.
Policy horizon	The prediction horizon of algorithms for setting policies is estimated at 50-100 years.

Installation costs

The cost of installing a DIRP[50] is estimated at € 14-16M. This estimate is broken down into the development of an early warning system (€ 12M), downscaling climate models (€ 1M) and a complete "*big data cloud*" platform (€ 2M).

[48] Shi, Y., Fu, H., TianAnd. Krzhizhanovskaya, V. V., Lees, M. H., Dongarra, J., & Sloot, P.M. A. (Eds.). (2018). *Computational Science – ICCS 2018. Lecture Notes in Computer Science.*

[49] Herman, J. D., Quinn, J. D., Steinschneider, S., Giuliani, M., & Fletcher, S. (2020). Climate Adaptation as a Control Problem: Review and Perspectives on Dynamic Water Resources Planning Under Uncertainty. In *Water Resources Research* (Vol. 56, Issue 2). Blackwell Publishing Ltd.

[50] Dynamic Real-Time Infrastructure Planning

Operating costs

In relation to operating costs, these are quantified at around € 160k per year. This amount covers the annual maintenance costs of the cloud platform (between € 1,300 and € 2,500 per year)[27], the people involved in its maintenance (between € 30,000 and € 50,000 per year)[28] and the maintenance of algorithms and early warning systems (€ 100k).

Social acceptance

The social acceptance of this type of technology is medium since it is a tool that is still to explore its total benefits. In similar technologies experimented in European projects such as SIM4NEXUS or currently in NEXOGENESIS[51], the social acceptance of learning tools (such as those based on serious games) to carry out political decision-making has its main acceptance in the understanding of the relationships between policies and the instruments necessary to materialize them. At the operational and planning level, these tools will have an adequate acceptance. This is because a simulation and understanding of policies and strategies will help regional authorities and administrations to take effective and efficient decision-making in the long term. Within this framework, a long-term improvement of potential instruments for adaptation and mitigation to climate change will impact on the sustainability and improvement of both rural and urban ecosystems.

Recipients

- Public administrations
- Hydrographic confederations
- Environment agencies at regional level
- Water management companies
- Entities for emergency management

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Floods
- Heavy rainfall

Conceptual fit within climate change adaptation

As a conceptual fit, this type of dynamic infrastructure planning systems will allow decision-making both at the operational and political level, based on potential events that generate a negative impact on them. This will allow regional administrations and authorities to design and plan policy instruments and incentives for adaptation to climate change. At the technological level, this technology has its fit due to the application of analytical technology at the same point from where the data is collected, combined with analytics based on large-scale historical data, combining data-based models together with climate prediction models.

Real or pilot cases where it has been applied

The following examples are based on the application of the *"Chef"*[52] tool to different real cases. This tool is a cloud engine to automate the provisioning of infrastructures and therefore bases its use and applications on the DRIP concept and methodology. These two cases are a small example:

[51] European Commission. (2020). NEXOGENESIS. Novel framework brings the EU one step closer to its water management and climate target.

[52] Progress Chef

Location	Responsible	Year	Description
USA	AppLovin	2019	Automation of the company's virtual infrastructure ensuring that systems can adapt and move fast enough to handle the growing needs of the company.
Israel	Bank Hapoalim	2019	Design of the network topology around Chef, in addition to the automation of processes related to security, integration and deployment of applications adapting the infrastructure according to the requirements.

Main stakeholders (organizations, companies, institutions, etc.)

- Public administrations
- Water management companies
- Companies providing digital and physical technology
- Research bodies related to water and climate change
- Entities based on climate data management

4.3.1.4 Extreme rainfall detection systems

(Authors: Aitor Corchero Rodríguez and Eloy Hernández Busto)

Areas or sectors where it applies:

- Early warning
- Water
- Health

Type of solution: IT "Information Technology" Solution[9]

Solution / Technology

Extreme rainfall detection systems are digital tools capable of determining extreme rainfall events using mainly hydrometeorological data and time series acquired through satellite information. In addition, these systems use statistical models for the determination of alerts to hydrometeorological events.

Basic description

Currently, and due to climate change, hydrometeorological events are increasing their frequency and intensity. That is why the appearance of tools to help the identification and detection of these events are proliferating. Normally, these detection tools are mainly based on in situ measurements of hydrometeorological stations for the detection of such events.

The most innovative element of these extreme event detection tools is that they use satellite information sources to perform the identification and detection of such events. That is why these tools are formed by a layer of integration of information from satellite repositories (e.g. Copernicus, ITHACA, etc.) or through the IMERG ("*Integrated Multi-satellite Retrievals for GPM*") algorithm that provides rainfall information from multiple satellites, in order to store this information in a database (in HDF5 format). In this sense, the information collected is usually related to precipitation measurement (e.g., *precipitationCal*, *precipitationUncal*, *HQprecipitation* and *IRprecipitation*).

Based on this information, this tool performs the detection by establishing confidence thresholds. These thresholds are currently calculated based on an analysis of historical information on the values of average annual rainfall. As a result, the information is displayed in a geospatial information system where the different alerts and/or risks are identified.

Implementation potential

Advantages	Disadvantages
• Real-time detection of extreme hydrometeorological events (e.g., hurricanes, tropical storms, convective storms, floods, and intense storms). • Systems that use satellite information to determine alerts. • Reduction of tool maintenance costs as there is no sensor network per se. • Recommended for large-scale decision making. • Integration of this rainfall detection system with other flood detection early warning systems.	• System performance influenced by the resolution of satellite information. • Low adaptability to changes in rainfall patterns since the alerts are based only on a statistical analysis at the time of implementation of the solution.

Potential barriers to implementation

The main barriers (or requirements) for the implementation of these systems are classified into the following blocks:

- Regulatory/Governance. At this level, the main barrier is in the establishment of the necessary alliances to obtain high-resolution satellite information. This point is key, as it is the main foundation of the tool.
- Institutional. Strict cooperation between institutions is necessary for the implementation of these systems. Particularly when you need to relate in real time different types of information at the basin scale.

Level of innovation today TRL = 7

Currently, there are some prototypes implemented that use satellite information for the detection of extreme events caused by climate change. In this sense, one of the tools that acts as an early warning system is the so-called ERDS ("*Extreme Rainfall Detection System*")[53]. This system allows the identification of hydrometeorological events by combining satellite information with predictions made by these systems. In this sense, the alerts are identified through a methodology of detection and establishment of confidence thresholds based on the performance of a statistical analysis (study of distributions) on historical data

Finally, another solution is that of NASA-TRMM ("*Tropical Rainfall Measuring Mission*") as a system for the detection of tropical storms considering precipitation information from *NASA GPM IMERG, PERSIANN, PERSIANN-DDS and GSMap*. In this sense, alerts are detected based on filters and thresholds marked by users.

Expected or desirable advances in the coming years

One of the main advances of these tools lies in the identification and development of methodologies to dynamically determine these confidence thresholds. In this way, these applications could become adaptive to the changing patterns of weather data. To do this, the trend will go towards the application of interrelated physical-climatic models with data-based models (machine learning and deep learning).

Interrelated with this concept, the calibration of climate models and their corresponding performance is a challenge in a large-scale field where different hydrometeorological events interact. That is why, in this sense, causality studies between the different events can provide an aid for future early detections of these events.

Finally, these tools will tend towards the use of morphological and geomorphological information from the different areas as mechanisms to contextualize the events and interrelate the nature of the different areas/regions with hydrometeorological events.

Expected results

The expected results and added value of the adoption of this type of technology have been quantified based on the following elements[54]:

Benefit	Measure
Detection of hydrometeorological events	80% flooding; 45% of convective storms; 85% of hurricanes and cyclones; 50% of storms that induce land dislocation; 85% of floods and tropical storms.
Information aggregation intervals	From every 15 min to 96 hours.

[53] ITHACA ERDS

[54] Mazzoglio, P.; Laio, F.; Balbo, S.; Boccardo, P.; Disabato, F. Improving an Extreme Rainfall Detection System with GPM IMERG data. Remote Sens. 2019, 11, 677.

Installation costs

The costs of using the application are currently free, therefore, the adoption of the information system has no costs. However, the installation costs would increase depending on the number of computer equipment such as computers and servers where the data can be stored (between € 1,000 and € 10,000) depending on the computing and storage capacity, specialized personnel capable of handling and understanding the data acquired as a computer engineer (between € 30,000 and € 50,000).[28] As a reference in terms of time series database costs we can estimate between € 200 and € 300 per year storing the data in the cloud.

Operating costs

As for operating costs, no specific data have been found. However, considering similar tools, the operating costs would be around € 110k. This figure would include the annual maintenance of monitoring systems and algorithms (€ 100k) depending on the number of sensors and data acquisition devices, and maintenance of the cloud system (€ 10k) which would include infrastructure, support, and data security.

Social acceptance

These systems are of medium-high social acceptance due to their interrelation with the development of climate change mitigation strategies. In short, these tools aim to reduce the risks of materialization of extreme hydrometeorological events and therefore contribute to mitigation against climate change.

Recipients

- Public administrations
- Hydrographic confederations
- Environment agencies at regional level
- Water management companies (dams, sanitation, water management, desalination plants, etc.)

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Floods

Conceptual fit within climate change adaptation

In relation to adaptation to climate change, this tool allows the detection of extreme hydrometeorological events based on satellite information. These types of tools allow to identify events such as hurricanes, cyclones, floods or tropical storms based on satellite predictions. Therefore, knowing in advance the occurrence of these events, these tools can be a mechanism for the elaboration of operational and political strategies to minimize the impacts of the occurrence of these events. On the other hand, and taking into account this occurrence on a global scale, these tools can support the development of innovative adaptation packages against climate change.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
USA	ITHACA	2019	Demonstration of the ERDS system of the ITHACA platform in the face of extreme hydrometeorological events in the USA.
USA	NASA	2019	Demonstration of NASA-TRMM as a digital tool to provide satellite information and predictions on extreme events.

Main stakeholders (organizations, companies, institutions, etc.)

- Watershed managers
- Companies providing digital and physical technology
- Water-related research organizations
- Regional administrations and administrative bodies (regional governments, ministries).
- Climate modelling companies

4.3.1.5 Hybrid Flash Flood Early Detection System

(Authors: Aitor Corchero Rodríguez and Eloy Hernández Busto)

Areas or sectors where it applies:

- Early warning
- Water

Type of solution: IT "Information Technology" Solution[9]

Solution / Technology

Flash flood early warning systems correspond to digital systems that use prediction techniques (classification and regression models, such as decision trees, neural networks, vector support machines, linear regressions, etc.) and systems of rules applied to heterogeneous information (e.g. flow, weather stations, hydrological stations, etc.) of river and drainage networks to determine flood alert states and assist in the development of actions to improve water storage and distribution, mitigate vulnerability and risks in exposed areas.

Basic description

As a mechanism for the identification and assessment of flood risk, this system corresponds to a digital platform that involves a layer of information integration (wind direction, wind speed, water level, rainfall intensity, amount of rainfall) based on Internet of Things systems. On this layer of *in-situ* monitoring of the information, an orographic analysis module of the area has been incorporated to associate the measurements with the morphology and geology of the region where the solution is implemented. With all this, the system applies real-time detection of flood events.

To do this, the system makes use of a precipitation prediction module using numerical models (equilibrium models, hydrometeorological models and hydrodynamic models), empirical models (frequency analysis of storms and floods, use of empirical and rational models) and models based on trained historical analysis (correlation analysis on critical scenarios, interpolation models). Complementing these early warning models, the methods and models of probabilities (Bayesian networks) are incorporated into the architecture for the determination of risk cases in the region where it is installed. Finally, the visual part of the platform corresponds to a geographical visualization in a web application.

The innovation and novelty of this system lies in the hybridization in the use of models to determine alerts and risk states considering flood events. Specifically, this hybridization that combines real-time techniques with techniques based on historical data allow the generation of holistic risk management, operational control plans, large-scale alert services, creation of contingency plans, predictions of disaster prevention actions and monitoring of control plans against natural disasters.

Implementation potential

Advantages	Disadvantages
• Holistic risk management in the face of natural disasters. • Large-scale monitoring and control of crises caused by these hydrometeorological events. • High flood response capacity. • It considerably reduces economic and human damage. • It helps in the management of resources thanks to planning against possible scenarios.	• Measuring devices require maintenance. • The models require calibration to adapt to the geographical changes of the basins. • They require an approach based on the knowledge of experts in the field for the definition of critical areas (orographic analysis). • Cooperation between institutions is essential.

Potential barriers to implementation

The main barriers (or requirements) for the implementation of these systems are classified into the following blocks:

Technological. In this sense, the main barrier lies in the selection and installation of sensors. In addition, the calibration of the sensors and the underlying models must be taken into account for proper operation as a whole. Apart from this, the interoperability of information is a handicap that influences the performance of these systems.

Institutional. Strict cooperation between institutions is necessary for the implementation of these systems. Particularly, when different types of basin information need to be interrelated in real time.

Economical. From an economic point of view, these types of solutions are expensive to implement.

Level of innovation today TRL = 8

The state of this technology is that of product in a large-scale demonstration. This system incorporates information (wind direction, wind speed, water level, rainfall intensity, amount of precipitation) from Internet of Things systems completed with orographic information of the area where it is implanted. The innovation of this system lies in the incorporation of alert at two levels: real-time early warning system and large-scale prediction system. At the level of results, these systems have allowed to reduce decision making up to 1-2 hours with machine learning methods applied.

Expected or desirable advances in the coming years

It is expected that in the coming years these systems will improve their ability to integrate data from different sources complementing it with a greater capacity for real-time analysis due to the evolutions in *in-situ* monitoring systems, which will improve communications with the implementations of 5G/6G networks throughout the world.

At the analytical and risk management level, these tools will evolve towards:

- Application of techniques to quantitatively understand the interrelation between the various events that influence the materialization of floods and the corresponding events and / or related effects.
- Establish a comprehensive KPI *(key performance indicator*) system[55] to determine the quantifications of the impacts and consequences of these events not only on the environment, but considering biodiversity, ecosystems, and population (infrastructure).
- Reinforcement in the incorporation of models and modules from other disciplines such as hydrological models, meteorological and climatic models, etc.

Expected results

The expected results and added value of the adoption of this type of technology have been quantified based on the following elements:

Benefit	Measure
Flood event detection	Range of time of 1-2 hours.
Time steps of predictions and calculations	The results with these techniques allow you to go from prediction steps of every 10 minutes to 1 hour.

[55] Also known as **key indicator**, is a measure of the level of performance of a process. The value of the indicator is directly related to a previously set target, and is usually expressed in percentage values

Installation costs

The installation costs of this type of solutions are highly dependent on the installations to be carried out based on the type and number of sensors (between € 150 and € 2,000 depending on the type of sensors and precision instruments)[56], professional weather stations (between € 500 and € 1,500)[57] and analytical modules to be considered. To these costs must be added the part involved in data analytics such as prediction systems (€ 6M), precipitation and early warning models (€ 3.5M).

Operating costs

As for the operating costs, they are considered susceptible to take into account the costs for annual maintenance of the monitoring systems and algorithms (€ 100k), maintenance of the cloud system (between € 1,300 and € 2,500 per year)[27] and the people involved in it (between € 30,000 and € 50,000 per year)[28].

Social acceptance

The social acceptance of this technology aimed at use by authorities and government entities is high. In this sense, the use and adoption of this technology on a large scale allows minimizing the risks of affecting extreme weather events within populations and / or areas vulnerable to flooding. In this way, an increase in lives saved and minimization of infrastructure losses have a positive impact on society. In the same way and related to environmental issues, these techniques allow to establish risk models in a holistic way. This aspect allows planning, designing, and monitoring actions that allow the regeneration of biodiversity, ecosystems and at the same time minimize the impacts caused by these natural disasters.

Recipients

- Public administrations
- Hydrographic confederations
- Environment agencies at regional level
- Farms

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Floods

Conceptual fit within climate change adaptation

This type of system allows the development of strategies for the implementation of measures and actions that minimize the risks caused by the appearance of extreme hydrometeorological events. In this sense, the high resolution of these systems (10m) attached to the possibility of being able to increase it with LIDAR technology (0.3m) will allow to create raster maps[58] that allow a much more adjusted operational decision making and planning. And finally, this more accurate decision-making will allow progress in the development of innovative adaptation actions against climate change in a cost-efficient way.

[56] TAIKO Meteorology. Precision instruments.

[57] TAIKO Meteorological. Professional weather stations.

[58] Esri (2016) Raster data

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
China (Lingbao)	China Water Institute	2018	Improvement of China's FFEWS system to reduce model accuracy to 10m.
China (Sichuan)	China Water Institute	2020	Improvement of the system in the characterization of rain episodes (in certain time phases). In addition, the system has been updated to host an ArcGIS visualization.

Main stakeholders (organizations, companies, institutions, etc.)

- Watershed managers
- Companies providing digital and physical technology
- Water-related research organizations

4.3.1.6 Satellite rain episode modelling systems for landslide prediction

(Authors: Aitor Corchero Rodríguez and Eloy Hernández Busto)

Areas or sectors where it applies:

- Water
- Urban planning and building
- Health

Type of solution: IT "Information Technology" Solution[9]

Solution / Technology

The solutions and products for the dynamic calculation of rainfall thresholds correspond to analytical and statistical modules to forecast the occurrence of landslides in areas near coastal and mountainous terrain, where these events are more frequent. Quantitative reconstruction of rainfall conditions that can cause landslides is the first step in identifying effective rainfall thresholds. This system is usually attached to early warning systems to make predictions of the occurrence of such landslides. To do this, the system considers the reconstruction of previous scenarios of rain episodes.

Basic description

These rainstorm prediction systems for the detection of landslide events are a technology that has been studied since the 90s[59]. Throughout these years, these systems have mainly focused on the constant increase in the spatiotemporal resolution of information. In addition, the evolution of these systems has been marked by the improvement of the precisions of the algorithms that calculate the thresholds automatically and dynamically based on past occurrences. Throughout this evolution, these systems have been using a physical modelling of rain episodes[60], the elaboration of empirical heuristics[61] and finally, the construction of prediction systems and optimization of parameters[62].

[59] T. Brunetti, M. Melillo, S. Peruccacci, L. Ciabatta, L. Brocca, How far are we from the use of satellite rainfall products in landslide forecasting?, Remote Sensing of Environment, Volume 210, Pages 65-75 (2018)

[60] M. Alvioli, R.L. Baum, Parallelization of the TRIGRS model for rainfall-induced landslides using the message passing interface, Environmental Modelling & Software, Volume 81, Pages 122-135. (2016)

[61] Piciullo, L., Garian, S.L., Melillo, M. et al. Definition and performance of a threshold-based regional early warning model for rainfall-induced landslides. Landslides 14, 995–1008 (2017).

[62] Bengtsson, L., Dias, J., Gehne, M., Bechtold, P., Whitaker, J., Bao, J., Magnusson, L., Michelson, S., Pegion, P., Tulich, S., & Kiladis, G. N. Convectively Coupled Equatorial Wave Simulations Using the ECMWF IFS and the NOAA GFS Cumulus Convection Schemes in the NOAA GFS Model, Monthly Weather Review, 147(11), 4005-4025. (2019)

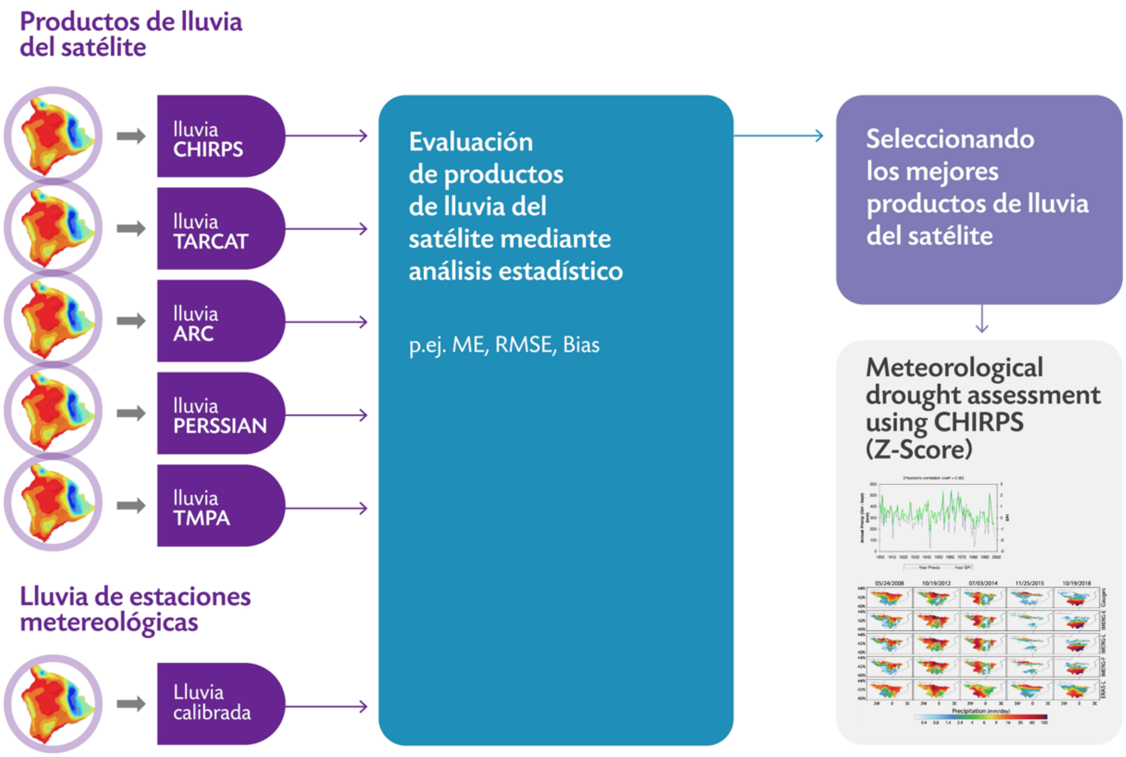

Figure 5. Satellite system for modelling rainfall episodes. Source: own elaboration.

Currently, the models that use the CTRL-T methodology (*"Calculation of Thresholds for Rainfall-induced Landslides-Tool"*)[63] are the most suitable to singularize precipitation events from continuous precipitation series. For each landslide, the tool (1) automatically selects the representative pixel, (2) identifies the most likely cumulative duration and precipitation conditions that are supposed to cause a landslide, and (3) calculates the empirical rainfall duration thresholds of the cumulative event considering various probabilities.

Implementation potential

Advantages	Disadvantages
• Rain event prediction system. • Calculation of automatic thresholds for the detection of landslide events. • Tool to complement flood early warning systems. • They are partially adaptable to climate uncertainties.	• They are systems that require a high computing time for the calculation of thresholds. • They are dependent on sensor measurements (accuracy). • The characterization of rainfall and land displacement events is a process that cannot be automated, so specialized labour is required. • High installation costs.

Potential barriers to implementation

The main barriers (or requirements) for the implementation of these systems are classified into the following blocks[64]:

Environmental/Orographic. For the large-scale adoption of these systems, rainfall and erosion impact studies based on historical information are required. This type of study is necessary so that the system can relate topographic and orographic information.

[63] Massimo Melillo, Maria Teresa Brunetti, Silvia Peruccacci, Stefano Luigi GarianAnna Roccati, Fausto Guzzetti, A tool for the automatic calculation of rainfall thresholds for landslide occurrence, Environmental Modelling & Software, Volume 105, Pages 230-243. (2018)

[64] Bodo Bookhagen and Manfred R. Strecker. (2007). Orographic barriers, high-resolution TRMM rainfall, and relief.

Institutional. Strict cooperation between institutions is necessary for the implementation of these systems. Particularly, when different types of information related to rainfall and climate predictions are combined.

Level of innovation today TRL = 5/6

Although this technology has been studied for the last decades, it is still in the demonstration and validation phase in controlled environments. One of the prediction tools that is gaining relevance is the one based on Melillo et al (2018). This system has the primary capabilities of (i) semi-automatically reconstructing rainfall events; (ii) calibrate parameters based on water balance models; (iii) calculation of thresholds based on probabilities based on a predictive system (*Max Probability Rainfall Conditions -MPRC*).

Other similar systems are those based on SREM2D *("A Two-Dimensional Satellite Rainfall Error Model")*[65] that consider stochastic errors in satellite rain predictions. These systems use flow simulations combined with climate prediction systems, rain satellite systems and rainfall sensors for threshold calculation.

Another of the proven solutions is the so-called LEWS ("*Landslide Early Warning Systems*") as a solution demonstrated in 12 different locations in a distributed way. In this sense, the tool incorporates a layer of systems based on the Internet of Things where the variables of precipitation, humidity, inclination, and depth of the terrain are measured. With this information, modelling and learning for alert detection is done by applying techniques based on data models. Specifically, the most used data models are those based on support vector machine techniques. *Support Vector Machine -SVM*) for the prediction of values. Alerts are generated based on a statistical analysis of predictions to determine confidence intervals.

Finally, the solution called *TeLEWS*[66] (*"Territorial Landslide Early Warning Systems"*) it combines Internet of Things systems under a layer of *"edge computing"* to determine alerts (monitoring instruments and techniques). On this layer and to complete the generation of alerts, this solution includes meteorological modelling (based on SIGMA models / systems - *Integrato Gestione System Monitoraggio Allerta*-[67] and *Saturated Unsaturated Simulation for Hillslope Instability -SUSHI*[68]) and rain prediction techniques to determine landslide events caused by precipitation.

Expected or desirable advances in the coming years

Over the next few years[69], these systems are expected to evolve towards greater use of satellite technology to deliver large-scale predictions. In terms of modelling and prediction, algorithms and tools are expected to evolve to better short-term prediction heights (currently models make predictions in 48-hour prediction windows). This last aspect is of vital relevance to elaborate robust solutions considering the predictions of rain episodes. In addition, these systems are expected to evolve in the resolution of satellite monitoring to reach levels of less than 1 kilometre.

[65] Fangliang Chena, Huiling Yuana, Rouchen Sun, Chunlei Yang. Journal of Hydrology. *Streamflow simulations using error correction ensembles of satellite rainfall*, 20. (2020)

[66] Luca Piciulloa, Michele Calvelloa, José Mauricio Cepeda. Earth-Science Reviews. Territorial early warning systems for rainfall-induced landslides, 20. (2018)

[67] Martelloni, G., Segoni, S., Fanti, R. et al. Rainfall thresholds for the forecasting of landslide occurrence at regional scale. Landslides 9, 485–495. (2012)

[68] Capparelli, G., Versace, P. FLaIR and SUSHI: two mathematical models for early warning of landslides induced by rainfall. Landslides 8, 67–79. (2011)

[69] Tapiator, F.J.; Villalba-Pradas, A.; Navarro, To.; García-Ortega, E.; Lim, K.-S.S.; Kim, K.; Ahn, K.D.; Lee, G. Future Directions in Precipitation Science. Remote Sens. 13, 1074. (2021)

Expected results

As expected, results of the adoption of this technology, and based on the empirical studies carried out, the benefits can be summarized as:

Benefit	Measure
Temporary tolerance	48-hour interval
Resolution of predictions	Each pixel behaves like a virtual rain gauge, and covers an area of 25x25 km^2

Installation costs

The calculation of the installation costs has been made based on estimates considering the modules and sensors to be installed. In this sense, the estimated installation costs would be around € 8-9M. Specifically, these systems require the installation of climate models (€ 6M), rainfall prediction models (€ 1-2M) and installation of rainfall sensors (€ 750k).

Operating costs

As for the operating costs, these costs can be estimated at € 150k per year. This amount includes the maintenance costs of systems, algorithms and network of rainfall sensors necessary for the calculation of thresholds (€ 100k), cloud maintenance (between € 1,300 and € 2,500 per year) and finally, experts in analysis and categorization of rainfall events and landslides (between € 30,000 and € 50,000 per year).

Social acceptance

The implementation and the results derived from this technology will have a high social acceptance because this type of tools will help to develop plans for landslide events aligned with heavy rain events. These episodes are derived from the effects of climate change in our region. That is why these systems will have an impact on society by reducing the costs of materializing these events, as well as reducing the mortality caused by these events.

Recipients

- Hydrographic confederations
- Environment agencies at regional level

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Floods
- Heavy rainfall
- Rainfall and/or hydrological variability
- Soil erosion

Conceptual fit within climate change adaptation

The solution presented helps to minimize the impacts caused by the appearance of landslides caused by episodes of heavy rain. Therefore, this solution is framed in the technologies of adaptation to climate change. Considering this aspect, this type of solutions will allow, in the long term, the elaboration of risk plans derived from the impact of climate change by predicting rain episodes with a higher resolution and a higher time horizon. This will benefit the realization of climate adaptation and mitigation plans in the different mountainous and coastal regions where this type of technology is installed.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Italy	IRPI	2018	Demonstration of the S2MRAIN-ASCAT system at a medium country scale for rainfall prediction and runoff thresholds.
Region of Liguria	IRPI	2018	Demonstration of the rain prediction system (CTRL-T) Liguria (5410km^2).
Rio de Janeiro	University of Salerno	2018	Demonstration of TELEWs in the Rio de Janeiro region to educate and determine operational alerts on landslides.
Nile River	Debre Tabor University	2020	Application of ESA satellite models, combined with a network of rainfall sensors for the prediction of the mentioned events.
Brazil	Nanjing University	2020	Application of SREM2D models for corrections of rainfall predictions.
India	Amrita School	2020	Demonstration of LEWS as a tool for event detection using SVM.
India	IRPI	2021	Demonstration of the S2MRAIN-ASCAT system at a country scale with large extension for the prediction of rainfall and runoff thresholds.

Main stakeholders (organizations, companies, institutions, etc.)

- Watershed managers
- Digital technology providers
- Artificial Intelligence and modelling companies
- Water-related research organizations

4.3.2 Water

4.3.2.1 Rain gardens

(Autores: Laura del Val Alonso y Xavier Martínez Lladó)

Areas or sectors where it applies:

- Water
- Urban planning and building
- Biodiversity and natural heritage

Solution typology: Nature-based solution[70]

Solution / Technology

Rain gardens are a Sustainable Urban Drainage (SUD) technique capable of capturing rainwater before it reaches the sewer network. Other common names for rain gardens are bioretention basins or vegetated basins.

Basic description

One of the expected effects of climate change is the increase in rainfall variability, which will lead to more extreme and frequent torrential rains. This trend causes existing urban drainage and treatment systems to reach their capacity limit more frequently. In this context, rain gardens offer a tool to reduce pressure on urban drainage systems.

Rain gardens are composed of a sunken landscaped bed capable of collecting and treating rainwater runoff from rooftops, driveways, sidewalks, parking lots and streets. These basin-shaped garden areas are designed to capture runoff, settle and filter sediments and pollutants. Runoff is channelled or directed into the basin, where it is temporarily stored until it slowly seeps into the ground.

Figure 6. Vista general de un jardín de lluvia. Source. Biblus.

[70] Nature-based solutions are those that are inspired and supported by nature, that are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. European Commission.

Rain gardens are classified into two types: infiltration gardens and filtration gardens[71].

Infiltration gardens allow runoff to pass through a series of layers of draining layers and sediments, dispersing water into the ground and thus controlling runoff volumes. It is advisable to include a drainage layer of coarse aggregate that prevents the washing/erosion of rain garden materials.

Filtration gardens also cause runoff water to pass through the vegetation cover and middle layers of rain garden soil. However, in this case, the water is collected in a pipe and led to an approved discharge point.

Additional information on design options and construction details can be found in the "Retention Manual" published by the Maryland County Department of Environmental Resources (USA). USA), in "The Oregon Rain Gardens Guide" published by the University of Oregon (USA). UU), in the guide "Designing Rain Gardens: A Practical Guide" published by *Urban Design London*, the guide "Rain Garden. Design and installation" and the "Basic Design Guide for Sustainable Rainwater Management Systems in Green Areas and other Free Spaces" published by the Madrid City Council

Implementation potential

Advantages	Disadvantages
• They allow to treat runoff water, not just retain it. • It favours the habitat for animals and plants. • Regulates thermal oscillations. • Prevents erosion.	• They have limitations to laminate the volumes of water generated by very intense rains. • Erosion of the facility can be complicated to control. • If not properly designed, they can generate odours or pests.

Potential barriers to implementation

According to Andrés-Doménec et al. (2021)[72] the main barriers in Spain to the implementation of urban drainage systems, such as rain gardens, are:

- Absence of a set of regulations or guidelines for its implementation at the national level.
- Technical resolution of clogging problems and decrease in infiltration capacity.
- Lack of participation, knowledge and organizational capacity.

Present level of innovation (TRL = 9)

It can be said that, although rain gardens are still the subject of research and development, their basic operation is known and there are multiple guides and recommendations for their design and installation. At present there are already companies specialized in its installation, although its use is not widely widespread.

Expected or desirable advances in the coming years

In recent years, a large part of the efforts related to this type of rainwater management solutions have focused on the search for fertilizers and materials that improve the

[71] Cahill, M., Godwin, D. C., & Tilt, J. H. Rain Gardens: Low-impact development fact sheet. LOW-IMPACT DEVELOPMENT FACT SHEET, Oregon State University, June. (2018)

[72] Andrés-Doménech, I.; Anta, J.; Perales-Momparler, S.; Rodriguez-Hernandez, J. Sustainable Urban Drainage Systems in Spain: A Diagnosis. Sustainability. 13. (2021)

decontamination power of these systems.[73]. Thus, for example, Wan et al. (2018)[74] proved that the use of wood chips as a filter medium removed up to 55% of the total nitrogen present in runoff water.

Expected results

One of the expected results of the installation of these systems is a reduction in the runoff absorbed by the drainage systems and subsequent treatment. Depending on the scale of the garden, a considerable reduction in grey water treatment costs can be achieved. On the other hand, these spaces are habitat for species that could hardly survive in highly urbanized areas. They are also spaces for the enjoyment of the neighbours, who can even participate in their construction or maintenance, with added value as an educational and social awareness element.

Installation costs

Installation costs vary depending on soil conditions, extent and the type and density of plants to be used. The Three Rivers Rain Garden Alliance provides a calculator to estimate the characteristics and approximate costs of installing a rain garden. This calculator is fundamentally focused for individuals who want to install a rain garden on their plot.

For larger-scale projects, such as the installation of a rain garden or green area in a city, the Madrid City Council published a "Basic Guide for the Design of Sustainable Rainwater Systems in Green Areas and other Public Spaces" analysing the average cost of rain gardens, giving an indicative range of 30 to 200 €/m^2.

Operating costs

Maintenance costs depend on the size and complexity of the garden. According to the practical guide "Designing Rain Gardens" the maintenance work during the first two years of the garden is the most intense. These include frequent watering, cleaning weeds and garbage, pruning, cleaning filters and pipes, and applying amendments and fertilizers. During the following years the work will be the same, limiting the irrigation and amendments, as well as the frequency of the rest of the activities.

The "Basic Guide to the Design of Sustainable Rainwater Systems in Green Areas and Other Public Spaces" establishes average maintenance costs between 1.5 and 4.9 €/(m^2-year).

Social acceptance

In principle, this type of infrastructure has great acceptance since it implies the generation of a landscaped space. However, if they are not built properly, they can generate odours or pests, producing the opposite effect.

Recipients

- City councils
- Water boards
- Environment agencies at regional level
- Companies with industrial facilities involving water management
- Neighbourhood associations

[73] Gilbreath, A.; McKee; L.; Shimabuku, I.; Lin, D., Werbowski; L. M., Zhu; X., Grbic, J. & Rochman, C. Multiyear Water Quality Performance and Mass Accumulation of PCBs, Mercury, Methylmercury, Copper, and Microplastics in a Bioretention Rain Garden. Journal of Sustainable Water in the Built Environment, 5(4). (2019)

[74] Wan, Z., Li, T., & Liu, Y. (2018). Effective nitrogen removal during different periods of a field-scale bioretention system.

Impact on adaptation to climate change

Risks arising from climate change to which this solution can help us to adapt

- Rainfall and/or hydrological variability
- Heavy rainfall
- Soil erosion

Conceptual fit within climate change adaptation

Rain gardens reduce surface runoff by increasing in some cases the recharge of the underlying aquifer and decreasing surface erosion. They are therefore a mechanism for mitigating the effects of increasing extreme climatic/meteorological events, such as increasingly intense rainfall or increasingly prolonged periods of drought. In addition, the infiltration of rainwater through sediments eliminates pathogens and reduces the concentration of nutrients, organic substances, and heavy metals, which would otherwise end up directly in rivers or lakes compromising the quality of surface water.[75]

On the other hand, in urban areas, they reduce runoff into sewage systems allowing greater adaptation of urban drainage systems to the increase in extreme rainfall events, increasing the recharge of underlying aquifers.

Real cases and pilots where the solution has been applied

Location	Responsible	Year	Description
La Atalayuela (Madrid)	Madrid City Council	2019	Park of 9.4 hectares that includes a complex of rain gardens capable of retaining 390m^3.
Prologis Park Sant Boi (Barcelona)	TYPSA; UPC	2019	This park is capable of draining 30 hectares, avoiding the effect of rapid flooding that usually occurs in September and October, increasing the resilience of the industrial park *ProLogis*.
West Gorton Park (Manchester)	*Manchester Climate Change Agency*	2020	This park cushioned the effects of Storm Christoph in 2021. The project from the EU GROW GREEN will help to improve it.

Stakeholders (organizations, companies, organizations, etc.)

- City councils
- Promoters
- Developers
- Landscape
- Neighbourhood associations

[75] Shah, S., Venkatramanan, V., & Prasad, R. (2019). Sustainable green technologies for environmental management. Sustainable Green Technologies for Environmental Management, February, 1–303.

4.3.2.2 Artificial wetlands for the treatment of excess rainwater and runoff

(Authors: Laura del Val Alonso and Xavier Martínez Lladó)

Areas or sectors where it applies:

- Water
- Urban planning and building
- Biodiversity and natural heritage

Solution typology: Nature-based solution

Solution / Technology

Artificial wetlands are a set of wetlands built and designed by man that allows the management, and in some cases the purification, of the discharges caused by the overflow of the sewage systems during intense rains.

Basic description

One of the main effects of climate change is the increase in rainfall variability, which will imply a greater frequency of torrential rains. In many cases, these types of weather events produce an excess of runoff, which can exceed the maximum flow rate capable of being treated by wastewater plants[76].

Consequently, part of this excess is discharged directly into surface waters affecting its quality. The management of these excesses can be done through grey infrastructures, such as underground tanks that end up redirecting the excesses back to the treatment plants, or with what are called green infrastructures, such as artificial wetlands, capable of naturally treating a large part of the pollutants present.

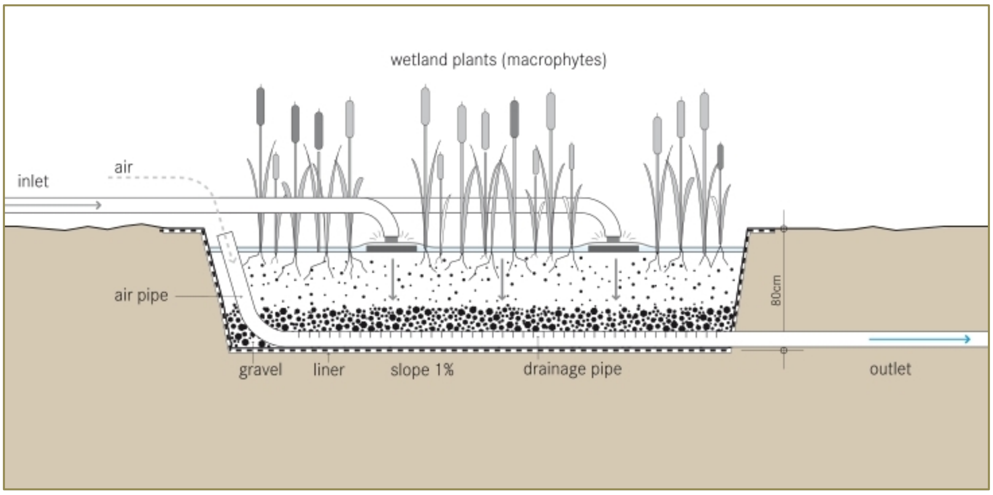

Figure 7. Constructed wetland scheme of vertical subsurface flow. Source: Swiss Federal Institute of Aquatic Science and Technology Technical drawings.

[76] Daniel Meyer, Pascal Molle, Dirk Esser, Stéphane Troesch, fabio Masi, Katharina Tonder, Johannes Pinnekamp &Ulrich Dittmer. (2014). Constructed Wetlands for Combined Sewer Overflow Treatment. Sustainable Sanitation Practice, Issue 18/2014.

Artificial wetlands are man-made areas in which the physical, chemical and biological processes of pollutant removal that normally occur in natural wetlands reproduce in a controlled manner[77].

There are different types of artificial wetlands depending on the direction of the effluent. In this way, we can differentiate between artificial wetlands of surface and subsurface flow, and between the latter, of horizontal flow and vertical flow[78]. Elements common to all wetlands are usually the presence of a granular substrate that facilitates the infiltration of water and the fixation of plants and bacteria, the presence of vegetation that contributes to oxygenation, the elimination of nutrients and the development of bacteria, and the effluent that circulates through the system.

On the other hand, we can differentiate between artificial wetlands for treatment, which include treatment systems with cane beds or soil filters with plants; and artificial filtration wetlands, consisting of basins filled with filter media such as sand or gravel and with vegetation that tolerates saturation conditions[79].

One of the cases studied on a real scale of an artificial wetland for the treatment of excess discharges from unitary systems is that of Gorca Maggiore in Italy[80]. In this case the system is composed of a set of artificial wetlands, which includes a) a contaminant removal zone with a grid, a sedimentation tank and 4 vertical subsurface flow lagoons; (b) a surface flow lagoon with multiple functions, such as pollution retention, buffering for flood events, maintenance of biodiversity and recreation; and (c) a recreational park with restored riparian trees. With this infrastructure, the artificial wetland of Gorca Maggiore can treat up to 640 l/s generated by a rain event of 10 mm/h. Anything that exceeds this volume is diverted to the surface wetland of additional free water.

Figure 8. Gorla Maggiore lake, Italy (Source: IRIDRA).

[77] MON arquitectura + biología. Los humedales artificiales: Componentes y tipos. iAgua.

[78] Global Wetland Technology. "Treatment Wetlands – Constructed Wetlands".

[79] AquaNES (2019). Combining constructed wetlands and engineered treatment for water reuse. Project deliverable D.3.1.

[80] Masi, F., Rizzo, A., Bresciani, R., & Conte, G. (2017). Constructed wetlands for combined sewer overflow treatment: Ecosystem services at Gorla Maggiore, Italy. Ecological Engineering, 98, 427–438.

Potential implementation

Advantages	Disadvantages
• Capable of biodegrading or immobilizing emerging pollutants better than grey infrastructures. • Permanent water storage in the deep layers of the wetland improves the resilience of the ecosystem against droughts. • They can provide a recreational area. • Improves the connectivity of urban ecosystems. • It offers protection against floods and avenues. • It needs little maintenance. • It generates little waste and sludge.	• Post-treatment may be necessary to comply with water reuse regulations[81]. • There may be long-term problems of clogging, generating a reduction in permeability. • Limitations in the elimination of some compounds. • In very cold climates biological degradation can be reduced, which would reduce the system's ability to assimilate nitrogen[79].

Potential barriers to implementation

The potential barriers to the implementation of artificial wetlands for the treatment of discharges from unitary systems is the lack of knowledge of the administrations of this type of systems, the need to involve different social actors, since they are usually infrastructures that have implications in the use of public spaces, or the need to comply with the legislation on water discharge that may involve the installation of additional treatment systems generating additional costs.

Level of innovation today (TRL = 9)

There are multiple cases of artificial wetlands implemented around the world. However, there are not so many real cases of treatment of unitary system discharges caused by sewerage overflow for which there is data on the performance of treatments. Even so, it can be said that it is a very mature technology, although its limitations and possible improvements are still being investigated.

Expected or desirable advances in the coming years

It is hoped that the increase in full-scale case studies will improve information on the effectiveness of systems and their limitations or factors for improvement. Some of the topics that need to be investigated are:

- Combination of different filter media.
- Retention limits of different contaminants.
- Effects on permeability.
- Risk of generating shortcuts in the flow of water that reduce the treatment capacity of the medium.
- Optimization of dwell times.

Expected results

It is expected that the biochemical and chemical demand for oxygen, indicators of the presence of organic pollution, will be reduced by more than 80% and 60% respectively. Dissolved solutes and total nitrogen could decrease by more than 50%. In the case of total phosphorus and total coliforms, the efficiency is much more variable, with an average of around 50%.

Installation costs

[81] Boano, F., Caruso, A., Costamagna, E., Ridolfi, L., Fiore, S., Demichelis, F., Galvão, A., Pisoeiro, J., Rizzo, A., & Masi, F. (2020). A review of nature-based solutions for greywater treatment: Applications, hydraulic design, and environmental benefits. Science of the Total Environment, 711, 134731.

The construction costs of such a facility vary greatly. As an indication, the values provided by Tao et al. (2014)[82] for several man-made wetlands built with the goal of buffering and treating the discharge of unitary systems in the U.S. The unitary cost of the wetland system in the city of Washington (Indiana) was € 2/m^3 compared to € 4/m^3 that would have cost the construction of a classic treatment system for the separation and physical/chemical treatment of this punctual excess. The artificial wetland at Harbor Brook (USA) had a total cost of €3.8M and was designed to treat 56,000 m^3/year of sewer overflow water. Assuming a useful life of 40 years, this means a cost of € 1.7 / m^3.

Operating costs

Maintenance costs are usually associated with personnel, pumps and flow control, and are around 1,700 €/ha-year[83].

Social acceptance

This type of green infrastructure has, in general, a great social acceptance, as long as they are well designed and do not generate bad odours or pests. They provide a recreational natural space and, in many cases, can be used as natural corridors.

Recipients

- City councils
- Water boards
- Public institutions (ministries or ministries) responsible for urban planning

Contribution to climate change adaptation

Risks arising from climate change to which this solution can help us to adapt

- Heavy rainfall
- Floods
- Rainfall and/or hydrological variability
- Protection of the water environment against pollution pressures

Conceptual fit within climate change adaptation

One of the main effects of climate change is the increase in the frequency and intensity of torrential rains. When one of these events occurs, runoff is generated that carries diffuse pollution. During these episodes the sewerage and treatment systems are not able to absorb the excess effluent due to runoff, which in many cases discharges directly into surface water.

Artificial wetlands are a cheap and integrated alternative with nature to greywater purification that would otherwise involve oversizing the drainage and purification systems of urban areas. In addition, they are a tool for protection against floods and avenues, in the case of being located near river areas.

[82] Wendong Tao, James S. Bays, Daniel Meyer, Richard C. Smardon and Zeno F. Levy (2014) Constructed Wetlands for Treatment of Combined Sewer Overflow in the US: A Review of Design Challenges and Application Status. Water 2014, 6, 3362-3385

[83] K. Gunes, B. Tuncsiper, F. Masi, S. Ayaz, D. Leszczynska, N. Fındık Hecan and H. Ahmad (2011) Construction and maintenance cost analyzing of constructed wetland systems. Water Practice & Technology Vol 6 No 3

Real cases and pilots where the solution has been applied

Location	Responsible	Year	Description
Gorca Maggiore, Italia[80]	IRIDRA OpenNESS proyecto	2012	Raft system designed to treat excess grey water caused by torrential rains before being discharged into the Olona River. The system treats one 150,000m^3/year in an area of about 3 ha. The area, where much of the retention and decontamination occurs, includes a wetland with *Phragmites* and other local species.
Artificial Wetlands- Experimental Purification Plant of Carrión de los Céspedes, Spain	Water agency from Andalusia CENTA		This artificial wetland is used as a secondary treatment. It is an artificial wetland of vertical flow plus an artificial wetland of horizontal flow. The artificial vertical flow wetland has an area of 317m^2, an average depth of 0.6 m, and a bottom slope of 1%. The waterproofing was made with high-density polyethylene plastic sheet 2.5 mm thick. It uses gravel as a substrate and has planted *Phragmites australis*. The artificial horizontal flow wetland has an area of 207 m^2, with an average depth of 0.8 m. Otherwise, it has the same structure as the previous one. Treats a flow of 15 m^3/day.  (Picture source: Depuración de Aguas del Mediterráneo)
Washington, Indiana, USA.	Bernardin, Lochmueller & Associates Inc.	2011	This system was built to respond to the need to treat sewer overflows caused by rainfall events of more than 250 mm. The wetland treatment system consists of a nutrient deflector box, a 15,120 m^3 pond, a meandering wetland, a gravel filter and a UV disinfection system in the drain.
Carimate, Italy	IRIDRA WWTP Carimate	2018	Sewer overflow treatment system consisting of a first stage of two beds for vertical infiltration, each of them divided into 2 separate hydraulic sectors for a total area of 8,500 m^2. The second stage is a free water surface wetland of 4,500 m^2. The system treats 500,000 m^3/year, 58% of all overflows produced.
Marrakech, Morocco[84]		2015	Reuse of grey water for irrigation of green areas. The system is able to treat 1.2 m^3/day

Stakeholders (organizations, companies, institutions, etc.)

- Ministries of the environment
- Local governments
- Water boards
- Management companies of the urban drainage network
- Companies specialized in the design and construction of artificial wetlands

[84] Laaffat, J., Ouazzani, N., Mandi, L.,The evaluation of potential purification of a horizontal subsurface flow Constructed Wetland treating greywater in semi-Arid environment, Process Safety and Environment Protection (2015).

4.3.2.3 Reservoir operational protocol adaptation

(Autores: Laura del Val Alonso y Xavier Martínez Lladó)

Areas or sectors where it applies:

- Water
- Energy

Type of solution: "Information Technology" Solution

Solution / Technology

Methodologies for the adaptation to the effects of climate change of reservoir operation protocols (storage and release).

Basic description

Reservoirs are fundamental structures for the regulation of river flows, and they effect of the availability of water for multiple sectors. In addition, in many cases, they are infrastructures that generate energy. In fact, they are in the strategic nexus water-energy-food-environment. On the other hand, they are one of the infrastructures for power generation and surface water management most exposed to the effects of climate change. Hydroelectric power generation is affected by increased rainfall variability and the consequent reduction in water availability. In addition, energy production also depends on the availability of the resource for other uses, in many cases of higher priority, such as domestic supply, agricultural use or minimum ecological flows. Climate change can therefore be expected to hamper decision making about how and when to release or store water.

Traditionally, emptying and storage periods have been regulated by so-called operating regulations, used to manage the uncertainty of inflows.[85] Operational regulations are designed to mitigate differences in water availability between dry and wet periods throughout the year, storing during the wet period and releasing flow during the dry period. These regulations are normally designed considering a long-term seasonality of inflows, which implies inefficient operation under climate change conditions. Improving reservoir operation protocols is therefore a fundamental strategy for mitigating the effects of climate change on the availability of water resources. This improvement can be approached from two points. The first, the identification of the moment in which the current protocols of a reservoir will not work properly, taking into account the forecasts of climate change. On the other hand, the use of predictive models and strategies to make the protocols dynamic and allow an optimization of the operating objectives of the reservoir. Both strategies are complementary.

[85] Feng, M., Liu, P., Guo, S., Shi, L., Deng, C., & Ming, B. (2017). Deriving adaptive operating rules of hydropower reservoirs using time-varying parameters generated by the EnKF. Water Resources Research, 53(8), 6885–6907.

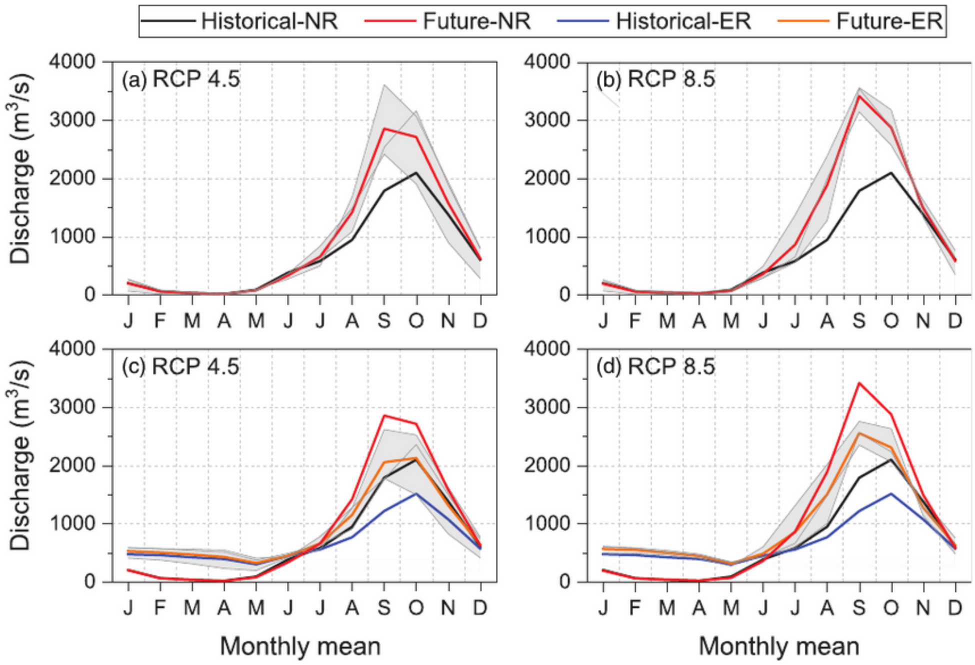

Figure 9. Example of application of predictive models to compare the annual discharge under current protocols (ER) and without protocols (NR) in different scenarios based on historical data and predictions (future). (Source: Padiyedath Gopalan, S, et al., 2020.).

One of the first steps in deciding whether it is necessary to make investments in adapting the operating protocols of a reservoir, is to know when and how these protocols will be obsolescent. This allows for an effective and reasoned use of available resources. A method that has recently been published[86] consists of the use of a *reliability-resilience-vulnerability framework*[87] with a set of *General Circulation Models*[88] under the four scenarios of the *Representative Concentration Pathways*[89] to compare the historical and future performance of the reservoir in the long term under its current operating protocols.

The method uses various tools to relate climate, hydrological, storage system data and its operation. First, a hydrological model with climate data is calibrated with historical data to be able to include in the analysis how climate change affects the entry of water into the system. On the other hand, a series of performance indices are applied to evaluate the possible operating protocols. Finally, the moment in which the current protocols will fail is identified respecting the information related to the uncertainty associated with future scenarios. This data helps the planning, prioritization and implementation schedule of realistic alternatives for

[86] Chadwick, C., Gironás, J., Barría, P., Vicuña, S., & Meza, F. (2021). Assessing reservoir performance under climate change. When is it going to be too late if current water management is not changed? Water (Switzerland), 13(1).

[87] The *reliability-resilience-vulnerability framework* is an approach whereby the performance of a system can be described from three different points of view. The frequency with which the system fails, i.e. reliability. How quickly the system returns to a satisfactory state once a failure has occurred, i.e. resilience. And the importance of the possible consequences of a failure, that is, vulnerability (Hashimoto et al. (1982) Reliability, resiliency, and vulnerability criteria for water resources system performance evaluation. Water Resour. Res.)

[88] *General Circulation Models* represent the physical processes of the atmosphere, ocean, cryosphere, and land surface. They are commonly used to simulate the response of the global climate system to rising greenhouse gas concentrations. (IPCC)

[89] *Representative Concentration Pathways* are scenarios that include time series of emissions and concentrations of the entire set of greenhouse gases and aerosols, and chemically active gases, as well as land use and cover. The word representative means that each pathway provides only one of many possible scenarios that would lead to the specific characteristics of radioactive forcing. The term trajectory highlights that not only long-term concentration levels are of interest, but also the trajectory followed over time to reach that result. (IPCC)

adaptation to climate change, improving efficiency in electricity production and reconciliation with the rest of the uses.

The second approach is the implementation of adaptive operating regulations, in which we try to optimize the emptying and storage periods, to cover the different uses of water in the optimal possible way, considering predictive models with climate change scenarios.[90].

Implementation potential

Advantages	Disadvantages
• These are implementation strategies that do not require a large investment. • They represent an alternative to the modification of infrastructure or creation of new ones. • There are green funds that may be interested in investing in renewable energies such as hydropower, which would involve investing in the adaptation of dam operation protocols to improve their performance. • It can be complemented with better models such as the one explained in Ap. 4.31	• It requires very technical knowledge for its implementation. • There is no single methodology for adapting reservoir operation protocols. This can reduce confidence in the solution and make it difficult to implement.

Potential barriers to implementation

- Very technical knowledge is required for the implementation of this type of strategy, which implies involving organizations or specialized consultancies.
- There are many new methodologies, so it can be complex to choose one or find several case studies applying the same.
- Mobilizing investment to implement such strategies can be difficult.

Level of innovation today (TRL = 5)

The set of methods and approaches that exists in what we can call adaptation of operating protocols is broad and there are many case studies that apply multiple variants of the same approach. There is, therefore, no single methodology that has been replicated in many cases. However, they are methods that are already being tested and applied in real cases, and that help to provide scientific information appropriate to the needs of water managers and professionals.

For example, identifying the time when the performance of current reservoir operating rules will worsen significantly due to climate change is something that is currently being investigated. In this case, the novelty is the way to present this risk factor in terms of time and to preserve the information on uncertainty, so that managers can adapt the operating protocols.

Expected or desirable advances in the coming years

The challenge of these strategies is the integration of physical, chemical and ecological processes, with the economic effects of reservoir operation strategies. Likewise, it is expected that in the coming years new tools such as integrated models or artificial intelligence will be applied to improve the predictions on which management strategies are based[91], generating, for example, dynamic regulations that adapt in real time to the predictions of flows, uses and energy consumption.

[90] Zou, H., Liu, D., Guo, S., Xiong, L., Liu, P., Yin, J., Zeng, Y., Zhang, J., & Shen, Y. (2020). Quantitative assessment of adaptive measures on optimal water resources allocation by using reliability, resilience, vulnerability indicators. Stochastic Environmental Research and Risk Assessment, 34(1), 103–119.

[91] Fu, G., Ni, G., & Zhang, C. (2019). Recent advances in adaptive catchment management and reservoir operation. Water (Switzerland), 11(3), 1–7.

Expected results

The expected results are difficult to quantify due to the novelty of these methodologies and the scarcity of case studies of their long-term application. Its application is expected to improve the efficiency of release and storage operations, the reconciliation of the different uses of water (hydroelectric, agricultural, environmental, recreational, urban supply, etc.) as well as the reduction of long-term risk.

Installation costs

Due to the scarcity of case studies on the same methodology, there are no estimates of implementation costs. As a guide we can take the figure offered in the "Methodological guide for the analysis and prioritization of measures of adaptation to climate change[92], where the cost of implementing a weather and climate prediction program for the management of the reservoirs of La Cala (province of Seville), El Tranco de Beas and the Mengíbar plant, the latter two in the province of Jaén, was assessed. The Cala and El Tranco plants are reservoir plants, and the release of flows in these facilities is conditioned to the needs of urban water supply and downstream irrigation. The Cala reservoir has a capacity of 59 hm^3 and covers an area of 437 ha. The El Tranco reservoir has a capacity of 498 hm^3 and covers an area of 1800 ha. On the other hand, the Mengíbar plant is a flowing plant without regulation capacity. It has a reservoir capacity of about 2.4 hm^3 covering about 79 ha. It was estimated that the cost of implementing a weather and climate prediction program for the management of the reservoirs would be about € 190,000.

Operating costs

Once the methodology is implemented, the main activity that would be required is the monitoring of the uncertainty of the results and continuous calibration of the predictive models. This implies expenses in personnel dedicated to this monitoring and maintenance activity, as well as their continuous training and the maintenance of the software and equipment used.

Social acceptance

There is no a priori agent or organization that may position itself against the implementation of this type of methodology. However, it is possible that, if the results of this methodology negatively affect the availability of water in any sector due to a change in the prioritization of uses, those sectors will be negatively positioned.

One of the uses that can be benefited is the ecological flow, since we can adjust the protocols dynamically to maximize the volumes of release destined to maintain the ecological flow of the river, while the releases are maximized for example for energy production at certain times of greater value.

Recipients

- Water boards
- Hydroelectric companies
- Irrigation communities
- Infrastructure operators

Relevance for climate change adaptation

Risks arising from climate change to which this solution can help us to adapt

- Rainfall and/or hydrological variability

[92] Solaun, K., Gómez, I., Urban, J. Gómez, J.C. (2016). Integración de la adaptación al cambio climático en la estrategia empresarial. Guía metodológica para el análisis y priorización de medidas de adaptación al cambio climático. Oficina Española de Cambio Climático, Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente. Madrid.

- Floods
- Heavy rainfall
- Droughts

Conceptual fit within climate change adaptation

Reservoirs are essential infrastructures for water supply and irrigation, especially in semi-arid and arid regions. The performance of reservoirs, with respect to energy production and water storage and availability, is expected to worsen with the effects of climate change: changes in precipitation patterns, increased temperature and, therefore, an increase in evaporation and an increase in the frequency and intensity of floods and droughts.

As for hydroelectric production, the tendency of the hydroelectric producible in Spain is to decrease (0.81% of the average). Rainfall has been reduced by an average of 50 to 60 mm per year. And the ratios that are being obtained show a reduction of 1% in precipitation, implying a reduction of 3.5 to 4% of the producible hydroelectric[93].

To tackle these problems, building new infrastructures is not always possible or desirable, especially if there is the possibility of improving the performance of existing ones by adapting them to the effects of climate change. Therefore, it is necessary to apply methodologies to adequately anticipate the malfunctions and performance of reservoirs that allow adapting their operating protocols.

Real cases and pilots where the solution has been applied

Location	Responsible	Year	Description
Paloma Reservoir, Limarí Basin, Chile	University of Chile. Research Center for Integrated Disaster Risk Management, Chile; Center for Sustainable Urban Development, Chile	2021	A method was applied for the assessment of the maximum time for which the reservoir's operating protocols were adequate taking into account future climate change scenarios. The study[94] concluded that protocols should be changed over the next few decades.
La Cala, El Tranco, Spain	Endesa	2016	This is a case study used for the assessment of adaptation to climate change by the Ministry of Agriculture and Fisheries, Food and Environment. One of the activities evaluated was the implementation of a program of weather and climate prediction and management of reservoirs, with the aim of increasing the production of hydroelectric power plants by improving the management of the reservoir, through new mathematical prediction models.
Lake Urmia, Iran	Amirkabir University of Technology, Teherán	2019	The Boukan Dam is the largest infrastructure built on the Zarineh-Roud River. The forecast-based, real-time adaptive optimal operating model for the Boukan reservoir maximizes discharges that feed the lake, while meeting irrigation, industrial and household needs[95].

[93] Herrero, R. Sobre los embalses y el cambio climático. iAgua. [Consultado el 8/11/2021]

[94] Chadwick, C., Gironás, J., Barría, P., Vicuña, S., & Meza, F. (2021). Assessing reservoir performance under climate change. When is it going to be too late if current water management is not changed? Water (Switzerland), 13(1).

[95] Gavahi, K., Jamshid Mousavi, S., & Ponnambalam, K. (2019). Adaptive forecast-based real-time optimal reservoir operations: Application to Lake Urmia. Journal of Hydroinformatics, 21(5), 908–924.

Figure 10. El Tranco Dam. Source: El Tranco Leisure and active tourism centre.

Main stakeholders (organizations, companies, institutions, etc.)

- Water operators
- Hydroelectric companies
- Water boards
- Institute of Water Engineering and Environment (IIAMA)
- Institute of Environmental Hydraulics of Cantabria (IH-Cantabria)
- INCLAM Group
- Association of Civil Engineers (CICCP)
- Spanish Committee of Large Dams (SPANCOLD)

4.3.2.4 Natural water retention measures for the renaturalization of wetlands

(Autores: Mireia Pla Castellana y Xavier Martínez Lladó)

Areas or sectors where it applies:

- Water
- Biodiversity and natural heritage

Solution typology: Nature-based solution

Solution/Technology:

Natural Water Retention Measures (NWRM) are multifunctional measures that aim to protect and manage water resources and address water-related challenges by restoring or maintaining ecosystems[96].

Basic description

The main objective of this type of action is to increase the water retention capacity of aquifers, soil and ecosystems in order to improve their status.

Some of the most common measures are[97]:

- Rechannelling of rivers: Returning rivers to their natural channel, recovering their water load.
- Renaturalization of the bed of the streams, for example, repopulating the bed of the rivers with more urban impact with native plants.
- Reconnection of seasonal streams, for example, drought prevention by controlling the water load of lakes and streams that only flow in the wettest seasons (spring and autumn).
- Renaturalization of the material of the riverbed, controlling the natural sedimentation of the very urbanized riverbeds, transformed into urban channels.
- Elimination of barriers, through the physical removal of water storage systems, which also retain sediments, and which directly impact downstream ecosystems.
- Natural stabilization of the banks, through the planting of native species that allow to stabilize banks and slopes.
- Renaturalization of polder areas[98], in which it drains.

[96] Office International de l'Eau. "*Natural Water Retention Measures*".

[97] Somarakis, G., Stagakis, S., & Chrysoulakis, N. (Eds.). (2019). ThinkNature Nature-Based Solutions Handbook. ThinkNature project funded by the EU Horizon 2020 research and innovation programme under grant agreement No. 730338.

[98] Del neerlandés, polder. Terreno pantanoso ganado al mar y que una vez desecado se dedica al cultivo.

Figure 11. Canalization (a) and subsequent restoration (b) of the Rombach River in Fuldera (Switzerland). Source: Pio Pitsch.

Potential implementation

Advantages	Disadvantages
• Control of the quantity and quality of runoff. • Decreased interference in the natural regimes of the receiving water bodies. • Better reuse of runoff for aquifer recharge. • Decreased flood risk. • Decreased risk of erosion and fracture of slopes, and mudflows. • Increase in the added value of the urbanizations, due to the improvement of the landscape and the environment. • Improvement of the aesthetic quality of an urban area, creating natural environments. • Reduction of the concentration of pollutants carried by runoff that reach the aquifer. • Improvement of the fauna and flora of the re-naturalized area. • Require less construction investment and are, therefore, considered low-cost stormwater drainage systems.	• There is a lack of knowledge regarding the application of these systems, their durability, the overall cost of construction and management. • The application of these systems entails the need to perform design and management validations, which can be extended over time. • The lack of specific information on its application in different climatic zones with different rainfall patterns. • Performance and service life are not deeply known, so they can lead to mistrust.

Potential barriers to implementation

The lack of a large number of full-scale experiences to reduce uncertainty is a major barrier when implementing natural water retention systems. On the other hand, in many cases, the state of the ecosystem or the area to be improved cannot be specified exactly. In addition, until the intervention is done, and data is collected to be able to make direct comparisons that facilitate the dissemination of the results in society, it is very difficult for the appreciation of the benefits of the system to grow.

Level of innovation today TRL = 9

All the systems included in the NWRM have been duly studied and implemented in many countries, with different problems. Its level of innovation is considered mature, but in many cases more information is needed for decision-making, so that the application of a natural system is chosen before a conventional infrastructure.

Expected or desirable advances in the coming years

The most important development that could be expected is its implementation on a larger scale. This implies that both the people involved in decision-making and the public choose an NWRM before conventional infrastructures.

Expected results

The expected results of the installation of these systems are a reduction in the runoff absorbed by the drainage systems and subsequent treatment. Depending on the scale of the system this can lead to a considerable reduction in the costs of treating runoff water. On the other hand, these spaces are a habitat for species that could hardly survive in highly urbanized areas. They are also locations that are enjoyed by neighbours, who can even participate in their construction or maintenance, having an added value as an element of education and awareness in society.

Installation costs

Compared to traditional infrastructures, also called grey, natural water retention structures are cost-effective solutions when tangible and intangible benefits are considered[99]. It is also important to consider the additional cost compared to the installation of conventional measures. For example, the Milwaukee Metropolitan Sanitation District compared the installation costs of different urban drainage strategies versus conventional infrastructure.

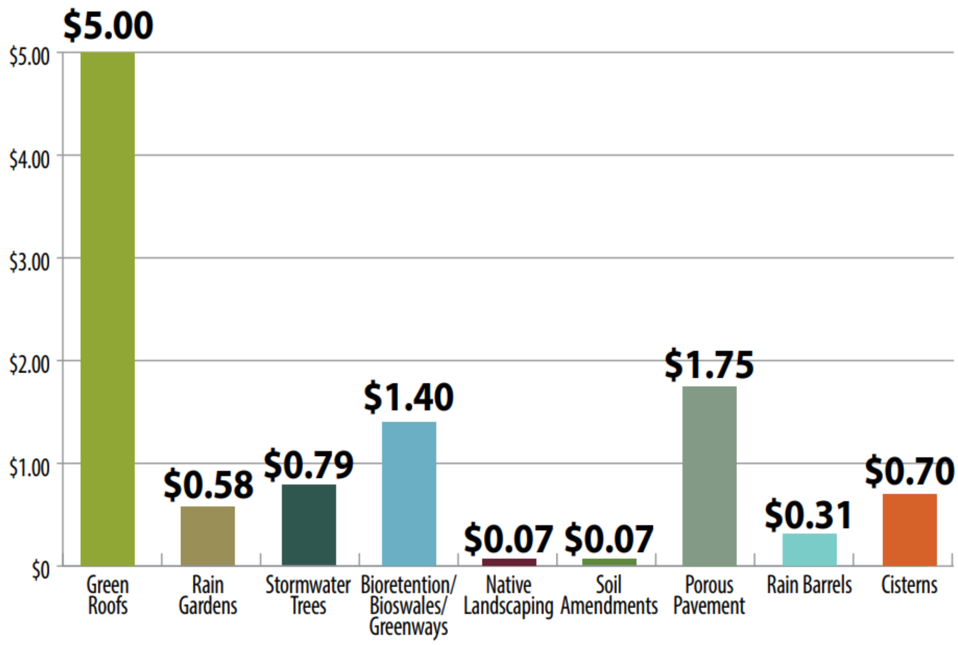

Figure 12. NWRM installation costs compared to grey infrastructure costs per unit area (square foot). Source: Milwaukee Metropolitan Sewerage District[100].

However, the costs are highly variable and depend on the solution that is proposed. End-to-end solutions will be more expensive than individual solutions. The materials used must also be considered (type of wood, quality of the meshes, type of plants and /or trees planted, if an initial recovery of the land is necessary, etc.).

[99] Acteon Environment, Office International de l'Eau. Synthesis document n°6 Cost-effectiveness of Natural Water Retention Measures What is the cost-effectiveness of NWRM?

[100] MMSD (Milwaukee Metropolitan Sewerage District), 2013. Regional Green Infrastructures Plan.

For example, in France, water agencies award grants to support the implementation of these measures. Higher subsidy rates are offered for implementing Natural Water Retention Measures (NWRM) (60-70%) than for conventional infrastructures (20-40%).

Operating costs

These are directly related to the size of the infrastructure and include the initial care of the areas, the hiring of temporary staff, as well as the problems that may arise sporadically. Once a *mature system* is considered, the costs related to the management of the zones decrease.

The economic cost of adopting an MRNA is, in many cases, sufficient to adopt one of these systems. A clear example is the town of Belford (USA), where there were frequent floods. In principle, the cost of implementing conventional downstream flood improvements was considered acceptable, around € 3 M[101]. However, it was estimated that the implementation of upstream Natural Water Retention Measures (NWRM), based on runoff mitigation measures, offered the same level of flood protection at a lower cost (€ 0.25 M). Economic efficiency made the latter the best alternative, as well as providing the same flood protection by attenuating flow, reducing sediment load, and substantially improving water and ecosystem quality[101].

As in the case of installation costs, it is also important to consider the incremental operating cost compared to conventional measures. In the case of Milwaukee, operation and maintenance costs were observed even lower than conventional strategies, highlighting the benefit of this type of strategy.

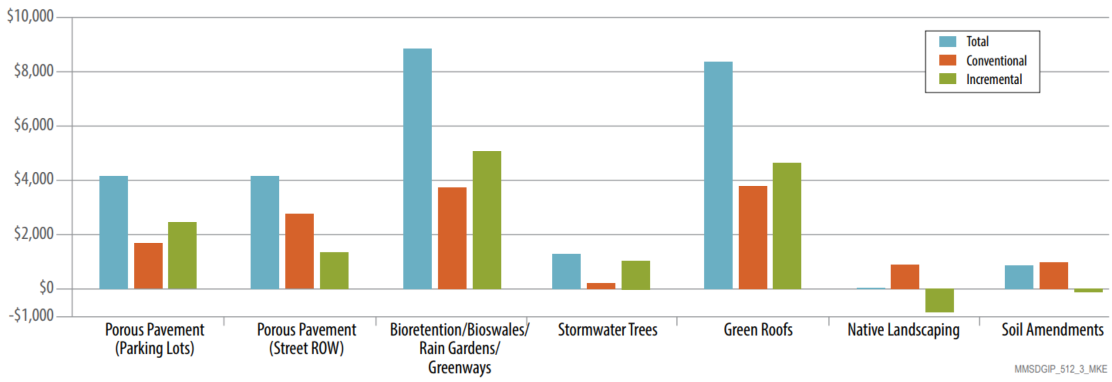

Figure 13. MNRA operation and maintenance costs compared to conventional infrastructure costs per unit area (square foot). Fountain: Milwaukee Metropolitan Sewerage District[102].

Social acceptance

This type of infrastructure has great social acceptance since they imply the generation of a landscaped space in communities, cities, denatured areas, etc. However, its construction and maintenance must be adequate. The installed measures must be maintained at least for the first 5 or 10 years, which would be the estimated time of maturation of the system. A clear example is the application of NWRM in the renaturalization of banks with slopes. Poor monitoring of the progress of these systems can generate future problems such as cracks and even collapse, which can generate a public health problem. In landscaped areas, poorly cared for trees and plants can die, and must be replaced.

Recipients

- Citizens.
- Municipalities.

[101] EU Technical report 2014-082. EU policy document on Natural Water Retention Measures By the drafting fo the WFD CIS Working Group Programme of Measures (WG PoM). 2014–082

[102] MMSD (Milwaukee Metropolitan Sewerage District), 2013. Regional Green Infrastructures Plan.

- Water boards.
- Environmental agencies at regional, national and international level.
- Companies with industrial facilities that involve water management, geological management, or urban management.

Relevance for climate change adaptation

Risks arising from climate change to which this solution can help us to adapt

MRNAs are structures that are implemented in different sectors, such as water, hydrological/geological risk management, biodiversity protection, ecological urban planning and adaptation to climate change.

Conceptual fit within climate change adaptation

Climate change is increasing the risk of extreme weather events, leading to an increased risk of flooding. Over the past century, we have been building man-made levees and large dams to protect people and their property from flooding. The current trend is to shift to more adaptive strategies using the various functions provided by natural ecosystems. In addition, these types of measures present a wide list of collateral benefits, such as improving water quality, recharging groundwater, improving habitat for many species, and positive impact on human well-being, creating natural green spaces, and improving the landscape.

Real and pilot cases where it has been implemented

Location	Responsible	Year	Description
Altos de la estancia, Bogotá, Colombia	UNESCO Chair in Sustainability – UPC	2015	The main objective of this project was the development and implementation of methodologies for the management of slip risk. Citizen awareness of the neighbourhood was sought for the reduction of risks in Altos de la Estancia, through the exchange of experiences, socio-environmental realization and awareness of the citizen property of the park. 
Moravia, Medellín, Colombia	UNESCO Chair in Sustainability – UPC	2013	The project began with the aim of solving the environmental problem caused by contaminated effluents (leachate) emitted by municipal solid waste deposited in the old Medellín landfill, through the implementation and use of appropriate technologies, based on natural treatment systems such as built wetlands and strips of vegetation or *buffer strips*, bioremediation and runoff water management.

Location	Responsible	Year	Description
			
Lèze catchment France	*Syndicat Mixte Interdépartemental de la Vallée de la Lèze* (SMIVAL)	2009 - 2014	The planting of containment hedges in the Lèze watershed was done to mitigate the risk of flooding. The containment hedges serve to delay and disperse the maximum flow of the river during floods, so that by partially obstructing the flow the barriers also allow the water to flow more slowly. Hedges also reduce the river's energy and erosion potential and help nutrients leak out, which contributes to improving the state of physicochemical elements and the quality of hydromorphology.
Danubio River, Kalimok, Brushlen, Belene Island Bulgary	*Office international de l'Eau* *ACTEON Environment*	2002 - 2008	The main objective of this project was the recovery of the natural wetlands that populated the banks of the Danube throughout the country. Because of the drainage of wells, these wetlands have been lost, generating an impact on the water quality and biodiversity of the river ecosystem: they purify the water, provide basic soils for the desolation of numerous species of birds, as well as their feeding habitats during hibernal migration. We wanted to manage the water of the river to ensure good irrigation of natural wetlands.

Agentes de interés (organizaciones, empresas, organismos, etc.):

- State government and regional governments.
- City councils of large cities.
- Water companies.
- Water boards.
- Universities and research centres (in the field of natural sciences: watershed management, geology, hydrogeology, meteorology, urban pollutant management, analytical chemistry, organic and inorganic chemistry, etc.).
- Neighbour's associations.
- Environmental engineering companies.
- Sustainable construction companies.

4.3.2.5 Floating photovoltaic systems

(Autores: Laura del Val Alonso y Xavier Martínez Lladó)

Areas or sectors where it applies:

- Water
- Energy

Type of solution: Technological solution

Solution / Technology

A floating photovoltaic system (FPVS) consists of a floating platform on which traditional photovoltaic panels can be mounted to reduce evaporation and produce electrical energy.

Basic description

One of the problems arising from the increase in ambient temperature will be the increase in evaporation in surface water bodies and the subsequent reduction in water availability. In this context, floating photovoltaic systems aim to generate renewable energy while minimizing the problem of evaporation.

As characteristic elements of these systems are the floating platform where the panels are installed, the anchoring systems, and in the case of large installations, the inverters that transform the electricity to alternating, which are also mounted on floating platforms near the panels[103].

There are several types of design: the "pure – floating" design that uses specially designed floats to install panels on them, systems based on pontoons and metal frames that can use generic floats, and the use of membranes and textile carpets that create a surface where to install the panels. There are also semi-submerged panels that offer advantages such as increasing the cooling effect of water or reducing materials in the installation.

The application of these systems as a measure of adaptation to climate change focuses on the protection of water bodies against increased evaporation. A study conducted on Lake Nasser in Egypt[104] concluded that covering the shallow areas of the lake generates a decrease in evaporation of 1/3 of what would be expected if the lake were completely covered. It was estimated that covering 15% of the lake's surface (depths of 0.0 to 3.0 m) could save 2.66 x 10^9 m^3/year and produce 1.7 x 10^9 MWh/year of solar energy.

[103] World Bank Group, ESMAP and SERIS. 2019. Where Sun Meets Water: Floating Solar Market Report. Washington, DC: World Bank

[104] Abd-Elhamid, H.F.; Ahmed, A.; Zeleňáková, M.; Vranayová, Z.; Fathy, I. Reservoir Management by Reducing Evaporation Using Floating Photovoltaic System: A Case Study of Lake Nasser, Egypt. Water 2021, 13, 769.

Figure 14. Floating solar panels in a vineyard in California (USA). Source: SPG Solar.

Implementation potential

Advantages	Disadvantages
• The cooling and absence of dust provided by water increases the efficiency of the panels. • They reduce the appearance of algae, so they improve the quality of the waters. • It does not compete with other land uses. • Synergies with existing electrical infrastructures of hydroelectric installations. • May involve improved water quality if there is a risk of algal blooms[105].	• Not all the associated costs are precisely known. • Operating on water is complex and therefore expensive compared to terrestrial systems. • The long-term effects on water quality of decreased sunshine are not known with certainty. However, studies of the effects of long-term shading of irrigation ponds show that this technique generates a reduction in photosynthesis and surface turbulence, generating a reduction in dissolved oxygen and a reduction in turbidity[106].

Potential barriers to implementation

In irrigation ponds without landscape or environmental value, it is not expected that there will be barriers that prevent their installation. However, the installation of panels in lakes or reservoirs can generate opposition from society due to its landscape and environmental value. Of particular importance is the latter, as the effects on water quality and the aquatic ecosystem in the long term are not known with certainty.

Level of innovation today (TRL = 9)

Although there are full-scale facilities and commercial products such as Ocean Sun's patented modules, FPVSs are a relatively new concept. Experiences with large installations are scarce and recent. Only a few large-scale demonstration projects have been deployed around the world, such as in China. In the case of the study of Lake Nasser in Egypt, the optimization of

[105] Sahu, A., Yadav, N., & Sudhakar, K. (2016). Floating photovoltaic power plant: A review. Renewable and Sustainable Energy Reviews, 66, 815–824.

[106] Maestre-Valero, J. F., Martínez-Alvarez, V., Gallego-Elvira, B., & Pittaway, P. (2011). Effects of a suspended shade cloth cover on water quality of an agricultural reservoir for irrigation. Agricultural Water Management, 100(1), 70–75.

the panels to reduce evaporation was sought, but there are many questions about what are the long-term effects on water quality or how to facilitate their installation or optimize productivity.

Expected or desirable advances in the coming years

The protective effect of the installation of panels on water reservoirs is known, however, the quantification of the extent to which evaporation is avoided is complicated and research is lacking. The same goes for the possible negative effects of blocking the incidence of light on water. In the coming years, it is expected that there will be advances in both lines to determine the real performance of the system and its possible impact on the ecosystem. On the other hand, an increase in the installation of floating solar panels is expected, which will increase knowledge about the costs and long-term effects of this technology.

Expected results

The study of Cazzaniga et al. (2019)[107] shows that only by covering 10.0% of a surface water tank can evaporation be reduced by more than 18%.

The first installation of floating solar panels was done in Japan, which was followed by several countries. Little by little the facilities have been increasing their capacity, until reaching the recent ones (2018), capable of producing more than 100 MWp[108].

The average life of these installations is between 5 to 10 years, which is the guarantee that the floats on which the panels are installed usually have.

Installation costs

Per watt-peak (Wp)[109], capital expenditures (CAPEX) remain slightly higher than those of onshore PV projects, mainly due to the costs of the floating structure (the number of floats needed depends on the design), the floating inverter platform (where relevant) and the anchoring and mooring system. The total CAPEX for FPV systems in 2018 ranged from €0.7 to €1.0/Wp, depending on the location, depth and variation of the body of water, and the size of the system. The costs of conventional systems are around de 0.46 €/Wp.

Operating costs

Operation and maintenance activities are more complex on water than on land. The panels and anchors must be inspected regularly, for which a boat is needed in most cases. One of the most tedious maintenance factors is the removal of bird droppings that use these floating islands to nest or simply perch. This increases maintenance and protection costs. One of the factors to consider in these facilities is that they suffer greater corrosion and wear than terrestrial systems, since they are subject to water and its continuous oscillation. Maintenance costs vary greatly depending on the location and country, reaching an average value of 8.7 €/KWp-year. The maintenance costs of an operator-scale PV installation are around 5 €/KWp-year.

Social acceptance

It is to be expected that the social acceptance of this technology will be low, since the installation of solar panels on bodies of water modifies the landscape. For this reason, it is

[107] Cazzaniga, R., Rosa-Clot, M., Rosa-Clot, P., Tina, G.M., 2019. Integration of PV floating with hydroelectric power plants. Heliyon 5, e01918.
[108] World Bank Group, ESMAP and SERIS. 2019. Where Sun Meets Water: Floating Solar Market Report. Washington, DC: World Bank

[109] El vatio-pico es la potencia eléctrica máxima generada en condiciones standard de iluminación (irradiancia espectral AM1.5G, 100 mW/cm^2) y temperatura (25ºC)

most likely that this technology will spread in those bodies of water that due to their size, location and / or use, are not perceived by the local population as of value.

On the other hand, it will be key for the future of technology to provide a quantification of the minimum surface to be covered in a body of water to optimize the reduction of evaporation, as proposed in the aforementioned study in Lake Nasser. This type of study, which demonstrates the value of these facilities in protecting the resource if properly applied and disclosed, can be a way to reduce the initial rejection of the installation of panels in parts of a body of water.

Recipients

- Associations of irrigators
- Hydrographic confederations
- Municipalities with supply ponds
- Investment funds
- Hydroelectric companies

Relevance in for climate change adaptation

Risks arising from climate change to which this solution can help us to adapt

- Temperature change
- Water stress
- Droughts
- Water quality

Conceptual fit within climate change adaptation

In arid and semi-arid regions, water scarcity is one of the main problems caused by climate change. Water reservoirs are common in these areas, especially in landscapes dominated by agriculture. Therefore, finding a way to reduce evaporation could save a large part of the resource. There are many methods to reduce the evaporation of water from surface reservoirs. However, the use of solar panels for shading involves the generation of renewable energy, which is an added value in the adaptation to climate change of these regions.

On the other hand, the increase in temperatures is leading to a decrease in surface water quality due to algal blooms. These can increase the organic matter in the water generating problems during purification, and even generate compounds that can be harmful. A decrease in heat stroke would help minimize these effects by inhibiting the growth of these microorganisms.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Lake Nasser, Egypt	Theoretical Study	2021	Covering 15% of the lake's surface (depths from 0.0 to 3.0 m) can save 2.66×10^9 m^3/year and produce 1.7×10^9 MWh/year of electrical energy.
Hyogo, Japan	Electricity Generation Authority of Thailand (EGAT)	2021	Japan is home to 45 of the world's 70 largest floating PV plants, including 24 in Hyogo. Umenoki is the largest floating PV facility in Japan. This plant has 7,750 kWp and one of its singularities is that it is installed in an irrigation pond.
Coal mining subsidence area, Panji (China)	Three Gorges New Energy	2018	The largest facility in the world with a capacity of 150,000 kWp

Location	Responsible	Year	Description
Pontecorvo (Italy)	Ciel & Terre International	2017	System capable of generating 343 kWp installed on an irrigation pond
Queen Elizabeth II Drinking Water Reservoir, London (UK)	Ciel & Terre International	2016	Installed power of 6,338 kWp
Floating photovoltaic plant in Sierra Brava, Cáceres, Spain	Acciona	2020	Irrigation pond in which only 0.07% of the surface has been covered with 3,000 photovoltaic modules with a peak power of 1,125 kWp

Main stakeholders (organizations, companies, institutions, etc.)

- Power generation companies
- Hydrographic confederations
- Management companies of the integral water cycle
- Hydroelectric companies

4.3.2.6 Reclaimed water for irrigation, industry and street cleaning

(Authors: Mireia Pla Castellana and Xavier Martínez Lladó)

Areas or sectors where it applies:

- Water
- Urban planning and building

Type of solution: Technological solution

Solution/Technology:

A tertiary treatment is a facility where water used in human activities undergoes different processes, which are a combination of physical, chemical and/or biological treatments. These treatments are able to eliminate suspended matter and dissolved substances, improving the quality of the purified water to apply it in new uses of value, seeking greater efficiency of the water treated by the Wastewater Treatment Plants (WWTP).

It is an additional system that allows to increase the quality of the purified water so that it can be used in uses not related to human consumption, such as the irrigation of parks and gardens, the cleaning of streets, industrial uses or the injection into aquifers, complying with the current quality regulations for the different proposed uses [110]).

Basic description

Reclaimed water is non-potable water, which is used in the irrigation of parks, the cleaning of streets in urban areas, as well as industrial uses. The reclaimed water is provided by the tertiary systems of the WWTPs. These waters are supplied through independent water networks.

Figure 15. The two images show the normalized urban use of reclaimed water. In image A, parks of many cities in Spain are already irrigated with reclaimed water. Image B, in Canalejas (Alicante) streets are being cleaned with reclaimed water. Sources: Canal de Isabel II & Diario Información.

[110] España. Real Decreto 1620/2007, de 7 de diciembre, por el que se establece el régimen jurídico de la reutilización de las aguas depuradas. Boletín Oficial del Estado, de 8 de diciembre de 2007, núm. 294, pp. 50639 a 50661.

WWTPs are composed of three stages of wastewater treatment, which are called *conventional*: a pre-treatment (removes and collects coarse waste), a primary treatment (separates particulate organic matter) and a secondary treatment (removes dissolved organic matter).

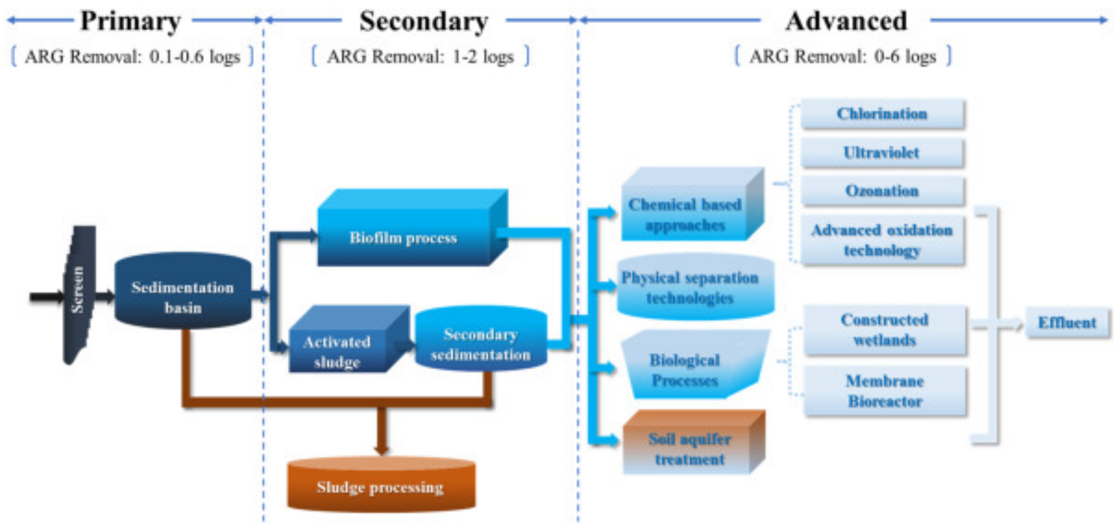

Figure 16. Generic wastewater treatment scheme. This treatment passes, first of all, the primary and secondary treatment phase. Finally, a tertiary or advanced treatment is applied, which sanitizes the water to be able to reuse it for aquifer recharge, industrial uses, street washing, irrigation of parks and gardens or improvement of wetlands. (Source: Pei, M. et al. 2019[111])

Tertiary treatments are additional processes that are incorporated into the WWTP after the process of removing organic matter to improve water quality. A tertiary treatment reduces the load of contaminants, such as salinity, nutrients, etc., allowing their reuse as an alternative water resource according to current legislation.

There are two types of tertiary treatment, with different processes:

- Basic treatment: involves a physicochemical system with filtration with sand filters and disinfection.
- Advanced treatment: involves technologies such as advanced sludge systems, and membranes for more restrictive uses (aquifer recharge) that require a removal of salts, as well as emerging polluting compounds.

Implementation potential

Advantages	Disadvantages
• Decrease in the use of drinking water for activities that are not strictly for human consumption. • Reduction of intensive use of water in industrial sectors. • Reduction of the intensive use of water in tourism. Spain is one of the countries with the most days of drought and also one of the most visited in the world. These two factors combined can be problematic if solutions such as reducing the use of water in hotels and resorts in showers and toilets, as well as the use of reclaimed water for garden irrigation and cleaning of common areas, are not applied. • Reduction of the pressures generated by the discharges to the channel of the effluents of the WWTPs.	• Deployment of the necessary network to house and transport the reclaimed water, and to reach cities and towns.

[111] Mengke Pei, Bo Zhang, Yiliang He, Jianqiang Su, Karina Gin, Ovadia Lev, Genxiang Shen, Shuangqing Hu. (2019) State of the art of tertiary treatment technologies for controlling antibiotic resistance in wastewater treatment plants, Environment International, Volume 131.

Potential barriers to implementation

The most important barriers to the use of reclaimed water in urban areas is the implementation of a tertiary system in a wastewater treatment plant, as well as the carbon footprint in case energy consumption occurs with non-renewable sources. This entails some barriers such as the construction budget, both the infrastructure itself and the reclaimed water transport network up to its point of consumption.

Also, the available space is a limiting factor to carry out such construction, because they must be relatively close to the WWTPs whose effluents they treat. In addition, the cost of pumping reclaimed water from the WWTP to the point of consumption can be significant which limits potential uses to those near the WWTP.

Level of innovation today TRL = 9

The level of innovation of these systems is 9, since the processes that are developed in the tertiaries are very well characterized and described and are commercially available. Spain is the European leader in water reuse with an estimated total volume of more than 400 hm^3/year, which represents between 7 and 13% of treated wastewater[112].

Likewise, it is noteworthy that the processes related to wastewater treatment are in constant development.

Expected or desirable advances in the coming years

The expected progress for the increasingly widespread application of reclaimed water is the creation of new guidelines, which impose mandatory water quality limits based on health and environmental risks of reuse.

Expected results

Over the next decade, an increase in the use of reclaimed water is expected, as well as the implementation of more efficient regeneration systems, which minimize both energy consumption and derived consumables.

An improvement in the social acceptance of the use of reclaimed water is also expected from the increase in the number of actions, but also from the updating and implementation of new regulations, such as European Regulation 2020/741[113] which will enter into force in 2023.

Installation costs

The construction of a tertiary infrastructure to obtain reclaimed water can entail very high amounts depending on the treatment system chosen and the control carried out. Starting with the adequacy of the land and the location of the different systems, and ending with the connection between primary and secondary systems with the tertiary one. The final costs will depend on the m^3 that the plant treats, being able to be infrastructures of 500,000 to more

[112] Asociación Española de Desalación y Reutilización (2019). Cifras de reutilización de agua en España.

[113] Parlamento Europeo (2020). REGLAMENTO (UE) 2020/741 DEL PARLAMENTO EUROPEO Y DEL CONSEJO de 25 de mayo de 2020 relativo a los requisitos mínimos para la reutilización del agua.

than € 5,000,000 depending on the technology implemented and volume of treatment [114],[115],[116].

Operating costs

Operating costs are directly related to the capacity of the plant, as well as how up-to-date the reclaimed water network that transports water to the municipalities is.

Different related reports indicate that the cost of operating tertiary systems is between 0.20 and 0.80 €/m^3 [117,118]. In general, the item that has more weight within the treatment of tertiary water is the energy consumption associated with filtration systems, which would represent 32% of the aforementioned costs.

Social acceptance

Reclaimed water has good social acceptance for the emptying of streets and the irrigation of parks and gardens. Instead, we have to work on social acceptance of its consumption, since the general idea is that it has a negative impact on human health.

The European regulation on the reuse of urban water for agricultural irrigation[113] has entered into force on 25 June 2021 and will be applicable within three years. This will improve the current view of reclaimed water and will allow us to move towards a more circular Europe, minimizing the pressure of natural water resources.

Recipients

- Citizenry
- Irrigation communities
- Urban gardening companies
- Governments
- City councils
- Water boards
- Environment agencies at regional level
- Water operators

Relevance for climate change adaptation

Risks arising from climate change to which this solution can help us to adapt

- Reuse of water resources.
- Improvement of water quality in aquifers.
- Reuse for agricultural irrigation, limits the overexploitation of aquifers.
- Maintenance of natural wetlands.
- Improvement of biodiversity.

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[114] Hernández, F., Molinos, M., y Sala, R. (2010). "Estudio de viabilidad económica para el tratamiento de aguas residuales a través de un análisis coste beneficio". Rect@, 11(1), 1-25.

[115] Lavee, D. (2011). "A cost-benefit analysis of alternative wastewater treatment standards: A case study in Israel". Water and Environment Journal, 25(4), 504-512.

[116] López, J. (2006). "Los costes de la reutilización de aguas" en Prats, D. y Melgarejo, J. (ed.), Desalación y reutilización de aguas. Situación en la provincia de alicante. Alicante, Fundación Coepa para la Formación.

[117] Martínez, F.J. (2004). Estudio agronómico y ambiental del riego con aguas residuales depuradas en el cultivo del arroz. Aplicación a una línea de riego en el parque natural de la Albufera (Valencia). Tesis doctoral. Editorial Universitat Politècnica de València, Valencia.

[118] Hernández, F. y Sala, R. (2005). "Eficiencia técnica en la depuración de aguas residuales: El caso de la comunidad valenciana". Rect@, 13(1), 46.

Conceptual fit within climate change adaptation

Water reuse will become increasingly necessary. Climate change is already generating problems of droughts, lack of rainfall, or torrential rains. This forces us to adapt and reuse as much water as possible.

The use of reclaimed water not only improves the reuse of water resources, but also allows control of overexploitation in areas that are already critical. Areas with an arid climate, such as the Mediterranean, are areas with water scarcity where the application of tertiary systems that produce quality reclaimed water is a necessity to be able to include all the variables of our society and face the transformation that climate change entails.

Real and pilot cases where the solution has been applied

Location	Responsible	Year	Description
Madrid	Canal de Isabel II	2021	Canal de Isabel II has an infrastructure that can supply more than 100 hm^3 of reclaimed water to 25 municipalities in Madrid, counting the capital, which have this service. In total, there are 32 plants with a distribution network of more than 650 kilometres and a total of 64 warehouses to store it. The amount of reclaimed water in 2021 that was used for urban uses is 33% higher than in 2020. And it is expanding, as the reclaimed water network is growing year by year, reaching more and more populations.
Canarias, Cabo Verde, Madeira	Technological Institute of the Canary Islands (ITC)	2017-2019	The objectives of ADAPTaRES are, on the one hand, to raise awareness through objective information from society, on the reuse of reclaimed water as an adaptive strategy to climate change and situations of water scarcity. It is intended, therefore, to demonstrate the reuse of reclaimed water and good practices, for a gradual adaptation to situations arising from climate change, associated above all with water scarcity.
Singapore	Singapore National Water Agency (PUB)	2016	Singapore has 5 wastewater regeneration plants. In 2019, approximately 145.5 million cubic meters of NEWater were produced in Singapore. NEWater is high-quality reclaimed water created by Singapore's water sustainability strategy. It is produced from treated used water that is further purified using advanced membrane technologies and ultraviolet disinfection. Singapore currently has the capacity to produce 40% of the water it consumes from reclaimed water.
Baix Llobregat, Catalonia, Spain	*Agència Catalana de l'Aigua* (ACA)	2006	The reuse of water from the Baix Llobregat treatment plant will increase the water resources of Catalonia by 50 million m^3 per year, avoiding that this volume of water has to come from the reservoirs at the head of the river.

Stakeholders (organizations, companies, institutions, etc.)

- Technology Centres
- Universities
- Water operators
- Construction companies
- Central governments
- Regional governments
- City councils

4.3.3 Health

4.3.3.1 Urban climate models. Thermal stress adaptation systems

(Author: Xavier Rodó)

Areas or sectors where it applies:

- Health
- Early warning
- Urbanism and planning

Type of solution: Technological solution

Solution / Technology

Heat stress adaptation system tested in Antwerp (Belgium) based on a 100-m high-resolution urban climate model to map heat waves and heat stress at the microscale (neighbourhoods, streets) (UrbClim)[119]. Allows the development of an early warning system to warn the most vulnerable population with daily updates.

Basic description

Managers of urban public spaces as well as ordinary citizens are particularly interested in characterizing well the spatial patterns of heat exposure within cities. These data provide a lot of information about the thermal shelter areas (cold), as well as the hot spots to avoid. Many studies have shown that ambient heat and heat waves pose a significant risk to people's health and can lead to death.

The website Temperature and mortality in Barcelona (TEMOB) of the Barcelona Public Health Agency (ASPBCN) and ISGlobal offers for the first time direct and reliable estimates of the relationship between heat and human mortality. Its impact is analysed from daily series of data for the period 1987-2016 and individualized for the 73 neighbourhoods of Barcelona. This product shows how these effects are not distributed homogeneously in the city, but vary according to the neighbourhoods depending on urban, socioeconomic and demographic aspects, which affects aspects of social inequality.

The platform uses a climate model adapted to solve the urban climate (UrbClim[120], VITO), as demonstrated in the project Climate-Fit City[121], and in particular for the city of Antwerp (Belgium), at scales of 100m that combines temperature and humidity information, to also generate a thermal comfort map. UrbClim uses ERA5 reanalysis, is developed by VITO (Belgium) and uses terrain maps, as well as intermediate-scale meteorological information, to produce a time mesh of temperature, humidity and wind speed.

The model was designed to assimilate and study the urban heat island (UHI)[122] and other urban climatic variables at a spatial resolution of 100m. The unique capabilities of UrbClim allow the generation of spatially explicit time series on an hourly scale of a diversity of indicators that can be derived in a post-processing of the information. This tool, in the case of Barcelona, has been combined with a statistical model of transfer between the effects of

[119] De Ridder, K., Lauwaet, D., & Maiheu, B. (2015). UrbClim – A fast urban boundary layer climate model. Urban Climate, 12, 21–48.

[120] García-Díez, M., Lauwaet, D., Hooyberghs, H., Ballester, J., De Ridder, K., & Rodó, X. (2016). Advantages of using a fast urban boundary layer model as compared to a full mesoscale model to simulate the urban heat island of Barcelona. Geoscientific Model Development, 9(12), 4439–4450

[121] Climate -fit.city

[122] An urban heat island occurs when a city experiences much warmer temperatures than nearby rural areas. The difference in temperature between urban and less-developed rural areas has to do with how well the surfaces in each environment absorb and hold heat.

temperature and mortality, screening these combined effects, by gender, age, level of education, socioeconomic and urban planning.

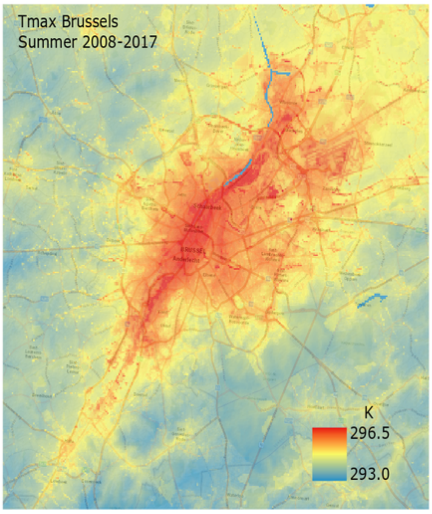

Figure 17. High resolution (100m x 100m) map of the city of Brussels, showing the UHI on average for the period 2008-2017 (Source: Copernicus, 2021).

Potential implementation

Advantages	Disadvantages
• Facilitates adaptation in other activities/sectors. • It allows to measure the reduction of the risks to which it adapts through an operational system in real time. • Immediate implementation and easy portability. • Very high spatial resolution with a proven product (e.g. integrated in COPERNICUS). • Attractive visualization of the results by the general public. • Allows evaluations for long-term adaptation (urban planning)	• Very specific solution for large municipalities. • It requires the implementation of the calculation system in a compatible computational architecture. • A large number of factors can result in a large amount of data to be analysed in real time. • Depending on the required time resolution (daily, weekly) there is a different calculation time and operating cost. • Technical support staff (although the service may be outsourced).

Potential barriers to implementation

The barriers (or requirements) for the implementation of the UrbClim model and a post-processing platform are classified into 3 blocks.

- Technological: It will be necessary to have an intensive calculation node if you want to run the simulations locally (alternatively you can subcontract the service at source to VITO or one of its associated institutes that develop services (ISGlobal). Additionally, it will be necessary to update the computer network and / or calculation architecture and the outputs of the system to the users involved (municipalities, public health agency, etc.)

- Data availability: Although UrbClim uses public open data for its start-up, if the utility is the operational generation of heat wave maps, it will be necessary to calibrate the model with updated data from Madrid (and other larger municipalities). Likewise, to perform the functions of transfer to mortality, it will be necessary to have health data at a level of ICD10, with anonymized information on gender, age and socioeconomic data.

- Roles and responsibilities of stakeholders. It will be necessary, among other requirements, to establish optimal communication channels for collaboration between providers of meteorological and public health data, to improve the synergy and communication necessary between the generation of maps and forecasts of risk of thermal extremes and associated mortality risk in different populations.

Level of innovation today (TRL = 9)

It allows to detect areas of high risk of temperature extremes within the neighbourhoods of the city and allows the generation of new early warning systems also during the night, minimizing the potential negative effects on health. UrbClim has been tested in 100 European cities and has made it possible to reproduce the urban heat island (IHP) of Barcelona during the summer at very high resolution and with a calculation time many orders of magnitude less than traditional climate models, as well as to identify if these temperature extremes have differentially affected population segments, gender or neighbourhood of origin.

On the other hand, in the current context of global warming, and in a scenario without adaptation, heat-related risks (increased temperatures and heat waves) are expected to increase. This is also a serious public health problem. In this sense, the TEMOB website also allows you to explore numerous climate indicators, obtained from the UrbClim urban climate model, at a high spatial resolution (100 meters). Thus, the tool shows different climate scenarios for different past and future periods, the latter calculated according to two emission scenarios.

Expected or desirable advances in the coming years

This tool is expected to become the reference model on an urban scale to be implemented in Europe. It will be in constant improvement, especially in the integration of the urban orography on the one hand and in the initialization from outside the contour conditions of the model. Coupling to the WRF[123] model to perform a dynamic rescaling of the input weather information to initialize the model will also mean a notable leap in the ability to reproduce the local climate.

At the level of risk generation and maps/scenarios of human mortality, there are collaborating groups of VITO (e.g. ISGlobal), which have been responsible for the development of the models of transfer from temperatures to mortality, which continue to work evolving these functions and all their integration (e.g. In the TEMOB).

Expected results

Direct application in public health policies and improvement in early warning plans for heat and cold waves. Operationalization of the service.

Installation costs

Installation costs vary depending on the objective or product pursued. If it is only the generation of historical base maps of urban heat island effects (2008-2017) based on reanalysis, you can go directly to Copernicus (ECMWF) and obtain them under license (<5,000 € according to licenses). If a more advanced version is required that also provides a resolution of 100m x 100m, these base maps can be obtained through another Copernicus license.

If, on the other hand, the computational version of the UrbClim model installed is also required for the generation of updated and future, seasonal scenarios, the Belgian company VITO offers a license to use and support at a reduced cost (e.g. budget on demand and depending on number. Municipalities, etc.) If the generation of risk analysis and adaptation to health products is also required, related to socioeconomic indicators, gender, inequalities, etc., there are other centres that provide these additional services.

[123] The *Weather Research and Forecasting* (WRF) model is a numerical calculation system for atmospheric simulation designed to meet the needs of both atmospheric research and prediction.

Operating costs

Maintenance costs depend on the type of installation and support required. A specific cost estimate is not available (it would be necessary to contact VITO), but this is estimated to be limited, given the amount of the '*tenders*' made by this company for the COPERNICUS program. For the extension to mortality by neighbourhoods, the cost is limited.

Social acceptance

Good social acceptance is expected given the degree of public awareness regarding climate change. Technology for which there is demand from social agents and / or provides social benefits beyond the adaptation of climate change. At the level of public management, the tool could create social tension if the information generated on the different impact on health by neighbourhoods, street blocks, etc. of socioeconomic, urban, climatic factors shows the inequalities by territories. In any case, the results can basically be used for internal public management, although all the results in principle are designed so that they can be provided in open access. It can conflict – if not coordinated – with other early warning systems where appropriate, which are in operation in other administrations (e.g., at the municipal level).

Recipients

- Municipalities and Regional governments
- Public Health System
- Town planning

Relevance for climate change adaptation

Risks arising from climate change to which this solution can help us to adapt

- Heat waves
- Temperature variability

Conceptual fit within climate change adaptation

UrbClim offers a unique product, for example, to dynamically solve the microscale and therefore the spatial heterogeneity within the city. It also allows to integrate the effect of climate with that of socioeconomic information, since it can show that areas with lower per capita income have worse accessibility to green areas, buildings with worse thermal insulation, higher temperatures within the city, etc.

Early warning systems are those that are being progressively established in public health, which makes sense. Prevention is one of the hallmarks of public health. As with air quality, the function of these models is to identify those areas most affected by heat. If demographic analysis is added to this, the most vulnerable population that lives there can be identified. It can be a good instrument to support the Plans against heat waves that some Regional governments have implemented.

Real and pilot cases where it has been applied

Location	Responsible	Year	Description
Barcelona, London.	ASPBCN, ISGlobal	2021	Within the European project Climate Fit City, the ASPBCN together with ISGlobal developed the web application.
100 European cities	ECMWF	2019	The European Centre for Medium-Range Weather Forecasting has developed historical simulations of this model with VITO, which appear on the COPERNICUS website. Madrid is one of the 100 cities included, so high-resolution maps based on historical data can be downloaded from the application. They do not serve, however, for future operational forecasting.

Stakeholders (organizations, companies, institutions, etc.)

- VITO
- ISGlobal
- Public Health Agencies

4.3.3.2 Intelligent air pollution control systems

(Author: Xavier Rodó)

Areas or sectors where it applies:

- Health
- Urban planning and building
- Early warning

Type of solution: Technological solution

Solution / Technology

High-resolution daily computation and mapping of *Wet Bulb Globe Temperature* (WBGT) values measured instrumentally at 2 meters high, combined temperature and humidity indicator (which should always be below 25°C to have no effect on health). It allows to establish daily those areas of extreme heat or shade (climatic shelter) in urban spaces, through the installation of WBGT sensors. Can result in high-resolution maps if combined with the *UrbClim* model.

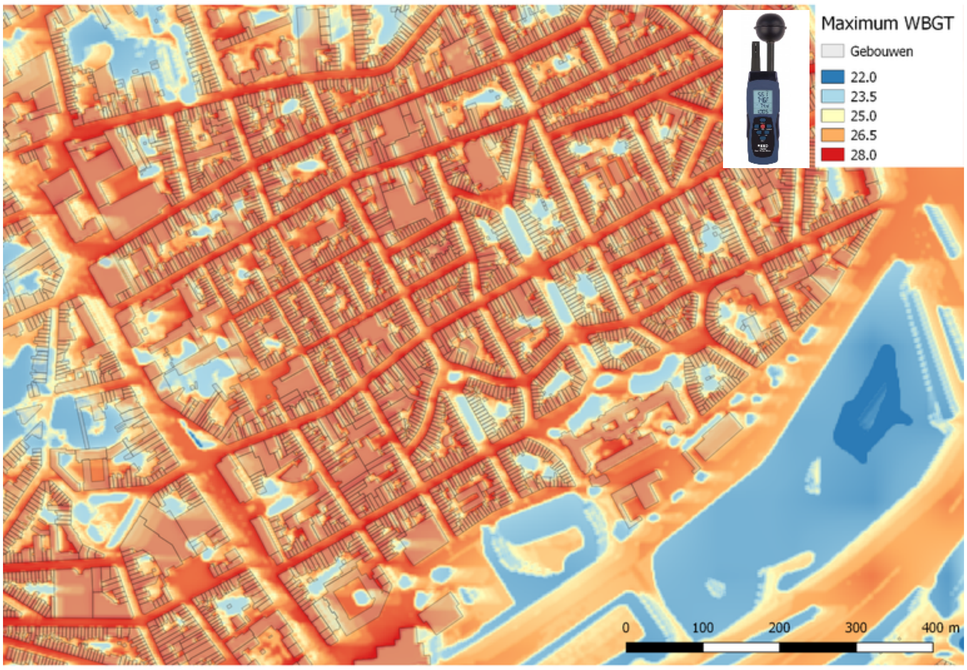

Figure 18. Example of thermal stress risk map in Antwerp derived from WBGT measurements and the application of the UrbClim urban model. Source: Dirk Lauwaet (VITO). The inner box shows as an example a typical WBGT sensor. Source: HTSEI.

Basic description

Temperature alone is not a good measure of physiological heat stress. The indicator called WBGT considers in addition to temperature, humidity, wind, solar irradiation angle and cloud cover. Sites with trees and/or bodies of water are those with the lowest temperatures, while the greatest thermal stress occurs in paved areas and streets where there is no shade.

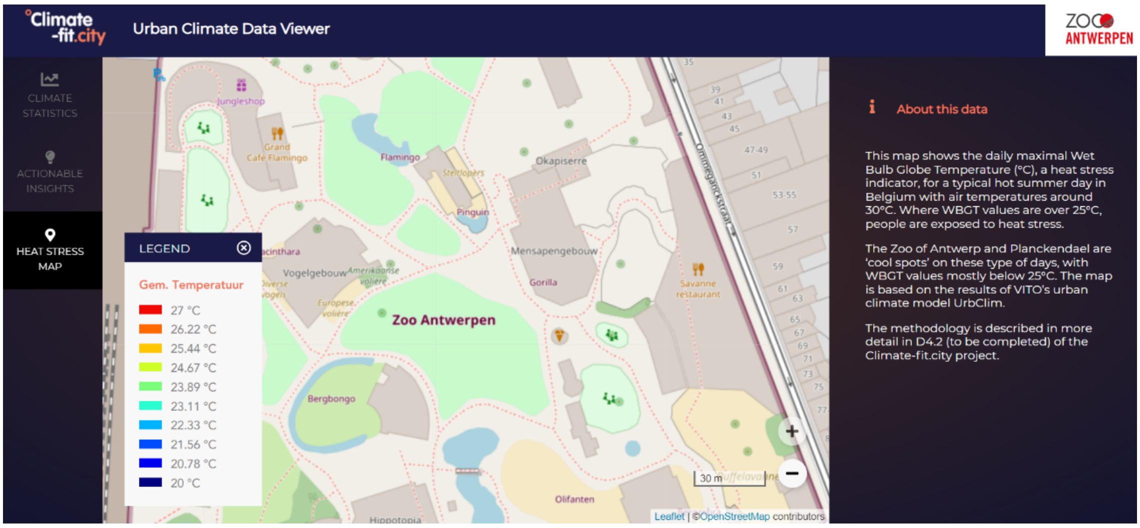

Figure 19. Example thermal stress risk map at Antwerp Zoo derived from WBGT measurements and the application of the UrbClim urban model (Source: Climate-fit.city.)

When it is necessary to assess the thermal stress of people in open public spaces, the measurement of air temperature is only part of the necessary measures. It is necessary to consider other parameters such as radiation, humidity and wind speed, variables that also play a fundamental role in individual thermal comfort. The effect of heat stress on the human body can be properly assessed with the WBGT, internationally recognized as the Thermal Comfort Index. In this link you can see an animation of the product obtained for the city of Almada (Portugal).

Implementation potential

Advantages	Disadvantages
• Facilitates adaptation in other activities/sectors. • It allows to measure the reduction of the risks to which it adapts. • Easy visualization of results. • Low cost. • Scalability by sections depending on the number of equipment to be installed.	• Vandalism with computers. • Intercalibration needed. • If you want to generate operational maps (e.g., daily), it requires dedicated technical staff. • To achieve resolution of a few meters requires the use of the Urban Model UrbClim.

Potential barriers to implementation

No major barriers to its implementation are detected. The technology is cheap, well recognized internationally and its use in combination with other public alert systems is clearly beneficial. Its low cost allows an immediate replacement of the equipment if it is damaged or suffer vandalism. They also allow citizen awareness and communication of the need to protect themselves from the heat in episodes of heat, increasingly frequent due to climate change. Also, through citizen science activities.

This approach has also been used at the level of individual buildings, particularly in those that did not have active cooling systems (or to optimize such systems), as they suffered from excessive thermal stress. It is expected that in the future this same methodology can also be applied to other types of buildings (hospitals, asylums, day centres, etc.)[124] .

[124] Hooybergs et al Climatic Change (2017) 144:721–735

Level of innovation today (TRL = 9)

Air temperature is a good indicator of heat, but not of human thermal stress. The use of the WBGT allows to better adjust to the effects on health, with a very cheap measurement technology and that can be complemented with a 3D model of the buildings and green spaces, as well as of the incident radiation. It differs from other thermal comfort indices based solely on temperature and humidity.

Expected or desirable advances in the coming years

Scale developments of thermal stress calculation are expected for individual buildings. This technology has been tested at scales of 1 meter of resolution, through the application of 3D models, which greatly increases its relevance and usefulness for public and private managers. In addition, in the case of Belgium, the WBGT is legislated within the thermal stress in the workplace, it is possible to estimate the number of potential hours lost for the particular case of outdoor workers. In the future, ALARO EURO-CORDEX simulations (from the Belgian Royal Meteorological Institute) will be used to generate simulations of climate change scenarios.

Expected results

It is expected that climate change will have a significant impact on the health of vulnerable groups mainly, but also on productivity. This effect is accentuated in open spaces in cities subjected to high thermal stress due to the increase in summer temperatures. This situation will increase as we move towards the end of the century.

Similar measures carried out in the cities where these systems have been installed provide clear evidence of the need to start adapting our cities to heat stress and climate change. Cooling public spaces and buildings in cities by implementing 'green' or vegetation-linked and 'blue' or water-bound infrastructures, such as shade elements, green roofs, etc. Instead of using more and more cooling systems that contribute to increasing greenhouse gases, they lead to significant energy savings while making a city more attractive.

Installation costs

Installation costs are limited and depend on the number of measuring equipment installed. According to 2019 costs, an individual WBGT team is around €350 plus VAT. To this we must add the installation of sensors in streetlamps, traffic lights or other points elevated 4-5 m to avoid pillage. You must provide the electrical and Wi-Fi connection to the network. You can opt for the power by an autonomous battery by solar panel that increases about €200 the individual cost of each sensor.

The operation in combination with the UrbClim model as well as the generation of maps must be considered according to the specific proposal on this model included in the solutions.

Operating costs

It is necessary to consider the costs of maintenance (calibration of sensors), electricity and internet services, equipment review and security, as well as the post-processing of information and the generation of products (maps, series, etc.)

Social acceptance

In general, a high acceptance is expected after an awareness process (communication campaign, advertising ...), or media (if there is no such communication action). There are no social agents positioned at the moment neither for nor against. It is a technology for which there is demand from social agents and / or provides benefits beyond the adaptation of Climate Change, as in the case of education and citizen awareness. The solution can be classified as specific, although it is easily applicable and following a modular implementation in stages, depending on the interest of the municipalities. You can therefore increase the resolution (e.g., more sensors) on demand. It may, however, conflict, if not coordinated, with other early warning systems, where appropriate, which are in operation within the competent authority.

New infrastructures that are already adapted to climate change will be more efficient. The advantage of these measures is that they are measures called '*no-regret*', they will always help improve the quality of life and the attractiveness of a green city committed to the health of its citizens.

Recipients

- Regional governments
- Municipalities
- Public Health System
- Tourist information offices
- Vulnerable population (elderly, children...)

Relevance for climate change adaptation

Risks arising from climate change to which this solution can help us to adapt

- Temperature change
- Heat waves

Conceptual fit within climate change adaptation

The translation of the effect of extreme heat waves on human health is not direct and needs to reproduce how the human body adapts or not, integrating that extreme increase. In several Belgian cities they use the WBGT index because it effectively integrates the perceived differences between shade and sun areas (up to 10ºC in Antwerp). This proposal represents a qualitative leap with respect to those that only use temperature as an indicator.

In the current situation of climate change, anything that improves the quantification of the exposure, in this case to heat, of the population, by areas and by the most vulnerable groups, can undoubtedly contribute to the adoption of the best possible solutions. That is, from the Administration it is possible to know in maximum detail which are the areas of greatest risk to the health of the most vulnerable people.

Real and pilot cases where it has been applied

Location	Responsible	Year	Description
Brussels, Belgium	VITO	2016	Application Think Nature
ClimateAdapt	Partnership between the European Commission and the European Environment Agency	2017	Antwerp UrbClim case
EH-GLOBAL-VITO-20	VITO	2017	Raster[125] values WBGT EH-GLOBAL-VITO-20
Ambers, Belgium	VITO	2019	Climate Data Viewer

Stakeholders (organizations, companies, institutions, etc.)

- VITO
- European Commission Health Service (Copernicus)
- UrbClim

[125] A raster consists of an array of cells (or pixels) arranged in rows and columns (or a grid) in which each cell contains a value that represents information, such as temperature.

4.3.3.3 Intelligent air pollution control systems

(Author: Xavier Rodó)

Areas or sectors where it applies:

- Health
- Urban planning and building

Type of solution: Technological solution

Solution / Technology

The iSCAPE (*Improving the Smart Control of Air Pollution in Europe*) project aims to integrate and advance the control of air quality and greenhouse gas emissions in European cities, through the development of sustainable strategies for passive remediation of environmental pollution, policy development and the stimulation of changes in the behaviour of citizens.

Dynamic response laboratories aim to achieve pollution reduction by focusing on objectives through an innovative approach led by a company or environmental consultancy, specifically focusing on the use of 'passive control systems' in urban spaces.

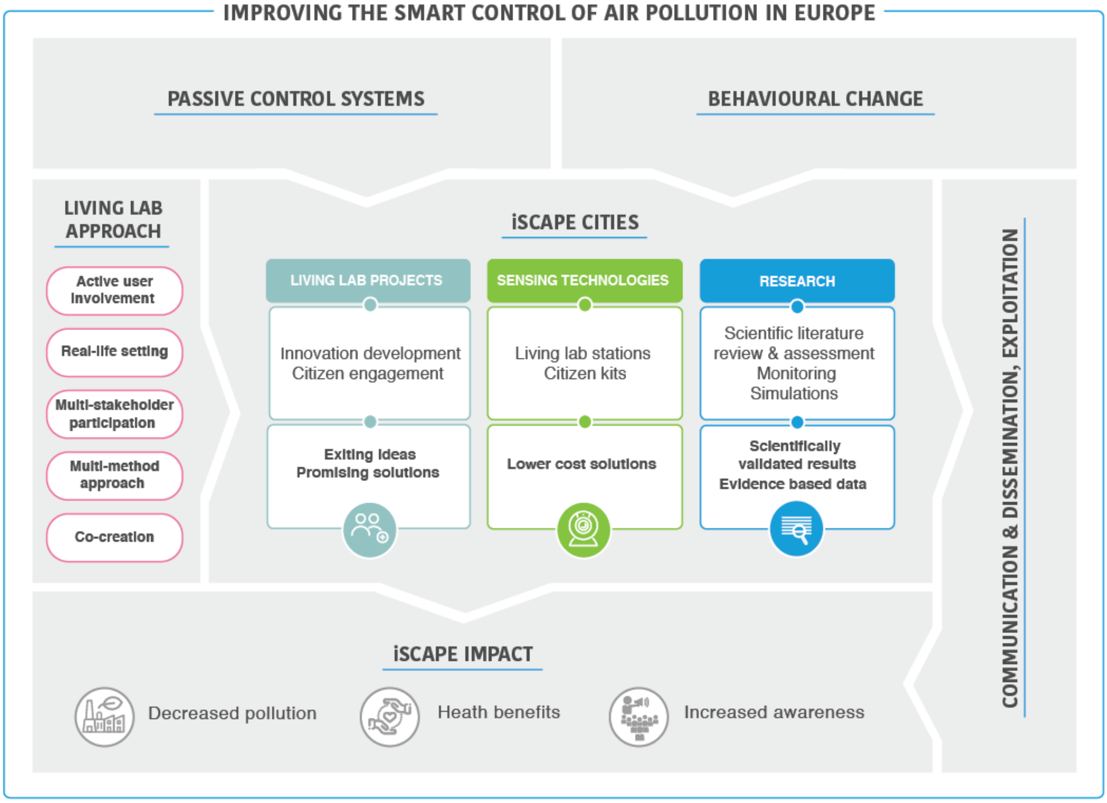

Figure 20. Operational diagram of the operation of the Living Labs of the iSCAPE project (Source: [iSCAPE project](#).).

These Living Labs stimulate dialogue between the citizens of each pilot city and urban managers, to highlight the non-technical challenges that the implementation of the new control and reduction measures may entail. In this way, rejection is minimized, interventions are optimized, leading to greater efficiency in the process and a greater degree of social acceptance due to the co-creation of urban implementation mechanisms during the journey of the local iSCAPE project.

Basic description

In the pilot cities and using each *Living Lab*, the team installed a network of meteorological and air quality sensors (both fixed and mobile) and demonstrated through comprehensive analysis and the help of numerical models, the expected benefits of interventions at the neighbourhood and city-wide scale. This was done for different aspects, from the quantification of pollutant concentrations to the calculation of exposure and risk. Similar initiatives have been made in Spanish cities, such as Bilbao and Barcelona, with the help and collaboration of students of master's degrees in *big data and machine learning* (e.g., ISGlobal/UB and Barcelona City Council and UPV/BC3 and Bilbao City Council).

iSCAPE relies on the concept of "*smart cities*" by promoting the use of low-cost sensors, involving citizens in the use and development of alternative solutions to environmental problems. An important role of iSCAPE was the promotion and subsequent elevation of the results obtained to public managers and competent urban authorities, providing scientific evidence of the solutions and how they could be implemented quickly and effectively.

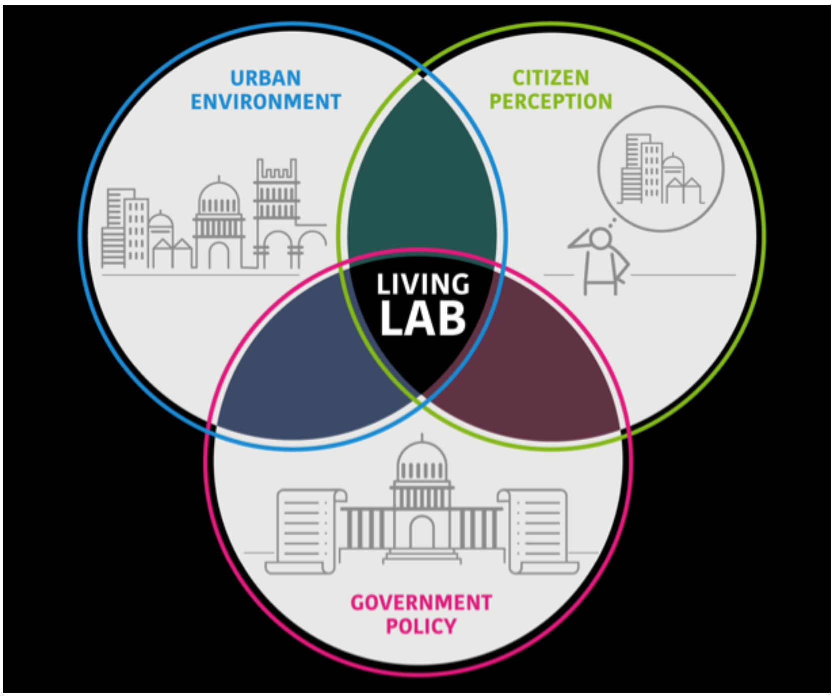

Figure 21. The ISCAPE Living Labs are not only a technological initiative, but at the same time they include the citizen and public managers in the promotion of behaviour change. (Source: iSCAPE).

Implementation potential

Advantages	Disadvantages
• Facilitates adaptation in other activities/sectors. Very versatile solution. • It allows to measure the reduction of the risks to which it adapts • Citizen science solution tested that minimizes the social rejection of interventions. • It ensures an inclusive development of the strategies and technological solutions necessary to act against pollution and the effects of climate change. • It promotes a sense of ownership of Living Labs among local communities and citizen managers, thus ensuring that solutions will be permanent beyond the duration of the project itself.	• Leadership in the model of citizen co-creation when compared with what other municipalities and Regional governments are doing. • Success depends on each situation or citizen environment. • It can promote the rejection of the competent authorities or the technicians in charge in each municipality.

Potential barriers to implementation

No major barriers to its implementation are detected. The technology to be used within living *labs* is cheap, and its use in combination with other equipment from the public air quality control network and weather stations is clearly beneficial. Its low cost allows an immediate replacement of the equipment if they break down. *Living Labs* also allow citizen awareness[126] and communicating the need to reduce urban pollution through joint actions with citizens to facilitate behaviour change – e.g., use of public transport, etc.

Level of innovation today (TRL = 8-9)

ISCAPE *Living Labs* is a consolidated project that has gone from the test phase to the operational operation phase associated with the cities in which it has been implemented.

Expected or desirable advances in the coming years

Given the optimal results of the project in the six pilot cities (Guilford, Bologna, Bottrop, Dublin, Hasselt and Vantaa) and in which *two Living Labs* continue their activity, it is expected that more cities will opt for the same experiences of co-creation of solutions between citizens, environmental consultancies and public managers.

Expected results

The solutions tend to be of two types, on the one hand, passive control systems and the stimulus to change behaviors. Once the solutions have been defined, the implementation of the solutions begins, which will be of two types. On the one hand, the use of remote monitoring technologies and the development of two types of categories of measurement kits (*high-level monitoring kit* and *low-cost monitoring kit*). In parallel, a campaign will be designed and carried out to analyze the efficiency of these solutions in relation to different urban areas (or cities) and in different seasons of the year.

Installation costs

The equipment has an estimated cost of € 250 + VAT and installation costs per equipment of about € 150 + annual VAT are foreseen.

Operating costs

The costs are limited, there may be assignment of public and / or private spaces, civic centres and a time harmonization that allows a reduction of personnel costs associated with these spaces. Maintenance involves the replacement of equipment every 3 years and the personnel costs necessary to carry out the replacement and set-up. They are estimated at about € 2,500 per year + VAT for each group of 20 sensors.

Social acceptance

High acceptance. The social agents are currently positioning themselves favourably for the co-creation of urban policies aimed at urban improvement and adaptation to climate change. In parallel, air quality remains, at least for some peninsular cities, an unsolved problem. There may be some rejection by those public sectors that consider that they are already being implemented. May need a communication/clarification strategy within responsible public administrations.

[126] Proyecto ISCAPE

Recipients

- Regional governments
- Municipalities
- Public Health System
- Educational centres or social activities in the neighbourhood.

Relevance for climate change adaptation

Risks arising from climate change to which it can help us adapt

- Heat waves
- Air quality

Conceptual fit within climate change adaptation

This integrated citizen-manager approach allows an optimal strategy to face the challenges of adaptation to climate change, which will require sacrifices that are often difficult to understand and assume. For example, the change in urban mobility patterns and behaviours, through the shared study of solutions that can lead to more sustainable, resilient to climate change and healthy cities, safeguarding the criteria of social equity.

Real and pilot cases where it has been applied

Location	Responsible	Year	Description
Guildford, Bologna, Bottrop, Hasselt, Vantaa, Dublin	iSCAPE Project EU	2019	Initiatives for passive monitoring and control of pollution, as well as the creation of patterns of behaviour change in the cities of Guildford, Bologne, Bottrop, Hasselt, Vantaa y Dublin.

Main stakeholders (organizations, companies, institutions, etc.)

- Local and regional administration
- Urban planning
- Public health agencies and departments
- Civic and social centres

4.3.3.4 Predictive platform for local arbovirus outbreaks

(Author: Xavier Rodó)

Areas or sectors where it applies:

- Health

Type of solution: Technological solution

Solution / Technology

Platform of mathematical models that predict the risk of local outbreaks of infectious diseases transmitted by arthropods, such as flies, mosquitoes, ticks, etc. called arboviral, based on the control of a series of variables including climatic, ecological, demographic and socioeconomic information of the region.

Basic description

ArboCat is a new platform for the prediction of autochthonous outbreaks of arbovirus, implemented for Catalonia with resolution at the level of municipalities (948 municipalities). ArboCat allows to calculate the Risk of Local Epidemic Expansion from the importation of cases by infected travellers from risk areas, by using a criterion for the classification of outbreaks as epidemics (for example, more than 10 autochthonous transmissions), and in this way public health experts can design action strategies, monitoring and control through the estimation of the probability of epidemic given the number of cases observed in a municipality.

In addition, by simulating different scenarios for the calculation of R_0 (e.g., climate change, on vector proliferation, economic and demographic projections, urban planning, landscapes) it is possible for medium-long term planning, to simulate future scenarios of epidemic risk under-high future conditions of global warming.

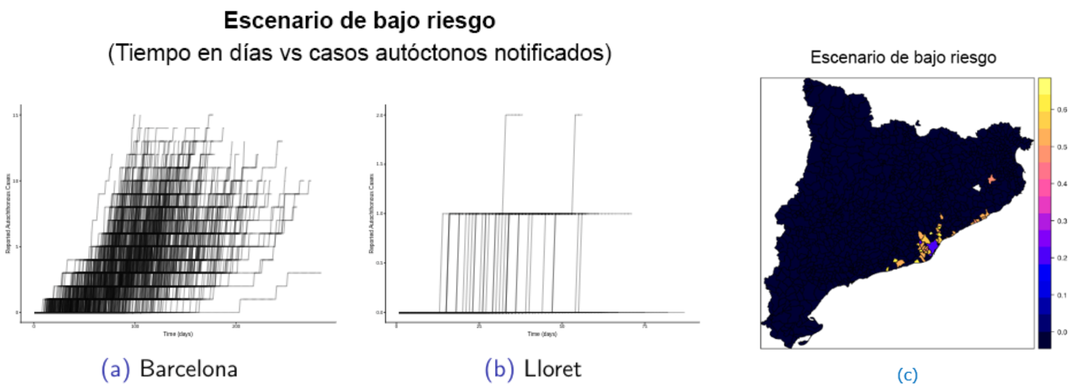

Figure 22. Example of probabilistic projection of epidemic outbreaks associated with a low-risk scenario for two municipalities with different risk conditions: (a) Barcelona, (b) Lloret. (C) Relative risk map in Catalonia for a low irrigation scenario. (Source: ISGlobal, 2019)

ArboCat consists of three sub-models that provide estimates of import rates and basic reproductive number (R_0)[127], and that they fit a stochastic compartmental model that provides the generation time. ArboCat provides simulations of the risk of autochthonous outbreaks and epidemic curves for scenarios of socioeconomic and climate changes, both present and future. The platform contains three coupled mathematical models that allow an easy visualization of

[127] A figure expressing the average number of cases of an infectious disease arising by transmission from a single infected individual, in a population that has not previously encountered the disease.

the risk of epidemic outbreaks at the municipal scale, as well as the magnitude and evolution of the same.

It is possible to select diverse epidemiological information at different levels and at the municipal level and to visualize the information related to the corresponding epidemic outbreaks. It is easily adaptable to any other geographical environment.

ArboCat uses a Markov Branching Process for the transit of people between different compartments (named depending on the status of individuals, such as susceptible or S, exposed or E, infected or I and recovered or R), to model outbreaks. Simulations start with a single imported case. Time evolution is governed by the daily probabilities of infected individuals progressing to E, I, R states. The model explicitly considers the monitoring of imported and autochthonous cases, as well as reported and non-notified cases. Not explicitly, the model considers the monitoring of mosquito dynamics (adjustment of the generation time for the E-I transition). The following diagram summarizes the entire process of transit of individuals between compartments.

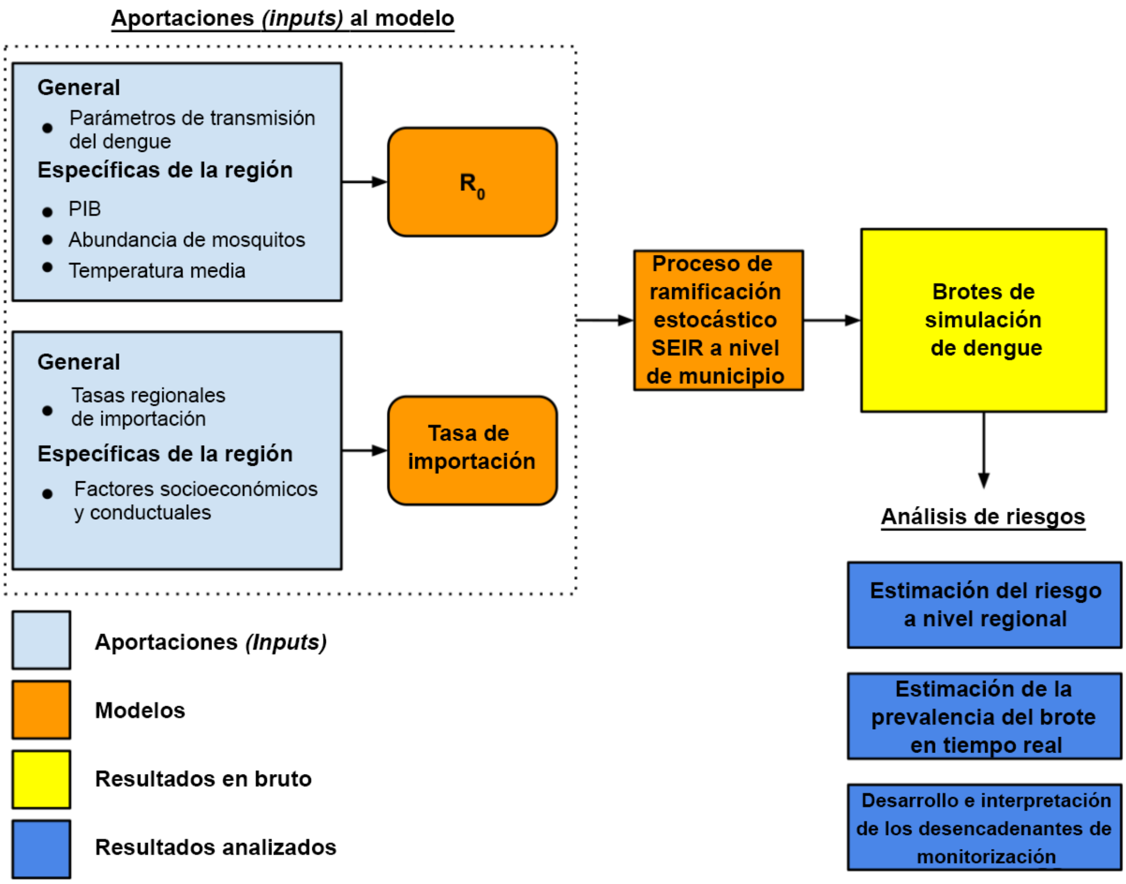

Figure 23. Typology of processes and structure of the models connected in ArboCat. Minimum initial data required and outputs in the form of risk analysis (Source: Arbocat.).

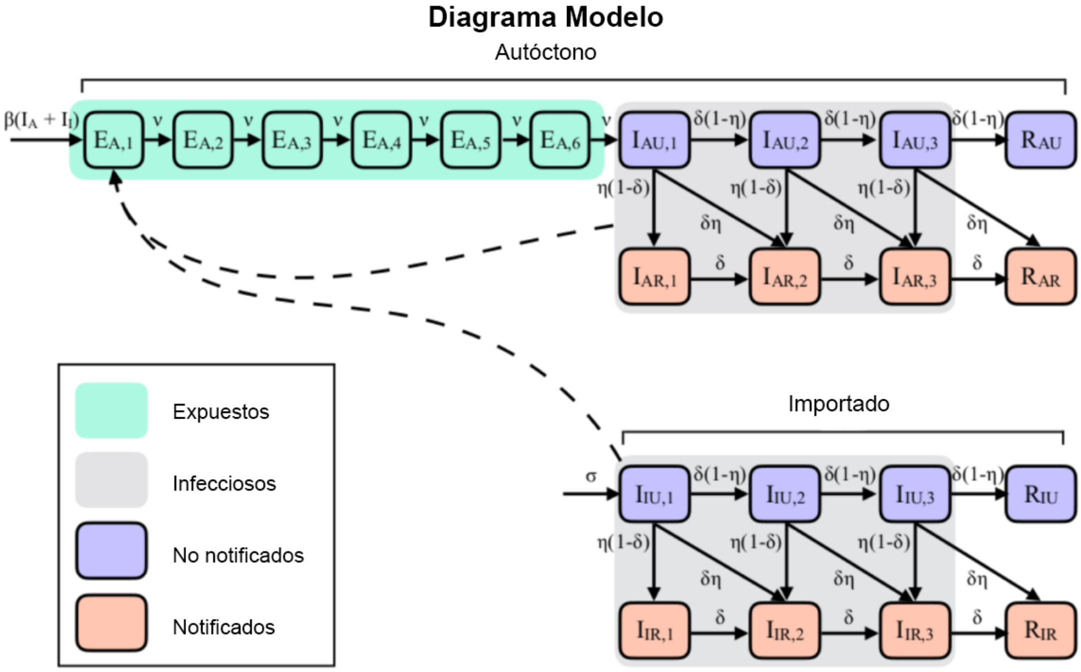

Figure 24. ArboCat platform flowchart (Source: Arbocat.).

Implementation potential

Advantages	Disadvantages
• It allows the operational forecasting of the risk of autochthonous outbreak. • There is no analogous tool based on the modelling of human populations that allows the generation of instantaneous risk maps. • Its modular nature optimizes information integration and intensive computation. • Continuous development of artificial intelligence and big data technologies by ISGlobal, improve the integration in each area and situation, of environmental and socioeconomic factors. • Easy visualization of results • Durability. • Portability.	• It needs effective coordination to integrate the different data providers and their network operations in the Community. • It requires the implementation of the calculation system in a compatible computational architecture. • Many factors can result in a large amount of data to be analysed in real time. • Depending on the required time resolution (daily, weekly) there is a different calculation time and operating cost. • Maintenance (although the service can be outsourced).

Potential barriers to implementation

The barriers (or requirements) for the implementation of the ArboCat platform are classified into 4 blocks.

- Technological. It will be necessary to have an articulated network between the different actors of the system that support the operational implementation of ArboCat. Additionally, it will be necessary to update the computer network and / or calculation architecture and the outputs of the system to the users involved (health centres, municipalities, public health, mosquito surveillance and control systems ...)
- Regulation. Although anonymized data is used in ArboCat, the use of personal data will have to be regulated when the detection of an infected case may be relevant for epidemiological control.
- Communication: It will be necessary to establish channels of communication and transmission of information fluid between all parties and actors involved (provision of meteorological data, patients by health, vector control, municipalities, nodes of the health system).

- Roles and responsibilities of stakeholders. It will be necessary, among other requirements, to establish optimal communication channels for collaboration between providers of meteorological, vector and public health data (through access to data from travellers diagnosed with an arboviral disease), to improve the necessary synergy between the generation of maps and forecasts of local outbreak risk in different populations.

Level of innovation today (TRL = 9)

There are currently no applications similar to ArboCat based on epidemic evolution for outbreaks of arboviruses such as *dengue*, *Zika* and *chikungunya*, etc. at European level. Those that exist are based either on statistical indices or on risk forecasting based on vector distribution (e.g., mosquitoes) and do not dynamically integrate imported cases infected by travellers returning from endemic areas. Clear and concise visualization, with easy integration of health, environmental and socioeconomic information. This tool is already in operational mode.

Expected or desirable advances in the coming years

Under a maintenance and supervision contract, updates of the simulations will be incorporated and uploaded to the platform during the time of proliferation of the tiger mosquito in the different regions, with the aim of improving the quality of the predictions. The international collaborations of the developer group (research institute in Catalonia, Spain) with the University of Texas at Austin, CDC, ECDC, as well as local partners (ASPCat, CREAF, VHIR, interdisciplinary network PICAT) guarantee a promising development of future improvements in the capacity and predictability of the platform to identify new threats to public health caused by arboviral infections.

It is also planned to increase the capacity to integrate environmental and socioeconomic data into the platform, as well as testing with alternative calculation algorithms.

Expected results

Risk maps of local arbovirus outbreaks (e.g., *dengue, chikungunya and Zika*) will be available in near-real time during the time of greatest risk of transmission, due to the proliferation of the competent and potentially carrier mosquito. Likewise, as local outbreak risk forecasts are generated, depending on the number of imported cases and the place, the scenarios and tools are provided to design adequate actions of the surveillance and public health system.

It is expected that in parallel and if necessary, this platform can be extended to other infections, as in the case of West Nile Virus (WNV).

Installation costs

Installation costs vary depending on local conditions for system deployment based on an initial installation license agreement (approximate cost: € 25,000) y annual renovation (6,250 €/year). Availability of compute time in compute cluster or parallel servers, data storage capacity, and a computer technician to support the installation are required.

Alternatively, you can contract the entire service remotely at source (initial license plus renewal), for which it will not be necessary to provide calculation time, storage or computer support (more than that necessary for the integration of the service on the website that is intended to be created or integrated into an already established reference platform).

Operating costs

Maintenance costs depend on the type of installation and support required. For a totally independent operation of origin, the need for a part-time software engineer for 6 months is estimated (e.g., control of the distributed calculation operation in computing cluster, generation of the simulations 1 month before and after the times of highest risk of transmission and post-processing of results for visualization). It must be added to the above, the cost of calculation time in a calculation cluster if the required resolution is daily or in servers connected in parallel if it is weekly. In Barcelona, the monthly calculation and data storage expenses for the platform were estimated at around 1,200€/month. In the case of a service contract, the cost is more limited and is estimated in total around 9,000€-10,000 €/year.

Social acceptance

In general, if the solution is well managed, a good acceptance is expected, given that this platform is an informative and management tool. The knowledge of the previous basal risk in a municipality can instead generate alarm, induce preventive measures that reduce the risk. This can be presented as a positive achievement and the new risk forecast can be revaluated after the actions (control by fumigation or others of mosquito populations, awareness campaigns, etc. The definition of which levels of information output are enabled for the public can be decided based on the need or opportunity. All results in principle are computationally designed so that they can be provided in open access, depending on the needs or will of the user.

Recipients

- Regional governments
- Municipalities
- Public Health System
- Attention to the traveller
- Mosquito control service

Relevance for climate change adaptation

Risks arising from climate change to which it can help us adapt

- Emerging diseases
- Social alarm
- Temperature variability

Conceptual fit within climate change adaptation

Predictive platform of local outbreaks of arbovirus allows the operational forecast (daily, weekly, monthly) of the risk of local outbreaks of arboviruses at the municipal level during the time of year climatically favourable to the spread of the disease due to the bite of *the Aedes albopictus* mosquitoes, which aligns with the need to cover information of high interest to the citizen. This enables prevention campaigns (fumigation of potential breeding areas, information campaigns, citizen awareness) and participation via citizen science (identification of vectors, e.g., MosquitoAlert). However, as a vector base system, ArboCat can use the Cramer database failing that.

Now, largely because of the globalization of trade and the displacements of people and the effect of climate change, in Spain we already have the *Aedes albopictus* mosquito (tiger mosquito) responsible of the transmission of several arboviruses such as dengue, chikungunya and Zika. The case of dengue is already a reality because several cases have been reported. There is also the threat of *Aedes aegypti*, whose distribution ranges are also expanding due again to the effect combined with climate change, and for example there is a risk of entry from the Canary Islands (as happened two years ago, although it could not finally be installed). The traffic of goods and people between the island of Madeira, where it is already installed, and the Canary Islands, makes this reality very likely. Another very different aspect is the outbreaks that these imports may be able to produce. With emerging diseases, the CCAES is carrying out risk assessments to know the probabilities it has of becoming endemic. In the case of dengue, the evaluation carried out concludes: "*The risk to public health of autochthonous dengue in Spain, in the current context, is considered low. Although it cannot* *be ruled out that new cases of autochthonous vector transmission may appear, the impact would be low given the mild nature of the disease*." The fight against the mosquito is not with adulticides (they talk about fumigation), but larval with the use, mainly of *Bacillus thuringiensis subsp. israelensis* (Bti)*. The awareness of citizens, a topic of capital importance to which ARBOCAT for its attractive visualization, can help.

Real and pilot cases where it has been applied

Location	Responsible	Year	Description
Catalonia, Spain.	ASPCat	2019	The ASPCat collaborated in the PICAT project (PERIS, GenCAT) that articulated the connection network between the Passenger Care system, the CAP and the Health Department and the mosquito control system. The ARBOCAT tool was presented publicly but has not yet been implemented operationally due to the COVID-19 pandemic.
Texas, USA.	Texas Public Health Agency	2017	The Dep. of Integrative Biology of the University of Austin (Texas), collaborator in ArboCat designed a similar system, although more simplified, that already works operationally, in this American state.

Main stakeholders (organizations, companies, institutions, etc.)

- IS Global
- Public Health Agency of Catalonia, Spain.
- Vall d'Hebron Research Institute
- Mosquito Alert

4.3.3.5 Monitoring of air quality by citizens (SMARTCITIZEN)

(Author: Xavier Rodó)

Areas or sectors where it applies:

- Health
- Contamination
- Early warning

Type of solution: Technological solution

Solution / Technology

Low-cost digitalization available to citizens offers unique opportunities in the context of '*Smart Cities*' or Smart Cities with tools to create '*Smart Citizens*'. Portable Kits generate real-time data while raising awareness of air pollution in urban areas.

In the same way, it contributes to creating interest and citizen participation in the search for solutions to such an important problem. The *Smart Citizen* project or platform, with the latest model *Smart Citizen* Kit 2.1., has +9000 registered users and more than 1900 sensors distributed in more than 40 countries.

Figure 25. Sensor installed in Barcelona within the BGG UIA project (Source: AIRLAB, ISGlobal).

Basic description

Low-cost sensors for measuring air quality (PM_{10}, $PM_{2.5}$, PM_1), meteorological (humidity, atmospheric pressure, temperature), greenhouse gases (eCO_2, TVOC), light and noise. The instrumentation is easy to install, with the equipment connected in Wi-Fi network for real-time data transmission.

This initiative connects with a growing and highly sensitized urban population, in which citizens themselves collect real environmental data and 'scientific' utility, that is, the citizen generates participatory science. *Smart Citizen* is also a platform that therefore empowers citizens by encouraging them to learn more about urban spaces and their role in communities. Although the project was started in 2012 by the *Fab Lab Barcelona* project and the Institute of Advanced Architecture of Catalonia, in 2019 its state-of-the-art hardware, the Smart Citizen Kit 2.1, was commercialized. Both Smart Citizen software and hardware are free and available for use under open-source licenses.

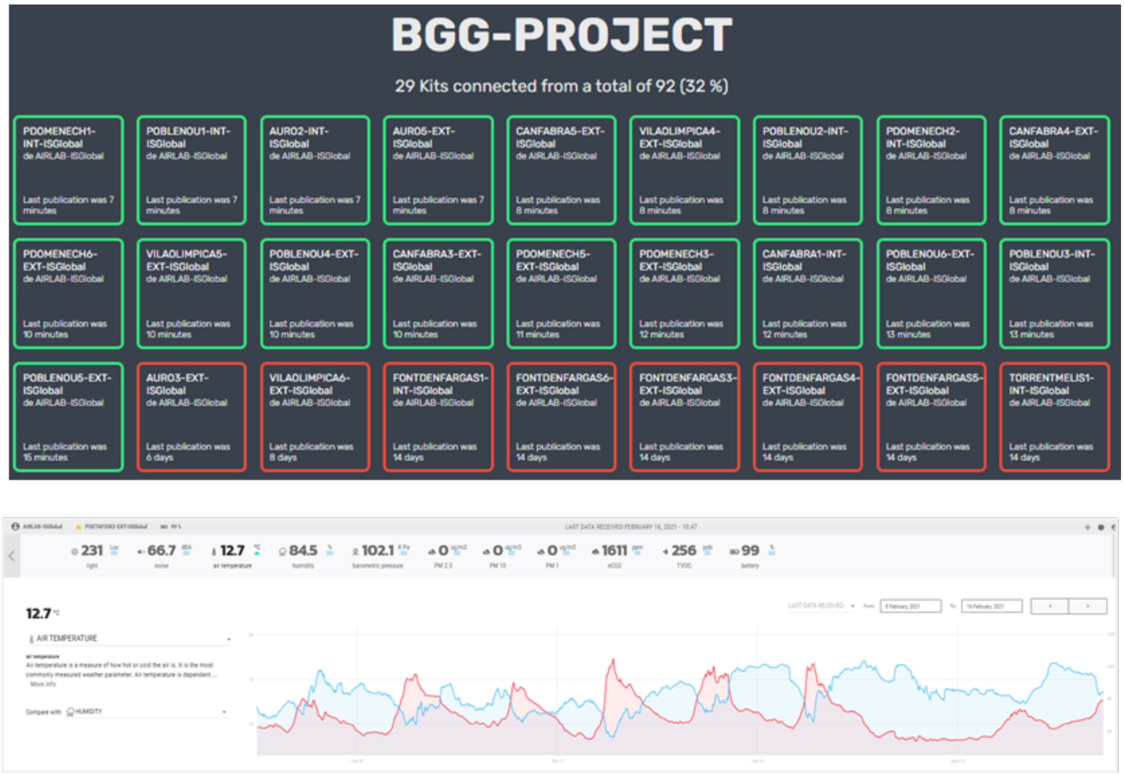

Figure 26. (superior) Example of SmartCitizen online connected kits (active green sensors) in 15 schools in Barcelona, as well as (bottom) example of data visualization compared between variables (Source: AIRLAB, ISGlobal).

Potential implementation

Advantages	Disadvantages
• Facilitates adaptation in other activities/sectors. • It allows to measure the reduction of the risks to which it adapts. • Easy display of the results via the Wi-Fi network. • Low cost and reduced maintenance. • Scalability by sections depending on the number of equipment to be installed, modular. • The Smart Citizen platform is open and online, as well as all documentation • There is a community forum. • It contributes to empowering citizens in the fight against climate change.	• Vandalism with computers. • Intercalibration needed regularly with more precise equipment. • If you want to generate operational maps (e.g., daily), it requires dedicated technical staff. • It needs electrical or solar panel connection as power.

Potential barriers to implementation

No major barriers to its implementation are detected. The technology is cheap, well recognized internationally, and its use in combination with other public alert systems is clearly beneficial. Its low cost allows an immediate replacement of the equipment if it is damaged or suffer vandalism. They also allow citizen awareness and communication of the effects of urban pollution and climate change.

Level of innovation today (TRL = 9)

Smart Citizen technology is already in a high degree of development and market exploitation, while its ease of use and features, position it as a real and very valid alternative to the centralized production of data and management, often opaque, of this type of information. The concept of empowering the ordinary citizen is innovative and of high value, also given the community forum and the many networked users around the world.

Expected or desirable advances in the coming years

Given their ease of use, the improvement of the sensors is foreseen, with greater stability and sensitivity of the measurements. Likewise, it is expected that the initiative will be established at the international level with the increase in the number of users, the participation of initial projects in international citizen science forums, as well as the usual publication of results in scientific journals.

Expected results

Various initiatives in the field of science and dissemination, in projects of municipalities for environmental monitoring (e.g., green schools in Barcelona and Amsterdam), as well as education in high school and first university courses, are using this type of low-cost equipment, in community experiences. These initiatives make it possible to characterize the levels of pollution in schools, hospitals and residential areas, a fact that motivates the search for solutions to minimize exposure to pollutants, also by municipalities and public health managers.

Installation costs

Installation costs are limited and depend on the number of measuring equipment installed. According to 2019 costs, an individual team of fab lab smart sensors is around € 300 plus VAT. To this we must add the installation of sensors in street lamps, traffic lights or other points elevated 4-5 m to avoid pillage. You have to provide the electrical and Wi-Fi connection to the network. You can opt for an autonomous battery by solar panel that increases about € 150-200 plus VAT the individual cost of each sensor.

Operating costs

It is necessary to consider the costs of maintenance (calibration of sensors), electricity and internet services, review of equipment and security, as well as that of the post processing of information and the generation of products and services (maps, time series, etc.)

Social acceptance

In general, it is expected a high acceptance (recommended communication campaign, advertising ...) of this technology, of which there is demand by social agents and / or provides social benefits beyond the adaptation of climate change. It is a very specific solution, although easily applicable and in a modular implementation planning by stages, municipalities, increasing the resolution (more sensors) on demand. It may, however, conflict – if not coordinated – with other pollution control systems, which are in operation in the competent authority, and with which it should be inter-calibrated from time to time.

Recipients

- Regional governments
- Municipalities
- Public Health System
- Vulnerable population (elderly/nursing homes, children/schools)

Relevance for the climate change adaptation

Risks arising from climate change to which it can help us adapt

- Heat waves
- Increase in air pollution

Conceptual fit within climate change adaptation

In a dynamic of accelerated climate change due to the emissions scenario that the planet is following, knowing reliably how much and how we pollute and emit greenhouse gases, can help mitigate these sources through a redistribution of pollutants (urban reorganization and regulation of circulation, emissions, etc.) and, also, to determine the mechanisms and spaces in which to preferably exercise emission control actions and minimization of risks by the most vulnerable populations. At the scale at which an extensive network of sensors can be deployed, it is impossible to arrive with complete and much higher cost stations.

It also responds to citizen awareness and empowerment regarding climate change and passes it from passive or spectator to active subject.

Real and pilot cases where it has been implemented

Location	Responsible	Year	Description
Barcelona	FabLab	2012	Smart Citizen application in Barcelona.
In different European cities thanks to the projects Making Sense, iSCAPE, Organicity and GROW Observatory.	EU	2015-2021	Deployment through the Making Sense, iSCAPE, Organicity and GROW Observatory projects.
Amsterdam	VITO	2019	Smart Citizen platform and participation forum. https://amsterdamsmartcity.com/

Agents of interest (organizations, companies, institutions, etc.)

- Ministry of Urban Planning
- Urban planning companies
- Ministry of Environment
- Public health agencies or departments
- Citizenship, social organizations, educational centres, etc.
- Organizations involved in communication of climate change and pollution

4.3.3.6 Absorption of air pollution by urban vegetation

(Author: Xavier Rodó)

Areas or sectors where it applies:

- Health
- Urban planning and building
- Biodiversity and heritage

Solution typology: Nature-based solution

Solution / Technology

Plant screens of young birch or other similar species in streets of heavy traffic as plant barriers against the ultrafine material caused by the combustion of vehicles, due to the toxic components they contain. The effectiveness of some plant species in reducing the concentrations of NO_2, PM_{10} and private individuals of smaller urban size is a highly debated issue and the use of shrub or tree species with hairy leaves (young birches), in the form of dense plant walls in streets with a lot of traffic, has found a very notable reduction in the concentration of fine particles in the surrounding air, contributing to the improvement of air quality[128,129].

Basic description

Exposure to particulate matter (PM_{10}, $PM_{2.5}$ and ultrafine particles) and NO_2 in the air from vehicle combustion has been associated with premature mortality and a range of inflammatory diseases, in connection with these pollutants. Among this range of particles, those below 1 micrometre (nanoparticles or ultrafine) are not measured because, so far, they are not regulated in European directives, but there is a forecast that they will be soon with the new regulations.

This is because they have been linked to a higher incidence of asthma, cerebral infarctions, myocardial infarctions and other heart conditions, diabetes, obesity, and dementia[130,131]. There is also evidence that exposure to traffic pollution reduces children's cognitive abilities, damaging their central nervous system and that ultrafine particles can reach heart tissue and damage the heart.

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[128] Maher, Barbara; Ahmed, Imad, A. M.; Davison, Brian; Karloukovski, Vassil and Clarke. Robert (2013). Impact of Roadside Tree Lines on Indoor Concentrations of Traffic-Derived Particulate Matter. Environmental Science & Technology 2013 47 (23), 13737-13744

[129] Wang, H. et al. 2019, "Efficient removal of ultrafine particles from diesel exhaust by selected tree species: implications for roadside planting for improving the quality of urban air," Environ Sci Technol,.

[130] Maher, Barbara Ann; Ahmed, Imad; Karloukovski, Vassil Vassilev; MacLaren, Donald; Foulds, Penelope; Allsop, David; Mann, David; Torres-Jardon, Ricardo; Calderon-Garciduenas, Lilian (2016). Magnetite pollution nanoparticles in the human brain. Proceedings of the National Academy of Sciences, Vol. 113, No. 39, 27.09.2016, p. 10797-10801.

[131] Maher, Barbara et al (2019). Combustion- and friction-derived magnetic air pollution nanoparticles in human hearts. Environmental Research. 176.

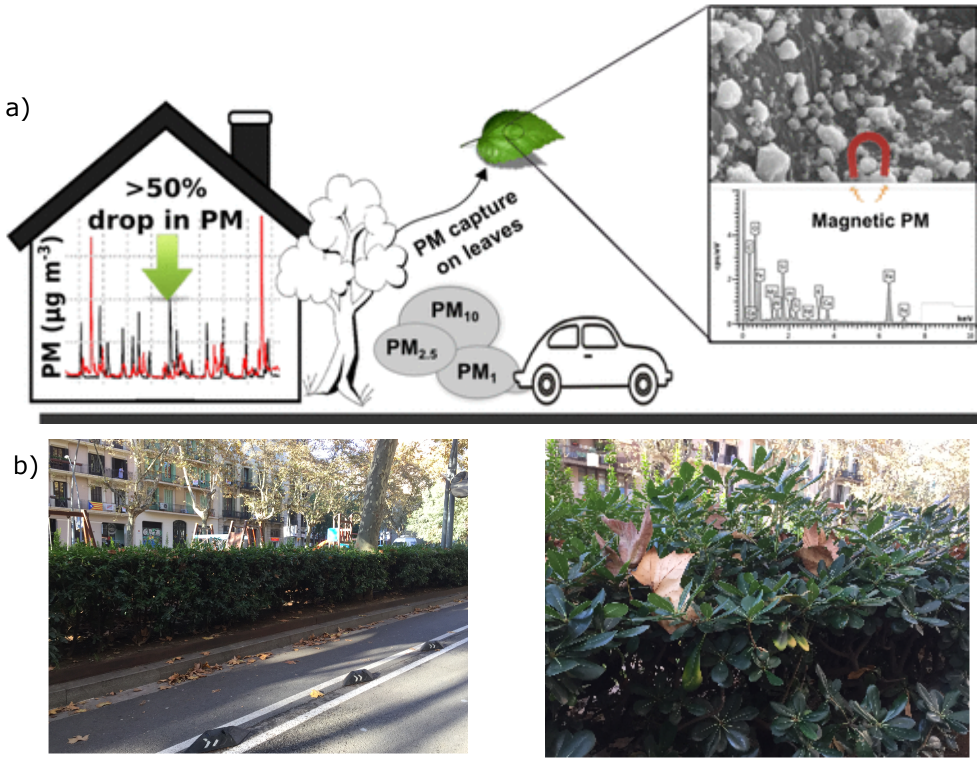

Figure 27 A) Schematic diagram illustrating the effect of shrub barriers on urban pollution (Source: Maher et al., 2013). B) Example of shrub hedge at half height in Barcelona, effective in capturing particles (Source: own elaboration).

Studies with young plants of some plant species (birch, but also yew) are highly effective in capturing a wide range of sizes of particulate matter. The installation of a dense line of young birch trees allows a reduction >50% in the levels of PM measured in the immediately adjacent houses, compared to those dwellings without these 'protective' barriers. These aggregates captured by leaf hairiness are rich in iron, such as spherical ultrafine particles derived from vehicle combustion.

Figure 28. Yew leaves (Taxus baccata), which have shown high retention capacity of ultrafine particles. Source (photo): Pxhere.

Potential implementation

Advantages	Disadvantages
• Facilitates adaptation in other activities/sectors • Co-benefits of vegetation for health (CO2 sink) biodiversity refuge, urban landscape improvement, etc. • It allows to measure the reduction of the risks to which it adapts. • Very low installation and maintenance cost. • Scalability depending on the streets or sectors to be intervened. • It has a very favourable cost/benefit ratio.	• Not all trees are suitable (and in the case of yew trees, the fruits can cause discomfort as they are poisonous). Birch trees produce pollen, which can cause allergies. • Vegetation belts can prevent air recirculation and increase pollutant levels[132]. • Technology poorly tested under natural conditions (only in a couple of locations in England has the effect been quantified directly). • There is a difference between doing it in a laboratory and in outdoor conditions. • Differences between the use of trees or shrubs can be noticeable in the ability to capture pollution. • Tall or high-crowned trees can trap pollution inside, being more harmful than beneficial for those exposed citizens. A tailor-made solution is needed in each case. • There is a need for a rainwater collection and irrigation plan adapted to collect higher concentrations of pollutants in sewage water. An associated water purification plan is required.

Potential barriers to implementation

No major barriers to its implementation are detected. The solution is very cheap and carries co-benefits in health, well-being, and access to recreational green spaces. Its low cost allows an immediate replacement of the bushes, if necessary. They also allow citizen awareness and communication of the need to protect themselves from the pollution generated by vehicles.

In the case of large trees, it can be problematic due to root growth in the case of some species. Also, because adult birches are deciduous and in winter run out of leaves, you must combine it with other alternative solutions.

Level of innovation today (TRL = 7-8)

There is no simple, cheap and effective way to remove particulate matter (and between it, in particular the ultrafine) that is easily breathed and penetrates organs such as the heart, brain, liver, etc. Most pollution regulation directives are based on PM mass measurements and therefore ultrafine (nanoscale) particles contribute very little to this total mass, even though they are the most numerous. These hedges of species with highly hairy leaves offer a very effective method of capture and removal of these highly dangerous particles, also successfully tested. Experiments with wind tunnels have shown that the leaves of these species trap a considerable number of particles with a diameter of less than 100 nanometres. Young birches are for now, the trees that show the greatest capacity to capture particles, removing up to 79 percent of those ultrafine particles from the air. They are followed by the most mature yews and birches with catches around 70 percent.[133]

Expected or desirable advances in the coming years

[132] VesaYli-Pelkonen et al, 2017.

[133] Maher, Barbara. (2019). Airborne Magnetite- and Iron-Rich Pollution Nanoparticles: Potential Neurotoxicants and Environmental Risk Factors for Neurodegenerative Disease, Including Alzheimer's Disease. Journal of Alzheimer's Disease. 71. 1-14.

It is expected that in the coming years this very economical and nature-based particle capture solution will be used massively as the first protection barrier in those roads of dense traffic or knots of urban congestion, and until the replacement of the combustion car fleet by an electric one occurs. This is if species adapted to the Mediterranean climate are found that offer benefits like those of birch and yew in Atlantic climates. It is then hoped that the investigation will be able to provide new data in this regard.

Expected results

The ideal 'traps' of particulate matter and nitrogen oxides would be species – even if arboreal, not just shrubs – that remain as hedges, that is, without letting them develop as tall trees and at most equal in height to one person. Birch trees, with a hairy leaf, stand out for their ability to trap particles up to less than 30 nanometres. Ideally these green walls should let air through and therefore not be totally watertight to the flow and drafts. In any case, it is worth noting the need to make an accurate assessment so as not to have an opposite effect, which would occur if the trees formed a dense and high crown, which would worsen pollution because they reduce ventilation and air mixing.

Ideally, the particles are kept in the leaves until the water takes them away by leaching due to heavy rains, which recovers their absorption capacity. This water must be treated through a wastewater treatment process.

Installation costs

The installation costs are limited and depend on the length of the route in which you want to do the action.

Operating costs

Minimum maintenance costs are estimated. Costs are foreseen derived from the recycling and purification of rainwater that collects materials derived from pollution, trapped in the vegetation cover.

Social acceptance

In general, a high acceptance is to be expected without the need for an awareness process (communication campaign, advertising ...). Technology for which there is demand from social agents and / or provides social benefits beyond the adaptation of Climate Change. Very specific solution, although easily applicable and in a modular implementation planning in stages, in municipalities and with unique vegetation and specially adapted to the climatic environment of interest.

These targeted actions are already contemplated in a framework of adaptation to climate change. The advantage of these measures is that they are measures called 'no-regret', they will always help improve the quality of life and the attractiveness of a green city and committed to the health of its citizens.

Recipients

- Regional governments
- Municipalities

Relevance for climate change adaptation

Risks arising from climate change to which it can help us adapt

- Heat waves
- Increase in air pollution

Conceptual fit within climate change adaptation

The present solution fits perfectly between adaptations to climate change through the reduction of exposure to pollutants from road traffic, which also contribute to it. It is a clear example of health co-benefits. At the same time, it is also clear that increasing vegetation cover contributes – albeit in a limited way – to reducing the urban heat island effect by reducing the km of asphalt on the streets. Clearly this nature-based solution has, as has been highlighted in recent publications, many other positive effects on influencing people's well-being. Recent STUDIES by ISGlobal show that greater proximity to urban green areas translates into a lower risk of mortality from chronic respiratory and cardiovascular diseases, as well as contributing to an improvement in people's mental and emotional health.

Real and pilot cases where it has been implemented

Location	Responsible	Year	Description
25 urban forests and parks in Baltimore, Maryland,	Univ. Helsinki	2017	Study in Helsinki metropolitan area for NO2 levels. The article contemplates the potential worsening of air quality conditions in conditions of poor air circulation.
Lancaster	Univ. Lancaster	2013	Application on streets of downtown Lancaster with different species to check their ability to retain particles.

Agents of interest (organizations, companies, institutions, etc.)

- City councils and regional governments
- Departments of urban planning and green areas
- Public health organizations
- Urban pollution control agencies.

4.3.4 Agriculture, livestock and food

4.3.4.1 Agrovoltaic energy

(Authors: Nil Álvarez and Carles Ibáñez)

Areas or sectors where it applies:

- Agriculture, livestock and food
- Energy
- Water

Type of solution: Technological solution

Solution / Technology

Agrovoltaic energy, also known as agrophotovoltaics, consists of taking advantage of the same area of land to obtain both photovoltaic solar energy and agricultural products. Solar panels coexist with crops on the same surface. This technique was originally conceived by Adolf Goetzberger and Armin Zastrow in 1981, but the concept did not begin to become popular until well into the twenty-first century.

Basic description

The installation of solar panels on crops can increase overall productivity per hectare since agricultural production is complemented by energy production. It is also a tool to protect crops from excess heat stroke or even frost and hail. The use of this technology has proven to be a useful tool for reducing water consumption, reducing the effect of heat waves on crops, and improving crop production and quality.

This system of combined land use allows to mitigate on the one hand the effects of climatic events on crops (droughts, hail or frost), since the correct orientation of the plates generates a microclimate under them. On the other hand, the generation of energy in parallel to the crop minimizes the economic risk of production and increases its energy independence.

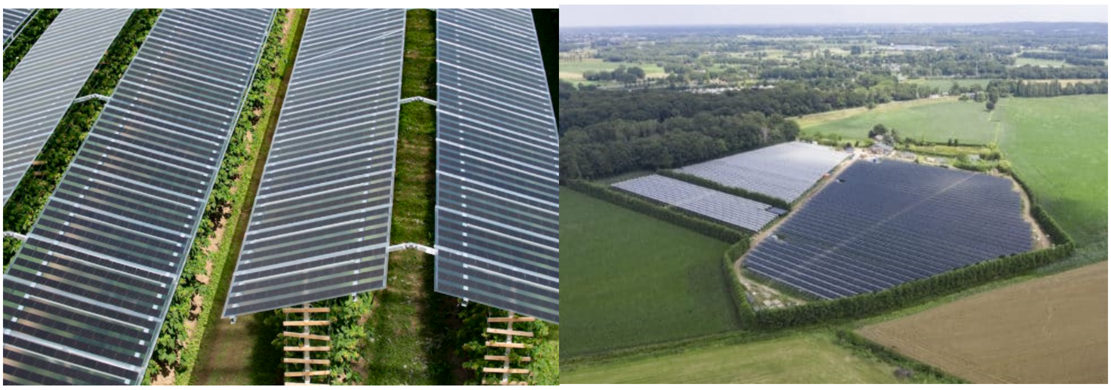

Figure 29. Agrovoltaic installation in Netherlands. Source: PV-magazine.

There is a wide variety of facilities that adapt to each type of crop, whether panels mounted in height to allow the passage of agricultural machinery, installed in parallel to greenhouses, on the margins of crops or between them alternating areas of cultivation and areas of solar exploitation.

Implementation potential

Advantages	Disadvantages
• Increase of more than 30% of the economic value of the farm due to the diversification of the agricultural business. • Reduction in greenhouse gas emissions. • Reduction of pressure on ecosystems and biodiversity. • Buffer energy costs in irrigated farms.	• Excess shade can lead to decreased production depending on the crop. • Geographical limitations as good exposure to sunlight is needed. • High initial investment. • Landscape impact.

Potential barriers to implementation

Not all crops are suitable to be adapted to this technology, and the location of the farm must be considered in terms of sun exposure.

Another barrier is the high cost of installation, which would be amortized throughout the operation. A possible solution proposed by some companies is to separate the farm from the photovoltaic, so that farmers and electricity producers are contacted to reach an exploitation agreement that benefits both.

Level of innovation today TRL = 8

These systems have been developing for years, having proven their efficiency both at the agronomic and energy level.

The level of development has reached the point of favouring the growth of the crop, since photovoltaic panels are used as parasols, so that they can be tilted to favour or hinder the passage of light at times of the year or the times of the day of greater insolation, according to the needs of the crop. The same goes for at night, where the panels can prevent frost, or in adverse weather events where the panels can protect the crop from hail.[134]

This technology is available for extensive crops, for greenhouses, intensive crops, etc. According to studies, crops of tomatoes, peppers, berries, and vineyards, are best suited for agrovoltaic practices, as they require shade to grow[135]. The design of the installation must be adapted to each situation, and a previous feasibility study must be carried out.

Expected or desirable advances in the coming years

The efficiency of photovoltaic panels is expected to improve markedly in the coming years, making agrovoltaic practices more profitable. Likewise, cultivation practices will be optimized to make the most of these facilities.

On the other hand, software is being developed capable of orienting the panels to optimize energy production while considering the insolation needs of the crop. This same software will be adapted to take into account the incidence of moonlight on the panels to reduce the risk of collision of migratory birds that can confuse the reflectance of the panels with aquatic areas.[136]

Expected results

By allocating the same area for agricultural and photovoltaic production, the productivity of that soil is significantly increased, and the amount of soil transformed is reduced, thus reducing the impacts on ecosystems. With current technology, it has been shown that some crops can

[134] Sekiyama, T.; Nagashima, (2019) A. Solar Sharing for Both Food and Clean Energy Production: Performance of Agrivoltaic Systems for Corn, A Typical Shade-Intolerant Crop. Environments, 6, 65

[135] Solar Plaza

[136] Green Concept Management. Desarrollo AgriVitiVoltaicos

increase their productivity, so it would benefit from the atmospheric protection offered by solar panels, while generating energy to be self-sufficient and generate an extra income on the same plot where previously it was only cultivated[134].

Installation costs

The costs of these facilities will be borne by the energy company that will operate the facility, and the farmer reaches an economic agreement for the transfer of his land for this activity. The costs associated with this type of installation are not far from those derived from a photovoltaic exploitation according to Agostini[137].

It must be taken into account that factors such as the location of the farm, the type of crop to which it is coupled, the degree of transparency necessary in the plates and the height of the installation will play an important role in the cost of said installation, being able to increase by about € 220-250/kW in the case of panels, and between 75-200 €/kW for the costs associated with the supports. As an example, an installation in Germany with adjustable panels at a height of 6m had a final cost of 850 €/kW[138].

Operating costs

Maintenance costs vary depending on the size and complexity of the installation. Typical maintenance tasks are regular inspections, cleaning of panels, maintenance of power distribution networks.

Social acceptance

A priori it is expected that these practices have a high social acceptance, since they favour the energy transition while they do not occupy and transform more soils by taking advantage of plots already destined for cultivation. In this way, by adopting agrovoltaic practices, the number of hectares necessary to favour the transition to renewable energies will be reduced, having a lower landscape effect compared to the implementation of these energies in natural areas.

Recipients

- Farmers
- Energy production and distribution companies
- Renewable energy cooperatives

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Rainfall and/or hydrological variability
- Heavy rainfall
- Soil erosion
- Insolation
- Extreme weather events

Conceptual fit within climate change adaptation

Agrovoltaic practices reduce the risk associated with traditional cultivation, since it not only provides protection to the crop, but by diversifying production the economic risk of this activity decreases. They are therefore a mechanism for mitigating the effects of climate change such

[137] A. Agostini, M. Colauzzi, S. Amaducci (2021); Innovative agrivoltaic systems to produce sustainable energy: An economic and environmental assessment, Applied Energy, Volume 281

[138] Emiliano Bellini. (2021) Cost comparison between agricoltaics and ground-mounted PV

as increased extreme weather events, increasingly intense rainfall or increasingly prolonged periods of drought. On the other hand, this practice contributes positively to 14 of the 17 sustainable development goals (Agostini et al, 2021163[137], Dinesh, H and Pearce, J.M. 2016[139]).

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Germany	Krug's Asparagus	2013	With a capacity of 5000 kWp in combination with a *Panax ginseng plantation*[140].
France	SunAgri	2018	Installation combined with the production of grapes, they have achieved a 20% reduction in water consumption and have improved the organoleptic qualities of the crop, as well as minimizing the effects of heat waves[141].
Spain	Green Concept Management	2020	17 projects in operation and more than 160 MWp in development.

Main stakeholders (organizations, companies, institutions, etc.)

- Environmental Ministry
- Energy companies
- Agricultural associations

[139] Harshavardhan Dinesh, Joshua M. Pearce, The potential of agrivoltaic systems, Renewable and Sustainable Energy Reviews, Volume 54, 2016, Pages 299-308, ISSN 1364-0321,

[140] Stephan SchindeleMaximilian Trommsdorff, Albert Schlaak, Tabea Obergfell, Georg Bopp, Christian Journey, Christian Braun, Axel Weselek, Andrea BauerlePetra HögyAdolf Goetzberger, Eicke Weber, Implementation of agrophotovoltaics: Techno-economic analysis of the price-performance ratio and its policy implications, Applied Energy, Volume 265, 2020, 114737, ISSN 0306-2619,

[141] Sun'Agri

4.3.4.2 Innovation in European crop varieties (INVITE project)

(Authors: Nil Álvarez and Carles Ibáñez)

Areas or sectors where it applies:

- Agriculture, livestock and food
- Water

Type of solution: Technological

Solution / Technology

Create innovations in the selection of European crop varieties to improve the efficiency and yield of such varieties under different production conditions and variations in biotic and abiotic pressures.

Basic description

An important adaptation tool in the agricultural sector is the improvement of European crop varieties so that they have greater climate resilience under sustainable growing conditions.

Figure 30. Species selected in the Invite project and of greater importance in the EU. Source: Invite.

One of the most interesting initiatives on innovation in the knowledge we have about European crop varieties and their adaptation to climate change is the INVITE project[142]. This project studies ten selected species used mainly for food and feed production, which constitute an important genetic improvement activity in the European Union. The ten species selected are apple, fodder grass, sunflower, soybean, wheat, corn, potato, tomato, rapeseed and alfalfa. These species were selected because they represent some of the main sources of propagation and food, which at the same time have a greater importance at the European level.

The goal is to contribute to the valorisation and promotion of varieties more adapted to sustainable management practices and more resilient to climate change. To achieve its overall goal, INVITE will implement several tools and strategies: First, it identifies bioindicators

[142] Innovation in plant variety testing in Europe (INVITE)

associated with the efficiency, sustainability and resilience of plant resource use and develops new phenotyping and genotyping tools to measure them. Second, it uses statistical models and tools to predict variety yields in a range of crop management environments and practices, while considering the economic return for farmers. And finally, it proposes organizational innovations to improve the management of variety testing networks and reference collections.

The results of the project will be available to all relevant stakeholders thanks to an active and open dissemination policy.

Implementation potential

Advantages	Disadvantages
• Greater adaptation of crops to climate change. • Capacity building to identify bioindicators. • Identification of best adapted varieties in 10 basic food species in Europe.	• It is not focused on crops or typical climates of the interior of the Iberian Peninsula. • The selected varieties only represent a part of our agriculture.

Potential barriers to implementation

As it is a project that is still being developed, it remains to be seen what the results will be. Although it promises interesting results, it is also necessary to consider the communication and dissemination barriers inherent in this type of project, which are intended to be prevented with a special working group to disseminate and train the interested agents of each territory.

Level of innovation today TRL = 6

The project began in mid-2019, and it is still too early to analyse the results. The project's expected completion date is June 30th, 2024.

Expected or desirable advances in the coming years

Due to the nature of climate change and its changing effects, it is expected that seed adaptations will be able to cope not only with a climatic condition such as water scarcity, but also that they are adapted to changing climatic phenomena and that they are resistant to various climatic factors to achieve greater resilience of crops.[143]

Expected results

The introduction of new varieties with high resilience to biotic and abiotic stresses, high adaptation to sustainable management practices and high efficiency in the use of resources, is essential for the adaptation to climate change of the agricultural sector. It is therefore necessary the progressive introduction of strategies such as those proposed in the INVITE project, where it is intended to improve variety testing protocols for variety characterization and yield testing to improve the speed, accuracy and efficiency of variety testing. INVITE will also provide information to stakeholders on the yield of varieties under a variety of comparable production conditions for major crop species exhibiting significant breeding activity in the EU.

Installation costs

[143] Cacho, O.J., Moss, J., Thornton, P.K. et al. The value of climate-resilient seeds for smallholder adaptation in sub-Saharan Africa. Climatic Change 162, 1213–1229 (2020).

In this case, and due to the nature of the solution, there is no cost associated with the implementation of this adaptation by producers. Possible future patents can have an impact on the price of the seed, thus becoming a direct cost for the producer.

For the purposes of the research being developed within the framework of the INVITE project, the project budget is € 8,160,752 of which the European Union has financed € 7,999,988.25 distributed among 28 institutions in 13 European countries.

Operating costs

This type of adaptation does not imply an associated operating cost, unless the adapted seeds are accompanied by specific cultivation practices, in which case the implications at the level of tillage, production and harvest among others will have to be studied on a case-by-case basis.

Social acceptance

A high social acceptance of these adaptations is expected, as they will contribute to improving crop varieties in Europe while affecting sustainable farming practices and more efficient uses of resources.

Recipients

- Farmers and producers

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Temperature change
- Changes in precipitation patterns and types (rain, hail, snow)
- Rainfall and/or hydrological variability

Conceptual fit within climate change adaptation

In a future scenario where periods of drought, combined with extreme weather events and scarcity of water resources are going to be a very determining factor for agricultural production[144] , it is vitally important to have projects like INVITE that seek solutions to ensure that food production is not affected.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Spain	CSIC	2017-2019	Study comparing adaptation to climate change by selecting fruit varieties adapted to fewer cold winters[145]

Main stakeholders (organizations, companies, institutions, etc.)

- Ministry of the environment
- Food companies
- Agricultural associations
- *Horizon 2020* Programme of the European Union

[144] El impacto en la agricultura y los costos de adaptación. International Food Policy Research Institute.

[145] Iñaki Hormaza Urroz. Adaptation to climate change by selecting fruit varieties adapted to less cold winters. [Agreed the 25/2/2022]

4.3.4.3 Adaptation to soil degradation (LIFE Desert-Adapt Project)

(Authors: Nil Álvarez and Carles Ibáñez)

Areas or sectors where it applies:

- Agriculture, livestock and food
- Biodiversity and natural heritage
- Water

Solution typology: Nature-based

Solution / Technology

Provide scientific evidence of the suitability of different agroforestry adaptation measures to recover and improve the quality of ecosystem services in degraded areas of the Mediterranean.

Basic description

Ecosystem services are resources (goods and services) or processes of natural ecosystems that benefit humans. Soils and agroforestry systems provide us with a wide variety of ecosystem services such as drinking water, flood protection, carbon fixation, biodiversity richness, food sources, etc.

It is, therefore, very important to maintain the quality of these ecosystem services, developing agroforestry adaptation measures that not only improve these ecosystem services, but also recover their functions in cases where the ecosystem has been degraded and at the same time adapt to climate change.

The main objective of *Life Desert-Adapt* is to demonstrate innovative strategies for adaptation to climate change to improve soil quality, conservation, as well as vegetation on both private and public farms located in areas of the Mediterranean at risk of desertification. The two specific objectives of the project are:

- Demonstrate the effectiveness of innovative adaptation technologies, to improve socio-economic development and environmental quality in 3 regions of the European Union (Spain, Portugal and Italy) already affected by climate change, applying the Models of Adaptation to Desertification (MAD) adapted to the specific conditions and opportunities of the site.
- Promote and replicate the MAD frameworks developed among stakeholders, particularly among local farmers seeking socio-economic opportunities for resilient land use and politicians that help replicate measures beyond the project framework.

MADs are specifically designed to counteract aridification and subsequent desertification of the land. A comprehensive ecosystem approach is taken to ensure that climate change adaptation goals are combined with improved ecosystem functions (e.g., carbon sequestration, water retention, biodiversity) and improved socio-economic development.

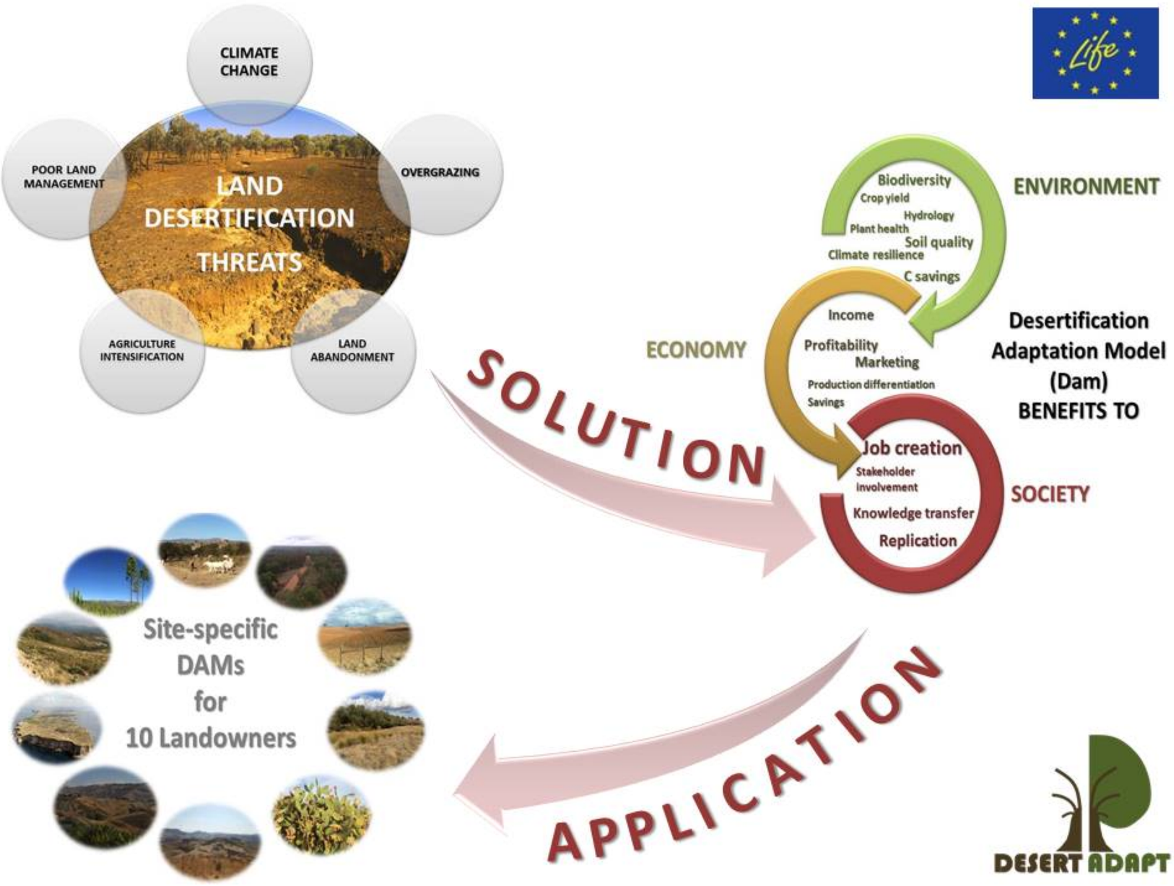

Figure 31. Working model of the LIFE Desert Adapt project. Source: ***Life Desert-Adapt***.

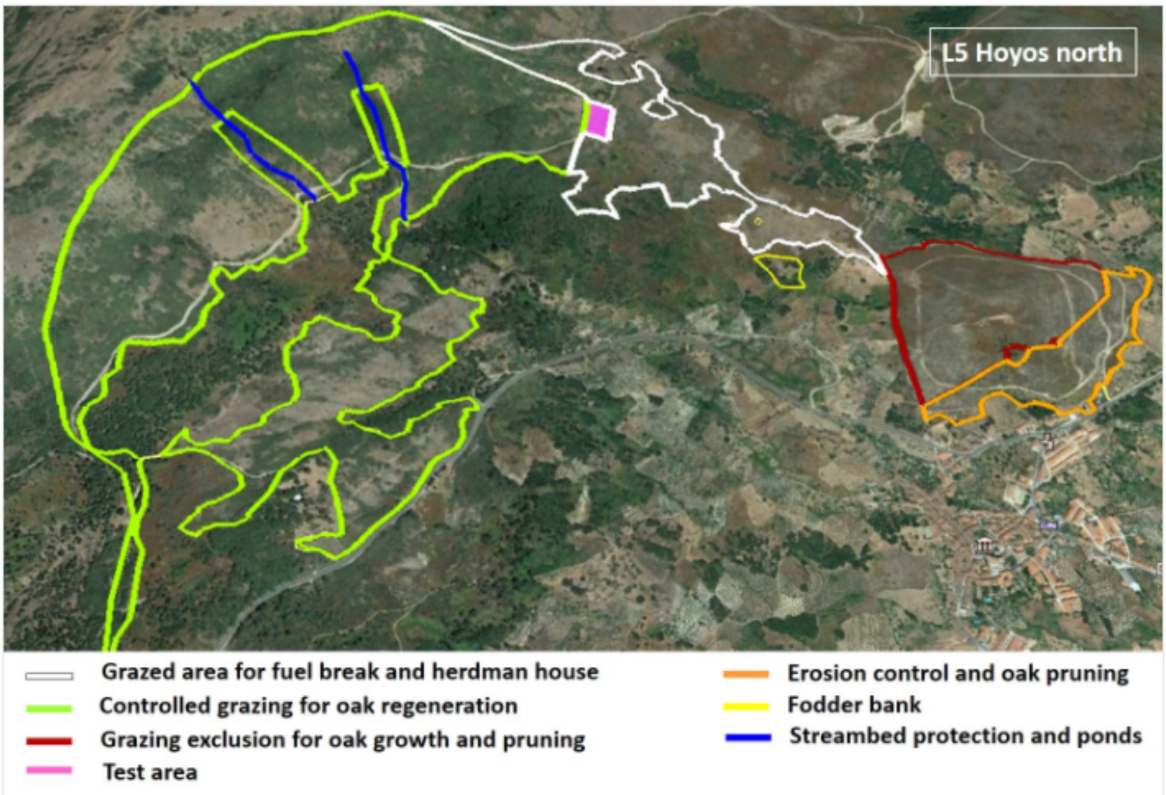

Figure 32. Case study: adaptation measures in the City of Hoyos. Source: *Life Desert-Adapt*

Implementation potential

Advantages	Disadvantages
• Applicable throughout the arid zone of the Mediterranean. • Vocation to promote and replicate the results of the project at the national level.	• Project in execution, the final results are missing and demonstrate the applicability of these.

Potential barriers to implementation

The main barrier when implementing nature-based solutions is the unification of criteria and the dissemination of these. Being natural ecosystems, the challenge lies mainly in the difficulty of creating "general solutions", so the most efficient thing is to generate guides of good practices and case studies such as the one proposed in the *Life Desert-Adapt* project that can later be adapted and applied to other areas with similar characteristics.

Level of innovation today TRL = 7

Throughout the project, which runs from September 2017 to September 2022, all the objectives that were set at the beginning of this have been developed. When the project is completed, the level of innovation and the results achieved can be better assessed.

Expected or desirable advances in the coming years

It is expected that in the coming years the agroforestry management criteria that have been proposed in different conservation projects will be unified so that public administrations can make use of this knowledge in their agricultural and environmental policies.

To evaluate the effectiveness of projects in obtaining the expected results, groups of indicators are established. These are analysed at the beginning of the project to evaluate the baseline, the status of these indicators in the conditions prior to the management of the farms included in the project, and at the end of the project, to verify their status after the implementation of the proposed management.

The indicators cover various aspects, ranging from environmental quality indicators to social and economic indicators. This reflects the nature of the project, which may aim to improve ecosystem services in the study areas while choosing options that are economically sustainable, to encourage partners and owners to continue implementation after the project and new owners to join.

Expected results

The project is expected to benefit local farmers, with income opportunities from new combinations of ecosystem products and services and through cooperatively organized promotions, sales and marketing.

Some of the results shown from the project include at least 8 selected viable revenue streams derived from; an increase in income of EUR 100 per hectare; an increase of 0.1 full-time equivalent jobs per hectare and an overall improvement in the internal return rate of at least 6%.

In addition, local biodiversity will benefit, through greater structural complexity of vegetation, greater attraction of pollinators and lower impacts on soil and the environment. Other results include the ability developed to prepare farmers for various certifications.

Installation costs

As it is a research and development project, no solutions have been implemented that have a specific installation cost. The project, which has had a budget of € 4,063,805 of which € 2,433,020 have been financed by the European Union, has focused on demonstrating the viability of certain agroforestry practices.

Operating costs

In this case, no expenses derived from the operation are detailed, which will depend on the practices developed and that do not have to be different from the costs associated with a traditional agroforestry management.

Social acceptance

Due to the nature of the project, which seeks to adapt and mitigate the effects of climate change, it will have a high acceptance by society, which already recognizes these as the main challenges to be addressed in the immediate future.

Recipients

- Farmers and producers

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Soil degradation
- Temperature change
- Rainfall and/or hydrological variability

Conceptual fit within climate change adaptation

One of the main effects of climate change, combined with poor soil management, is desertification. This project aims to find mechanisms to combat this problem, helping us to manage soils more sustainably and making them more resilient to climate change.

Adaptation to climate change is of particular importance for the Mediterranean region which is experiencing increasingly negative effects, such as drought and extreme temperatures, more than in other areas of Europe. The project focuses on adaptation measures aimed at reversing current trends in desertification and creating more climate-resilient local communities. In addition, it will also address the priority of mitigation policy, by restoring vegetation cover and soil organic matter content, resulting in CO_2 fixation from the atmosphere.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Hoyos (Spain)	Ayuntamiento Hoyos	2017-present	Pilot area of 182 ha dedicated to pasture and agricultural production where regenerative land management measures have been applied improving the production of nuts, conservation and improvement of ecosystem services such as management to prevent fires or erosion control among others, as well as the implementation of social services.[146]

[146] Desert Adapt. Preparating desertification areas for increased climate change.

Location	Responsible	Year	Description
Valverde del Fresno (Spain)	Valverde del Fresno City Council	2017-present	Pilot area of 160 hectares of forestry and agricultural production where economic management measures have been applied to the territory by improving the production of pistachio and chestnut, the collection of rockrose for marketing; actions to improve ecosystem services such as erosion control, wildlife protection, construction of insect shelters, waste management and reforestation, all implementing social services.[147]
Malpartida by Plasencia (Spain)	Viveros forestales la Dehesa SL	2017-present	Pilot area of 100 ha of conreo where regenerative agriculture measures have been applied to improve production and conserve ecosystem services and biodiversity. Among others, the presence of bees has been encouraged, grazing measures have been improved and adaptation measures to climate change have been taken.[148]

Main stakeholders (organizations, companies, institutions, etc.)

- Ministry of the environment
- Ministry of agriculture
- Agricultural associations
- Nature Protection Service (SEPRONA)
- LIFE Programme of the European Union

[147] Project Case Study Desert Adapt in Valverde del Fresno.

[148] Project Case Study Desert Adapt in the forest nurseries of La Dehesa S.L.

4.3.4.4 Smart Agriculture

(Authors: Nil Álvarez and Carles Ibáñez)

Areas or sectors where it applies:

- Agriculture, livestock, and food
- Water

Type of solution: Technological

Solution / Technology

Smart agriculture consists of the use of new technologies in the field of agriculture and livestock to increase the quantity and quality of production, making the most of resources and minimizing the environmental impact. The implementation of technology in agriculture or livestock will also strengthen food security in the world.

Thanks to these new technologies, a farmland can be divided into as many plots as internal differences have that land: variations in the composition of the substrate, existence of depressions, propensity to stagnation of water, presence of predators or degree of porosity, among other characteristics, and apply on each plot a personalized treatment to get the most out of it.

Basic description

Smart agriculture based on Internet of Things (*IoT*) technologies allows farmers to collect real-time data related to plant irrigation and plant protection processes, with the aim of increasing production, improving product quality, and predicting diseases, while optimizing agricultural resources and processes.

The results of a pilot application demonstrate a potential reduction of up to 22% in total irrigation needs and significant opportunities for optimization in the efficiency of pesticide use. The system offers opportunities for innovation targeting and climate change adaptation options and could help farmers reduce their ecological footprint[149].

Among the technologies that are being used in smart farms are:

- Drones capable of identifying plants with nutrition deficit or areas of the crop with water scarcity,
- Internet of things to automate systems such as irrigation or the application of nutrients according to needs,
- Intelligent sensors that measure in real time both environmental conditions and those of the crop,
- *Big data* technology to process massive data obtained with the previous systems that allows better decision making,
- *Blockchain* technology to trace the entire production system saving market costs if you have to, for example withdraw a product, and
- Artificial intelligence to automatically interpret the images obtained by drone and the data generated with the sensors, among others.

[149] Adamides G, Kalatzis N, Stylianou A, Marian N, Chatzipapadopoulos F, Giannakopoulou M, Papadavid G, Vassiliou In Neocleous D. Smart Farming Techniques for Climate Change Adaptation in Cyprus. Atmosphere. 2020; 11(6):557.

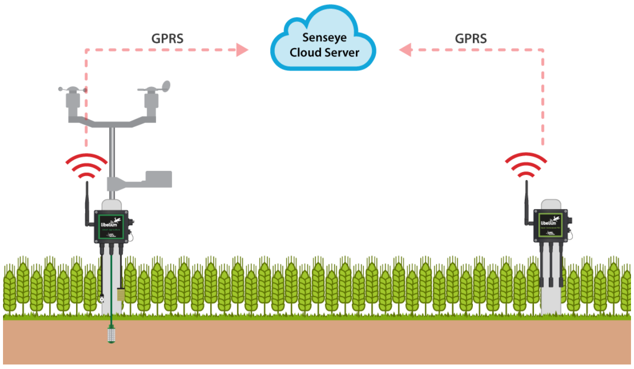

Figure 33. Smart agriculture project in England. Source: Libelium.

Implementation potential

Advantages	Disadvantages
• Increased production • Water saving • Increased quality • Cost reduction in treatments and management • Pest detection • Increasing the sustainability of production	• High initial investment • High degree of specialization • Constraints for smallholder farmers

Potential sweeps for implementation

The main challenge to implement these technologies is the technical aspect. Advanced training is required to implement a complex system such as the one proposed. On the other hand, it requires considerable economic investment if it is to be applied on a large scale.

Level of innovation today TRL = 7

Very advanced technologies are used that have been developed and widely tested in other areas, so innovation in this case more than technology is the use that is given.

Expected or desirable advances in the coming years

It is expected that the costs of these technologies will be reduced in the coming years, becoming acceptable not only for large producers but also for medium and small farmers.

In this sense, *Tran*[150] demonstrates in its 2017 study that a sensor and communications system can be installed to measure ambient temperature and humidity, luminosity and soil moisture for just under € 100.

Expected results

With the implementation of smart agriculture technologies, it is possible to improve the quantity and quality of the crop while making better use of resources and reducing the number of fertilizers and pesticides used, so that a more sustainable and efficient production is achieved.

[150] Tran, Minh Quang & Phan, In & Takahashi, Akihiko & Thanh, Tam & Wei, Son & Bar, Hope & Hong, Chau. (2017). A Cost-effective Smart Farming System with Knowledge Base. 309-316.

Installation costs

Installation costs will vary depending on the sensors and equipment to be installed, the data collection system and the desired automations.

The variability of installation costs is great, so a personalized study is required for each case. As an example, the American company *Lets Nurture offers*[151] services to develop the communications interface of a smart farm for a price of around € 10,000, to which must be added the investment in sensors and communication equipment. On the other hand, as mentioned above, Tran and his colleagues have demonstrated the feasibility of incorporating a small kit of sensors and communications for just under € 100 for small farmers.

Operating costs

Once the sensors and the data collection and processing system are installed, the operating costs are those associated with the maintenance of the equipment and the communications and energy supply network.

Social acceptance

A high social acceptance is expected as they are very widespread technologies in other sectors and enjoy great popularity. However, conventional farmers and producers may be reluctant to incorporate these new technologies, so that outreach and training work will have to be done to avoid that "fear of change" is a barrier in this regard.

Recipients

- *Farmers and producers*

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Temperature change.
- Water stress
- Changes in precipitation patterns and types (rain, hail, snow)

Conceptual fit within climate change adaptation

In a scenario of climatic instability and population increase, the adaptation of agriculture to these changes is paramount. This technology allows to reduce the use of resources making productions much more sustainable and resilient.

The adaptation to climate change of Mediterranean crops is addressed from an integrated digital agronomic perspective and with the aim of making smart agriculture viable for small farmers.

[151] Let's Nurture. "How much would it costs to develop an IoT based proof of concept (PoC) for Smart Farming System?"

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Almeria	University of Almeria	2020	Case study within the Internet of Food & Farms project[152]. Applied to the production of tomatoes in greenhouses.
Córdoba	Sensowave	2020	Case study within the Internet of Food & Farms project[153]. Applied in decision-making in beef production.
Spain	UAB/SNiBA	2018	ERDF project that aims to make the intensification of livestock compatible with an increase in competitiveness in a sustainable way and respectful of animal welfare.[154]
Sardinia	Consulmedia/ Agribio	Present	Agriculture 4.0 project using Libelium sensor data. The facility is designed to measure the essential aspects of an ecological plantation by limiting the environmental impact by using energy and natural resources responsibly; improving soil fertility and maintaining water quality.[155]
Andalusia	Agricultural and Fisheries Research and Training Institute	2020	Synthesis document of different technologies and sensors to measure temperature, humidity, solar radiation, CO_2, wind and rain. Applicable in greenhouse crops.[156]

Main stakeholders (organizations, companies, institutions, etc.)

- Ministry of the environment
- Ministry of agriculture
- Agricultural associations
- Food companies

[152] Internet of Food & Farm (IOF). "Chain-integrated greenhouse production".

[153] Internet of Food & Farm (IOF). "Decision-making optimization in beef supply chain".

[154] SNiBA (2019) SNiBA-UAB leads the SMARTFARM project.

[155] Libelium (2021) Precision agriculture and automatic risk in organic crops with technology Yacht of Libelium.

[156] Servifapa (2020) Use of SClimate Advisors in Greenhouse Crops. Junta de Andalucía. European Union.

4.3.4.5 Adaptations of agriculture to climate change (LIFE AgriAdapt Project)

(Authors: Nil Álvarez and Carles Ibáñez)

Areas or sectors where it applies:

- Agriculture, livestock and food
- Water

Type of solution: Technological

Solution / Technology

The solution offered to adapt agriculture to climate change is the creation of a web tool that collects relevant information on adaptation measures for different types of agriculture depending on their climate.

Basic description

European farmers and stockbreeders have and will have to adapt to a changing climate, through measures that go beyond simple adjustments *to ad hoc* practices. In order to limit the vulnerability of their farms to increasingly variable climate risks, adaptation must be designed and carried out in a sustainable manner.

For this, it is necessary a database, which is made available to producers, with relevant information on adaptation measures to the risks derived from climate change.

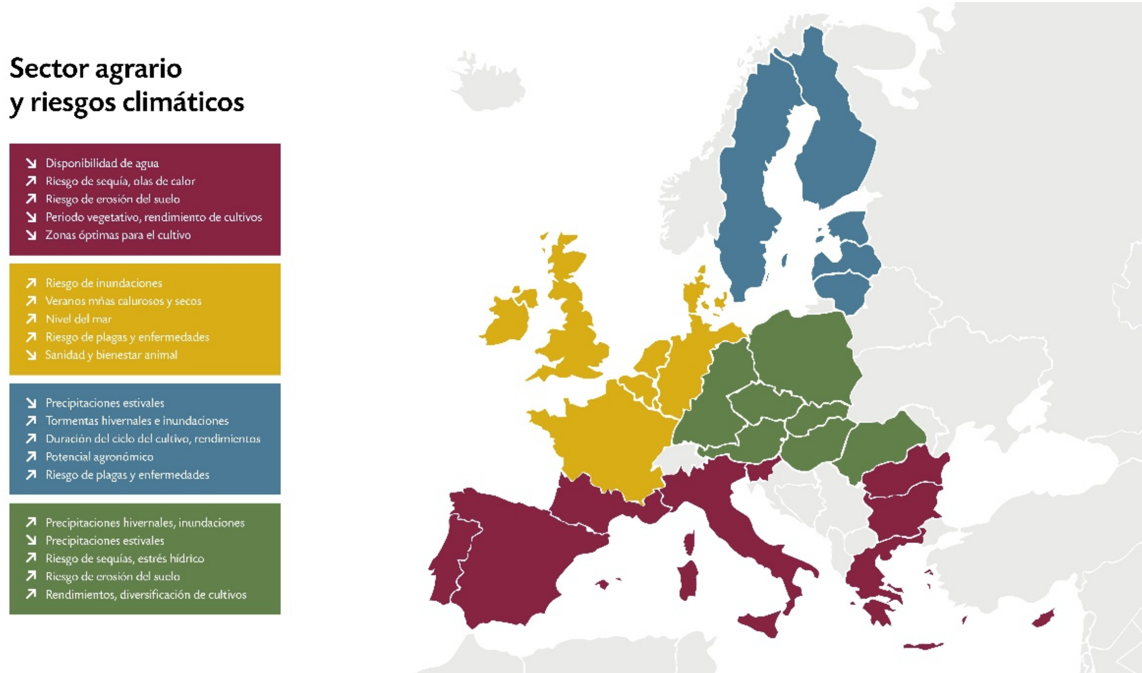

Figure 34. Map of the climatic risks associated with the different European agricultural sectors according to their climatic zone. Adaptation from Life AgriAdapt.

In this sense, the LIFE AgriAdapt project is given as an example, whose objective is twofold: to assess the vulnerability of the main European agricultural products to climate change; but also, to propose sustainable adaptation plans that allow these systems to become more resilient.

As a result, an adaptation web tool will be generated that aims to highlight the main results of the monitoring of more than 120 pilot farms in Germany, France, Spain and Estonia, sharing them with the largest number of users in Europe.

Implementation potential

Advantages	Disadvantages
• Accessible from its website. • Applicable to all types of crops and climates.	• Great difficulty in transforming agricultural recommendations into obligations. • Reluctance to change on the part of traditional farmers.

Potential barriers to implementation

The main barrier that this type of project has for its implementation is the dissemination that is made of them. In this case, there are many climate change adaptation measures described in the web tool that if not properly disseminated will not serve the purpose they were created.

Level of innovation today TRL = 9

The project ended in 2020, so the resources are already available online.[157]

Expected or desirable advances in the coming years

It is expected that more projects of this style will be carried out with the aim of expanding the number of case studies to be able to provide solutions to other types of cultivation that have not yet been studied.

On the other hand, it would be desirable to advance in the process of legislating certain agricultural practices that are known to favour adaptation and mitigation to climate change while being more sustainable. In this regard, those responsible for the *LIFE AgriAdapt* project met during the project with the European Commission, the Joint Research Centre and the European Parliament. They also worked with policy makers at national and regional levels. There were also exchanges with entities such as the Food and Agriculture Organization of the United Nations (FAO), and the European Earth Observation Programme "Copernicus".[158] In this way, it is intended to influence the Common Agricultural Policy, which from 2021 includes measures to adapt to climate change.

Expected results

The proposed adaptation measures are expected to enable farmers and ranchers to adapt to climate change, making their activity less vulnerable and more sustainable.

Adaptation measures are proposed for arable crops, permanent crops and livestock. Among many others, these measures include more diverse crop rotations, increased crop diversification, multifunctional margins, use of local and better adapted varieties, adaptation of planting, pruning and harvesting dates, use of green covers, key inline design, etc. All these proposed measures, and many more, can be consulted in the Layman report of the project.

Installation costs

As it is a research and development project, no solutions have been implemented that have a specific installation cost. The project, which has had a budget of € 2,161,437 of which € 1,295,347 have been financed by the European Union, has focused on providing solutions by applying good practices in cultivation and livestock systems.

[157] AgriAdapt (2020) Sustainable adaptation measures.

[158] AgriAdapt (2020) Report Layman.

Operating costs

In this case, no expenses derived from the operation are detailed, which will depend on the practices developed and that do not have to be different from the costs associated with a traditional agroforestry management.

Social acceptance

Measures to adapt to climate change have a high social acceptance. In this particular case, in which it is intended to adapt agricultural and livestock production to be resilient to climate change, there is no doubt that it will enjoy a high social acceptance. However, special attention should be paid to groups of farmers and ranchers who may reject the proposed measures for fear of change. In this case, it will be necessary to work to train these groups and train them to see the advantages of the proposed measures.

Recipients

- Farmers and producers
- Cattle

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Temperature change
- Soil degradation
- Thermal stress
- Forest fires
- Soil erosion
- Water stress
- Heat and cold waves
- Changes in precipitation patterns and types
- Droughts

Conceptual fit within climate change adaptation

In the arid and semi-arid Mediterranean region, an approximate reduction of 20% in water availability is expected by the middle of the twenty-first century, measures such as those proposed in this project, will help adapt and combat these scenarios of water scarcity, desertification and loss of soil productivity.

These measures provide solutions to adapt cultivation and livestock production to problems arising from climate change such as water scarcity, desertification, droughts and biodiversity loss, among others.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Spain	AgriAdapt	2016-2020	Data have been collected from 32 Spanish farms during the project. Conventional, organic crops, dairy farms, livestock, pastures, vineyards and horticulture have been used. From this monitoring, management proposals have been generated for the adaptation of this type of crops to climate change.[159]
France (South)	AgriAdapt	2016-2020	Data has been collected from 15 farms in the south of France during the project. Conventional, organic crops, dairy farms and livestock have been used. From this monitoring, management proposals have been generated for the adaptation of this type of crops to climate change.

[159] Agricultural holdings of the project AgriAdapt

Location	Responsible	Year	Description
Germany	AgriAdapt	2016-2020	Data have been collected from 19 farms in southern Germany during the project. Arable crops, vineyards and fruit trees and dairy and pig farms have been used. From this monitoring, management proposals have been generated for the adaptation of this type of crops to climate change.
Estonia	AgriAdapt	2016-2020	Data have been collected from 28 farms in Estonia during the project. Arable crops, vineyards, fruit trees and cattle farms have been used for meat, milk and sheep. From this monitoring, management proposals have been generated for the adaptation of this type of crops to climate change.

Main stakeholders (organizations, companies, institutions, etc.)

- Ministry of the environment
- Ministry of agriculture
- Agricultural associations
- Food companies
- LIFE Programme of the European Union

4.3.5 Urban planning and building

4.3.5.1 Permeable pavements in docks renovation in port areas

(Authors: Joan Sabaté, Irene Rafols)

Areas or sectors where it applies:

- Urban planning and building
- Water

Solution typology: Technology solution and management strategy.

Solution / Technology

Urbanization project of Amsterdam docks for increasing the permeability of the soil and vegetation, taking advantage of the need to repair the existing dikes.

Basic description

Due to growing structural problems, the necessary renovation of Amsterdam's dock walls will change the waterfront spaces that are so ubiquitous in the city and represent an opportunity to integrate new functions into the city's waterfront spaces.

The thesis *Resilience by renovation*[160] proposes that designers combine the renovation of dock structures in Amsterdam to make urban spaces in front of canals more adaptable to climate change. The processes underlying the renovation of the pier wall and climate change are analysed using three spatial scales: the city, the neighbourhood, and the canal front. These three scales reveal how spaces in front of city canals contain processes in urban ecosystems. "Nature-based solutions" concepts of "green infrastructure" and "ecosystem-based adaptation" can be used to propose city-scale and water-edge solutions.

The constructive elements implemented are elements marketed in the construction sector. The innovation relies on taking advantage of the repair works of the walls to completely transform the urban environment to increase resilience to the effects of climate change. This transformation is based on two principles; first, expanding the areas with vegetation cover and the biodiversity of the urban environment, and second, reducing the water that drains to the public network. In this sense, the project proposes the replacement of impermeable pavements by drainage systems and incorporating unpaved areas with vegetation cover.

One of the most exciting contributions is to visualize necessary infrastructure works as opportunities for change, overcoming the palliative attitude posed by environmental impact studies.

The proposal analyses various types of solutions to be applied in conjunction: 1) reduction of the loads that act on the walls 2) elimination of parking lots, 3) elimination of heavy pavements, 4) reinforcement -construction of provisional metal screens filled with sand, 5) complete replacement of the wall.

[160] Teh, Noelle, Resilience by renovation: opportunities for nature-based climate change resilience alongside the renovation of Amsterdam's quay wall waterfronts, TU Delft Architecture and Build Environment, 2020

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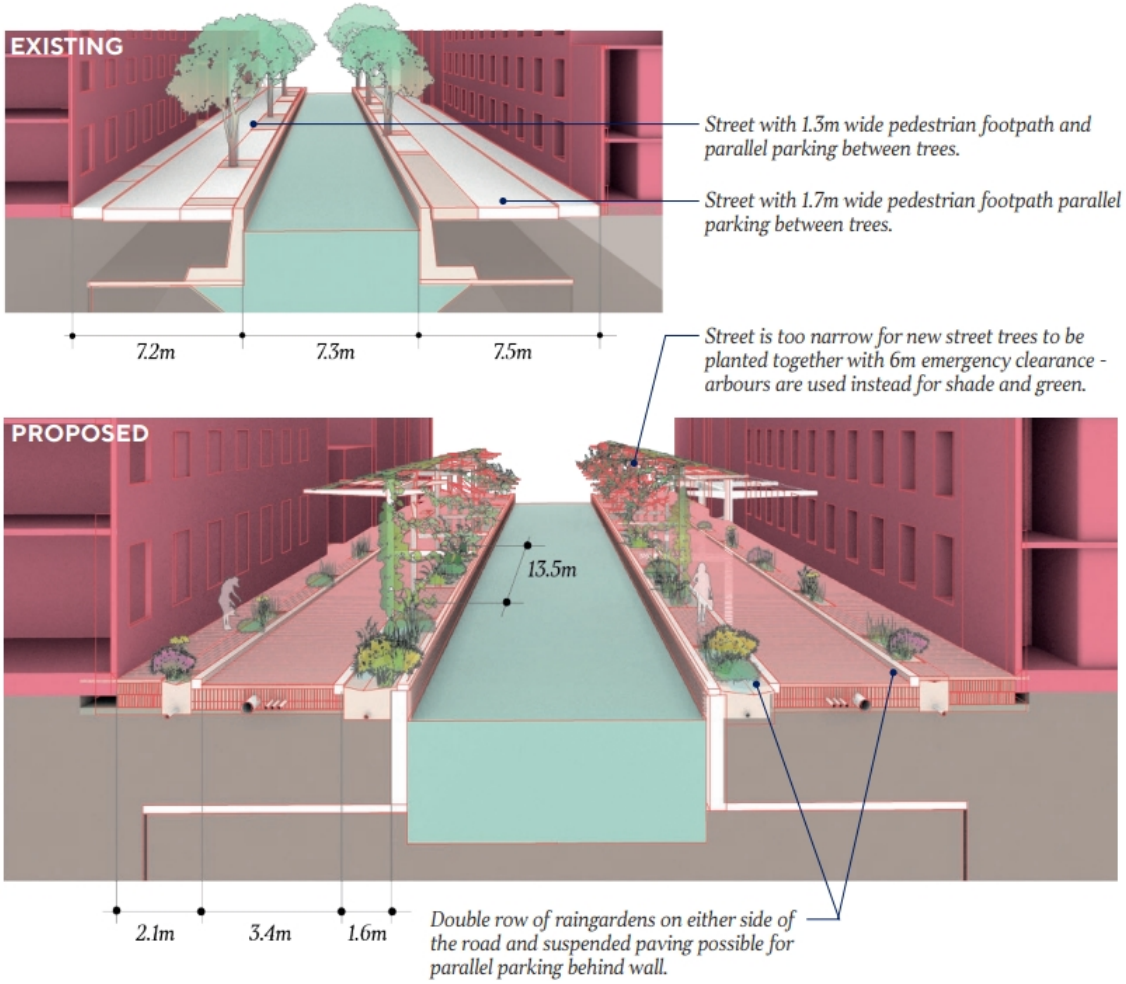

Figure 35. Proposal for the transformation of the pavements in front of the docks. (Source: Teh, N; Harteveld, M; Lammeren, R. MSc MADE Thesis: Resilience by renovation, Opportunities for nature-based climate change resilience, MSc Metropolitan Analysis, Design & Engineering.).

Implementation potential

Advantages	Disadvantages
• The proposal goes beyond the usual palliative measures of the impact studies of infrastructure works, to propose a positive transformation in environmental terms • Reduces the supply of runoff water to drainage systems • Improves the urban image in the areas of action	• This project is a specific proposal for a particular situation. Applying only the analysis model in other cases will probably be more interesting. • Designers should analyse the possible influence of runoff water input on the bases of dock walls in greater detail.

Potential barriers to implementation

This project is a specific proposal linked to the renovation of Amsterdam's docks, which seems well studied in this context. Extrapolation to other places with similar urban situations, such as river edges or canals, should be studied in detail. The possible washing of the foundation of the walls and the correct drainage of these should be evaluated.

Finally, designers should assess the advantages, in this specific case, of the phreatic infiltration of rainwater compared to the solution of direct discharge into the channel.

Current level of innovation (TRL = 9)

Expected or desirable advances in the coming years

There is a significant number of works on the effect of soil waterproofing in urban environments, and its impact on the concentration of peak rainfall flows and on reducing aquifer recharge. This fact is especially relevant in hot and dry climates, with heavy seasonal rain, which will increase even with climate change. The proposals for green roofs and draining pavements go in this direction, and their interest goes in parallel to the increase in solutions marketed with a remarkable degree of effectiveness[161].

At the same time, there are some problems concerning the quality of the washing water of the pavements destined for traffic - dragging of fats and fuel residues - which would probably require a differential treatment.

On the other hand, the increased infiltration of rainwater into the soil would allow a new approach to maintaining urban vegetation in dry periods, reducing the need for irrigation in summer periods. The management in the local subsoil itself of the waters provided by the drainage systems could be an exciting approach to reducing the use of water for irrigation.

Expected results

From a replicability point of view, there are two interesting lines of work:

- The project's methodology analyses the infrastructure works to be executed and proposes a realistic and, at the same time, transformative environmental improvement action.
- Pavement and drainage surface technologies are an alternative to channelled drainage of runoff.

One of the exciting contributions of this proposal is the approach to the problem of urban infrastructures, analysing the opportunities that can mean the execution of this type of work to transform the environment positively. In most cases, we still see a level of mutual distrust between the engineers in charge of significant infrastructure works and environmentalists who try to reduce these negative impacts, limiting joint work. The proposal of this thesis goes in the right direction to overcome this type of barrier.

At the same time, the analysis of surface drainage, especially that which reverts to increases in flows of sewerage networks and purification, is a sufficiently essential and still underdeveloped issue to take advantage of the examples already being produced. A part of this work, which also affects unpaved areas, is collected in greater detail in the Rain Gardens tab.

Installation costs

The replacement cost of a drainage pavement is similar to or lower than many conventional pavements. In the case of a drainage pavement of concrete pavers, based on gravel and sand filling, the average cost[162] is 25.35 €/m^2.

This cost can be increased if infiltrated water management is included with localized containment or conduction systems.

[161] Andrés-Doménech, I.; Anta, J.; Perales-Momparler, S.; Rodriguez-Hernandez, J. (2021) SustainableUrban Drainage Systems in Spain: A Diagnosis.Sustainability,13,2791.

[162] Generador de precios de la construcción, CYPE, 2021

Treatments such as ditches with vegetation or draining green areas, or rain gardens, can have a somewhat lower cost[163] of between 15 and 25 €/m^2.

A fundamental concept to take advantage of resources in an orderly manner is opportunity. The incorporation of draining pavements must occur when it is necessary to replace the pavement, either due to its deterioration or due to the change of surface uses such as pedestrianization.

Operating costs

The cost of operation and maintenance is similar to traditional pavements. In the case of drainage pavements of concrete pieces 167, cobblestone type, it is about 0.30 €/m^2. Meanwhile, due to the need for vegetation maintenance of vegetation 195, green solutions can vary between 2.0 and 5.0 €/m^2 year depending on the species and the space use.

Social acceptance

The result of spaces with draining pavements is generally more attractive than conventional pavements so that social acceptance will be positive. Suppose this change is associated with more space for the pedestrian to the detriment of road traffic or vehicle parking. In that case, the population's reluctance may be greater in some sectors and occasionally require prior dissemination work.

Recipients

- City councils and other administrations that act on public space
- Developers of urban complexes
- Urban planners, architects, engineers, and other technicians who develop projects in these areas
- Manufacturers or distributors of products for urban paving

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Reduction of runoff due to heavy rainfall that will increase with climate change
- Increasing urban biodiversity
- (Indirect) reduction of road traffic
- Improving groundwater management

Conceptual fit within climate change adaptation

This is an example of runoff water management integrated into a necessary public work.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Resilience by Renovation, Amsterdam	TU Delft.	2020	Thesis on the transformation of the urban space of the docks of Amsterdam

[163] Sara Perales Momparler & Elena Calcerrada Romero (2018) Guía Básica de Diseño de Sistemas de Gestión Sostenible de Aguas Pluviales en Zonas Verdes y otros Espacios Públicos, María Soledad Checa y Manuel de Pazos, Dirección General de Gestión del Agua y Zonas Verdes, Ayuntamiento de Madrid.

Location	Responsible	Year	Description
Madrid	Canal de Isabel II	2021	Center of excellence and research channel for the experimentation of sustainable urban drainage techniques. In the experimental plant of Meco, the techniques aimed at retaining the first rainwater and reducing the volume of water that is transported through the sewerage networks and the filtering of this rainwater, which contains a greater pollutant load, will be tested. Within this space, four spaces are being built for different vegetation covers, three porous surfaces and two drainage ditches, all of them with facilities for the measurement of drained flows in both quality and quantity. In Meco, with weather conditions similar to those that exist in most of the municipalities of the Community of Madrid, the drainage capacity of different materials that could be used in urban developments will be tested and tested. In addition, the plant will be able to artificially simulate other different climatic conditions to analyse the behaviour of these techniques in different climatic scenarios.
Passeig de Sant Joan Barcelona	Lola Domenech y Teresa Galí	2018	Remodelling of 30,000m^2 of pavement, an important part of these, draining.
BBVA, Madrid	Herzog & de Meuron	2015	Drainage pavements and green roofs at BBVA headquarters in Madrid.

4.3.5.2 Use of mycelium for thermal insulation

(Authors: Joan Sabaté e Irene Rafols)

Areas or sectors where it applies:

- Urban planning and building
- Energy

Solution Typology: Specific technology

Solution / Technology

Use of mycelium to create thermal insulation materials. The material can be grown in panels, containers, or directly filling cavities of other materials, such as composite panels.

Basic description

Mycelium is the set of hyphae that form the vegetative part of a fungus. With the growth of up to one millimetre per hour, these white filaments form a complex network that can cement the substrate used for their development. Mycelium acts, in this way, as a biological binder of various by-products of agricultural or forestry activities.

Ecovative Design[164], a diverse group of engineers, biologists, artists, and designers, dedicated to developing high-performance and environmentally conscious materials based in New York has designed mycelium structures for various applications. These products include edible products, pure mycelium foams for applications in cosmetics, or mycelium structures with agricultural by-products or wood residues.

Figure 36. Mycelium panel and vegetable fibres. (Source: Ecovative.).

These stronger structures have been developed by *Ecovative Design* under the name *MycoCompositeTM*. The cultivation process is carried out in a mold with the shape of the final product, with a hemp substrate and a duration of 7 days. These products are already successfully used as commercial packaging for various cosmetic products[165].

[164] Ecovative Design LLC is a materials company based in New York (USA), which offers sustainable alternatives to plastics and Styrofoams for packaging, building materials and other applications by using mushroom technology.

[165] Souza, Eduardo. (2020) "Mushroom Buildings? The possibilities of mycelium in architecture". Architecture Platform.

Biohm, a product research and development team based in London has developed a specific product for architecture. This product, generically called Mycelium – and unlike *MycoCompositeTM*, is not yet available on the market – is described on the *Biohm* website as "the world's first accredited mycelium isolation product".

The technical characteristics of mycelium compounds vary depending on the manufacturers' claims. In the case of *MycoCompositeTM* products, which have tests under ASTM $_{C518}$ standard, it achieves a thermal conductivity of 0.039 W/mK, at 10ºC, similar to other organic insulation products. The data announced on the *Biohm* website improve these results to 0.024W/mK. In contrast, other studies reduce these values to 0.088 W/mK[166].

Implementation potential

Advantages	Disadvantages
• The "cultivation" of insulation panels for construction means a radical change in the conception of building materials • It allows to develop customized products, even produced directly inside panels of other materials, adapted to the characteristics of each project • The technical characteristics declared by product development teams are highly competitive with other insulators, including plant-type insulators • The life cycle of mycelium – like most products of plant origin – is unbeatable, produced from vegetable waste and compostable at the end of its life cycle.	• Its use in construction may still be delayed due to the need for further experimental development • There is a lack of contrasting analyses of product performance, especially in the case of Biohm • There is no data on the final cost of the product in the market • It is necessary to guarantee durability compatible with the building: Ecovative Design figures them in 30 years and Biohm as "at least as durable as conventional ones"

Potential barriers to implementation

The main barrier is the low level of product development and its non-existence in the market.

Once this development phase has been completed, it will probably be necessary to justify the product's durability and its compatibility with other construction materials such as wood very consistently. We should work on the idea that putting a "fungus" in the house cannot negatively impact the conservation of the building.

Level of innovation today (TRL = 5)

Expected or desirable advances in the coming years

It is about turning an experimental development into a commercial product incorporated into the market, which guarantees compliance with performance, thermal, acoustic, fire behaviour, stability, and durability.

Expected results

Depending on the results of its industrialized production and its cost, an introduction into the market can be expected in evident competition with other organic insulators such as wood fibre, cellulose, hemp, sheep's wool, or recycled fibres. The resulting product must guarantee durability compatible with use in buildings.

Concerning these materials, the mycelium can provide, according to the data presented by the manufacturers, a better behaviour against fire, which these materials must supply by incorporating borax salts or other additives.

[166]Patrick Pereira Dias, Laddu Bhagya Jayasinghe, Daniele Waldmann, (2021) Investigation of Mycelium-Miscanthus composites as building insulation material, Results in Materials, Volume 10.

Installation costs

Mycelium compounds are cost competitive with other similar products such as wood wool. The cost of the raw material of mycelium compounds is located between 0.07-0.17 $ US/kg.

On the contrary, the production process of mycelium-based insulations requires containers with the shape and dimension of the final product, which are immobilized for one or two weeks, which can lead to a higher final cost.

Operating costs

The use of mycelium insulators should not increase the cost of maintenance.

Social acceptance

To achieve good social acceptance, it will be necessary to create an image of an innovative ecological product, which allows overcoming the concept of rot associated with fungi.

Recipients

- Developers of highly sustainable buildings
- Architects, engineers, and other technicians who develop projects in these areas
- Companies, manufacturers, or distributors of construction products

Impact on adaptation to climate change

Risks derived from climate change to which we can help adapt

- Temperature change
- Heat waves
- Cold/frost waves

Conceptual fit within climate change adaptation

It is a new thermal insulation product with good acoustic properties, especially fire, which will compete with others on the market in climate change. Insulating materials will have a fundamental role in reducing energy consumption and resilience to sudden changes in temperature.

Real or pilot cases where it has been applied

There are experiences of its use in packaging. In buildings, the use is still exceptional, as in the case of some experimental constructions shown in the Moma of New York.

4.3.5.3 Floodable urban spaces

(Authors: Joan Sabaté and Irene Rafols)

Areas or sectors where it applies:

- Urban planning and building
- Agua

Solution Typology: Technology solution

Solution / Technology

Urbanization of free space between buildings in Rotterdam, to accommodate various facilities such as basketball courts or skateboard courts. These spaces become three large rainwater retention ponds in case of heavy rains.

Basic description

The intensity of the rainfall regime is a phenomenon that worries the City of Rotterdam, which sees how many places in the urban area are flooded every year. The consistory has long been promoting the construction of underground tanks that capture and retain rainwater[167]. But these infrastructures are expensive and often invisible, and their effects are not very evident in the eyes of taxpayers.

For this reason, the municipal government has incorporated a new strategy consisting of new water storage systems coming to the surface to become explicit and even contribute to improving the environmental quality of urban space, reinforcing the identity of neighbourhoods or the enjoyment of citizens.

Following this logic, in 2011, the municipal government decided to allocate € 4.5M to construct a rainwater retention system in the Benthemplein neighbourhood. Apart from its hydraulic function, the work had to signify the space and provide it with attractions that appealed to the users of the buildings surrounding it. To this end, a participatory process was promoted that brought together teachers and students from Graphic Lyceum and Zadkine College, users of the theatre and gymnasium, members of the adjacent church, and residents of the Agniesebuurt neighbourhood

This project is part of the Rotterdam Water City 2030 project, developed by the Rotterdam City Council and the administrations involved in water management and the City Deal Climate Adaptation. It is a strategy that includes all areas of water management, the redesign of the sewerage system separating wastewater and managing rainwater on the surface, underground retention tanks, flood places, and groundwater management.

[167] In 2001 the Waterplan 1 was elaborated, which had a revision in 2007 with the Waterplan, renewed until 2030. These projects see the water problem in Rotterdam as a development opportunity. Actions have been incorporated regarding green roofs, draining pavements, flooded gardens and more recently usable public spaces that flood in case of heavy rains.

Figure 37. Water Square, Benthemplein Rotterdam, aerial vision. (Source: Google).

Figure 38. Water Square, Benthemplein Rotterdam, flood skating rink. (Source: Cathrotterdam (Wikimedia)).

Implementation potential

Advantages	Disadvantages
• The use of floodable outdoor spaces to laminate heavy rainfall is much cheaper than the construction of underground reservoirs. • This system complements traditional runoff management systems • It can be easily replicated in other urban situations. • This same concept can be applied in parks and unpaved outdoor areas. This situation, much more widespread, implies lower maintenance costs because it is not necessary to proceed with its complete cleaning in each filling cycle • It makes visible the management of rainwater and the infrastructures it requires	• The implementation of flood spaces requires significant dimensions of free urban land, with restricted use, which can be difficult to dispose of in existing environments. • Floodable outdoor spaces require proper maintenance, especially after flooding, due to the possible accumulation of sludge and favour pests if proper maintenance is not carried out Its characteristics can generate barriers that hinder accessibility

Potential barriers to implementation

The implementation of this system in tight urban areas, especially in Southern Europe, where higher urban density, may run into a lack of adequate spaces for occasional flooding.

There could be contradictions with the regulations of flood zones - which limit public uses - that should be revised to apply this model.

Level of innovation today (TRL = 9)

Expected or desirable advances in the coming years

The management of runoff due to heavy rainfall cannot be based solely on increasing the size of sanitation networks. This perception is already widely shared by the people in charge of its management and requires complex and coordinated strategies such as those developed by the Rotterdam administrations.

The incorporation of runoff management in the design of public space either with the use of draining pavements, surface drainage systems or the creation of flood spaces, seems the best of options and will increase in the coming years.

Expected results

It is interesting to highlight the global approach to the problem of runoff management carried out by local authorities and water management in Rotterdam, which includes resilience and adaptation to the effects of climate change as crucial data.

It is foreseeable that flood area projects will be much more common in the coming years. It would also be desirable that they be framed in a strategy designed globally to manage runoff.

Installation costs

The *Water Square* project cost € 4.50M in 2013. The surface of the action is 9,000m^2, so the unit price was € 500/m^2. This cost is compatible with the usual expenses of urbanization in the Netherlands and much lower than the construction of a buried tank of the same capacity, which would also have required a superficial urbanization of similar cost to that executed.

Operating costs

The cost of maintaining a floodable urban space is mainly due to the need for significant and specific cleaning after each flood. The extra cost of these operations, concerning the maintenance of a non-floodable public space, will depend on the number of annual flood situations and the amount of sludge that can reach the flood zone. It will also depend on whether mobile perimeter protection is necessary during the flood period, following legal regulations and the risk of accidental fall. If these protections are to be removable, they must include the assembly and disassembly in each episode of heavy rain. As a reference for other systems, it is estimated that the maintenance cost of a wet retention pond -with permanent water- is between € 0.5 and € 1.5/m^2 per year[168].

Social acceptance

Social acceptance is good, as it means a better urban space. This acceptance could be conditioned to the correct maintenance of the space after each great rain.

Recipients

- Municipalities and managers of the urbanization of urban spaces

[168] Jeroen C.J.H. Aerts, A Review of Cost Estimates for Flood Adaptation, Institute for Environmental Studies, (IVM), VU University Amsterdam, 2018

- Responsible for the management of water resources and subsoil
- Responsible for emergencies and contingency plans against meteorological phenomena
- Architects, engineers and other technicians who develop urban projects
- Water and subsoil management
- Responsible for emergencies and contingency plans in the face of meteorological phenomena
- Architects, engineers, and other technicians who develop urban projects

Impact on adaptation to climate change

Risks derived from climate change to which we can help adapt

- Rainfall and/or hydrological variability
- Heavy rainfall
- Water stress

Conceptual fit within climate change adaptation

It is a new thermal insulation product, with good acoustic properties and especially fire, which will compete with others on the market.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Water Square, Rotterdam	Municipality of Rotterdam	2013	Urbanization of an urban space with a flood zone to retain rainwater.
La Marjal Alicante	Municipality Alicante	2013	Floodable urban park.
Tåsinge Square Copenhaguen	GHB Landscape Architects	2014	Square in the city centre with permeable pavements and flood spaces

4.3.5.4 Bioengineering applications to reduce the risks associated with avalanches

(Authors: Joan Sabaté and Irene Rafols)

Areas or sectors where it applies:

- Urban planning and building
- Early warning
- Biodiversity and natural heritage

Solution typology: Nature-based solution

Solution / Technology

"PHUSICOS: *According to Nature*" consists of using nature-based solutions to reduce the risks associated with extreme weather events, especially in vulnerable areas such as rural mountain areas, which are technically feasible, cost-effective, and applicable at the regional level.

Basic description

In the Pyrenees and other European mountains, studies have indicated that landslides and subsequent flooding have decreased in places where forests have conquered grasslands, especially in the highest part of the grasslands. In some cases, reforestation has proven helpful in coping with extreme hydroclimatic events by reducing the intensity of the threat.

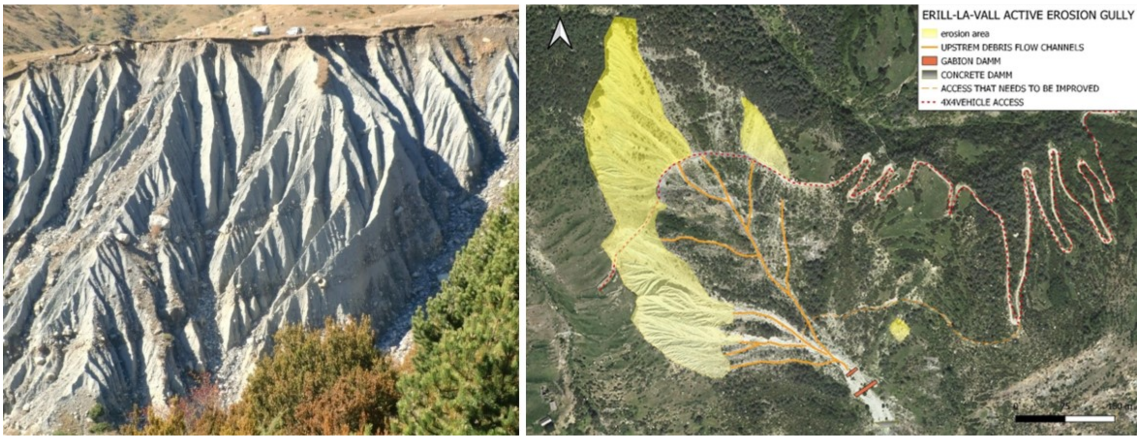

Figure 39. slope of strong erosion (canchal) and stone catchment basin on the village of Erill la Vall. (Source: Phusicos.)

However, this positive impact is very local and, more importantly, does not include the broader socio-economic implications of land abandonment and reduction in pasture size. Reforestation in relevant environments needs to be demonstrated and monitored to understand the implications of tree species, drainage systems and agropastoral practices.

The Pyrenees Consortium Working Community (CTP) is reaching out to local communities in these vulnerable natural areas to engage them in a dialogue of design strategies, financing schemes, monitoring systems, services and related policies. The proposed demonstrations will be carried out in collaboration with the planned work of the municipalities and proposals for projects that receive funding from the Spain-France Territorial Cooperation Operational Program (POCTEFA) for 2014-2020.

This program focuses on "Promoting the protection, development and sustainable use of local resources" and "Promoting climate change adaptation and risk prevention and management."

One of the objectives is to propose land-use changes to stabilize the entire basin and valleys with the support of local communities.

The PHUSICOS project, in collaboration with the Working Community of the Pyrenees Consortium (CTP), has developed different projects in the Pyrenees. Specifically on the A-136 road, between Santa Elena and Artouse, in Barènges or the municipality of Erill la Vall, near the Aigüestortes National Park.

Implementation Potential

Advantages	Disadvantages
• Lower environmental impact by reducing the transport of heavy materials, often by helicopter • Greater integration into the environment • Use of local materials and labour • Less expensive maintenance operations than with traditional systems • Improving the safety of people living in the area • Support for rural tourism by facilitating access and ensuring security	• Bioengineering technologies are still socially considered as minor measures, in the face of situations of significant risk

Potential barriers to implementation

The use of bioengineering techniques in avalanche containment, slope control, and adaptation of hydrological channels is widespread at the moment.

There is a danger of considering this type of work as exclusively landscape or of limited duration.

Level of innovation today (TRL = 7)

Expected or desirable advances in the coming years

The increase in adverse or catastrophic weather events is linked to climate change. It will increase significantly in the coming decades. It is necessary to count on economic and lasting protection and mitigation technologies that are compatible with the maintenance of landscape values and biodiversity.

Bioengineering solutions are a fundamental pillar of this mitigation strategy. They should be the first to be applied, reserving those most complex systems to situations that bioengineering cannot address.

Expected results

The extension of nature-based solutions as a common form of e-control. The extension of nature-based solutions as a standard form of erosion, avalanche, and waterway management.

Implementation costs

The project is already implemented and no construction costs are indicated.

Installation costs

The maintenance costs of bioengineering solutions are not higher than traditional ones, such as metal meshes or similar.

Social acceptance

Social acceptance is medium-high; no social agents are positioned against this solution and yes in favour. This acceptance could be conditioned on the perception of unreliability or durability of nature-based solutions strategies.

Recipients

- Municipalities and administrations of mountainous areas
- Responsible for the management of natural parks
- Responsible for emergencies and contingency plans in the face of meteorological phenomena
- Technicians who develop projects in these areas

Impact on adaptation to climate change

Risks derived from climate change to which we can help adapt

- Avalanches
- Landslides
- Floods

Conceptual fit within climate change adaptation

One of the most vivid consequences of climate change is increasing more intense and frequent weather events. In mountainous areas or areas with sloping and unstable terrain, these phenomena increase the risk of landslides, avalanches, and floods.

Using nature-based solutions can reduce the risk of these types of events and improve the ecosystem by interacting with conservation strategies.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Norway, Germany, Austria, Italy, Spain, France, Andorra.	Horizon 20220 project, led by NGI, with CREAF (ESP) and the Consortium of the Working Community of the Pyrenees	2020	Phusicos Use of nature-based solutions in geological or hydrological irrigation situations in mountainous areas
Multiple countries	Horizon 2020 CEE Project, coordinated by the University of Bologna (UNIBO) with *Naturalea* (Spain)	2020	Operandum Project for the use of nature-based solutions in 10 natural environments
United Kingdom	*University of Oxford*	2021	Nature-based Solutions Initiative Oxford University Research Programme, to assess the potential of NBS
Sri Lanka	The Asian Disaster Preparedness Centre	2020	NBS for landslide Risk Proposals for nature-based solutions for avalanche and landslide risk prevention in Sri Lanka

4.3.5.5 Integration of photovoltaic panels in green roofs (Project Resilio)

(Authors: Joan Sabat and Irene Rafols)

Areas or sectors where it applies:

- Urban planning and building
- Water

Solution typology: Nature-based solution

Solution / Technology

Project of implantation of roofs that integrate vegetal surfaces with photovoltaic solar panels, that allow to accumulate and manage the rainwater. A computer system manages all these roofs according to weather forecasts.

Basic description

The municipality of the city of Amsterdam plans to implement 10,000m^2 of green-blue roofs, which integrate vegetation and solar production, of which 8,000m^2 would be located on public residential buildings.

Figure 40. Vegetation cover with solar panels. Source: Resilio.

Amsterdam is experiencing the effects of climate change: flash floods due to heavy rains, higher temperatures and increased droughts.

The RESILIO project aims to address critical urban climate challenges related to flooding, heat, water supply, energy consumption and urban liveability by reusing the roofs of Amsterdam's climate-vulnerable neighbourhoods. The 10,000 m^2 area of smart blue green roofs is expected to help the city adapt to climate change by reducing the impacts of heavy rainfall, urban heat island effect and drought, while improving building insulation, biodiversity and quality of life.

A system of cells separates the plant substrate from the waterproofing layer, allowing the accumulation of water up to about 70 l/m^2. Motorized gates allow you to control the capacity of this lightweight cistern. This system has "smart flow control" that anticipates heavy rainfall or drought, releasing or retaining water accordingly. The roofs are connected in a network, allowing remote regulation of rooftop water levels based on weather forecasts and water management settings. RESILIO is based on 5 years of R&D of smart blue green roof technology performed by several of the project partners.

Following the proven success of the individual blue green roofs in Amsterdam, RESILIO will build an intelligent roof network that will enable real-time data exchange for dynamic water levels. Therefore, a completely new scale and type of adaptive urban water management is created for the first time in Europe and around the world.

Implementation potential

Advantages	Disadvantages
• Vegetation cover limits urban heat island effects, reduce roof reflectivity, increases biodiversity and allows for more intense social use of the roof • From the thermal point of view, they provide inertia -especially if they accumulate water- and to a lesser extent contribute to the overall thermal insulation of the building • The retention of water produced by the substrate and vegetation generates a rolling effect of runoff, increased in this case by the accumulation of water under the substrate and the management of this accumulation depending on the weather • The photovoltaic panels incorporate the generation of renewable energy and, in situations of water stress, increase the water available for vegetation, by increasing the catchment area with respect to the vegetal surface. • The evapotranspirative effect of the plants reduces the surface temperature of the roof, improving the performance of the photovoltaic panels. It is estimated that the green roof improves the performance of the panels: + 3.6% and $ 2,595 in 8 months.[169] • This model has a high replication capacity and can be implemented in a short period of time.	• In existing buildings, the implementation of green roofs, and especially those that accumulate water, is limited by the bearing capacity of the structure. • The water accumulation model is also limited by the slope of the roof, since the maximum height of the water is limited to 10-12cm and with usual slopes of 2% with only 5-6m this height differential is already reached. Therefore, in new buildings, the use of roofs without any slope is recommended. • The new common space created requires a management that must be implemented, and that is widely justified with the multiple benefits it generates. • The effect of this 10,000m^2 roof program on the actual management of runoff is limited by the relatively low storage capacity. Specifically, about 700m^3 can be stocked, a very small amount if we consider the value of heavy rain.

Potential barriers to implementation

The implementation of this system in existing buildings is limited by the load capacity of the roofs and by the cost of implementation. These difficulties can be reduced in the case of actions on the roof that involve a change of waterproofing and improvement of the insulation. A relatively simple option is to remove the materials that generate existing slopes and take advantage of the weight reduction to incorporate the new vegetation cover.

The current cost in Spain is still high, mainly due to its novelty. A more widespread implementation of the model will result in cost reductions that are not justified by their complexity or by the unit cost of materials.

Level of innovation today (TRL = 9)

Expected or desirable advances in the coming years

Greater public support for this type of solutions would be desirable, encouraging it both in new plant actions and in rehabilitations.

Expected results

In hot climates the vegetation cover provides the thermal stability desirable in summer, both by the mass itself and by the effect of shading and evapotranspiration of the plants. The use

[169] UTS, lendlease & Junglefy (2021) "Green Roof & Solar Array – Comparative Research Project." Final Report.

of green covers often raises controversy in these climates about the need - or the meaning - of their irrigation in summer. The lack of water is one of the most pressing problems arising from climate change in subtropical areas, and especially serious in the Mediterranean basin. In this sense, the incorporation of photovoltaic panels that generate shade on the roof and provide additional rainwater harvesting surface, appears as a great opportunity.

Installation costs

The cost of the project is €4.8M which includes costs of creation, management and dissemination of the proposal. There is no existing data on the m^2 cost of the solution on site. The current cost of a similar system in Spain can be around 80-100 €/m^2 in new buildings, without the control system.

Operating costs

The cost of maintaining a vegetation cover is not high and can vary significantly depending on the use of the cover and its image. If we are willing to accept the presence of green and flowering herbs in spring, but yellow in summer, maintenance is limited to a couple of annual visits, between 2 and 4 €/m^2 per year for a cover of about 100m^2. In addition, the durability of waterproofing is increased by maintaining a more stable temperature, which can lengthen the replacement time of the membrane.

Social acceptance

Social acceptance is still variable. There is a strong pressure to incorporate vegetation in the city, but at the same time there is an almost ancestral rejection of the proximity of green to our house, and especially to the roof since it is associated with its deterioration.

Recipients

- Municipalities and urban managers
- Responsible for housing development and management
- Urban planners and urban regulators
- Architects, engineers and other technicians who develop projects in these areas

Impact on adaptation to climate change

Risks derived from climate change to which we can help adapt

- Rainfall and/or hydrological variability
- Increased temperatures, heat waves
- Heavy rainfall
- Water stress

Conceptual fit within climate change adaptation

It is a very interesting integration of existing strategies in the market, incorporating a management system that is felt effective.

Real and pilot cases where it has been applied

Location	Responsible	Year	Description
Amsterdam[170]	Amsterdam City Council and 9 local partners	2020	Installation of green roofs, with accumulation of rainwater, photovoltaic panels and integrated water management.
Daramu House	Jonathan Evans y Philip Thalis	2020	Building for commercial use, with wooden structure and vegetation cover with photovoltaic panels
Low Impact Mediterranean Architecture, LIMA	Joan Sabaté and Christoph Peters, De La Salle School of Architecture, Ramon Llull University, Barcelona	2010	Experimental prototype of housing with near-zero emissions throughout the life cycle.

Main stakeholders (organizations, companies, institutions, etc.)

- Administrations that affect urban plans or city management.
- Public and private buildings developers.
- Architects, engineers and other technicians linked to the activity.
- Construction companies.

[170] RESILIO, Resilience nEtwork of Smart Innovative cLImate-adapative rOoftops.

4.3.5.6 Thermal analysis system associated with the smartphone

(Authors: Joan Sabat and Irene Rafols)

Areas or sectors where it applies:

- Urban planning and building
- Energy

Type of solution: "Information Technology" Solution - IT

Solution / Technology

ThermalFY has developed a real-time thermal analysis software that allows the collection and interpretation of thermal data from your smartphone or web browser.

Basic description

Capturing images with a thermal camera has proven to be extremely useful in the analysis of the energy efficiency of buildings. In new construction it allows to detect execution errors, such as poor placement of the insulations, infiltrations due to lack of sealing or other defects of project or execution.

In rehabilitation it allows a detailed approach of the strategies for the reduction of energy consumption, the limitation of condensations or the improvement of interior comfort -detection of air infiltrations, overheating due to excessive sun exposure, etc. It is also an excellent tool to carry out a check, once the work is executed, of the correct execution of the works. ThermaFY has developed a thermal analysis software with different applications that uses a thermal camera associated with a smartphone.

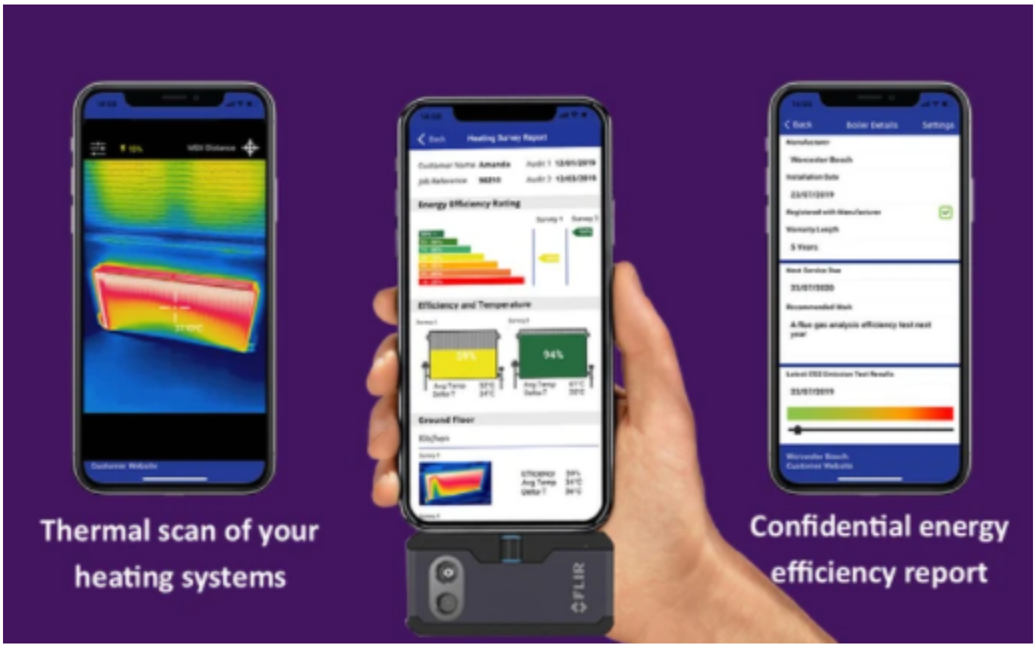

Figure 41. Visualization and thermal analysis of a radiator. Source: ThermaFY.

For efficiency in buildings, they have developed the ThermaFY ECO software that allows three types of actions to be carried out:

- Visualize and capture temperature data
- Measure: the useful values through image and data processing
- Generate visual reports to show the results in a format understandable to the client.

ThermaFY's imaging camera captures images and temperature data. Its software under the Microsoft Azure platform uses machine learning to calculate useful metrics through image and data processing. Visual reports display the results in a format understandable to end users.

The company offers a home review using its technology, at a very affordable price, and directly markets its equipment.

Implementation potential

Advantages	Disadvantages
• ThermaFY is a thermal analysis tool applicable to many areas, including an image analysis and a final report. • It is a useful tool for verifying the efficiency of thermal systems, including entire buildings. • Its low price and ease of use allows its use for a much larger number of users.	• It does not provide outstanding novelties with respect to other existent thermal analysis programs on the market.

Potential barriers to implementation

There are no barriers to its implementation.

Level of innovation today (TRL = 9)

The use of thermal cameras is widespread in the energy efficiency sector, and the analysis of images does not offer much difficulty. Without knowing exactly what the developed software provides, since on the web it is described only in commercial terms.

Expected or desirable advances in the coming years

The use of this type of analysis instrument will increase significantly.

Expected results

It would be desirable to incorporate this type of analysis into the energy certifications of existing buildings.

Installation costs

There is no data on the web of the cost of the equipment, but there is a policy of guarantee and return of the equipment, which presupposes its sale.

Operating costs

The cost of the program is € 150, to which we must add an additional € 300 for the purchase of the thermal camera associated with the mobile phone.

Social acceptance

Social acceptance is very high, since thermal images are attractive, facilitate the understanding of the problem and generate an image of control and security.

Recipients

- Companies dedicated to energy efficiency
- Responsible for housing development and management
- Architects, engineers and other technicians who develop projects in these areas

Impact on adaptation to climate change

Risks derived from climate change to which we can help adapt

- Changes in temperatures
- Thermal variability
- Heat and cold waves

Conceptual fit within climate change adaptation

This is an interesting integration of the capabilities of *smartphones* with the addition of a thermal camera. At the moment there are already several brands that incorporate directly into their smartphone a thermal camera.

Real and pilot cases where it has been applied

Location	Responsible	Year	Description
United Kingdom	ThermaFY Eco Solutions	2021	Thermal analysis software from data from a thermal camera associated with a smartphone.

Agents of interest (organizations, companies, organizations, etc.)

- Promoters of public and private buildings
- Architects, engineers and other technicians linked to the activity
- Construction companies

4.3.5.7 Wind catchment towers

(Authors: Joan Sabat and Irene Rafols)

Areas or sectors where it applies:

- Urban planning and building
- Thermal stress
- Increased temperatures / heat waves

Type of solution: Technological solution

Solution / Technology

Traditional ventilation and cooling system in very hot and dry countries. Through towers open on the sides, and oriented to the wind, the circulating air is captured and introduced into the interior of the building by their own thrust. Occasionally this air is passed through spaces with water or with wet surfaces (porous jars) to generate an adiabatic cooling[171], only useful with low humidity.

Basic description

Natural ventilation and cooling have played a key role in providing comfort conditions in warm countries. Wind collectors are traditional passive cooling systems and one of the most familiar elements in Iranian architecture. They can significantly influence the reduction of cooling loads and provide the necessary ventilation rate of buildings.

Figure 42. Bâdgirs (wind catchers). Source: Kheirkhah, P. y Nasrollahi N.

The paper published by Professors Parham Kheirkhah and Nazanin Nasrollahi of Llam University in Iran aims to provide an in-depth review of recent developments and applications of wind collectors in modern architecture[172].

[171] Adiabatic or evaporative cooling occurs with the change of state of water, whose passage from liquid to gas requires energy, which it takes from its environment, producing a temperature reduction effect.

[172] Parham Kheirkhah Sangdeh, Nazanin Nasrollahi, Windcatchers and their applications in contemporary architecture,Energy and Built Environment,Volume 3, Issue 1,2022, Pages 56-72.

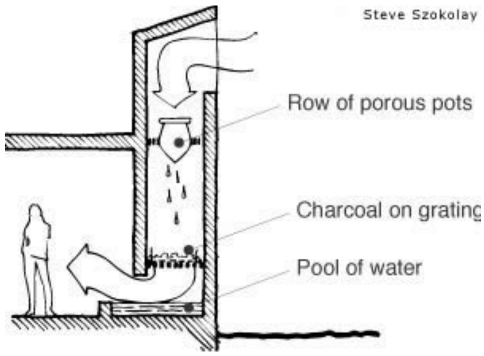

Figure 43. Wind tower with evaporative system. Source: Szokolay, SV, 1980.

The efficiency of the wind collector is analysed according to its basic parameters, i.e., height, configuration and cross-section. This comprehensive review reveals that these factors have significant impacts on the performance of wind collectors.

The operation of various types of wind collectors is analysed depending on the different configurations, such as the number of holes or the wind speed. The study also includes the most modern designs of wind collectors, which in some cases include fans, water sprinkler technologies to force adiabatic cooling (due to evaporation) and their use in contemporary buildings, such as schools, stadiums, greenhouse and others.

Implementation potential

Advantages	Disadvantages
• It is a traditional ventilation and cooling system, very effective in hot and dry climates, which works passively without any need for energy input. • The recovery of traditional passive technologies, this is without external energy contribution, is a strategic line of work for the reduction of energy demand and that is not in contradiction with the use of other more complex technologies or that require external energy. • This model has a great capacity for replication as a natural ventilation system. Its use as an adiabatic cooling system, with water evaporation will be useful in areas with low humidity, since otherwise the feeling of embarrassment could increase due to excess humidity.	• The use of wind catchers can be complex in existing buildings, as it requires significant space. Despite this, it can be considered to integrate this concept into existing spaces, such as patios of lights or community stairs.

Potential barriers to implementation

The main barrier to the implementation of this solution, and others of a passive nature, is the ignorance and distrust they generate. Architecture long ago abandoned the control of the comfort of buildings and gave all the prominence to mechanical technical systems. This situation is changing little by little, but many people still prefer to rely on mechanical equipment, and energy inefficient because they are oversized, to guarantee comfort conditions.

Level of innovation today (TRL = 9)

Expected or desirable advances in the coming years

The analysis of the operation and measurement of the results of passive systems, such as the one proposed in this paper, is essential to be able to compare their effectiveness with active systems, which are perfectly coded.

Expected results

The recovery of passive strategies such as transverse ventilation, thermal inertia, wind collectors or solar chimneys, represents an important factor in obtaining buildings with very low demands. This demand reduction effort should accompany high-efficiency production systems and distributed electricity generation.

Installation costs

The cost of these systems, in new works, is included within the general costs with almost no increases. In rehabilitation works, the transformation of patios or stairs into ventilation ducts with these systems should preferably be studied.

Operating costs

The operational cost is practically zero.

Social acceptance

There is no social awareness of these technologies, in any case a certain distrust. As these are inconspicuous options, their development will depend on the success of the prototypes that are made. That is why it is so important that the projects that integrate them are well developed.

Recipients

- Responsible for housing development and management.
- Communities of owners, housing cooperatives and related social groups.
- Architects, engineers and other technicians who develop building projects.

Impact on adaptation to climate change

Risks derived from climate change to which we can help adapt

- Increase in temperatures
- Heat waves

Conceptual fit within climate change adaptation

It is a very simple and economical technology to alleviate the effects of overheating buildings.

Real and pilot cases where it has been implemented

Location	Responsible	Year	Description
Colorado, USA	DesignBuildBLUFF / Colorado University (USA)	2012	*Windcatcher House* Housing in a desert area with adobe walls and cooling with wind towers.
Ahmedabad, India	Nimish Patel & Parul Zaveri	1999	Torrent Research Centre Research centre with natural ventilation and evaporative cooling.
New Gourna, Egypt	Hassan Fathy	1952	Nursery school One of the best examples of contemporary reinterpretation of the architectural and constructive tradition of Arab culture.

4.3.5.8 Resilience strategy for the Ebro River

(Author: Laura del Val Alonso)

Areas or sectors where it applies:

- Urban planning and building
- Finance and insurance
- Water
- Biodiversity and Natural Heritage

Solution typology: Nature-based solution

Solution / Technology

Set of measures aimed at minimizing the risk of flooding in the axis of the Ebro, either by giving more space to the river, facilitating the opening of alternative flood channels, or through temporary reservoirs to capture excess flow.

Basic description

Floods are the natural risk that causes the greatest number of economic losses in our country, damaging homes, buildings, industries and infrastructure in its path. The effects of climate change, together with human activity and urbanization processes, are making floods increasingly frequent and of greater magnitude. For this reason, flood risk prevention plans are being adjusted to adapt the most vulnerable areas to the inevitable occurrence of these phenomena.

This is the case of the Ebro River basin. Along the Ebro River basin, 1,721 km of Significant Potential Risk Areas (ARPSI) have been identified. These are river stretches in which the risk of flooding is very high. One of the ARPSI is the entire middle stretch of the Ebro River from the mouth of the Iregua River, in Logroño (La Rioja), to La Zaida[173] (Zaragoza).

To respond to this increase in flood risk and to minimize the periodic losses involved, the Ebro Hydrographic Confederation has designed a pioneering strategy in our country, the *Ebro Resilience* strategy to be applied along the middle stretch of the Ebro River.

The *Ebro Resilience* strategy brings together a set of actions of various kinds:

- Improvement of structural defences: repairing linear defence infrastructures, such as specks or walls that protect urban centres.
- Improvement of the drainage capacity of the channel: open branches in the vegetation, carving the bed of these branches to facilitate the mobilization of sediments with normal flows, as well as in setting back specks to return space to the river.
- Permeabilization of infrastructures creating relief channels: the relief channels are longitudinal areas to the main channel, excavated at a lower level than this, which facilitates the diversion of water in situations of avenue.
- Establishment of security perimeters against overflows: These actions aim to protect as much as possible the urban centres when an avenue circulates outside the established channel, being able to affect downstream towns. To do this, linear infrastructures are levelled, such as roads or highways, which serve as protection to the urban area.
- Generation of temporary flood areas: Areas of agricultural use that allow to cushion an avenue expanding the flood zone.

[173] Water Commissariat, Ebro Hydrographic Confederation. Prevention, protection, preparation and repair: measures to reduce the risk of flooding on the Ebro axis. Digital Magazine of the Insurance and Compensation Consortium.

Implementation potential

Advantages	Disadvantages
• The actions framed in the strategy also contribute to improving the state of the riparian ecosystem. • Prioritizes the use of nature-based measures, minimizing the use of grey infrastructures.	• Rejection of the population for lack of understanding of measures that do not involve the construction of traditional infrastructures such as dikes or specks. • High initial investments. • It requires the coordination of different bodies at local and basin level.

Potential barriers to implementation

The use of nature-based solutions may be perceived by the population as too weak a measure to cope with the magnitude of the risk to which they are subjected. This requires an important communication work to publicize the operation of the measures carried out, and their behaviour during a flood of the river.

Measures involving the modification of existing infrastructures require important coordination between municipal governments and institutions at the basin or regional level.

It is essential to define which actors are involved in the maintenance of the measures and allocate budget items for this from the beginning.

Level of innovation today (TRL = 9)

The *Ebro Resilience* strategy is not only a pioneer in our country, but also at European level. In fact, the European Commission grants this initiative co-financing through the *LIFE EBRO RESILIENCE* P1 project in 2021.

Expected or desirable advances in the coming years

This project represents a pilot action at European level, in which it is intended to adapt two areas of the middle area of the Ebro River for 4 years, to evaluate the results during the remaining 2 years.

Thus, it is expected that the results of this project will allow to evaluate the effectiveness of the strategy and the different solutions of adaptation to the risk of flooding that compose it, in such a way that its implementation can be prioritized in other vulnerable areas of this and other basins.

Expected results

The expected results of the *Ebro Resilience* project are[174]:

- Curb the increased risk of flooding.
- Reduction of damage to infrastructure, buildings and agricultural holdings.
- Reduction of the danger of floods in urban centres while improving the circulation of the flow.
- Increased knowledge of the population regarding flood risk and existing protection strategies.
- Improved coordination between administrations.
- Improved predictive capacity.
- Improvement of the state of water bodies.

[174] Ebro Resilience Project. 2020. General strategy of actions.

Installation costs

The LIFE EBRO RESILIENCE P1 budgets about €7M for the execution of the adaptation measures of the two sections of the river, the one located between the mouth of the Iregua River, in Logroño (La Rioja), and La Zaida (Zaragoza), includes a total of 324 km of channels and lower sections of tributaries, from which it supposes an area of influence with 1,033,000 inhabitants.

Operating costs

No information was found on the long-term maintenance costs of the proposed strategies.

Social acceptance

It is expected that the battery of actions for the adaptation of the middle section of the Ebro River will have a good acceptance, if all social agents are involved, such as conservation organizations, farmers and neighbours, as well as the ability of the project to adequately communicate the objective of each action.

Recipients

- City councils
- Farmers' organizations

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Floods

Conceptual fit within climate change adaptation

Floods are the climatic phenomenon that generates the most economic losses in our country. In addition, its intensity and magnitude are increasing because of climate change.

Although the floods in the middle section of the Ebro do not usually involve human lives, the material damage is considerable. According to the Consorcio de Compensación de Seguros, the economic costs not related to the agricultural sector derived from the floods produced between 2005 and 2017 in this section amounted to € 33.4M €. To these losses must be added the compensation to the agricultural sector through the Combined Agricultural Insurance System, the subsidies of local and regional governments to boost productivity, and the costs of repairing infrastructures carried out after each of the avenues.

In this sense, floods represent one of the most important risks derived from climate change, which not only affects our homes, infrastructures, and the productive sector, but also the one that insurance has to face. On the other hand, it is a problem directly related to the state of water bodies and their conservation. That is why risk reduction necessarily involves improving the management of water resources and the natural environment associated with the channels, through adaptation measures based on nature.

Real and pilot cases where it has been applied

Location	Responsible	Year	Description
Alfaro, La Rioja	Project Ebro Resilience		There are several actions in the section of the town of Alfaro: 1. Setback of 710 m of speck. 2. Increased permeability by generating alternative channels ("Courage") Construction of a relief channel
Paraje de La Nava, La Rioja	Project Ebro Resilience	2019	Removal of 1,806 meters of defence parallel to the axis of the channel, for its subsequent reconstruction set back (between 100 and 300 meters) in a length of 1,376 meters, and recovery of 30 ha of riverside space,

Main stakeholders (organizations, companies, institutions, etc.)

- Hydrographic confederations
- Government institutions dedicated to the management of natural resources and infrastructures
- Nature conservation associations
- Research institutes and universities
- Insurance Compensation Consortium
- Emergency Response Agencies
- City councils

4.3.6 Biodiversity and natural heritage

4.3.6.1 Drones to fight forest fires

(Authors: Nil Álvarez and Carles Ibáñez)

Areas or sectors where it applies:

- Biodiversity and heritage
- Water

Typology of the solution: Concrete technology

Solution / Technology

Drone with the ability to collaborate in the extinction of fires making better use of water thanks to its patented misting technology.

Basic description

One of the clearest effects of climate change is the increase in forest fires, high temperatures combined with long periods of drought have made these phenomena more recurrent in recent years.

For this reason, the Wild Hopper project, funded by the H2020 funds of the European Union, is developing a drone capable of fighting these forest fires more quickly, making more precise use of water and reducing the risks to human lives.

Figure 44. Wild Hopper (Source: DH.)

This platform can transport water to be released and nebulized using a patented technology. This is a more efficient and precise use of water than the traditional way of dropping water by gravity at a certain speed. This drone can also act at night without putting any life at risk with a reduction in the cost of ownership of 5 to 10 times lower than seaplanes or helicopters.

Drones are already being used to evaluate the fires in their different phases, helping the decision making of the extinguishing teams. They are also used for the search for survivors and for damage assessments. The project presented here goes a step further and aims to use drones also to fight fires directly[175].

Implementation potential

Advantages	Disadvantages
• Precision of discharge over fires. • Patented misting system for water optimization. • Operable both day and night. • It does not put human lives at risk. • Speed of reaction. • Lower acquisition and operation cost than traditional means.	• Load capacity of 600 litres and need for more than one device to do effective work. • Short range compared to traditional media. • Flight time less than traditional media.

Potential barriers for implementation

The biggest challenge today is to demonstrate its effectiveness in real cases and train the competent agents for its use.

Level of innovation today TRL = 6

The project is in the development phase, having already patented the water misting technology and having carried out flight tests.

Expected or desirable advances in the coming years

It is expected that in the coming years real tests will be carried out to demonstrate its effectiveness and efficiency in fighting fires.

Expected results

A more efficient use of water is expected, as well as greater precision in the application of this in firefighting tasks. At the same time, the risk to human health will be reduced as they are unmanned aerial vehicles.

Installation costs

As it is an ongoing project, the values of the acquisition cost of unmanned vehicles are not available. As a guideline and to illustrate the cost of developing this technology, the Wild Hopper project has a budget of € 3,550,687.50 of which € 2,485,481.25 have been financed by the European Union through H2020 funds for the period from November 1 2019, to April 30th 2022[176].

Operating costs

As it is a project in progress, this data is not available. It can be considered that these costs will be those associated with the maintenance and wear of the vehicles.

Social acceptance

High social acceptance is expected, as it brings advances in firefighting while reducing the risk of accidents substantially.

[175] Drone Hopper (2020) Video "Drone Hopper Heavy Duty Commercial Drones"

[176] WILD HOPPER – Heavy -Duty UAV for day and night firefighting

Recipients

- Public administration
- Companies in charge of forest management
- Firefighters' associations
- Industries with internal fire protection operations.

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Forest fires
- Heat waves
- Thermal stress
- Water scarcity

Conceptual fit within climate change adaptation

The risk of fires increases with climate change. To the high-risk areas, others will be added, traditionally low risk, in which it will increase. Among other solutions to the problem, new extinction methods such as the one proposed here must be implemented. At the same time, this technology aims to make more efficient use of the water used for firefighting, adapting also in this case to the climatic risk of water scarcity.

In this framework, solutions such as those proposed by the Wild Hopper project are essential to adapt to these changes.

Real or pilot cases where it has been applied

The project is in the development phase and has not yet been implemented in real cases.

Main stakeholders (organizations, companies, institutions, etc.)

- Fire Department of the different Regional governments
- Ministry of the environment
- Emergency military units.
- Companies involved in management of forest masses (e.g. TRAGSA)

4.3.6.2 Urban green infrastructure

(Authors: Nil Álvarez and Carles Ibáñez)

Areas or sectors where it applies:

- Biodiversity and heritage
- Urban planning and building
- Health

Solution typology: Nature-based solution **¡Error! Marcador no definido.**

Solution / Technology

It is a comprehensive design solution with a double main objective: on the one hand, to promote biodiversity in urban areas and on the other to use it to improve the quality of life and adapt to climate change.[177]

Basic description

The EU defines Green Infrastructure as a "strategically planned network of high-quality natural and semi-natural areas, designed and managed to provide the greatest amount of ecosystem services and protect biodiversity, both in rural and urban settlements".

Green Infrastructure is an integrating tool for Nature-Based Solutions. Its main objective is the protection of natural capital, while avoiding the construction of expensive infrastructures in those cases in which nature can provide more economical, durable, and innovative solutions, and generate employment. It is a novel approach that seeks to provide environmental services that contribute to protecting human health, saving energy, fighting climate change, improving air and water quality by offering spaces for leisure and recreation such as parks, gardens, squares, wooded areas, urban flowerbeds, vertical gardens, and botanical gardens among others. That is why the Ministry for the Ecological Transition and the Demographic Challenge (MITECO) has a *National Strategy for Green Infrastructure and Ecological Connectivity and Restoration.*[178]

Green infrastructure, as a complex and complete organizational fabric present in all municipalities, implies and relates from the base to different municipal departments: urbanism, environment, parks and gardens.

These spaces have multiple environmental benefits for urban environments, but also social benefits. Urban green infrastructures help improve air quality, reduce noise, mitigate extreme temperatures in summer and flood peaks in episodes of torrential rainfall. They are also places of recreation for citizens and favour education, aesthetic value, and the maintenance of social relations.

The design of green infrastructures in urban areas is a nature-based solution that has been increasingly used as a strategy for adaptation to climate change. MITECO has developed a *Methodological Guide for the identification of the elements of green infrastructure in Spain* that considers, among other things, the ecosystem services they provide.

Its main objectives are the regeneration of degraded areas through eco-design techniques, the enhancement of urban biodiversity, the improvement of connectivity and functionality of different urban and peri-urban green areas, the promotion of the public use of green spaces and the improvement of the capacity to adapt to climate change.

[177] Urban green infrastructure. Spanish Association of Public Parks and Gardens, Spanish Federation of Municipalities and Provinces and +Biodiversity.

[178] MITECO (2021) National Strategy for Green Infrastructure and Connectivity and Restoration Ecological

Figure 45. Ejemplo de infraestructura verde en la fachada del Palacio de Congresos Europa, en la ciudad de Vitoria. Source: Basotxerri

Some of the most emblematic interventions that have already been carried out include the urban rehabilitation of Avenida Gasteiz in Vitoria with eco-design techniques and the creation of a green façade in the Palacio de Congresos Europa. The rehabilitation of Gasteiz Avenue basically consisted of the construction of a rehabilitated river corridor, the planting of trees lined up along the new channel and the construction of pedestrian streets. The installation of a vertical garden on the façade of the Palacio de Congresos Europa composed of native species has contributed to the improvement of the thermal and acoustic insulation of the building, the reduction of air pollution and the improvement of the aesthetic quality of the environment.

Implementation potential

Advantages	Disadvantages
• Mitigation and adaptation to the impacts of climate change. • Reduction of flood hazards and regulation of flows. • Water supply • Reduction of pollutants present in both the atmosphere and the hydrosphere. • Increase the resilience of ecosystems. • Training and education constituting a resource as a natural demonstrative laboratory that increases the environmental awareness of society. • Improvement in the mental health and social interaction of citizens.	• Risk of spread of non-native species. • Increase in wildlife that can lead to damage to infrastructure and an increase in disease transmission vectors.

Potential barriers to implementation

The main challenge to apply these solutions in urban areas is to find and enable the spaces to implement these green infrastructures. With such a high land occupation, it becomes a challenge to implement these measures.

To facilitate its implementation, the Spanish Federation of Municipalities and Provinces (FEMP), the Association of Green Infrastructure Management Companies (ASEJA) and the Spanish Association of Public Parks and Gardens (AEPJP) make available to all interested agents a "Informative Guide of the Municipal Green Infrastructure"[179] It is a reference document to develop projects for the design and implementation of green infrastructure in different populations, which includes a large number of national and international examples that, extrapolating them, can be used for the particular needs of each place. This guide also details the barriers that can be found in the implementation of green infrastructures while providing solutions for each case.

Level of innovation today TRL = 7

Solution implemented locally, although applicable to other cities.

Expected or desirable advances in the coming years

It is expected that in the coming years urban areas will become examples of green architecture, and that they will offer their inhabitants the benefits that these spaces provide.

Expected results

The proliferation of green spaces improves the air quality of cities while helping to infiltrate surface runoff water allowing the recharge of underground aquifers. The construction of biological corridors not only favours urban biodiversity, but also provides a recreational space for citizens, positively influencing their mental health.

Implementing these, and many other nature-based solutions, achieves a higher quality of life for citizens while protecting biodiversity and addressing climate change.

Installation costs

Depending on the dimensions and the type of green infrastructure you want to design, the costs will vary greatly. As an example, the rehabilitation of the vertical façade of the Palacio de Congresos Europa in Vitoria in which 33,000 plants of 70 different species grow in a total area of 1,492 m^2, of which 1,000 m^2 belong to the vertical garden and 492 m^2 to the vegetable parasols that cover the windows had an installation cost of € 387,705.[180]

On the other hand, the Parque de la Marjal, the first flood park in Spain that has received awards for its good functioning and that is a European reference in its design and functionality, had a tender budget of 3.67 million euros --VAT excluded-- financed by Aguas de Alicante.[181]

Operating costs

The operating costs are associated with the maintenance of these infrastructures such as pruning, conditioning spaces, waste management, or cleaning tasks.

Social acceptance

This type of action has a very high social acceptance since it increases the number of urban green areas increasing the quality of life of its inhabitants.

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179 Guide to municipal green infrastructure. ASEJA, Spanish Federation of Municipalities and provinces, +Biodiversity and Spanish Association of parks and public gardens.

180 Victoria-Gasteiz City Council (2014) Thermal conditioning of the north, south and west façade of the Palacio de Congresos Europa.

181 Europe Press (2015) Alicante inaugurates the floodplain urban park 'La Marjal', an anti-flood infrastructure.

Recipients

- Public administration

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Temperature change
- Soil degradation
- Thermal stress
- Water stress
- Heat and cold waves
- Changes in precipitation patterns and types
- Droughts

Conceptual fit within climate change adaptation

In the example of the green infrastructure created in Vitoria-Gasteiz, as well as in most urban green infrastructures, the main challenges of adaptation to climate change that they face are changes in rainfall pattern, rising temperatures, increased risk of flooding, heat and cold waves, water stress and soil degradation. All these effects can be amortized by good planning of urban green infrastructures, making our cities much more resilient and much less vulnerable to climate change.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Vitoria-Gasteiz	Vitoria City Council	2012	Rehabilitation of Avenida Gasteiz with eco-design techniques and the creation of a green façade in the Palacio de Congresos Europa.
Madrid	Canal de Isabel II	2019	Construction of a pilot plant to develop sustainable urban drainage techniques to improve the quality of drainage water in urban areas.
Madrid	Madrid City Council	2020-2030	Madrid's Green Infrastructure and Biodiversity plan proposes more than 180 concrete actions, some of which are already underway and others that will be implemented.[182]
Parque de La Marjal	Alicante city council	2019	A pioneering green infrastructure throughout Spain capable of collecting up to 45 million litres of rainwater.[183]
Barcelona	Barcelona city council	2020	"Terrats d'en Xifrer" has turned roofs of buildings into gardens and small urban orchards that neighbours can enjoy, while improving the impermeability of the building and its soundproofing and thermal insulation.[184]

Main stakeholders (organizations, companies, institutions, etc.)

- Association of Green Infrastructure Management Companies (ASEJA)
- Spanish Federation of Municipalities and Provinces (FEMP)
- Spanish Association of Public Parks and Gardens (AEPJP)
- Ministry of the environment

[182] Community of Madrid. Green infrastructure and biodiversity plan.

[183] SUEZ (2019) La Marjal Park, an example of urban green infrastructure.

[184] Barcelona City Council. Xifré's rooftops

4.3.6.3 Measures to adapt to desertification (Alvelal Association)

(Authors: Nil Álvarez and Carles Ibáñez)

Areas or sectors where it applies:

- Biodiversity and heritage
- Agriculture and food
- Water

Solution typology: Nature-based solutions

Solution / Technology

Provide adaptation and management measures to recover and improve the quality of ecosystem services in degraded areas of the Mediterranean.

Basic description

Ecosystem services are resources (goods and services) or processes of natural ecosystems that benefit humans. Soils and agroforestry systems provide us with a wide variety of ecosystem services such as drinking water, flood protection, carbon fixation, biodiversity richness, food sources, among others. It is, therefore, important to maintain the quality of ecosystem services by developing agroforestry adaptation measures, which not only improve them, but also help to recover their functions in those cases where they have been degraded, and at the same time help their adaptation to climate change.

In this sense, the Alvelal association carries out projects to combat desertification, basing its scope of action both on natural systems and agricultural areas in the area of the steppe highlands of Granada, Almería and Murcia.

The following are some examples of practices carried out in natural areas:

- Transformation of the reforestation pine forests of the 60's into less dense Mediterranean forests, through selective thinning and the planting of other endemic species.
- Planting trees and shrubs in degraded areas, to fix soil, capture CO_2 and increase biodiversity.
- Actions to increase rainwater capture, reducing runoff and slowing down erosion: construction of "swales[185]" or water retention curves and rainwater capture ponds that help reduce erosion, while accumulating surface or infiltrated water. These actions also favour the increase of biodiversity in species of insects, pollinators, amphibians and birds
- Selection of tree and shrub species by the team of Alvelal technicians and the administrations, to choose species from the vegetation series corresponding to the ecosystem.
- Cereal plantations between trees and shrubs to create nesting areas for steppe birds.
- Geolocated monitoring and follow-up over time, to evaluate the successes of the projects.

Some examples of the management carried out in agricultural areas are:

- Regenerative soil techniques: organic amendments for soil, vegetation cover, and key line cultivation, among others.[186]
- Water capture techniques: swales, rainwater capture ponds, among others.

[185] A "swale" is a trench that is built parallel to the slopes and that serves to reduce the risk of erosion and favors the infiltration and retention of water in the field.

[186] Association AlVelAl (2019) Regenerative Agriculture Protocol.

- Techniques for the promotion of biodiversity such as planting hedges to increase biodiversity, creating ponds, combining several crops on a farm, among others.

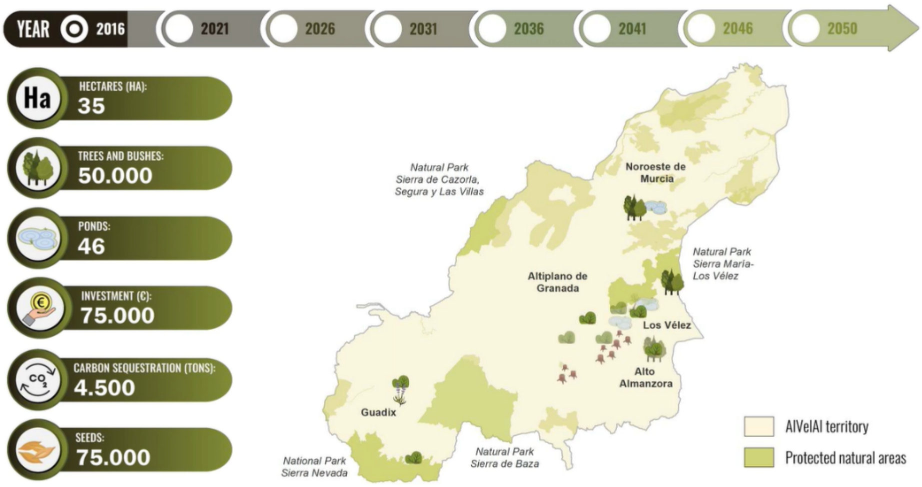

Figure 46. Representation of the actions carried out by the Alvelal Foundation in its territory in 2016. (Source: [Alvelal.)](#)

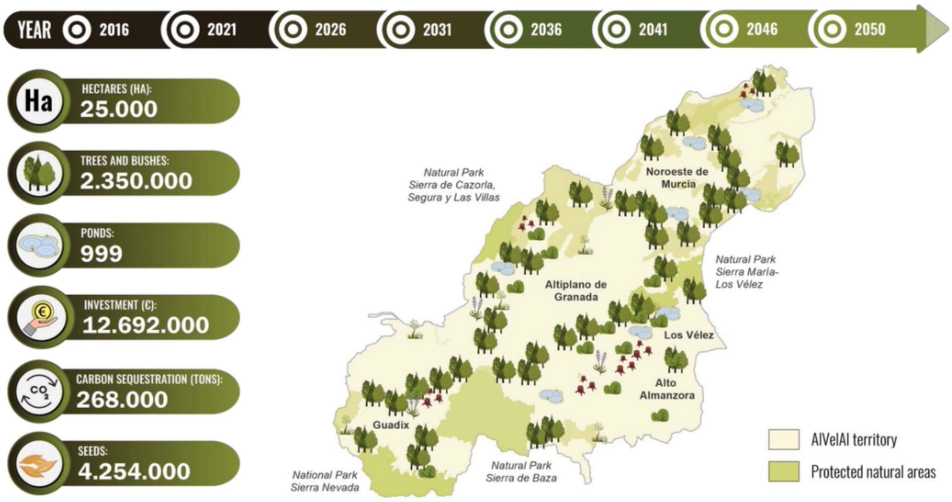

Figure 47. Representation of the expected actions in the territory of the Alvelal foundation for the year 2050. (Source: [Alvelal.)](#)

Implementation potential

Advantages	Disadvantages
• Reduction of desertification through sustainable use of the territory. • Recovery of ecosystem services. • Increase in biodiversity. • Increasing climate resilience. • Integral management of the territory.	• Need for a specific environmental study for each area. • Risk of introducing non-native species if adequate information is not available.

Potential barriers to implementation

The main barrier to implementing these measures is the lack of public funds and the lack of coordination of the administration in terms of competences. It would be necessary to harmonize the actions and coordinate the competent bodies in each situation.

There is also a risk associated with the implementation of measures to prevent desertification. In many cases a viable solution to the problem is to reforest areas or replace current vegetation. In these cases, if it is not done under scientific criteria and with the support of experts, a non-native species could be introduced into an ecosystem in which it could displace other species.

Level of innovation today TRL = 7

Agroforestry management techniques and measures to mitigate the effects of desertification are widely known and tested.

Expected or desirable advances in the coming years

It would be desirable that certain habits of gracing and forest management that help curb desertification, such as vegetation cover, crop rotation or fallow, among others, go from being recommendations to being conditions legislated by the European Commission.

However, given the difficulty of imposing such agricultural practices, it is to be expected that specific financing will appear to compensate and positively discriminate against those who apply them.

Expected results

If corrective and preventive measures are applied, we will adapt our agroforestry systems to climate change, being much less vulnerable to the associated meteorological phenomena.

Installation costs

As it is not a question of implementing technologies, but of applying good practices, the associated costs are derived from the work of tillage and crop management. These good practices help to increase the net benefits of crops, as they contribute to reducing the loss of fertile soil, increase the quantity and quality of nutrients available in the soil, structurally fix soils and increase the water availability of these, among many other benefits that make these practices beneficial not only from an ecological point of view, but also economic.[187]

Operating costs

The operating costs vary greatly depending on the type of technique to be implemented, the area to be covered and the operators required for this action. In any case, as discussed above, these costs are covered by the improvement of the economic benefits provided by these techniques.

Social acceptance

Due to the nature of the proposed measures, which seek to adapt and mitigate the effects of climate change, it will have a high acceptance by society, which already recognizes these as the main challenges to be addressed in the immediate future. Special attention will have to be paid to farmers and ranchers, who may be reluctant to change if they do not understand the benefits that come with it.

Recipients

- Farmers and producers
- Cattle farms
- Ministries of environment and municipalities
- Farmers' and producers' associations

[187] Association AlVelAl (2021) Video on Regenerative Agriculture. Return on financial capital.

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Desertification
- Temperature change
- Soil degradation
- Thermal stress
- Forest fires
- Soil erosion
- Water stress
- Heat and cold waves
- Changes in precipitation patterns and types
- Droughts

Conceptual fit within climate change adaptation

In the arid and semi-arid Mediterranean region, an approximate 20% reduction in water availability is expected by the middle of the twenty-first century, measures such as those proposed here, will help adapt and combat these scenarios of water scarcity, desertification and loss of soil productivity.

One of the main effects of climate change combined with poor soil management; it is desertification. This project aims to find mechanisms to combat this problem, helping us to manage soils more sustainably and making them more resilient to climate change.

Adaptation to climate change is of particular importance for the Mediterranean region which is experiencing increasingly negative effects, such as drought and extreme temperatures, more than in other areas of Europe. The project focuses on adaptation measures aimed at reversing current trends in desertification and creating more climate-resilient local communities. In addition, it will also address the priority of mitigation policy, through the restoration of vegetation cover and soil organic matter content, which has an impact on CO_2 capture from the atmosphere.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Almeria-Granada-Murcia	Alvelal	2016-present	The Alvelal association develops 4 return projects and focuses part of its efforts on combating desertification. The restoration of El Cortijico in the Sierra María-Los Vélez NP is an example of the work carried out since the foundation. On the other hand, the foundation provides training to extend good soil protection practices against desertification.[188][189]
International	FAO	2012-present	Action Against Desertification is an initiative of African, Caribbean and Pacific States to promote sustainable land management and restore dry and degraded lands in Africa, the Caribbean and the Pacific. This initiative is being implemented by FAO and its partners with funding from the European Union under the tenth European Development Fund (EDF).[190]
Andalusia	Junta de Andalucía	2015-present	The Life Adaptamed project articulates adaptive management measures for the protection of ecosystem services in three Protected Natural Areas (Cabo de Gata, Doñana and Sierra Nevada) in the face of a climate change scenario. Among others, measures to adapt and mitigate desertification have been studied and implemented.

[188] Association AlVelAL (2021) Restoration in Monte Público El Cortijo, Los Chaveses and El Estrecho.

[189] Association AlVelAL (2021) Plant Covers Workshop in Taberno.

[190] FAO, Action against desertification. Extension of the Great Green Wall of Africa.

Main stakeholders (organizations, companies, institutions, etc.)

- Ministry of agriculture
- Ministry of the environment
- Food companies
- Agricultural associations

4.3.7 Industry and Services

4.3.7.1 *Digitalization of the supply chain*

(Authors: Queralt Plana Puig)

Areas or sectors where it applies:

- Industry and services
- Early warning
- Transport and mobility

Type of solution: Technological solution

Solution / Technology

The digitalization of the supply chain is the result of the use of technology in every aspect of this chain leading to greater transparency and allowing companies to minimize their own operational risk, as well as effectively identify and remediate partners at risk.

Basic description

A Digital Supply Chain (DSC), also known as Industry 4.0 or Smart Industry, is a set of processes that integrate advanced technologies and better insights into the different functions of each party involved in that chain (see Figure **48**). This allows each participant involved in the supply chain to make better decisions about the sources of the materials needed the demand for the products and the relationships between them.

Figure 48. Outline of digital technologies of a digitized supply chain (Source: Drew.)

In a first step for digitalization, it is necessary to make a complete integration on supply chain management including demand planning, asset management, warehouse management, transportation and logistics management, procurement, and order fulfilment. In addition, this also involves the instrumentation of the equipment to generate process monitoring data, as well as the extraction of that data and its storage.

The instrumentation of the supply chain is carried out with sensors and monitors, a set that is known as the Internet of Things (IoT). The technology set is used to monitor manufacturing and logistics processes. And the data obtained is centralized in a database and shared with the parties involved in the supply chain for a detailed monitoring of the product manufacturing, transport, etc.

The digitalization of supply chains can also contain climate models where they manage and operate chains according to climate restrictions and favour the climate change mitigation.

One of the industrial sectors that has benefited the most from the digitalization of industry and supply chain is food processing. In this sector, Industry 4.0 concepts improve traceability, monitoring and control of food quality, as well as an improvement in safety, processing, and automation. Also, the prediction of demand and consumer preferences, allow to reduce the losses and the mistreatment of processed products. For example, in this sector, digitalization mainly consists of the installation of sensors and the integration of tools for the data centralization and processing.

In the agricultural sector, the use of technologies for the digitalization of this sector is based on the use of drones for the control of fields based on computer vision. Other sectors, such as the automotive sector, their digitalization consists of the robotization of some stages of the process. In the same sector, computer vision is also being implemented as a defect detection system in the production process. Or, in the medical sector, part of the digitization is based on the use of bio-3D printers.

Implementation potential

Advantages	***Disadvantages***
• Solution available on the market • Connect and relate data sources by improving processes and preventive maintenance • Efficiency in the management of the resources of a company or activity • The company evolves with technological evolution • Product cycle visibility • Reduction of the mistreatment of raw materials and manufactured products	• Exposed to computer attacks on the system • High investment in technological infrastructure • Training and preparation of staff on the operation of IoT tools

Potential barriers for implementation

According to Agrawal et al. (2019)[191] the main barriers to the digitalization of the supply chain are:

- The digital transformation of a supply chain requires effort, resources and money
- Companies need the commitment and support of management and senior managers
- New training and technical skills with the aim of increasing production and efficiency
- Change in company culture by promoting collaboration and communication between different points of the supply chain

Actual level of innovation (TRL = 9)

Currently, the more advanced tracking of raw material assets as they move through the supply chain allows companies to proactively identify available alternative assets. In addition, real-time tracking is useful for companies that ship volatile materials or other hazardous materials so that they are in a better position to take additional steps to reduce the risk of a spill or leak.

In addition, predictive analytics incorporating climate models can be employed to forecast both supply constraints and future demand in advance. Depending on the future dynamics of supply and demand, companies may consider changing production altogether.

[191] Agrawal, P., Narain, R., & Ullah, I. (2019). Analysis of barriers in implementation of digital transformation of supply chain using interpretive structural modelling approach. Journal of Modelling in Management, 15(1), 297–317.

Expected or desirable advances in the coming years

Currently, digital tools can alert producers about delays in imports and/or exports or the inability to meet demand due to an anticipated decline in production. As these systems improve and begin to incorporate climate models into their analyses, they will become more predictive and enable companies to develop better climate resilience in their supply chains[192].

Expected results

Digital transformation has been a top priority in different industries. Specifically, the expected results of this transformation are:

- Creating a competitive advantage by improving operating models and operations, thus improving operating margins and accelerating sales. In the long term, overall results should improve.
- Gain deeper and more elaborate insight, and improve decision-making based on data extracted from the supply chain and not on human perception.
- Improve the customer experience. This implies better product management (delivery times, availability, etc.), and a more specific and dedicated follow-up of the product in the hands of the customer.

Installation costs

In this case, no overall value of the cost of digitizing a supply chain has been found, nor any specific examples. However, the costs for the digitalization of the supply chain depend on the sector of the supply chain, the scope of the transformation in the chain and the deadlines in which it is to be done.

Operating costs

The digitalization of supply chains reduces operating costs. Boston Consulting Group presents a reduction in costs between 10-20% although without specifying the time required to observe this reduction[193].

The reduction in costs can also be seen reflected in the reduction in final product losses by reducing the availability of the product in inventory and optimizing production according to demand.

Social acceptance

It is to be expected that social acceptance will be high since the technology exists in the market and the implementation benefits the supply and quality of the product to the customer, as well as the environment adapting to climate change. In addition, technology facilitates the adaptation of other activities and /or sectors and does not adversely affect them.

Recipients

- Industries in any sector
- Service companies

[192] Marshall K. & Schiavo A. (2020). In the path of destruction: Preparing for climate change in the chemical industry. Lux Research. Publication..

[193] Boston Consulting Group (2021). Digital Supply Chain.

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Temperature variability
- Emissions into the atmosphere
- Heavy rainfall

Conceptual fit within climate change adaptation

Currently, digital tools can warn of delays in import and/or export, or the impossibility of meeting demand due to an anticipated decrease in production. By improving these systems and including climate models in system analysis, they favour prediction and enable companies to build climate-resilient supply chains.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
USA	Dow, M&D	2019	Development of a tool to alert manufacturers to supply chain disruptions
Global	BASF, IBM	2021	Tool based on artificial intelligence and machine learning to support supply and replenishment decisions
Global	Walmart	2021	Automation of warehouses in distribution centres, and development of an e-commerce tool to reduce shipping time and cost.

Main stakeholders (organizations, companies, etc.)

- Companies in the digital sector (including hardware and software companies)
- Companies in the robotic sector
- Multinational and transnational organizations
- Companies in any industrial sector

4.3.7.2 *Treatment of fruit and vegetable processing effluents with microalgae (LIFE ALGAECAN)*

(Author: Queralt Plana Puig)

Areas or sectors where it applies:

- Industry and services
- Water
- Agriculture and food

Typology of the solution: Specific technology

Solution / Technology

Life ALGAECAN technology consists of a wastewater treatment from the fruit and vegetable processing industry based on the cultivation of heterotrophic microalgae.

Basic description

In the context of climate change, it is necessary to implement the circular economy in industries to make them more sustainable and thus reduce the environmental impact. Europe is the world's second largest producer of fruit and vegetables. And the processing industry is one of the largest industrial sectors at levels of production, growth, consumption, and export[194].

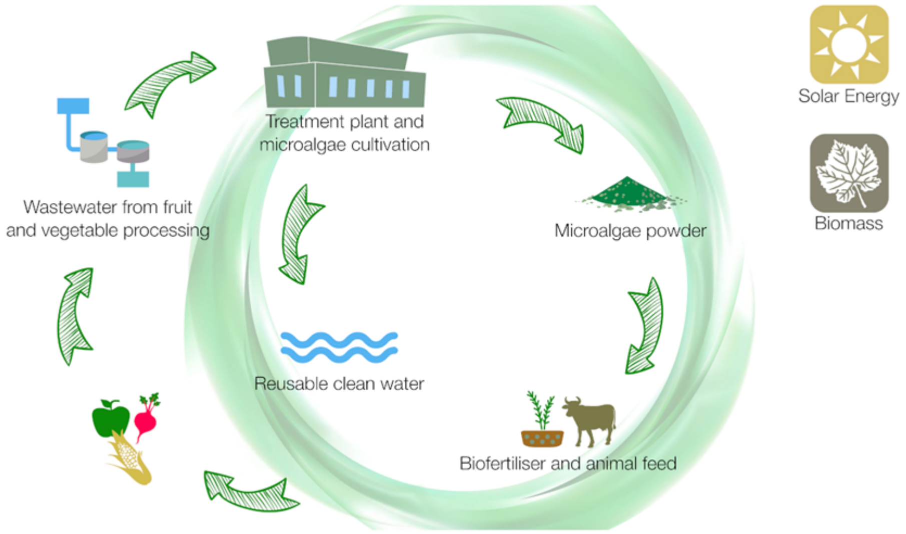

Figure 49. Diagram of the circular flow of the system proposed in the LIFE ALGAECAN project

The European project LIFE ALGAECAN (LIFE16 ENV/ES/000180) promotes compliance with the main EU directives on the environment and applied in the fruit and vegetable production and industrial sector. In addition, the project aims to demonstrate the technical and economic viability of an innovative concept for the treatment of industrial waters from fruit and vegetable processing, provide a cost-effective process for the in-situ treatment of streams rich in organic matter, nutrients and salts, implement the prototype in two facilities and demonstrate a commercial interest of the technological proposal and the product obtained.

In this context, the project proposes a model of sustainable and circular treatment of effluents with high and salty loads. Specifically, the prototype of this system has three main stages: (1) microalgae culture system, capable of consuming the organic matter and nutrients contained in the water; (2) separation by centrifuge to recover clean water; and (3) spray drying to

[194] LIFE ALGAECAN project

recover dry microalgae[195]. The system is contained in two detachable containers and is powered by solar energy and biomass. Its treatment capacity is 2 m^3/d of wastewater.

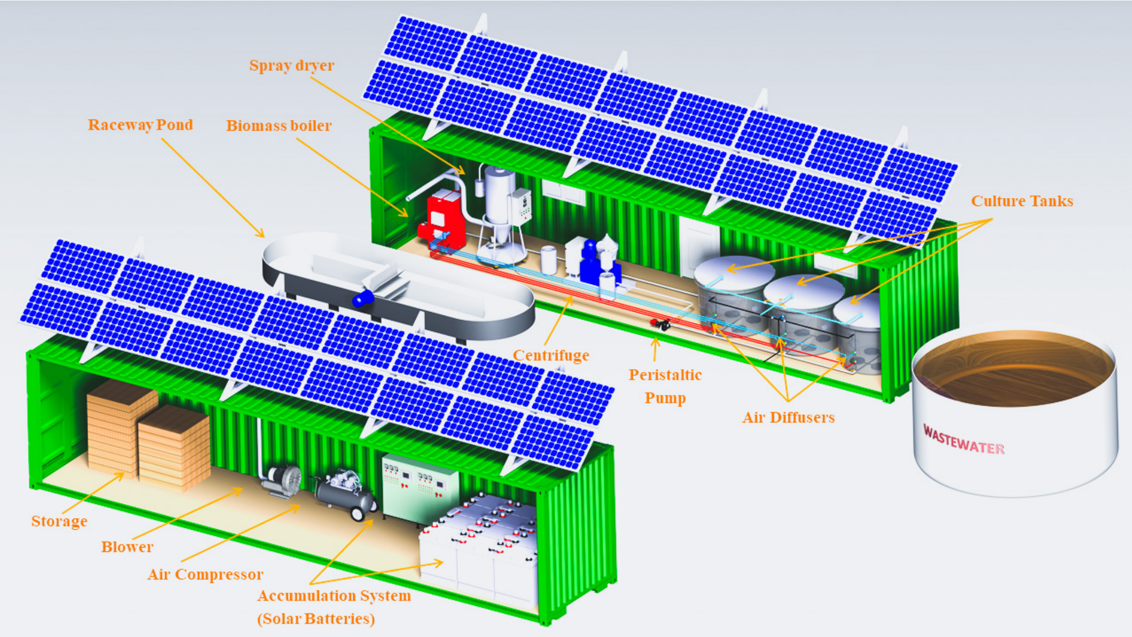

Figure 50. Diagram of the configuration of the LIFE ALGAECAN prototype.

In addition to the high quality of the water for reuse for cleaning or irrigation, this process also obtains a commercial product used to produce biofertilizers, animal feed, bioplastics, etc. During the development of the project, a production of 1.5 kg of microalgae per m^3 of treated wastewater was demonstrated. Product that can be used as a fertilizer with a nutrient content of 6% N, 2.5% P_2O_5 and 1.5% K_2O, and as a raw material to produce animal feed with a content of 15% lipids, 40% protein, and 20% carbohydrates.

From a technological point of view, it is a simple treatment with low associated costs at the level of operation (both from the point of view of the process and energy consumption). This allows you to install the prototype wherever you want.

Implementation potential

Advantages	***Disadvantages***
• Technologically simple solution. • Reduced operating costs. • Use of renewable energies (solar energy and biomass) • Regeneration of high quality water for cleaning or irrigation. • Production of a commercial by-product. • Modular system for easy transport and installation. • Reduction of drinking water consumption. • Reduction of water stress.	• Risk of contamination of microalgae that affects their quality.

[195] L. Garrote, J.M. Martín-Marroquín, DE. Hidalgo. (2020) Microalgas heterótrofas como innovador sistema de tratamiento de aguas residuales del procesado de frutas y verduras. Revista AquaPress.

Potential barriers for implementation

The implementation of this technology is mainly limited by the industrial sector where it has been applied (only in the fruit and vegetable processing industry) and by the reduced number of the demonstration cases (two cases, one in Spain and one in Slovenia).

At the technological level, it also presents limitations such as the risk of contamination of microalgae that affects their quality, the unstable flow of wastewater, the overcoming of preferences for chemical fertilizers or the scale of algae production.

Actual level of innovation (TRL = 9)

The by-product of this treatment system has commercial interest since it can serve as a raw material to produce biofertilizers, animal feed, etc. The effluent can be used as irrigation water or for cleaning equipment and facilities. On the other hand, being powered by renewable energies minimizes the carbon footprint and operating costs of the process.

Expected or desirable advances in the coming years

The design of the prototype, its implementation, the dissemination of the results, and the dissemination of good practices has been carried out during the project (October 2017 – December 2020). After its completion, it is expected that the use and installation of this technology will increase over the years given the benefits it entails in front of climate change and a circular economy.

Expected results

With this prototype to treat wastewater from the fruit and vegetable processing industry based on a microalgae culture, the following results are expected[196]:

- Production of high-quality water, without pathogens and xenobiotic compounds. The quality of the effluent allows the water to be reused, for example, for irrigation and/or cleaning, or to pour it into a channel.
- Reduction of the environmental impact associated with the generation of sludge waste compared to conventional water treatment systems.
- Reduction of the cost of industrial water treatment from fruit and vegetable processing compared to conventional water treatment processes.
- Reduction of nutrient losses associated with the generation of sludge residues.
- Obtaining a microalgae product that can be used as a fertilizer or as a raw material for the manufacture of animal feed.
- Reduction of water stress by being able to produce fit-for-purpose water.

Installation costs

The installation costs of the LIFE ALGAECAN system for the different application cases are not published and are therefore unknown. In this case, only the total cost of the project of € 1.7 M during the 3 years of the project duration (October 2017 – December 2020) is known. Apart from the construction of the prototype of the algae treatment system, these costs include laboratory testing for its design, prototype development, pilot testing, economic market studies, dissemination and dissemination of results, etc.

Operating costs

Compared to the cost of operation with a conventional water treatment plant (for example, a biological treatment of active sludge), with this system they can be reduced by 80%. This reduction could be greater using solar radiation and/or biomass as energy alternatives or revenues from the sale of commercial by-products.

[196] Results from Life Algaecan project.

Social acceptance

Social acceptance of this technology is expected to be high. The technology presented exists in the market and its efficiency and benefit have already been demonstrated in two case studies. In addition, this technology is of high interest in the industrial sector of fruit and vegetable processing and has social benefits beyond the climate change mitigation.

Recipients

- Fruit and vegetable producers
- Fruit and vegetable processing industries
- Government agencies

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Water stress
- Droughts

Conceptual fit within climate change adaptation

Water scarcity is one of the main problems arising from long-term climate change impacts in warm and arid areas. The reuse of water in industry implies a greater autonomy of the production plants, which allows a greater resilience with respect to climate change.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Segovia, Spain	Huercasa	2017	Application of the LIFE ALGAECAN system in the vegetable processing industry
Bezje, Slovenia	Vipi	2017	Application of the LIFE ALGAECAN system in the fruit processing industry

Main stakeholders (organizations, companies, etc.)

- Fruit and vegetable processing companies
- Government organizations

4.3.7.3 Circular water use systems in industrial areas

(Author: Queralt Plana Puig)

Areas or sectors where it applies:

- Industry and services
- Water
- Urban planning and building

Type of solution: Technological solution

Solution / Technology

Industrial wastewater treatment system for recovery and reuse in cooling towers, boilers and/or demineralized uses.

Basic description

This solution promotes the increase in the availability of reclaimed water, to promote the circular economy of water within the industrial sector, and thus reduce the demand for conventional water treated in a water treatment plant and consequently, mitigate the effects of climate change (such as water scarcity). In addition, wastewater is not only reusable resources, but also energy sources and material components that can be extracted, treated, stored and reused.

Industrial water can be recovered from the wastewater treatment plant (WWTP) with Near Zero Liquid Discharge (NZLD) systems or with Water Reclamation Plant (WRP). Especially, NZLD systems, a part of producing high quality water for reuse, allow to maximize the production of this water and minimize energy consumption. In Figure 51, NZLD system is presented including the different units and water cycle from the use of natural water to reuse through the recovery of resources and reuse of resources, and the stages of treatment.

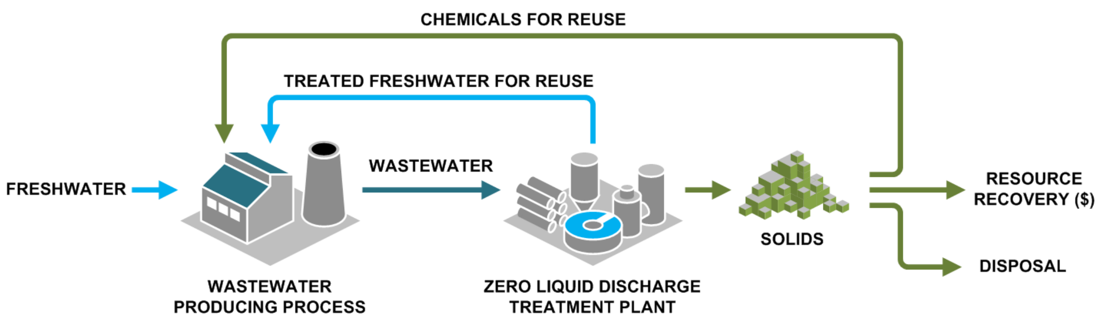

Figure 51. Diagram of a near-zero liquid discharge system Source: Saltsworks.

For example, in the Petrochemical Complex of Tarragona (Catalonia, Spain) since 2012 they have a treatment plant for the regeneration of urban water for boilers and cooling towers[197]. This plant has a filtration stage, another of reverse osmosis and finally one of disinfection with UV and sodium hypochlorite. With the construction of a new industrial wastewater treatment plant in this same complex and the objective of increasing the availability of reclaimed water by improving its quality and the recovery of energy and material resources, within the framework of the European ULTIMATE project, it is desired to install an NZLD treatment system that combines advanced reverse osmosis and membrane distillation for the recovery of water

[197] Sanz, J., Suescun, J., Molist, J., Rubio, F., Mujeriego, R., & Salgado, B. (2014). Reclaimed water for the Tarragona petrochemical park. Water Science and Technology: Water Supply, 15(2), 308–316.

from the WWTP of the same industrial complex. On a pilot scale, this system has already been shown to be a new source of water for this industrial complex.

Implementation potential

Advantages	***Disadvantages***
• Reduction of the extraction and treatment of water from natural sources. • Reduction of water stress in the region. • Reduction of water and energy production costs.	• Sometimes the technology is not available on the necessary industrial scale • Limited uses of reclaimed water in accordance with RD1620/2007

Potential barriers for implementation

Several authors [198, 199 and 200] agree with the main barriers to the implementation of a circular economy. Applied to the specific case of industrial water use systems, the main barriers can be grouped into four main blocks:

- Economic. The cost of developing and adopting technologies, and how these costs translate to the total cost of by-products. These added costs are holding back the demand for reusable products versus single-use products. In addition, capital intensive is required and the return period is long. At the enterprise level it can be unprofitable.
- Market. There is no reliable market. Externalities are not reflected in the previous one and new public infrastructures are required for the management of resources so that the reuse and use is effective.
- Regulatory. The existing legal framework does not promote or require circular economy initiatives in the water sector.

Actual level of innovation (TRL = 9)

Circular industrial water harvesting systems already exist and are used in the market. In this case, the innovation is based on the optimization of the new NZLD treatment system, maintaining affordable costs while minimizing emissions.

Expected or desirable advances in the coming years

Increased water demand and decreased water availability because of climate change impact can affect the sustainability of industrial estates, especially those located in areas where water scarcity is high or even already arid. The start-up of a regeneration plant to feed only industrial water and avoid the consumption of resources from the production of drinking water would help increase the water security of large industries. By developing a new and locally available water supply source, industrial growth in a water-scarce region has been supported, while promoting the sustainability of local industry.

Expected results

With water scarcity, the growth of water demand and the limited supply of conventional water, the expected results with the implementation of circular systems for the use of industrial wastewater are:

- Alternative to the use of drinking water from public supply, thus reducing the demand for drinking water by the industrial sector.
- Improving water efficiency within an industry.

[198] Red vasca de municipios sostenibles (2019). Guía para la promoción de la economía circular desde el ámbito local. Udalsarea 2030. Ed. Ihobe, Sociedad Pública de Gestión Ambiental.

[199] Xarxa de Ciutats I Pobles cap a la Sostenibilitat (2018). Economía Circular y Verde en el mundo local: Cómo pasar a la acción y herramientas para los entes locales. Diputación de Barcelona y Fundación Fórum Ambiental.

[200] Kuchinow, V. (2020). La infraestructura necesaria para alojar a la industria circular. Economía industrial, ISSN 0422-2784, Nº 416, 2020 (Ejemplar dedicado a: Transición Eco-Industrial), págs. 75-84.

- Generation of circular flows in the same industry or industrial estate closing the water, energy and material cycles. And allowing better control of them in terms of quantity and quality of the resources.
- Reduction of environmental burdens favouring the protection of the biodiversity of the region.
- Reducing desertification and water scarcity in the region.

Installation costs

The costs of installing a circular system to take advantage of wastewater in industrial areas will depend on the flow of water to be regenerated, the processes to be implemented to treat the water, and the quality of water to be obtained. Also, the installation cost depends on the manufacturer of each business unit and the agreement agreed with each consortium, industrial complex or company. In the case of the NZLD pilot system to be installed in the petrochemical complex in the context of the ULTIMATE project, it is unknown since it is still under construction. On the other hand, and under the same NZLD concept, the company SAMCO Technologies that is specialized in the design of industrial water treatment solutions, presents that the necessary costs for the equipment, engineering, design, installation, and commissioning of an NZLD plant to treat 1,000 to 3,000 gallons per minute (between 0.6 and 2 Mm^3/d) can cost between 25 and 50 M$ (i.e. between 22 and 44 M€ depending on the currency conversion in December 2021). For an NZLD system with treatment capacity between 1 and 20 gallons per minute (between 6.5 and 130 m^3/d), the cost can vary between 250,000 and 2 million $ (between 220,000 and 1.7 million €).

Operating costs

In the same example of the Tarragona Petrochemical Complex, the production costs in 2012 of the wastewater regeneration plant indicated by the operating companies were 0.5 €/m^3 [197]. Also, an economic study was carried out integrating an ion exchange process for the demineralization of water and offering higher quality water to the companies of the industrial complex. In this case, operating costs rose to €1.2/m^3.

Social acceptance
It is to be expected that social acceptance will be high since the technology exists in the market. Also, there is demand from industries and brings benefits in them beyond adaptation to climate change reducing water stress and desertification of the regions where they are located.
Recipients

- Industries in any sector
- Government agencies
- Companies in the water sector

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Droughts
- Water stress
- Rainfall and/or hydrological variability

Conceptual fit within climate change adaptation

The main consequences of climate change are negative effects on water availability and quality. The implementation of a circular system for the use of industrial wastewater not only reduces the consumption of drinking water but also reduces water stress and prevents desertification or droughts in the region where the circular flow of water is promoted.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Petrochemical Complex of Tarragona, Spain	Petrochemical Complex of Tarragona	2012	Regeneration and consumption of industrial wastewater in the same petrochemical complex.
Zona Franca Barcelona, Spain	Consorcio Barcelona Zona Franca	2018	Development of the EcoCircularZF project to generate symbiosis between the industries of the consortium and manage resources and waste effectively. This project includes the regeneration and internal use of the water flows of the industrial estate.

Main stakeholders (organizations, companies, etc.)

- Companies in any industrial sector
- Industrial consortia
- Municipalities and government organizations
- Companies that manufacture and install water treatment systems
- Engineering companies in the water sector

4.3.8 Energy

4.3.8.1 Dynamic Line Rating

(Author: Carmen M. Torres Costa)

Areas or sectors where it applies:

- Energy

Typology of the solution: Technological solution

Solution / Technology

The DLR (Dynamic Line Rating) system uses the continuous variation of the thermal capacity of an electrical voltage line, due to environmental and climatic conditions, to minimize grid congestion. This is done dynamically and in real time, depending on the variation of variables such as ambient temperature, solar radiation, wind speed and wind direction.

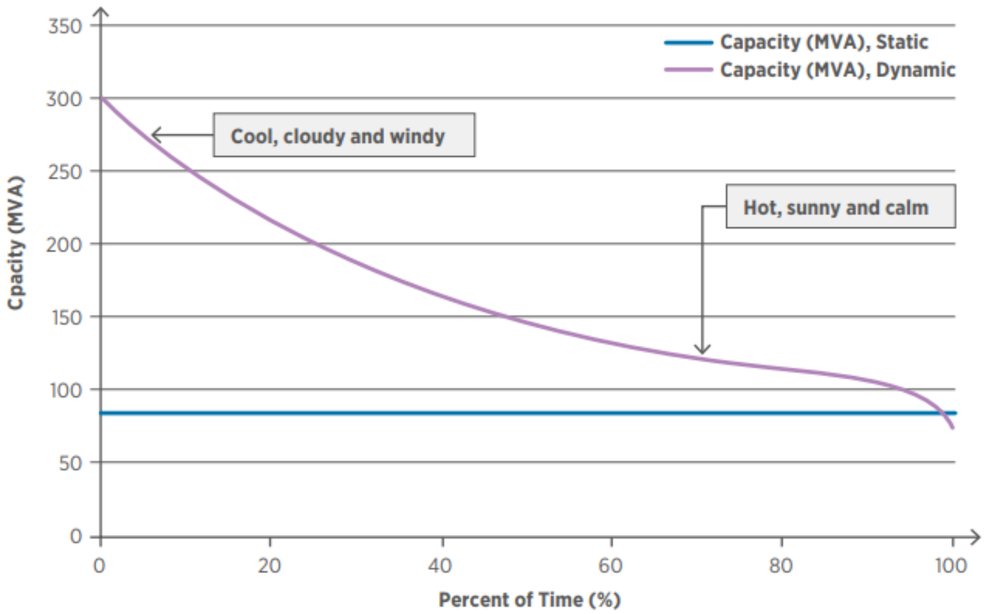

Figure 52. Graphical representation of ampacity behaviour[201] with a DLR and SR[202] system as a function of time. (Source: IRENA. 2020. Dynamic line rating. In Innovation landscape brief.)

Basic description

The direct and indirect effects of climate change can be catastrophic and require rigorous analysis. Many of the components of the power grid, such as transformers and power lines, are directly vulnerable to weather conditions[203]. Grid congestion is a problem that commonly arises when grid components reach their thermal limits due to large electricity flows, when demand exceeds the maximum current capacity (or ampacity) of the grid.

Traditionally, operating systems have used the most unfavourable weather conditions to calculate the ampacity of transmission and distribution conductors (the network cables).

[201] Ampacity: maximum current, measured in amperes, that a conductor can transport continuously under normal conditions of use without exceeding its temperature rating.

[202] ST: Static Rating, conventional, as opposed to DLR.

[203] Cradden, L. C., & Harrison, G. P. (2013). Adapting overhead lines to climate change: Are dynamic ratings the answer? Energy Policy, 63, 197–206.

However, the ampacity of a driver is constantly changing and depends on various factors as the mentioned.

DLR systems can monitor the power grid with sensors, offering the possibility of estimating the ampacity of a transmission line in real time by observing the weather conditions of the environment[204].

Implementation potential

Advantages	Disadvantages
• Reduction of the network congestion • Optimization of active resources • Continuous development of artificial intelligence and big data technologies to facilitate the use of DLR. • Efficiency improvement and costs reduction • Synergies with renewable energies with the with variable generation (VRE [205]), solar and wind energy, by enabling their integration in the net and increasing their profitability.	• No-direct operating costs are foreseen, but they have not been evaluated in existing projects. • The optimization of the algorithms is needed for the ampacity calculation in large-scale applications (national networks and cross-border exchanges). • The variety of factors implies a massive amount of data that must be analysed in real-time.

Potential barriers for implementation

The barriers (or constraints) for the implementation of DLR systems are classified in two areas:

- Technological. These requirements include line identification, sensor installation, communication, analysis, and data validation. In addition, hardware for equipment, software for algorithms and data analysis, and communication protocols would also be necessary.
- Roles and responsibilities of stakeholders. Improved communication channels will be needed, among other requirements, for collaboration between meteorological data providers, owners of renewable energy facilities, power supply companies or generators and transmission and distribution system operators to improve the understanding of energy supply and demand flows.

Current level of innovation (TRL = 9)

There are currently some countries with DLR initiatives and that have already implemented some projects. The Flexitranstore project, in the Framework Programme of Horizon 2020, is a demonstration project at two sites, the first on the Electro Ljubljana power grid (Slovenia), and the second in north-eastern Bulgaria on the 220 kV power line between Karnobat and Varna. The project aims to demonstrate sensor technology that enables electrical system operators to effectively manage and prevent sudden failures. These failures are often fatal, especially during extreme cold conditions. In this way, it is intended to increase the safety and reliability of the system by reducing freezing phenomena and facilitating transboundary energy exchanges.

Expected or desirable advances in the coming years

From the implementation of the methodology *flow-based market coupling*[206] in 2015 (basically, a mechanism to integrate different electricity markets), in the first capacity calculation region corresponding to the Central-Western European area, some transmission system operators include DLR in the calculation of transmission capacity between countries. This can increase the volume of electricity marketable between countries in the European market. Between

[204] IRENA. (2020). Dynamic line rating. In Innovation landscape brief.

[205] VRE Variable Renewable Energy.

[206] Cross-border electricity exchanges on meshed AC power systems, ETSO, May 2004. Co-ordinated auctioning: a market-based method for transmission capacity allocation in meshed networks, ETSO, April 2001.

2017-2018, the thermal limit of conductors increased by 20% in cold conditions when electricity demand was high. In addition, about this methodology of integration of European markets, with the *Decision nº 02/2019 of the Agency for Cooperation of Energy Regulators* (ACER), in the central capacity calculation region (called CCR "Core") that includes transmission operators from 13 central-continental European countries, the obligation is established to gradually replace seasonal limit limits with a dynamic limit in trading on the pan-European intra-daily market[207].

Expected results

Small changes in weather conditions can have a considerable impact on the ampacity of a transmission line. Assuming a 20-mile-long (32 km approx.) aluminium conductive steel-reinforced transmission line, with a static line rating of 787 amps at 40°C, zero wind and a midday in summer, changes in ampacity can be seen under various weather conditions:

Weather conditions[208]	Ampacity changes
• Temperature	
2 °C	+/- 2%
10 °C less	+11%
• Solar radiation	
Cloud cover	+/- in percentage
Night	+18%
• Wind speed increment of 1 m/s	
45º	+35%
95º	+44%

Installation costs

There is little information about the installation costs of the projects that have been carried out, but in 2014 a project was carried out to implement a DLR system in Texas (USA) financed by the *US Department of Energy's Smart Grid Demonstration Program*. This project covered five transmission lines of 345 kV and three of 138 kV, and it had a cost of $4.83 billion.

Operation costs

Not all associated costs are precisely known.

Social acceptance

It is to be expected that social acceptance will be good since the implementation of the DLR system would not entail any substantial change in the electricity grid system. From the aesthetic point of view, the installation of the sensors in the voltage lines would be almost imperceptible due to their small size. In addition, with this system it is expected to achieve a reduction in economic costs and an aid in the integration of renewable energies into the electricity grid system, which tackles a very important issue of general concern.

Recipients

- Electrical network
- Suppliers
- Investment funds
- Solar energy companies
- Wind energy companies

[207] Once the prices of the daily markets are coupled, the intra-daily markets are addressed; necessary to adjust the forecasts of electricity production and consumption of the agents of the electricity market in the face of unforeseen events, breakdowns, unavailability and the variability of resources inherent in renewable energies.

[208] Source: IRENA. 2020. Dynamic line rating. In Innovation landscape brief

Impact to the climate change adaptation

Risks arising from climate change to which it can help us adapt

- Temperature change
- Heat waves
- Cold waves
- Temperature variability

Conceptual fit within the adaptation to climate change

One of the main implications of the increase in the average ambient temperature in the transmission and distribution of electricity is the reduction of the maximum rated power of the equipment and the increase in the loss of energy in the grid system[209].

Real-time dynamic sorting systems are likely to represent the most cost-effective adaptation method for lines that typically have thermal limitations. Not only because they serve as a measure to prevent overheating, but they also facilitate energy transmission by adapting the grid to a more variable supply from renewable sources[210].

Real or pilot cases of application

Location	Entity	Year	Description
Germany	TransnetBW, Tennet TSO, Amprion, 50Herzt Transmission	2015	Implementation of DLR in many heavily loaded airlines, integrating most of the distribution centres of German transmission operators. Different approaches were employed for weather forecasts based on local and regional measurements, as well as seasonal environments. Nominal capacity increased to 200%.
EBelgium	Elia	2017	Elia implemented DLR, which resulted in a thermal rating (due to cold winds) of more than 200% of the seasonal rating on the power lines.
Bulgaria	Elektro-Slovenija	2017	Use of sensor technology that allows electrical system operators to effectively manage and prevent sudden failures, increasing system safety and reliability by reducing freezing phenomena and facilitating cross-border energy exchanges.
France	RTE	2012-2018	Optimization of wind farms, of which most are connected to the sub-transmission network below 63 kV and 90 kV.
Transmission lines Spezia-Vignole, Bargi-Calezano, Misterbianco-Melilli and Benevento-Foiano, Italy	Terna	2013	Implementation of DLR equipment in the transmission lines allowing greater amounts of current in favourable weather conditions and allowing greater integration of the electrical energy generated in wind farms near the lines.
Texas (USA)	US Department of Energy's Smart Grid Demonstration Program	2014	The real-time capacity of the 138 kV lines increased on average by 8–12%, while the 345 kV line showed an increase of 6–14%.
Uruguay	UTE	2018	The implementation of DLR increased transmission line ratio dynamically at low-level hours, in addition to hourly forecasts, it helped to reduce wind power constraints.

[209] Braun, M., & Fournier, E. (2016). Adaptation Case Studies in the Energy Sector - Overcoming Barriers to Adaptation.

[210] Cradden, L. C., & Harrison, G. P. (2013). Adapting overhead lines to climate change: Are dynamic ratings the answer? Energy Policy, 63, 197–206.

More examples and practical evidence of DLR applications in different regions of the world can be found in the article Erdinç, et al. (2020)[211].

Main stakeholders (organizations, companies, institutions, etc.)

- Electricity companies
- Suppliers
- Public energy institutions & companies

[211] Erdinç, F.G.; Erdinç, O.; Yumurtacı, R.; Catalão, J.P.S. A Comprehensive Overview of Dynamic Line Rating Combined with Other Flexibility Options from an Operational Point of View. Energies 2020, 13, 6563.

4.3.8.2 Copernicus Climate Change Service – Energy Sector

(Author: Carmen M. Torres Costa)

Areas or sectors where it applies:

- Energy
- Industry and services

Type of solution: IT solution

Solution / Technology

Copernicus Climate Change Service – Energy Sector (C3S Energy) develops state-of-the-art climate visualization tools, which use high-resolution calibrated input data, to visualize past and present climate and energy variations across Europe, as well as build future scenarios.

Basic description

The tools developed within the C3S Energy project are mainly derived from the work of two proofs of concept, CLIM4ENERGY (C4E) and *European Climate Energy Mixes* (ECEM), with additional elements of the work of other projects. The C4E and ECEM demonstrators are based on the co-design of the energy industry with the collaboration of approximately 30 energy users.

The main objective of this type of tool is to provide key information on climate indicators relevant to the European energy sector. This includes data in terms of electricity demand and energy production from wind, solar and hydroelectric sources[212].

These types of solutions produce reference datasets for climate variables. Energy variables (e.g., demand and power generation) are generated by transforming climate variables using a combination of statistical models, physical base data and measured energy supply and demand data from sources such as ENTSO-E (European network of transmission system operators) among others.

The platform provides data for the European domain, multiple variables and multiple time scales of climate and energy systems. The user will be able to select a climatic or energy variable and a period. Based on these input selections, a map is generated that shows the selected information visually, as well as information about weather and energy (data sheets, methods and assumptions, key messages, case studies, and FAQs).

Implementation potential

Advantages	Disadvantages
• Holistic approach of multiple variables and temporal perspectives. • Synergies with other artificial intelligence and big data platforms/ technologies.	• The decision making derived from its use requires a great capacity for data analysis. • Focused only on the variability of renewable sources, not on affectations in the most stable productions

[212] Operational service for the energy sector. Copernicus.eu. Last access: November 12th 2021.

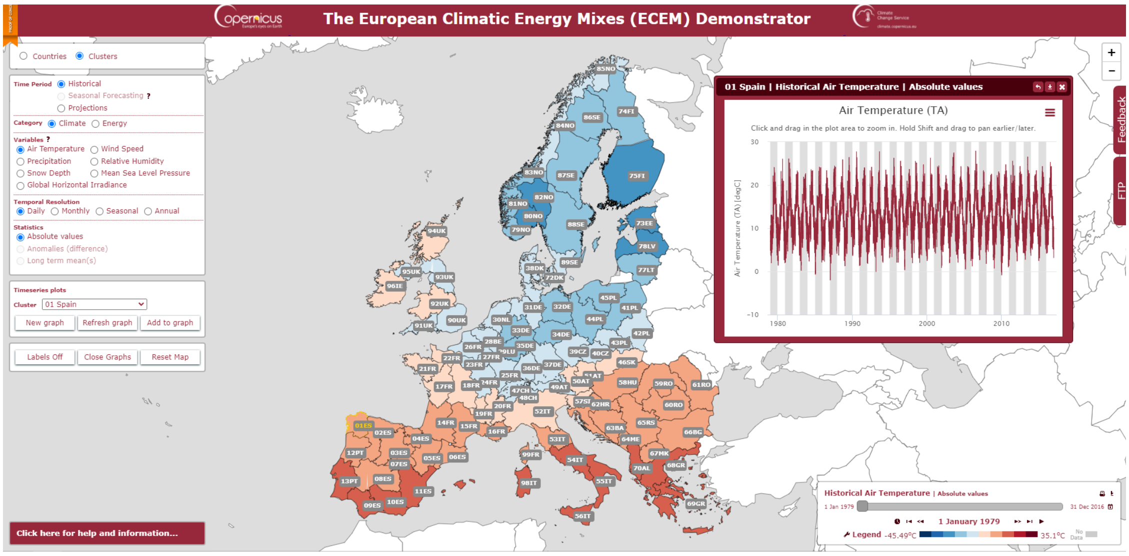

Figure 53. Visualization of the map by clusters for the variable temperature and the daily historical detail for cluster 1 of Spain (Galicia). (Source: ECEM.)

Potential barriers to implementation

Although the C3S Energy service is still under development, there are no expected barriers preventing its implementation. The ultimate goal is to have a state-of-the-art visualization tool to show climate and energy variations across Europe by incorporating the advances of the proofs of concept already developed.

Current level of innovation (TRL = 7)

The data will cover a range of time periods that will allow to visualize changes in any of the variables from the past to the present day, or in the future (predictive).

The tool ensures that the country's energy mixes adequately reflect climatic conditions, including their variability, and will therefore allow end-users to better assess the optimal supply mix that can meet demand in the most cost-effective way. The tool offers a coherent approach to the climate variables and indicators used in the balance of energy supply and demand, an added value with respect to current practice in the sector, where climate data and ESCII[213] derivatives are not always physically homogeneous and/or in equilibrium.

Expected or desirable advances in the coming years

The *European Climatic Energy Mixes (ECEM)* proof-of-concept model was successfully completed in March 2018. The work carried out so far consisted mainly of the production of climate indicators and energy indicators in a historical data series. The next phase will continue to improve the operational tools developed by combining the demos of ECEM and CLIM4ENERGY[214]. A key component of the C3S Energy project will be the development of supporting documentation to ensure that the data provided by these tools is traceable, properly described, and considers the associated uncertainty and its appropriate orientation to the end user.

Expected results

[213] Energy Sector Climate Intensity Index.

[214] CLIM4ENERGY is an on-line visualization portal (beta version) with the cooperation of 7 climate research centers and 9 energy professionals, which shows from case studies, the importance of the value chain between essential climate variables and energy variables.

Historical dataset allows:

- The investigation of an event in the context of recent history
- Simulation for solving questions of type "What if...?" To be assessed based on the combination of current energy status and climatic factors.

Data analysis can help anticipate future risks by:

- Seasonal energy forecasts.
- Climate projections.

Installation costs

The C3S ECEM proof of concept was launched with a budget of €1.6M[215].

Operating costs

It has not been possible to find data regarding this aspect.

Social acceptance

High acceptance. Technology for which there is demand from social agents and/or provides social benefits beyond adaptation to climate change.

Receipts

- Electricity network
- Suppliers
- Investment funds
- Electricity generation companies (solar, wind and hydro)
- Meteorological agencies
- Institutions and agents whose decision-making depends on weather forecasts: early warning in natural disasters, epidemiological models, alert for air pollution, etc.

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Temperature variability
- Rainfall and/or hydrological variability

Conceptual fit within climate change adaptation

The transformation in the energy sector is taking place in the face of a variable and changing climate. Given the weather and climate dependence on both renewable energy and demand (even in the case of a large electric energy storage capacity), it is important to develop robust climate-based tools to advise energy planners and policymakers.

It will be beneficial to anticipate major climate-driven changes in the energy sector, either through long-term planning or through medium-term operational activities. It can also be used to investigate the role of temperature in electricity demand in Europe, as well as its interaction with the variability of renewable energy generation.

[215] Alberto Troccoli (2016) Climate Service and Technology: a Key Tool of Climate Change Adaptation for the Energy Sector.

Application case studies

Location	Responsible	Year	Description
Europe	Copernicus	2009 - 2010	Identification of the spatial contrast between northern and southern Europe in winter 2009/10: colder than normal in the north, warmer than normal in the south. The historical data provided can help to understand how past weather events would affect the system today if they were repeated.
Spain	Copernicus	2003	Impact of heat waves in summer on supply and demand in Spain The analysis of the data provided was used to examine the climatic factors that drive high demand events in Spain. At the same time, the historical climatic effects on the current supply of renewables in summer were explored. In addition, trends in the demand and supply of renewables in future climate change conditions were investigated.
United Kingdo m	Copernicus	2009 - 2010	Impact of extreme winters on future production systems With the analysis of the data provided, the occurrence of winters such as that of 2009/10 in future climate projections in the United Kingdom was explored. Thus, the impact of cold and lasting winters under different electrical mixes was studied using the eHighway2050 scenarios.[216]

Main stakeholders (organizations, companies, institutions, etc.)

- World Energy and Meteorology Council
- University of East Anglia
- Météo-France
- CEA
- ARMINES
- EDF
- The Met Office

[216] El proyecto e-Highway2050 está respaldado por el Séptimo Programa Marco de la UE y tiene como objetivo desarrollar una metodología para respaldar la planificación de la Red de Transmisión Paneuropea, centrándose en 2020 a 2050, para garantizar un suministro seguro de electricidad renovable y la del mercado paneuropeo.

4.3.8.3 Energy adaptation map

(Author: Carmen M. Torres Costa)

Areas or sectors where it applies:

- Energy

Type of solution: IT Solution

Solution / Technology

A collaborative web platform for the inventory of successful case studies and projects in the field of climate change adaptation in the energy sector[217].

Basic description

The platform includes the mapping of successful climate change adaptation solutions in the energy sector at international level, for dissemination and exchange of information. The visualization allows the search by subsector: infrastructure, generation, transmission, end of life, demand; and by type of technology: hydroelectric, wind, biofuel, thermal, nuclear, solar technology, etc.

The Energy Adaptation map is the result of the collaboration of different entities, such as: Ouranos, a non-profit organization that develops and coordinates climate change projects and their impacts; the Climate Change Adaptation unit of the *Natural Resources* government division of Canada; and the map is integrated into the weADAPT platform, an open space for network exchange on issues of adaptation to climate change. Although their scope is global and solutions can be found from the different continents, the largest number of them are in Western Europe and North America.

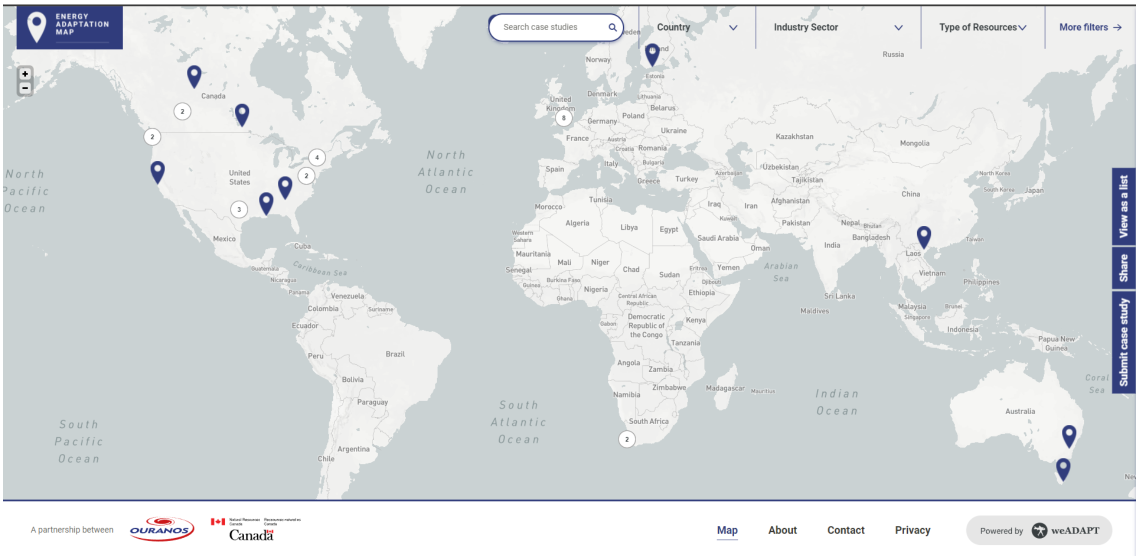

Figure 54. The Energy Adaptation Map[307].

The map currently contains more than 30 case studies covering different casuistries:

- Informative:
    - Supply and demand prediction, e.g., *Increasing network resilience with specialized weather forecasts.*
    - Climate Services, e.g., *Risk assessment of gas transmission and distribution infrastructure in the United Kingdom.*

[217] Energy Adaptation Map

- Management:
    - Regulatory exemptions and contracts, e.g., *Response to increased heat stress in summer for nuclear power plants.*
    - Financial Risk Management and Insurance, e.g., *Using Climate Change Risk Assessment Wisely, Risk Assessment Study in Ireland.*
    - Design and operation, standards, practical guides, tools and planning, e.g., *Construction of ice roads*[218] *under conditions of climate change.*
    - Fees and demand management, e.g., *Energy demand reduction with efficiency standards.*
    - Governance and reorganization, e.g., *Promoting resilience to extreme weather events in New York.*
- Physical:
    - New generation, porting and transformation capacity, e.g., *Use of generators to run pipes during power outages.*
    - Protection of equipment and infrastructure, improved and alternative materials, e.g., *Protection of infrastructure against storms in the context of climate change.*

Implementation potential

Advantages	Disadvantages
• Already in operation. • Global representativeness. • Different subsectors represented: commissioning/installation, generation, demand, transmission and distribution, end of life.	• Possibility of failure in follow-up/participation • Little detailed information on the case studies not documented in the report prepared by Ouranos[219]. • It is not clear the review of the quality and verification of the information available for the cases not included in the mentioned report.

Potential barriers to implementation

The web is already up and running. No barriers or limitations to its use are expected.

Current level of innovation (TRL = 9)

Expected or desirable advances in the coming years

Achieve greater recognition as a reference website for the consultation of successful application cases in the field of adaptation to climate change in the energy sector.

Expected results

The platform will increase the visibility of new and innovative climate adaptation actions in the energy sector.

Installation costs

Low. Being a collaborative online platform, its installation cost is mainly derived from the creation of the website.

Operating costs

Low. Those derived from the maintenance of the website, management and review of the entries and advertising/outreach.

[218] Infrastructures for land communication and transport with the particularity of being of ice and snow unlike conventional roads. They are accessible in the winter period and are built on large bodies of water, such as lakes, serving to connect inaccessible places by land.

[219] Adaptation Case Studies in the Energy Sector

Social acceptance

It is expected that social acceptance will be good.

Recipients

Actors involved in decision-making regarding the implementation of solutions that address adaptation to climate change in the energy sector.

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

All, depending on the specific case study.

Conceptual fit within climate change adaptation

Enables practitioners, researchers and policymakers to access information on how proactive actors in the energy sector respond to the challenges of present and future climate change and impacts.

Real cases or pilots where it has been applied

No other similar websites are known for the registration of climate change adaptation projects specific to the energy sector and with its specialized search engine.

Main stakeholders (organizations, companies, institutions, etc.)

- Ouranos
- WeAdapt
- Natural Resources Canada

4.3.8.4 Earth-air heat exchanger

(Author: Carmen M. Torres Costa)

Areas or sectors where it applies:

- Energy
- Urban planning and building

Type of solution: Technological solution

Solution / Technology

Geothermal air conditioning method of summer ventilation and winter heating widely used in passive houses[220]. Based on the Provençal or Canadian Well principle[221], it is an exchanger installed underground that can capture heat from and / and dissipate heat to the ground.

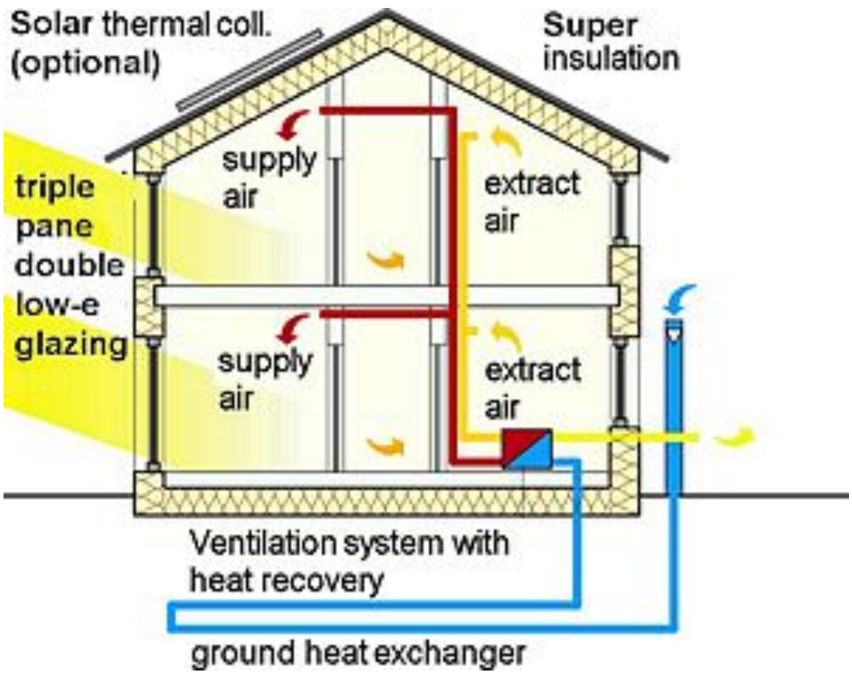

Figure 55. Ventilation system with heat recovery using earth-air heat exchanger. (Source: Passivhaus Institut.)

Basic description

The earth-air heat exchanger serves to provide fresh air in a building after being circulated through an underground pipe that, according to weather conditions, can cool or heat taking advantage of the thermal inertia of the Earth. As seen in the figure, the air itself serves as a thermal conductor while the pipe serves as a heat exchanger while transporting air to the building.

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[220] These types of houses are built following the criteria established in the PassivHaus standard (passive house in German), which through design strategies seeks to reduce energy demand as much as possible. Basic principles include efficient thermal insulation, rigorous infiltration control, and maximum indoor air quality, as well as harnessing the sun's energy for better air conditioning.

[221] The operation of the Provencal or Canadian Well is based on the physical principle that governs the variation of temperature of the ground with depth. At an approximate depth of 2 meters the temperature remains stable, that is, it is not affected by the weather conditions of the surface, so that the temperature of the ground corresponds to the average temperature of the place, it is what is known as thermal inertia of the terrain.

Mainly used as a natural air conditioning system, it can be used in winter to preheat the incoming air or to cool air in summer. Therefore, its use is interesting in locations with severe climatic conditions (arid regions)[222].

Implementation potential

Advantages	Disadvantages
• Easy installation and design. • Potential adaptation to different soil types. • The working fluid is air and does not require supporting energy in the case of sufficient wind speeds. • Requires little maintenance with low operating costs. • Energy saving, adaptation/mitigation combination.	• High installation cost. • Condensation inside the tube and the proliferation of microorganisms must be controlled. • The air outlet temperature is not uniform. • Thermal performance depends a lot on the local conditions present in the upper parts of the unburied pipe.

Potential barriers to implementation

An important aspect to consider in its implementation is the passive nature of its operation and that, therefore, the specific conditions of the location where it is intended to be installed must be considered for its operation to be effective. Its installation can be very profitable from the point of view of maintenance and operation costs, but this depends on the location, altitude, temperature of the earth, temperature-humidity ratio, solar radiation, type of soil, water table, and of course the efficiency of the insulation of the building, etc.

Thus, it would not be recommended in places with shallow bedrock and elevated water table, or humid heat weather conditions. However, its use in wet soils is more efficient than in dry soils. Regarding the ventilation air quality, the use of this equipment is related to the reduction of the concentration of pollutants[223]. However, it should be noted that in humid environments the appearance of mould colonies can pose health risks, so humidity must be controlled with passive drains (in the presence of sufficiently deep-water tables and permeable soils) or by the support of dehumidifier or desiccant systems.

Current level of innovation (TRL = 9)

Based on an old technique, new designs have been generated for greater efficiency, considering the specific yields and the use of locally available materials.

Expected or desirable advances in the coming years

In recent years, design studies have moved towards their efficient implementation in larger buildings, in the ventilation of agricultural production greenhouses and in the development of *water to earth heat exchangers*[224] as a technological alternative. In addition, mathematical models and simulators of the different types of configurations are developed to optimize their use according to location, soil, climatic conditions and architectural design.[225].

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[222] Sakhri, N., Menni, Y., Chamkha, A.J., Salmi, M., Ameur, H. (2020). Earth to air heat exchanger and its applications in arid regions - an updated review. TECNICA ITALIANA-Italian Journal of Engineering Science, Vol. 64, No. 1, pp. 83-90.

[223] Use of earth air tunnel HAVC system in minimizing indoor air pollution

[224] T'Joen, Christophe; Liu, Liping; and Paepe, M. De, "Comparison of Earth-Air and Earth-Water Ground Tube Heat Exchangers for Residentialal Application" (2012). International Refrigeration and Air Conditioning Conference. Paper 1209

[225] S.F. Ahmed, G. Liu, M. Mofijur, A.K. Azad, M.A. Hazrat, Yu-Ming Chu, Physical and hybrid modelling techniques for earth-air heat exchangers in reducing building energy consumption: Performance, applications, progress, and challenges, Solar Energy, Volume 216, 2021.

Expected results

In the context of climate change, the efficient design of refrigeration pipes offers a sustainable alternative to reduce or eliminate the need for conventional compressor-based air conditioning systems, for locations in non-tropical climates. In addition, the benefit of obtaining a controlled, filtered and tempered air intake is added, which is especially interesting in the case of buildings with proper insulation.

The economic performance of the ground earth-air exchangers is positive for refrigeration applications. In temperate climates, if the system is correctly designed, it avoids a conventional air conditioning system with great savings, although for this an efficient insulation is essential. Although in temperate climates the economic performance is justified as a cooling system, a small help is also obtained in the heating system in winter.

Installation costs

In general, they are described as elevated mainly due to the excavation phase. In addition, it must be highlighted that it depends on the configuration and materials used depending on the characteristics of the building to be conditioned. For a one-story building and an area of 100 square meters, the initial costs including materials, control devices, filters, fan, excavation, installation, and technical design would be around € 7,000-13,000[226].

Operating costs

They are described as low, and mainly due to maintenance in cases where an energy supply is not necessary for forced ventilation. The maintenance cost for different pipe lengths is estimated at approximately 120 €/year and about 100 €/year for the energy consumption of a fan if necessary. It is assumed that the system produces annual energy savings between 64%[227] and 12%[228].

Social acceptance

It is a technological solution for geothermal air conditioning of special interest in arid or semi-arid regions (hence it can be as an intermediate-range solution). As it is an improvement of an available technique, it has a rapid potential application and without problems of social acceptance.

Recipients

- Construction companies
- Architects
- Urban designers
- End-users

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Temperature variability
- Cold/frost waves
- Heat waves

[226] Mostafaeipour A, Goudarzi H, Khanmohammadi M, et al. Techno- economic analysis and energy performance of a geothermal earth- to- air heat exchanger (EAHE) system in residential buildings: A case study. Energy Sci Eng. 2021;9:1807– 1825.

[227] Pakari, A.; Ghani, S. Energy Savings Resulting from Using a Near-Surface Earth-to-Air Heat Exchanger for Precooling in Hot Desert Climates. Energies 2021, 14, 8044.

[228] Huang, Su, Energy performance evaluation and optimisation of ground source heat pump systems, Doctor of Philosophy thesis, Sustainable Buildings Research Centre, University of Wollongong, 2015

Conceptual fit within climate change adaptation

It is a technique in line with the reduction of climatic stress of special interest in regions of climatology with high contrast of temperatures such as arid or semi-arid regions.

Real or pilot cases where it has been applied

Housing, public buildings, commercial/industrial buildings, agricultural production buildings, greenhouses.

Location	Responsible	Year	Description
Madrid, Spain	Metro de Madrid / Geoter	2011-2021	Tertiary use building: Main office headquarters of Metro de Madrid in Plaza de Castilla; and residential use building 56 homes, San Sebastián de los Reyes. In both the air conditioning includes 56 perforations of 150 meters deep
Extremadura, Spain	Polytechnic University of Madrid / University of the Basque Country	2011	Evaluation of passive heating and cooling capacity and its influence on the reduction of energy demand in an office building and validation of the mathematical simulation methods used.

Main stakeholders (organizations, companies, institutions, etc.)

- Construction companies
- Companies specialized in geothermal and aerothermal solutions

4.3.9 Transport and mobility

4.3.9.1 Resilience of transport infrastructures to extreme events (Project RESIST)

(Authors: Queralt Plana Puig and Carmen M. Torres Costa)

Areas or sectors where it applies:

- Transport and mobility
- Urban planning and building
- Industry and services

Typology of the solution: Specific technology

Solution / Technology

Within the framework of the European H2020 RESIST project, a prototype unmanned aerial vehicle (UAV, *Unmanned Aerial Vehicle*) has been developed for visual contact inspection of critical transport structures such as bridges or tunnels.

Basic description

One of the effects of climate change is the increased frequency and intensity of extreme weather events that can cause damage to infrastructure and hinder traffic, which negatively affects mobility. The European project H2020 RESIST (RESilient transport InfaSTructure) aims to increase the resilience of transport operations to avoid disruptions during natural events. It aims to protect users of European transport infrastructures, as well as to provide optimal information to operators and users of transport infrastructures.

In the context of this project, transport infrastructure monitoring systems, a backend platform for the inspection process, and a system for integrating all information under an architecture also defined in the context of the project have been developed.

In the context of systems for monitoring the state of transport infrastructures, a prototype of an aerial robotic system was developed. This aerial system consists of two robots: a contact inspection robot and a visual inspection robot[229].

- The contact inspection robot is responsible for all measurements that require physical contact of the sensor with the surface of a bridge or tunnel (see Figure 56). This robot includes ultrasonic sensors and a radiometric sensor.
- The second robot integrates a laser tracking station and an Unmanned Aerial Vehicle (UAV). The UAV creates a ceiling effect that allows a contact inspection with the infrastructure to be evaluated.

The laser tracking station on the ground accurately measures the position of a reflector prism mounted on the UAV to estimate the deflection of the bridge or tunnel. In addition, it is responsible for installing the permanent vibration sensor modules on the surface of bridges and tunnels.

[229] Sanchez-Cuevas PJ, Ramon-Soria P, Arrue B, Ollero A, Heredia G. Robotic System for Inspection by Contact of Bridge Beams Using UAVs. Sensors. 2019; 19(2):305.

Figure 56. Prototype of an unmanned aerial vehicle for contact measurement. The visual inspection robot aims to autonomously take pictures of bridges and tunnels with sensors developed to find and classify visual defects. Source: Jimenez-Cano et al, 2019[229].

Implementation potential

Advantages	***Disadvantages***
• Resilience to damage due to weather conditions. • Optimization of preventive maintenance tasks. • Adaptation to the effects caused by climate change. • Improved traffic flow in the face of infrastructure disruption.	• The UAV requires a complex control system dedicated to the contact phase. • System with a TRL of 7. Little tested in real environments. • Low efficiency of the aerial system to carry out inspections of the bridge beams autonomously.

Potential barriers to implementation

It has a high applicability, but it is still necessary to validate the system and evaluate the operating limits by comparing the results of the inspection of the robotic system with results obtained from a classic experimental campaign.

Actual level of innovation (TRL = 7)

Currently, this prototype surpasses the mainly manual, less efficient, and more expensive existing inspection methods. In addition, a small and lightweight multirotor design is proposed that is able to fly near the bridge to points of difficult access and adhere to it thanks to the aerodynamic "roof" effect. This is an improvement over other articulated aerial robot designs whose payload requirements are high, resulting in large, heavy platforms that are slower and more complex to control.

Expected or desirable advances in the coming years

In the continuation of the RESIST project, the advances of the UAV prototype will focus on the end user of the technology and the application of inspections[230]. The goal of these advances is to improve the applicability of this technology, increase TRL, and make the technology a competitive business option.

[230] Antonio E. Jimenez-Cano, Pedro Sanchez-Cuevas, Pedro Grau, Anibal Ollero and Guillermo Heredia. Contact-Based Bridge Inspection Multirotors: Design, Modeling, and Control Considering the Ceiling Effect, IEEE Robotics and Automation Letters, October 2019, Vol. 4, No. 4, pp. 3561-3568.

Expected results

With the system presented in the context of the RESIST project, positive results are expected for the evaluation of transport infrastructures. Specifically, the expected results of the prototype are:

- Based on the anticipation of the state of the infrastructures, substantial improvement of the continuity of the mobility of people and goods, even in the case of serious interruptions due to natural or man-made circumstances.
- Resistance to damage due to extreme weather conditions, including reduced maintenance and modernization needs.
- Contribution to achieving reliable modal exchanges that allow a continuous and fluid flow of traffic even during or after an interruption.
- High level of resilience of transport infrastructure for sustainable development and impact and adaptation to the conditions of climate change.

Investment costs

After the initial investment for the acquisition of the equipment, no installation cost is required since it is a manageable and mobile robotic system. Nor has any overall value of the cost of developing the prototype been found, only the overall financing of the project is known. In this case, it is almost 5 M€ for 36 months (September 2018 – August 2021). That, apart from the design, development, and construction of the aerial robotic system, it includes the development of other tools (such as a cognitive computer vision system, ultrasonic sensors, a photogrammetric computer vision system, ...), the installation of the proposed solutions in two case studies with real infrastructures affected by severe conditions, risk analysis of the system, the dissemination of the work done, etc.

Operating costs

The operating costs of the aerial robotic system are unknown. The impact of the use of this technology compared to conventional inspection systems of critical transport infrastructures such as tunnels and bridges is also unknown. That is, the ratio between the operating costs of the two systems (proposed vs conventional).

Social acceptance

It is to be expected that social acceptance will be high since the technology is already designed, developed and tested. In addition, the implementation benefits both the expert personnel who carry out inspections of transport infrastructures and the users of them.

Recipients

- Service companies that perform inspections of critical transport infrastructures.
- Companies dedicated to the maintenance of transport infrastructures.
- Companies that own transport infrastructures.
- Government institutions.
- Users of transport infrastructures.

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Landslide
- Floods
- Avalanches

Conceptual fit within climate change adaptation

Extreme weather conditions because of climate change impacts cause a deterioration of critical transport infrastructures such as tunnels or bridges. Regular and highly automated inspections allow detailed monitoring of the state of these infrastructures, as well as reducing deterioration and / or accidents due to weather effects, offering a more continuous and fluid service.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
Puente de la Cartuja, Seville, Spain	Robotics, Vision and Control Group, University of Seville	2018	Experimental validation of the aerial robotic system
Puente Grazalema, Cadiz, Spain	Robotics, Vision and Control Group, University of Seville	2018	Experimental validation of the aerial robotic system
Pilot project 1, T9 bridge of the Egnatia motorway, Greece	ICCS, Greece	2018	To validate the RESIST technology, simulations were used to assess the impact of various extreme events such as strong winds, floods, earthquakes, explosions, etc.
Pilot project 2a, Millaures viaduct on the A32 motorway, Italy	ICCS, Greece	2018	To validate the RESIST technology, simulations were used to assess the impact of the various extreme events as in pilot project 1, and to evaluate the individual solutions proposed in each scenario.
Pilot project 2b, Santa Petronilla tunnel of the A32 motorway, Italy	ICCS, Greece	2018	To validate the RESIST technology, a real-time evaluation and demonstration of the proposed system was carried out, in an environment where GPS is not available.

Main stakeholders (organizations, companies, etc.)

The main collaborators of the RESIST project are:

- ICCS (Greece)
- Egnatia Motorway (Greece)
- Tecnositaf (Italy)
- FEHRL (Belgium)
- European Dynamics (Luxembourg)
- CATEC (Spain)
- US (Spain)
- CNR (Italia)
- ICS-FORTH (Greece)
- Goethe University Frankfurt (Germany)
- TU Graz (Austria)
- BGU (Israel)
- RiSA (Germany)
- D.Bairaktaris & Associates (Greece)
- ERRA (Greece)
- Sphynx Technology Solutions (Switzerland)
- LSystems (Belgium)

And as third-party collaborators areNETIVEI ISRAEL (Israel) y Realaiz (Serbia).

4.3.9.2 Development of a decision support system to increase the resilience of road transport infrastructures (PANOPTIS Project)

(Authors: Queralt Plana Puig and Carmen M. Torres Costa)

Areas or sectors where it applies:

- Transport and mobility

Typology of the solution: Specific technology

Solution / Technology

Tool that combines multisensory technology with climate models to increase resilience and management of roads or other transport infrastructures.

Basic description

The European project H2020 PANOPTIS it wants to increase resilience, that is, the ability of roads and other transport infrastructures to adapt to unfavourable weather conditions caused by climate change, such as extreme weather events, floods, avalanches, slope detachments or earthquakes. Figure **57** presents an example of a road condition monitoring system in the context of the project containing a smart label system, micro-climate measurement stations for the region, and road infrastructure monitoring components.

In the context of this project, a decision support system (DSS) has been developed that integrates a broad set of functionalities to help infrastructure managers make operational and strategic decisions. Decisions regarding how to assume the damages derived from an extreme phenomenon and the subsequent recovery[231]. In this context, regionalized climate change scenarios are combined with simulation tools and real data, to improve infrastructure management in the planning, maintenance and operation phases.

Specifically, the PANOPTIS DSS tool integrates the following technologies:

- Climate, atmospheric and multi-risk models for the quantification of the different types of climatic, hydrological and atmospheric stresses in transport infrastructures (especially focused on roads).
- Network of micro weather stations and point sensors "smart tags" for continuous monitoring of the change in weather conditions and other parameters such as temperature, air and soil humidity, vibrations, etc.
- High-resolution and long-, medium- and very short-term weather forecasting models and tools (fore and now casting) for the accurate assessment of the impact of weather events on transport infrastructures. Geotechnical and structural simulation tool.
- Geotechnical and Structural Simulation Tool (SGSA) for the assessment of the vulnerability of specific geotechnical and structural elements in the road network.
- Multi-Hazard Vulnerability Modules (MHVM) modules, combining the effects of infrastructure ageing with those of exposure to various natural or human-induced hazards.
- Damage maps. Use of maps of damage generated after a catastrophe (floods, fires, ...) through the Copernicus EMS emergency service and based on high-resolution satellite images. These maps allow a general, fast and synoptic analysis of a wide geographical area, and to identify extensive damage.
- Combination of multi-sensor data with multispectral analysis, computer vision techniques and machine learning for damage diagnosis in multiple infrastructures.

[231] Proyecto PANOPTIS

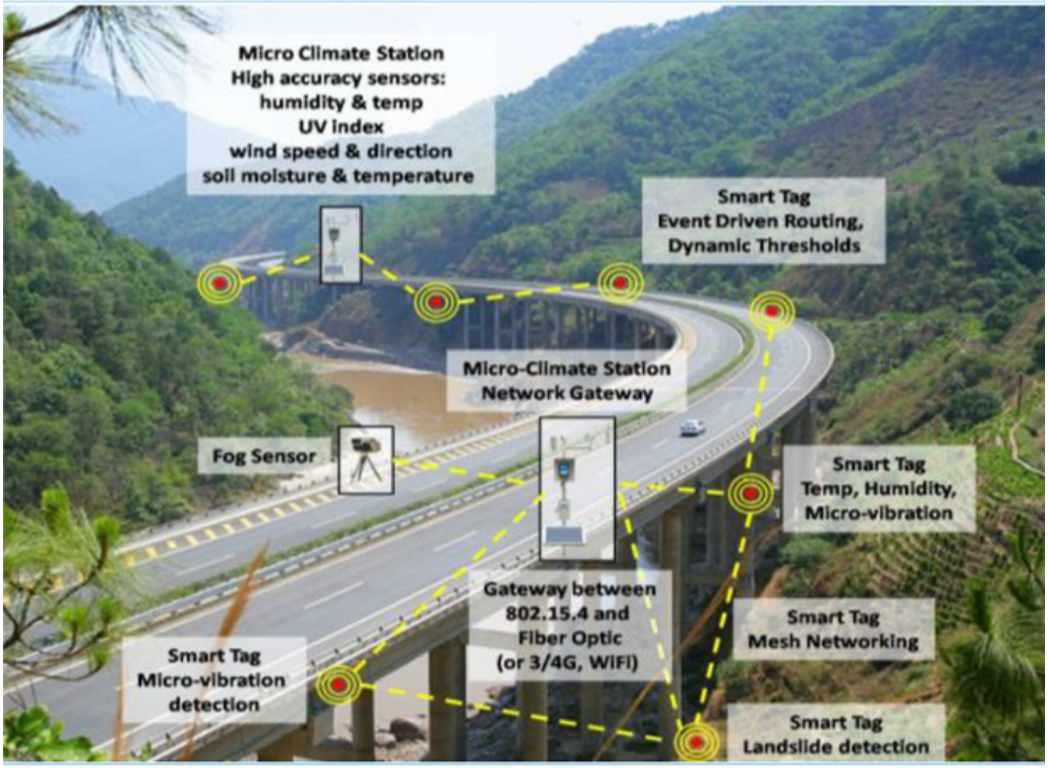


Figure 57. Example of a network of efficient labels, micro-climate stations and connected road infrastructure components (Source: Project PANOPSIS)

- Mobile mapping techniques using drones for the detection and evaluation of defects and damage in both routine road maintenance operations and crisis management.
- Holistic Resilience Assessment Platform (HRAP). This platform makes it possible to assess the global resilience of all road infrastructures in real time.
- Integration of all tools into a platform containing a Common Operational Picture (COP), an Incident Management System (IMS) and a decision-making tool (DSS).

Implementation potential

Advantages
• Reduce the need to carry out urgent maintenance tasks. • Resilience to damage due to extreme weather conditions. • Optimization of infrastructure management. • Adaptation to the consequences of climate change.

Potential barriers to implementation

The solution presented allows a high applicability in different situations and transport infrastructures. The PANOPTIS DSS tool does not have direct negative consequences on transport infrastructures as it is a digital platform to help decision-making. But decisions made based on the platform can negatively affect infrastructures.

Actual level of innovation (TRL = 7)

PANOPTIS started in June 2018. During the first two years, the platform was designed and all the technologies that integrate the PANOPTIS tool were prepared. During the second phase of the project, starting in the summer of 2020, ACCIONA Ingeniería began to implement all the technologies and methodologies developed in section 2 of the A-2 motorway, of 77.5 km, as it passes through the province of Guadalajara.

Expected or desirable advances in the coming years

At present, all the tools used in the project are ready for use. The next step is expected to be to integrate the tools into a common platform with a graphical interface, to make them easier for infrastructure managers to use.

Expected results

With the PANOPTIS project system, positive results are expected to improve the resilience of transmission infrastructures and ensure the availability of the transmission network reliably in the face of unfavourable conditions.

The expected results of its use are:

- Substantial improvement of the mobility of people and goods, even in the event of serious disturbances due to natural or anthropogenic circumstances.
- Increases the resilience of infrastructure components to damage caused by extreme weather conditions, including reduced maintenance and refurbishment needs.
- Provides resilience to transportation infrastructure.

Installation costs

The costs of installing the sensors to obtain *on-site* data from the monitored infrastructures are unknown, only the global financing of the project is known. In this case, it is approximately €5 M for 40 months (June 2018 – November 2021). This budget was dedicated to the design of the integration platform, atmospheric modelling, data collection and processing, vulnerability assessment and resilience assessment of the infrastructures studied, geospatial services, integration of tools and development of the graphical interface for users of the tool.

Operating costs

The costs of using the platform, with the integration of the tools presented, are unknown, but it is expected to obtain significant savings by optimizing maintenance actions and extending the life cycle of the infrastructures.

Social acceptance

It is expected that social acceptance will be high since the implementation benefits both the expert personnel responsible for the management of transport infrastructures, as well as the users of them.

Recipients

- Service companies that perform inspections of critical transport infrastructures.
- Agents or companies dedicated to the development and maintenance of roads, bridges and tunnels.
- Companies that own transport infrastructures.
- Government institutions.
- Users of transport infrastructures.
- General Directorate of Roads.
- Investment funds.

Impact on adaptation to climate change

Risks arising from climate change to which it can help us adapt

- Landslide
- Floods
- Heavy rainfall

Conceptual fit within climate change adaptation

Extreme weather conditions caused by the effects of climate change can lead to a deterioration of transport infrastructure. The PANOPTIS Project seeks to increase the resilience of roads in the face of unfavourable weather conditions, such as extreme weather events or floods, which may, among other things, destabilize the slopes.

Real or pilot cases where it has been applied

Location	Responsible	Year	Description
A2 motorway (connects Barcelona and Madrid), Spain	ACCIONA	2020	Implementation of technologies and methods integrated in PANOPTIS
Motorway to Thessaloniki Airport, Greece	Egnatia Odos	2020	Implementation of technologies and methods integrated in PANOPTIS

Main stakeholders (organizations, companies, etc.)

The main collaborators of the PANOPTIS project are:

- AIRBUS (France)
- NTUA (Greece)
- Acciona (Spain)
- Egnatia Motorway (Greece)
- Future Intelligence LTD (United Kingdom)
- Universidad de Twente (Netherlands)
- Hyds (Spain)
- IFSTTAR (France)
- FMI (Finland)
- AUTH (Greece)
- SOFiSTiK (Greece)
- CORTE (Belgium)
- C4Controls (United Kindom)

4.3.10 Financial system and insurance activity

4.3.10.1 Integrated valuation of environmental services and calculation of compensations (InVEST)

(Authors: Laura del Val Alonso y Xavier Martínez Lladó)

Areas or sectors where it applies:

- Finance and insurance
- Urban planning and building

Type of solution: IT Solution

Solution / Technology

Software for estimating the economic value of environmental functions and services, consisting of giving an economic value to natural capital, that is, to the biotic and abiotic elements that contribute to providing such environmental services.

Basic description

The Millennium Ecosystem Assessment (2005) defines environmental services or ecosystem services as "the benefits that people derive from ecosystems" and can be classified into four categories[232]:

- Support services. They are those that provide the basic infrastructure for the sustenance of life (capture of energy from the sun, the formation of soils and the cycle of water and nutrients)
- Regulatory services. They are those who manage climate, pollution and natural hazards such as diseases.
- Provisioning services. They are those who provide the products on which life depends (food, water, energy and materials).
- Cultural services. They refer to the provision of landscapes or elements that a meaning for humanity (religious, spiritual or simply attractive or aesthetic)

The valuation of environmental services is essential to design urban infrastructure projects, design legislative tools, calculate compensations and prioritize actions. It can also be used to study the trends and interactions of complex systems, allowing for example to study the effects of climate change and possible adaptation measures helping to prioritize investments. And finally, they are a communication and learning tool, which helps us to put in context and compare very different sectors under the same prism.

One of the newest software to map the benefits of nature in cities is InVEST[233].

[232] European Academies Science Advisory Council (EASAC). (2009). Ecosystem Services and Biodiversity in Europe. In Jahrbuch für Wissenschaft und Ethik (Vol. 14, Issue 1).

[233] Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C.K., Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M. Mandle, L., Hamel, P., Vogl, A.L., Rogers, L., Bierbower, W., Denu, D., and Douglass, J. 2018. InVEST 3.7.0.post22+ug.h3b687e57fad0 User's Guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.

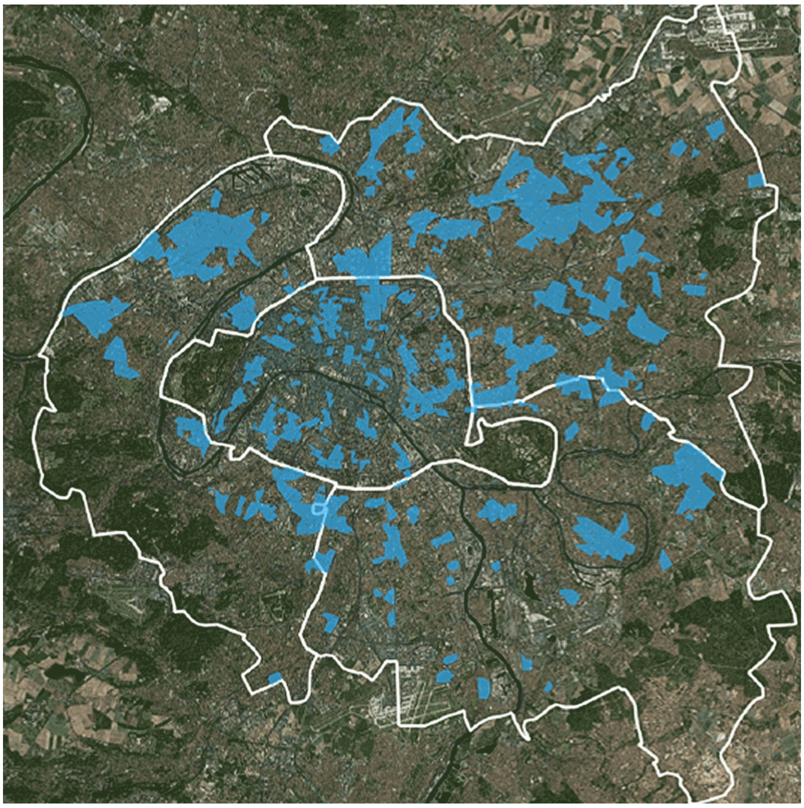


Figure 58. Paris map of areas with low green area and low income level, in which InVEST software identifies that increasing green space coverage will have a positive impact by reducing inequality (Source: Standford.

Implementation potential

Advantages	Disadvantages
• Free license software. • InVEST considers a wide range of environmental services • InVEST has a team in charge of maintaining the software and an associated user community	• May require specific knowledge to run the models • Need an interdisciplinary team of experts • Distrust and lack of knowledge about nature-based solutions

Potential barriers to implementation

These types of tools are focused on facilitating the implementation of nature-based solutions, since they allow quantifying benefits on society at different levels. However, these types of solutions are still perceived by certain sectors as unreliable, insufficient, or not very tangible. This perception can be a barrier to the implementation of this type of analysis. On the other hand, the application of this tool requires information and data from multiple sectors, which implies the availability of a multidisciplinary team capable of collecting and integrating the information to be able to use the model properly.

Level of innovation today (TRL = 9)

There are much software for the evaluation and quantification of environmental services such as *i-Tree, ARIES*, *Costing Nature, and SolVES*. However, in contrast to these tools, InVEST can integrate a large number of urban environmental services at the same time, has already been successfully tested in different cities around the world and has reported on a myriad of different urban contexts (e.g., planning for flood prevention, climate adaptation, biodiversity conservation and public health)[234].

On the other hand, although at the research level there are several tools and cases in which this type of analysis has been applied, it is not an extended practice at the level of planning and decision making, so its use remains innovative.

Expected or desirable advances in the coming years

The use of these tools is expected to become popular at all levels of planning and decision-making. Especially in climate change adaptation projects, where the interaction between multiple sectors and solutions is complex to foresee.

Expected results

The main result of this type of analysis is greater efficiency in the allocation of investments since it avoids allocating investments to useless or inappropriate actions for the problem that is intended to be tackled. On the other hand, it allows us to compare more subtle actions based on nature (difficult to quantify), with traditional infrastructure projects, which are usually perceived as more tangible and easier to quantify and, therefore, to promote or defend.

Installation costs

It is a free license software, so they do not have any installation cost. Therefore, the costs associated with its use are the hours of qualified personnel, in charge of collecting all the information and processing it, in order to run the models and interpret and present the results properly. Especially expensive can be the collection of all the necessary information.

Operating costs

The software has behind it a team dedicated to the maintenance of the software, as well as a community of users that confers a potential for growth and long-term robustness. This means that maintenance costs are reduced, thanks to the support given by the initiative.

Social acceptance

It is expected that this type of tools will have a high acceptance. Few sectors are against the use of an economic quantification approach to environmental services. In principle, it is recommended to use this tool as guidance and always evaluate the results beyond the economic implications to avoid confrontation in projects or sensitive situations for society.

Recipients

- Government agencies responsible for urban infrastructure development at all scales: state, regional and local.
- Organizations in charge of the administration of territories with multiple uses
- Nature conservation organization.
- Construction and infrastructure design companies that have an impact on the environment.
- Environmental consultants.
- Energy companies.

[234] Hamel, P., Guerry, A. D., Polasky, S., Han, B., Douglass, J. A., Hamann, M., Janke, B., Kuiper, J. J., Levrel, H., Liu, H., Lonsdorf, E., McDonald, R. I., Nootenboom, C., Ouyang, Z., Remme, R. P., Sharp, R. P., Tardieu, L., Viguié, V., Xu, D., … Daily, G. C. (2021). Mapping the benefits of nature in cities with the InVEST software. Npj Urban Sustainability, 1(1).

Relevance for climate change adaptation

Risks arising from climate change to which this solution can help us adapt

- Temperature change
- Thermal stress
- Temperature variability
- Heat waves
- Cold/frost waves
- Forest fires
- Changes in wind patterns
- Cyclones, hurricanes and typhoons
- Storms, including blizzards, dust and sandstorms
- Tornadoes
- Changes in precipitation patterns and types (rain, hail, snow)
- Rainfall and/or hydrological variability
- Saline intrusion
- Sea level rise
- Water stress
- Droughts
- Heavy rainfall
- Floods
- Increase in vector-borne diseases

Conceptual fit within climate change adaptation

Climate change affects multiple aspects of our lives and the environment where we live. Analysing in an integrated way all these aspects and their interactions is essential to be able to take appropriate and measured adaptation measures to the problems of each site.

Real and pilot cases where it has been applied

Location	Responsible	Year	Description
Shenzhen, China	Natural Capital Project Partners	2021	To inform urban planning, the Shenzhen city government has adopted the use of the Gross Ecosystem Product (GSP), which calculates the monetary value of ecosystems' contribution to society to report on investments in ecosystems and track policy performance. Using InVEST , they calculated that Shenzhen's natural infrastructure avoids $25 billion due to the impact of extreme weather runoff. Sediment retention resulted in an avoided cost of USD 8.5 M for 2018. The natural infrastructures reduced the daily air temperature by an average of 3 °C in the built-up areas during the summer days, which translates into benefits of 71,000 USD/day for the whole city.
Twin Cities, USA	Natural Capital Project Partners	2021	In twin cities, USA, the possible effect of a change in land use, from golf courses to urban, has been studied. InVEST software has estimated that land use change will reduce environmental services, while maintaining these spaces as parks would increase them.
Paris, France.	Natural Capital Project Partners	2021	The Ile-de-France region encompasses Paris and its metropolitan area, including large tracts of agricultural land. Given the population increase around Paris, urban land has increased from 18% in 1982 to 23% in 2018. The use of InVEST software has revealed a reduction in environmental services in the area of 8% associated with this increase in urban area.

Main stakeholders (organizations, companies, institutions, etc.)

- Stanford University
- Chinese Academy of Sciences
- Stockholm Resilience Centre
- The Nature Conservancy
- University of Minnesota
- WWF
- Urban planning and infrastructure development agencies at all scales (town halls, councils, and ministries).
- Non-governmental organizations
- Investment banks
- Companies that want to invest in adaptation strategies or evaluate the environmental cost of their investments.
- Environmental bodies that can use this analysis to assess the suitability of certain measures and their alternatives.

4.3.10.2 Major Natural Hazard Prevention Fund

(Authors: Laura del Val Alonso and Xavier Martínez Lladó)

Areas or sectors where it applies:

- Finance and insurance
- Urban planning and building
- Agriculture, livestock and food

Typology of the solution: Governance / Management strategy

Solution / Technology

The Fund for the Prevention of Major Natural Hazards (FPRNM), known as the "Barnier fund", created by the French government by Law No. 95-101 on 2 February 1995 on strengthening environmental protection, was initially intended to finance compensation for the expropriation of properties exposed to a significant natural hazard. Currently, the FPRNM finances investment actions. For example, grants allocated in the framework of the development of an action programme for flood prevention.

Basic description

Insurance transfers the risk from an insured person, object or organization to an insurer. In the case of the effects of climate change such as extreme weather events, insurance is a fundamental tool since it prevents financial damages from becoming long-term economic damages[235]. However, insurance companies and institutions must be solvent in the face of increased risk due to climate change.

One of the measures to control or reduce this increase in risk is precisely the adaptation to climate change of the insured assets. Among the many ways available to the insurance sector to accelerate and facilitate the adaptation to climate change of its policyholders is the generation of funds that invest in adapting certain sectors or areas with greater risk[236].

One of the best-known examples is the Fund for the Prevention of Major Natural Hazards (FPRNM), known as the "Barnier fund", which has become the main tool in France for the financing of natural risk prevention policies.

The types of actions financed by the FPRNM are rehousing measures, temporary evacuation, and relocation in case of imminent risk (e.g., Risk of landslides), the implementation of measures to reduce vulnerability to certain natural hazards, and the design and implementation of regulations, such as the preparation of risk prevention plans at the national level or the generation of awareness campaigns. In this sense, it is a very useful tool to finance adaptation projects to the natural risks that are increasing because of climate change, in areas where the vulnerability of the population, infrastructure or productive capital is very high.

[235] European Union. (2018). Using insurance in adaptation to climate change.

[236] Hidalgo Pérez, A.I. (2020) Impactos, vulnerabilidad y adaptación al cambio climático en la actividad aseguradora. Oficina Española de Cambio Climático. Ministerio para la Transición Ecológica y el Reto Demográfico, Madrid.

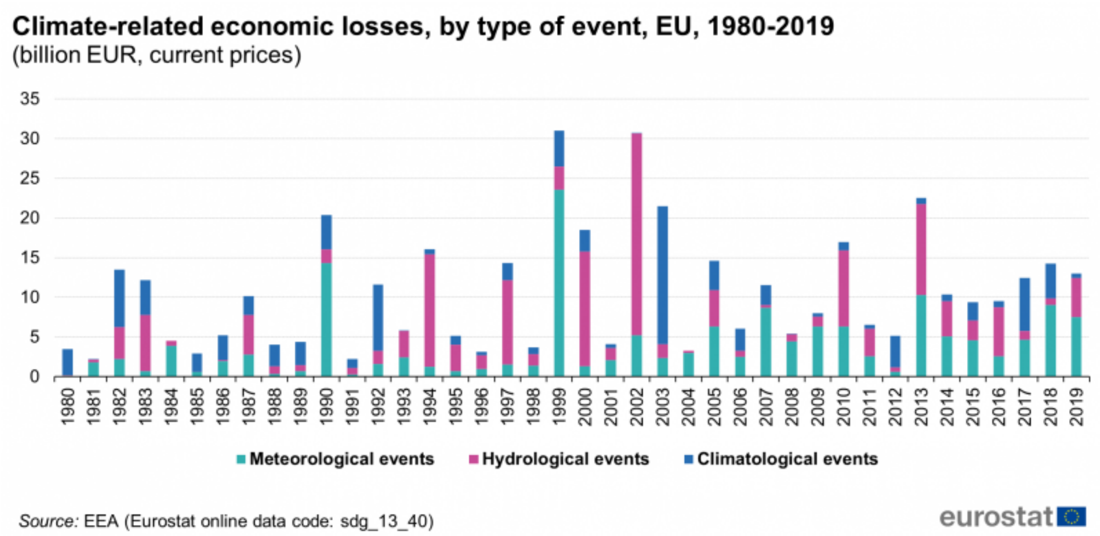


Figure 59. Evolution of losses due to climatic events in the European Union. Source: Eurostat.

Implementation potential

Advantages	Disadvantages
• It is a direct incentive to implement climate change adaptation measures. • Can facilitate prioritization of adaptation investments.	• The climate models used to estimate risk and premium increases have great uncertainty due to the non-linearity of climate behaviour.

Potential barriers to implementation

No opposition beyond that which could lead to a rise in insurance policy prices is to be expected.

Level of innovation today (TRL = 9)

The innovation would lie in its introduction within the framework of the financing of climate change adaptation strategies in Spain. In our country, incentives for insurance premiums are reduced, since, being a regulated sector, the risk is distributed among practically the entire population.

Expected or desirable advances in the coming years

This type of funds are not implemented in all countries, despite being a very versatile tool for adaptation to climate change. A widespread implementation of such financing tools would therefore be desirable. On the other hand, in the specific case of the FPRNM, improvements are expected in its governance, control of expenditure and connection with natural resource management entities such as confederations or bodies in charge of identifying risk[237].

Expected results

It is to be hoped that these funds will finance priority projects for the prevention of risks arising from the effects of climate change in areas where the risk is very high. In this way, specific programs are likely to be generated. This is the case of the Flood Prevention Action Programme (PAPI) in France.

[237] Federation, F. I. (2016). Toward better prevention of and protection against natural hazards.

Implementation costs

The FPRNM is financed by a contribution consisting of a percentage of the additional natural disaster premiums of insurance contracts. This percentage was 12% in 2009. This source of funding reached 194 million euros in 2014. Since its creation in 1995, insurance contracts have contributed a total of 1,500 million euros to finance this fund.

Operating costs

The operating costs in this case would be included in the figures provided in the "installation costs" section. Operating costs are related to personnel and costs of keeping the fund running.

Social acceptance

It is to be hoped that this type of funds will have good acceptance in society since they imply one more tool to co-finance adaptation measures, especially from the private sector. However, they could produce rejection if the percentage contributed to the fund implies an increase in the price of insurance premiums. However, if these risks are not included in the premiums, the risk is fully borne by citizens.

Recipients

- Administrations at regional or national level
- Insurance and reinsurance companies
- Agricultural and tourism sector

Relevance for climate change adaptation

Risks arising from climate change to which this solution can help us adapt

- Forest fires
- Extreme wind
- Cyclones, hurricanes and typhoons
- Changes in precipitation patterns and types (rain, hail, snow)
- Floods

Conceptual fit within climate change adaptation

These types of funds can help and incentivize the adaptation of infrastructures, properties and activities to a higher incidence of catastrophic events derived from the effects of climate change, which would reduce long-term losses to insurance and investors. These types of subsidies and incentives are mainly designed for specific and extreme risks such as floods, fires, and storms of all kinds, although their application could be extended to adaptation to risks with a more progressive impact.

Real or pilot cases where it has been applied

This is a very specific initiative so there are no comparable cases with this that can be used as additional examples.

Agents of interest (organizations, companies, organizations, etc.)

- Institutions at the national level
- Insurance companies
- Insurance Compensation Consortium

4.3.10.3 Assessment of financial stress from climate change

(Authors: Laura del Val Alonso and Xavier Martínez Lladó)

Areas or sectors where it applies:

- Finance and insurance

Typology of the solution: Governance / Management strategy

Solution / Technology

The assessment of financial stress derived from climate change involves estimating the possible losses caused jointly by physical and transition risks with the aim of assessing the resilience of corporations and banks in the medium and long term.

Basic description

Climate change is a source of risk that affects all sectors of the economy, including the financial sector. We can define two types of risk, physical risk and transition risk.[238]

- Physical risk is the impact on the economy that the increase in the frequency and magnitude of natural disasters derived from climate change, such as floods, landslides or fires, can have.
- The risk of transition is, however, the negative impact that the implementation of energy transition policies can have on certain sectors of the economy, for example, in sectors with a high dependence on polluting resources such as the extractive industry or the petrochemical industry.

In recent years, several central banks within the European Union have carried out risk analyses of their respective financial sectors. Given the complexity of the interactions between economic sectors, policies and climatic phenomena, the methodologies proposed by each initiative vary and have been improved in each study. We can say that the most recent study, and the most ambitious or methodologically complex, is the one carried out in 2021 by the European Central Bank. The study analyses the interactions between the energy transition and physical risk, covering both the direct and indirect impact on businesses and banks of the most serious and frequent natural disasters.

The methodology used by the ECB consists of defining specific climate change and macroeconomics scenarios, analysing climate and financial data, and using climate models to estimate risk transmission. The methodology makes it possible to compare the future costs and benefits of future climate policies. The results of the study highlight the economic benefits for all entities of implementing agile climate change adaptation and mitigation policies that ensure a progressive and orderly transition. The study reveals that the economic effects of climate change will materialize in certain regions and sectors. Therefore, for the most exposed companies, the effects of not taking measures to adapt to climate change can be important. In addition, the study reveals that the risks arising from adaptation are much lower than the long-term physical risks.

[238] European Central Bank. (2021). ECB's economy-wide climate stress test. In Occasional Paper Series (Issue 281).

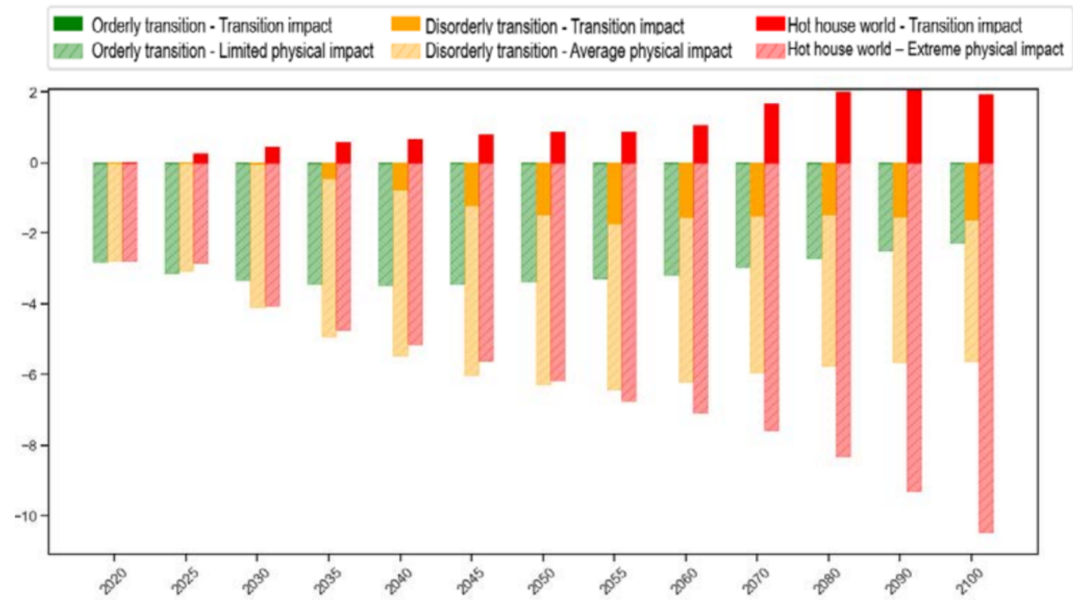


Figure 60. Impact on GDP over time in relation to the scenario of orderly transition without physical risk. Filled bars represent the impact on GDP of transition costs, while dashed bars represent the impact on GDP of physical risk damage. Filled and discontinuous bars are cumulative when the effects are negative. All GDP effects are calculated with respect to the ordered transition scenario without physical risk, which explains why the transition costs in this scenario are zero. (Source: European Central Bank. ECB's economy-wide climate stress test.)

Implementation potential

Advantages	Disadvantages
• It is an integrated methodology that considers not only the risks arising from climate change, but also the implications of a transition to low-carbon technologies. • It is an analysis that can have a great weight to move large investors and corporations in the direction of adaptation and mitigation to climate change, to the extent that certain carbon-intensive technologies may increasingly be less accepted by the consumer, less driven by the Administration, or both.	• A large amount of data is needed for the analysis to be complete.

Potential barriers to implementation

The main barriers may come from the complexity of the replicability of the study, derived from the amount of data needed and the complexity of the analysis itself. On the other hand, this methodology may need to be adapted for application to smaller sectors or scales, or also updated by virtue of the accumulated data of variation of the climate and the economic-financial environment.

Level of innovation today (TRL = 7)

The European Central Bank study enhances other existing studies as it is the only methodology that considers the interactions of physical and transition risks at the enterprise level over a long time horizon. In addition, it is the first analysis of this nature that considers such a high number of entities: 4 million corporations around the world and 1,600 banks at European level. These developments imply that it has not been replicated in any other circumstance or scale.

Expected or desirable advances in the coming years

In the case of the methodology used by the ECB, in addition to improving the quantity and quality of input data, in the future the methodology could improve in two aspects. First, by relaxing the static balance sheet hypothesis to take into account the feedback effects between banks and the real economy. On the other hand, the effects of transition and physical risks could be incorporated into the retail portfolios of banks, asset managers and insurance companies.

Expected results

It is expected that the results of this type of studies will position large corporations, banks and investment funds in favour of the implementation of climate change adaptation and mitigation policies. This would catalyse investment in climate change adaptation strategies, as well as the movement of capital flows from carbon-intensive to low-carbon technologies.

Implementation costs

It was not possible to consult the cost of the study carried out by the European Central Bank.

Operating costs

Normally, these are specific studies that do not entail maintenance costs.

Social acceptance

It is not expected that there will be no opposition to the conduct of this type of study.

Recipients

- Central banks at the state level
- Public bodies
- Financial institutions
- Financial risk rating agencies

Relevance for climate change adaptation

Risks arising from climate change to which it can help us adapt

These types of assessment methodologies consider all the physical and economic risks to which the banking and insurance sector may be subjected.

Conceptual fit within climate change adaptation

Climate change represents a source of systemic risk, which directly affects the banking and financial sector, especially those entities whose investments are concentrated in certain economic sectors or geographical areas vulnerable to the effects of climate change. Objectively analysing the cost of assuming the effects of climate change without palliatives in the face of different adaptation and transition scenarios is key for large corporations, investment funds and banks, since they will be able to adapt their investments in time so as not to suffer or minimize losses.

Real and pilot cases where it has been applied

Location	Responsible	Year	Description
Europe	European Central Bank (BCE)	2021	The BCW publishes in 2021 the results of the climate stress test on the economy. The report considers for the first time the interconnectivity of physical and transition risk, evaluating different scenarios of action against climate change 30 years from now. The objective is to analyse the resilience of 4 million corporations around the world and 1600 banks at European level.
Netherlands	Nederlandsche Bank (DNB)	2018	The DNB carried out one of the first studies to assess the risk resistance derived from an energy transition[239]. The study aimed to assess the five-year transition risk of Dutch banks, insurers and pension funds. The effect of different policies of transition, development and implementation of technologies and evolution of the confidence of the population was evaluated. The study concluded that the implementation of immediate measures to ensure a progressive and coordinated transition would avoid losses to the sector.
France	Banque de France (BdF) Autorité de Contrôle Prudentiel et de Résolution (ACPR)	2020	The Bank of France (BDF) together with the ACPR made a pilot analysis[240] assessing the 30-year effect of physical risks and energy transition risks on the different risks to which nine banks are subjected and, on the assets, and liabilities of 15 insurance institutions. The results of the study revealed that French banks and insurers are subject to moderate risk. Most of the assets and liabilities are in France, which is one of the countries in the Union least affected by climate change.
Spain	Spanish national bank	2022	Following the line marked by the ECB study, the Bank of Spain (BdE) could have published in 2022 the results of the stress test for the Spanish financial sector. At the moment, the BoE estimates that the effects on the sector are moderate.

Stakeholders (organizations, companies, institutions, etc.)

- Central banks at the state level
- Investment funds
- Pension funds
- Insurance and reinsurance companies
- Public bodies

[239] De Nederlandsche Bank N.V. (2018), "An energy transition risk stress test for the financial system of the Netherlands", Occasional studies, Vol. 16, Issue 7, Amsterdam

[240] Autorité de Contrôle Prudentiel et de Résolution and Banque de France (2021), A first assessment of financial risks stemming from climate change: The main results of the 2020 climate pilot exercise, Analyses et syntheses, No 122/2021, Paris, April

4.3.10.4 Promotion of aid for adaptation to flood risk (The case of Campo de Cartagena in Murcia)

(Authors: Laura del Val Alonso and Xavier Martínez Lladó)

Areas or sectors where it applies:

- Finance and insurance
- Urban planning and building
- Water

Typology of the solution: Governance / Management strategy

Solution / Technology

Public subsidies to anticipate and prevent the impacts of floods by adapting buildings exposed to flood risk and reducing their vulnerability.

Basic description

The insurance sector has identified in recent years an increase in the frequency and intensity of risky climate events associated with climate change[8]. Floods and atypical cyclonic storms are the events that most affect the insurance sector in our country. It is therefore crucial for the long-term resilience of the insurance sector that measures are taken to reduce vulnerability to flooding in those areas at greatest risk.

One way to promote the adoption of flood risk adaptation measures is to provide public funds to subsidize adaptation actions in areas where risk and vulnerability are high.

A pilot case in our country is the one approved in 2020 by the Ministry for the Ecological Transition and the Demographic Challenge for the Campo de Cartagena (Murcia)[241]. This decree approved the granting of public aid in 5 municipalities in the area. The criteria for selecting the beneficiary municipalities and the distribution of funds among them are the flood compensation made by the Insurance Compensation Consortium (CCS) in recent years. In this case, the CCS also contributes its accident and expert experience in the selection of eligible projects.

Some of the activities financed have been the purchase of equipment to avoid or mitigate the impact of a possible flood (e.g. barriers or pumps), the execution of works for the adaptation of buildings (e.g. waterproofing or sealing) and the relocation of vulnerable elements or equipment (e.g. electrical panels)[242].

[241] Real Decreto 1158/2020, de 22 de diciembre, which regulates the direct granting of subsidies for the development of pilot plans to promote the adaptation of the flood risk of existing buildings, equipment and facilities or farms in the municipalities of Los Alcázares, San Javier, Torre-Pacheco, Cartagena and San Pedro del Pinatar (Murcia).

[242] Consorcio de Compensación de Seguros, 2017. GUÍA PARA LA REDUCCIÓN DE LA VULNERABILIDAD DE LOS EDIFICIOS FRENTE A LAS INUNDACIONES.

Figure 61 Impact of floods in Los Alcázares. Adaptation actions contemplated in the pilot cases of the PIMA Adapta and that probably have served for the application of the subsidies of RD 1158/2020. (Source: MITECO , 2020. Guía de adaptación al riesgo de inundación. Caso piloto en Edificaciones. Caso piloto Ayuntamiento de los Alcázares -Murcia-)

Implementation potential

Advantages	Disadvantages
• Improves coordination between administrations. • Increases society's perception of flood risk. • Contributes to improving spatial planning.	• The destination of aid and its effectiveness must be adequately monitored.

Potential barriers to implementation

It is essential to properly study the needs at the national level, so that the actions are as effective as possible in terms of preventing impacts on people and things, and that the actions are as representative, allowing their scalability in the future. It is also necessary to carry out awareness-raising and communication campaigns on transparent measures to ensure the acceptance and involvement of all social partners.

A barrier that may arise is coordination between state administrations at different levels (state, regional and municipal) or of different political signs. It is for this reason that the intervention of apolitical institutions, such as the insurance consortium or the hydrographic confederations, is crucial for the success of this type of action.

Level of innovation today (TRL = 9)

This pilot case is the first in our country in which public funds are allocated, with this scope and perspective, for the reduction of flood risk on existing public and private infrastructures.

Expected or desirable advances in the coming years

Within the use of this type of financing tools, it is also intended to raise awareness among society and economic agents of the risk to which they are subjected to facilitate the participation of all actors in the implementation of measures. It is hoped that the experience and information gathered in this pilot will serve to better understand the effectiveness and limitations of this type of measure and thus improve its application in other territories.

Expected results

It is to be hoped that these small adaptation actions involving reduced investments will minimize the risk and reduce the cost of future flooding.

Installation costs

The costs of implementing these types of actions can vary greatly depending on the magnitude of the risk and the typology of the area. In the pilot case of the Campo de Cartagena, a public aid lot of about € 3 million was approved for adaptation of 5 municipalities Los Alcázares, San Javier, Torre-Pacheco, Cartagena and San Pedro del Pinatar. This is an area with a high risk of suffering the effects of DANAs (Isolated Depressions at high levels) and where 90,000 people live in a flood zone. These measures should minimize the economic impact of these events, that between 2005 and 2019 were estimated in about 180 million €[243].

Operating costs

Could not find information.

Social acceptance

It is expected that this type of investment will have a high acceptance, since in the areas affected by recurrent floods the population is very sensitive to the effects. However, it is necessary to adequately communicate the objective of the aid and the usefulness of the various measures to ensure the acceptance and cooperation of all actors.

Recipients

- City councils
- Regional governments
- Entrepreneurs and citizens

Relevance for the climate change adaptation

Risks arising from climate change to which it can help us adapt

- Floods
- Landslides

Conceptual fit within climate change adaptation

The insurance sector is detecting an increase in the frequency and intensity of phenomena derived from climate change. This increase, although still bearable by insurers, is expected to increase in the coming decades, so it is necessary to take adaptation measures. The climate risk with the greatest effect on the insurance sector in Spain is flooding. Therefore, taking measures to progressively reduce the vulnerability of buildings and infrastructures where the risk is greatest, is essential to ensure the solvency of the insurance sector.

Real and pilot cases where it has been applied

Location	Responsible	Year	Description
Campo de Cartagena, Spain	Ministerio de Transición Ecológica y el Reto Demográfico	2021	Due to the high impact derived from the isolated depression at high levels that occurred in September 2019 in the Campo de Cartagena area, the Ministry for the Ecological Transition and Demographic Challenge granted a total of 3 million euros for the development of pilot plans to promote the adaptation of the flood risk of buildings, equipment and facilities or existing operations in the municipalities of Los Alcázares, San Javier, Torre-Pacheco, Cartagena and San Pedro del Pinatar (Murcia).

[243] Consorcio de Seguros, 2021. El camino a la adaptación frente al riesgo de inundación: La promoción de ayudas. Revista Digital del Consorcio de Seguros

Main stakeholders (organizations, companies, institutions, etc.)

- Ministry of the environment
- Insurance Consortium
- Engineering companies
- Construction companies

4.3.10.5 Pilot projects for the adaptation to the risk of flooding of infrastructures and buildings

(Authors: Laura del Val Alonso and Xavier Martínez Lladó)

Areas or sectors where it applies:

- Finance and insurance
- Urban planning and building
- Water

Type of solution: Technological solution

Solution / Technology

Pilot projects for the cost-benefit evaluation of different adaptation measures in various types of buildings and infrastructures subject to flood risk.

Basic description

Floods today represent the main natural risk derived from climate change, since they generate the highest number of human losses and economic costs compared to other risks derived from climate change. Adaptation to this risk with which our society must coexist is fundamental.

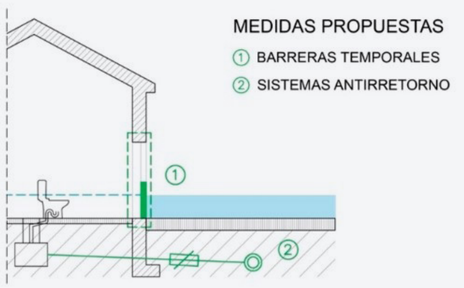
In this sense, one of the most important and innovative efforts at the national level is the one being carried out by the General Directorate of Water in collaboration with the Insurance Compensation Consortium (CCS) under the framework of flood risk management plans. With the aim of promoting the implementation of measures for the adaptation to the risk of flooding of buildings, both public and private, the General Directorate of Water has generated a series of practical guides to facilitate the assessment of vulnerability and implementation of adaptation measures.

In parallel to the promotion of these guidelines, the Directorate-General for Water is implementing a series of pilot projects to demonstrate the cost-benefit (cost-benefit evaluation) of adaptation measures. Each pilot case takes into account different types of infrastructures, sites and solutions.

The methodology used is developed in 4 phases[244]:

1. The first phase consists of characterizing the risk to which the area in question is subjected, through the collection of spatial and temporal information on environmental and socioeconomic variables.
2. The second phase is to make an analysis of vulnerability to floods. To do this, flood zones, entry-exit points of flows, and flow flows and velocities are identified depending on the level of flooding.
3. In a third phase, and after the joint analysis of risks and vulnerabilities, possible measures of self-protection and mitigation of a possible flood would be proposed. The approach proposes four types of adaptation measures in order of priority, which are aimed at avoiding, resisting, tolerating, and finally withdrawing the use of space because it is considered an unapproachable level of risk.
4. In a final phase, the cost-benefit analysis would be carried out. The study is carried out based on the data of the compensation paid by the CCS. This is the key result of the project, which will provide information necessary for prioritized and effective decision-making in the face of a generalized adaptation in our country to the risk posed by floods.

[244] Consorcio de Seguros, 2021. Casos piloto de adaptación al riesgo de inundación. Revista Digital del Consorcio de Seguros



SITUACIÓN ACTUAL	T=10	T=100	T=500
Altura de agua (m)	0,25	0,4	0,5
Probabilidad anual	0,1	0,01	0,002
Daño	14.750,00 €	23.600,00 €	29.500,00 €
Daño incremental	737,50 €	1.725,75 €	212,40 €
Daño anual medio			2.675,65 €
Daño 30 años			80.269,50 €
PROPUESTA DE ADAPTACIÓN			
BARRERAS TEMPORALES	4 barreras desmontables 1 x 0.68 m		3.000 €
	2 barreras desmontables 1.5 x 0.68 m		2.500 €
INSTALACIONES	Sistemas antirretorno en sanitarios		2.000 €
COSTE ESTIMADO TOTAL €			7.500 €
Reducción teórica del riesgo			100%
Beneficio/Coste			10,7

Figure 62 Cost-benefit analysis of flood adaptation measures in homes in the municipality of Cebolla (Toledo) (Source: Consorcio Seguros.)

Potential implementation

Advantages	Disadvantages
• It allows to involve the whole society in the resolution of the same problem, generating synergies and close collaborations between very different agents. • It is a mechanism for raising awareness of the risk with which communities coexist. • The cost of actions, if coordinated, is low compared to the possible costs of a flood.	• Isolated measures do not have such a significant impact. Integrated planning and implementation of different types of measures is required.

Potential barriers to implementation

The main barrier to the implementation of these measures is the coordination between the different social agents and the administrations, not only for the design of the adaptation plan but also for the implementation of the measures and coordinated action in case of emergency. For this reason, the participation of society from the beginning of the design of the plan is essential to ensure that all the agents involved assimilate the measures and take responsibility for their success.

Another important barrier may be the costs of implementation, especially if the measures identified require some type of work, which small municipalities cannot assume with their own resources.

Level of innovation today (TRL = 9)

Although the measures individually do not seem innovative, this set of pilot cases represents the first study to be done at national level and considering such a wide range of casuistries. The results aim to collect information with which the CCS can evaluate the effectiveness in terms of cost-benefit.

Expected or desirable advances in the coming years

It is expected that the results of this study will generate concrete examples of success, which will facilitate the massive and prioritized implementation of flood adaptation measures throughout our country. This will represent a general reduction in insurance sector losses due to compensation arising from the effects of floods, which are expected to increase progressively because of climate change, if no adaptation measures are implemented, or if the implementation is not effective in reducing risk.

Expected results

The implementation of these measures is expected to drastically reduce the impact on human lives, and economic losses. For example, in the case of the multipurpose building of the polytechnic school of engineering of Gijón (Asturias) it was estimated that the implementation of the set of adaptation measures would mean a reduction of economic losses of up to 85% considering the investment made.

Installation costs

The installation costs of these measures will depend enormously on each case. However, an average cost can be estimated based on the investment costs and estimated losses of the cases implemented under the study of the General Directorate of Water[244] :

Cases		***Loses***	**Adaptation measures**
Gijon	*Multipurpose building of the Polytechnic School of Engineering*. It includes classrooms, research teams, and laboratories. (Described in the case study)	25,000,000 €	145,000 €
Cuenca	*Hospital - Recoletas Residence*. Equipment of 20 medical specialties, 24-hour emergency service, diagnostic imaging equipment, laboratory, surgical block, sterilization centre, resuscitation room, rehabilitation, and physiotherapy room, and 35 rooms for individual use.	920,000 €	197,000 €
Cebolla, Toledo	*Municipio de Cebolla en Toledo,* con 3.263 habitantes.	80,000 €	7,500 €
Los Alcázares, Murcia	*The municipality of Los Alcázares in Murcia*, with 15,674 inhabitants. The town is located in the area of confluence between the Rambla de la Maraña and various branches. This causes the entry of water in a dispersed way throughout the urban area.	4,000,000 €	55,000 €

The ratio of the investment between the cost of the measures implemented and the expected losses in events with a recurrence between 25 and 30 years is 0.08. Which means that for every euro of the expected loss we would have to invest around € 8 cent, to avoid around 70% of the losses. Although the percentage of effectiveness of the measures depends a lot on the vulnerability and risk of each case.

Operating costs

This type of action requires an economic commitment to carry out maintenance. Without having specific references to the maintenance costs of the measures specifically mentioned, a very general orientation can be given. Routine maintenance ranges from cleaning the installed elements to replacing or repairing them. The average cost of this type of operation can vary between 2 to 5% of the total cost of the building or infrastructure. The repair costs of a building, for example, are estimated at around 10% of the total cost of the building[245].

Social acceptance

If the participation of all social agents in the design and implementation of the measures is done properly, it is to be expected that they are generating great acceptance. Otherwise, the lack of understanding and involvement of social agents and an entire community can lead to the failure of the implementation of the measures or their implementation when the time comes to act in the face of a flood event.

[245] Maintenance of civil works.

Recipients

- Municipalities and town halls
- Neighbourhood associations
- Trade and industry associations

Relevance for climate change adaptation

Risks arising from climate change to which it can help us adapt

- Floods

Conceptual fit within climate change adaptation

Floods are the climatic event that generates the greatest losses for the insurance sector today. Climate change is increasing the frequency and intensity of these events, so it is necessary to act to ensure the long-term solvency of insurance companies. It is, therefore, crucial to implement adaptation measures to floods in a prioritized and escalating manner. For this, information is needed on the effectiveness of adaptation measures of all kinds and in multiple situations, which allow generating efficient action plans, which ensure the highest level of prevention with the least number of resources.

Real and pilot cases where it has been applied

Location	Responsible	Year	Description
Fraga (Huesca)	Directorate-General for Water Fraga City Council	2020	The municipality of Fraga (Huesca) suffers recurrent flooding when occupying part of the floodplain. One of the measures that have been proposed in this case is the implementation of uses that are compatible with the risk of flooding. Specific actions have also been proposed to prevent the entry of water into certain buildings such as the health centre, day centre and schools. This is a complex case because of the number of buildings vulnerable to flooding.
Hospital - Residencia Recoletas (Cuenca)	General Water Agency	2020	The Recoletas Hospital in Cuenca suffers periodic flooding of the Júcar River. The pilot case aims to reduce the flood risk of the building. To do this, a setback of one of the specks is first proposed to give more space to the river. On the other hand, to safeguard the structure of the building and protect the interior, anti-return systems are implemented, perimeter walls are built, folding hydraulic gates are installed and electrical, air conditioning, hot water and other vulnerable equipment installations are transferred to higher floors. These measures, which have a cost of about € 197,000, will avoid a cost for flood damage of about € 920,000.  Flooding of the Júcar as it passes through the Recoletas Hospital-Residence (Cuenca) (Source: MITECO)

Location	Responsible	Year	Description
Multipurpose building of the Polytechnic School of Engineering of Gijón (Asturias)	General Water Agency	2020	The building of the Polytechnic School of Engineering of Gijón is in an area very vulnerable to flooding. The increased risk in this area is a consequence of an urban model that has removed the flood zone from the river and that has generated obstacles and waterproofing, which added to an increase in the frequency and intensity of torrential rainfall events makes this area subject to periodic episodes of flooding. In this case it is intended to prevent water from reaching the building. On the other hand, it is also intended to move all laboratories and research equipment to the upper floors of the building. Without adaptation measures, the estimated losses would exceed €30 million in 30 years.

Main stakeholders (organizations, companies, institutions, etc.)

- Insurance Compensation Consortium
- Hydrographic confederations
- Directorate-General for Water
- Local bodies such as town halls

5 Annex

5.1 Complete list of innovative technologies and solutions

*Sectors: A- Water, AG – Agriculture, livestock and food, AL – Early warning, BIO – Biodiversity and natural heritage, C – Cultural heritage, E – Energy, FA – Finance and insurance, IS – Industry and services, SA – Health, T – Tourism and URB – Urban planning and building.

**Types of solutions: TEC – Concrete technologies, STEC – Technological solutions, NBS – Nature-based solutions, IT – Solutions based on Information Technologies and GOB – Governance or strategic management solutions.

	Name of solution	Sector *	Type **	Effects of CC	Location	Solution / Technology	Source of reference
1	Rain Gardens	A	NBS	Rainfall and/or hydrological variability	INTERNATIONAL	A rain garden is a sunken landscaped bed that collects and treats stormwater runoff from rooftops, driveways, sidewalks, parking lots, streets, and lawns. Other common names for rain gardens are bioretention basins or vegetated basins.	Cahill, M., Godwin, D. C., & Tilt, J. H. (2018) Gilbreath, et al. (2019) Shah, S., et al. (2019) Wan, Z., Li, T., & Liu, Y. (2018)
2	Artificial wetlands	A	NBS	Heavy rainfall	ITALIA	Set of artificial wetlands that allow the purification of surplus grey water in urban areas, provide protection against floods and floods and improve the connectivity of urban ecosystems.	Masi, F., et al. (2017) Gardiner, E. P., et al. (2019) Liquete, C., et al. (2017)
3	Recharge of aquifers with reclaimed water	A	NBS	Water stress	SPAIN	Reactive barriers to increase the purifying capacity of the first meters of reclaimed water infiltration during aquifer recharge.	Proyecto MAR
4	Natural water retention measures for the renaturalization of wetlands	A	NBS	All	INTERNACIONAL	Natural water retention measures (NWRM) are multifunctional measures that aim to protect and manage water resources and address water-related challenges by restoring or maintaining ecosystems.	Nakamura, F., et al. (2020) Piégay, H., et al. (2020) Life Vallees Ardennaises Life Riverscape Lower Inn Natural Water Retentiton Measures
5	Reuse of treated water for agricultural irrigation	A	NBS	Water stress	SPAIN	The REUSAGUA project focuses on the use of reclaimed water together with information and communication technologies with the aim of developing management practices and protocols for irrigation management, necessary to achieve sustainable agricultural production.	Proyecto REUSAGUA
6	CREAT	A	IT	All	USA	Web decision support tool designed to assist in conducting a risk analysis of the effects of climate change on facilities involving the management of water resources of some kind.	Baranowski, C. (2021)

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7	Water Contamination Risk Alert System	A	IT	Increase in water-related diseases	CYPRUS	Risk management system for large-scale water pollution events (European project PathoCERT).	Proyecto PathoCERT
8	STOP-IT	A	IT	All	NORWAY	Natural and cyber risk management platform on water infrastructure.	Proyecto STOP-IT
9	Evaluation of the performance of reservoirs in the face of the effects of climate change	A	IT	Rainfall and/or hydrological variability	CHILE	Methodology to identify the moment when the current exploitation protocols of the reservoirs fail under a changing climate, treating and adequately presenting their uncertainties.	Chadwick, C., et al. (2021)
10	SCOREwater - Spain	A	IT	Temperature change	SPAIN	Use of monitoring of environmental variables and integration with Artificial Intelligence technologies to evaluate adaptation strategies to climate change.	SCOREwater Case Barcelona
11	SCOREwater – The Netherlands	A	IT	Temperature change	THE NETHERLANDS	Use of monitoring of environmental variables and integration with Artificial Intelligence technologies to evaluate adaptation strategies to climate change.	SCOREwater Case Amersfoort
12	SCOREwater - Germany	A	IT	Temperature change	ALEMANIA	Use of monitoring of environmental variables and integration with Artificial Intelligence technologies to evaluate adaptation strategies to climate change.	SCOREwater Case Göteborg
13	Raineo®	A	STEC	Heavy rainfall	EUROPA	Modular system for the collection and use of rainwater.	PIPELIFE
14	Indirect Potable Reuse through aquifer recharge	A	STEC	Water stress	SPAIN	Indirect Potable Reuse through aquifer recharge.	DEMOWARE Fajnorová, S., et al. (2021)
15	Floating photovoltaic systems to reduce evaporation	A	STEC	Temperature change	EGYPT	Floating photovoltaic system (FPVS) to cover the water zone of a lake to reduce evaporation and produce energy.	Abd-Elhamid, H. F., & Javadi, A. A. (2011) Waheeb Youssef, Y., & Khodzinskaya, A. (2019)
16	SubSol	A	STEC	Droughts	THE NETHERLANDS	Injection and recovery into an aquifer to cover supply peaks derived from periods of drought.	SubSol
17	Circular Water Neighborhoods	A	STEC	Droughts	THE NETHERLANDS	Simulation-based framework for quantitative assessment of the performance of decentralized systems at the neighbourhood scale, in which different technologies can be linked to provide beneficial effects in multiple areas of the urban water cycle (Bouziotas et al., 2019).	Bouziotas D., et al. (2019)
18	NEREDA	A	STEC	Droughts	THE NETHERLANDS	Nereda is the wastewater treatment technology that purifies water using the unique characteristics of aerobic granular biomass.	NEREDA
19	ADAPTaRES	A	STEC		SPAIN - PORTUGAL	The ADAPTaRES project includes a whole series of actions aimed at demonstrating the capacity to adapt to climate change in Macaronesia through the reuse of treated wastewater, efficient irrigation and the prevention and reduction of pollution, which help overcome existing regulatory, social, economic or technological barriers, all accompanied by an important effort in awareness-raising actions, information and qualification at all levels of society.	Proyecto ADAPTaRES

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20	Decentralized Sewer-mining	A	TEC	Droughts	GREECE	Decentralized systems for the use or mining of wastewater.	Makropoulos. C., et al. (2018)
21	Agro-forestry and crop diversification	AG	NBS	Temperature variability	EUROPE	Agro-forestry system resilient to climate change.	Climate ADAPT
22	Methods of managing desertified areas to adapt to climate change	AG	NBS	Soil degradation	ITALY - SPAIN - PORTUGAL	The main objective of Desert-Adapt is to demonstrate innovative strategies and technologies for adaptation to climate change to improve soil quality, conservation, as well as vegetation on farms located in areas of the Mediterranean at risk of desertification.	DESERT ADAPT
23	Método Alternate Wetting and Drying (AWD) para el cultivo de arroz	AG	NBS	Water stress	SPAIN	Solution that combines elements of adaptation and mitigation of climate change in rice cultivation. The solution is to introduce changes in water management and stubble management in the crop, with the aim of reducing water consumption, greenhouse gas emissions.	Proyecto Ebro-ADMICLIM Martínez-Eixarch, M., et al. (2018)
24	Alternative production of aromatic plants compared to traditional crops	AG	NBS	Changes in precipitation patterns and types (rain, hail, snow)	SPAIN	The development of alternative crops to traditional ones, such as the extensive production of aromatic and medicinal plants, opens up new agricultural opportunities with innovative practices, more adapted to the environment and the effects of climate change expected in the coming years and especially aggressive for cereal crops.	Plataforma sobre Adaptación al Cambio Climático en SPAIN
25	Climate adaptation to shifting fish stocks (CLOCK)	AG	NBS	All	EUROPA	Horizon 2020 research project that argues that the combination of fisheries management, science and the socio-ecological systemic approach is necessary to advance the adaptation of fisheries to climate change.	Proyecto CLOCK
26	Smart Farming Techniques for Climate Change Adaptation	AG	IT	Temperature change	CYPRUS	Smart agriculture techniques for adaptation to climate change designed for small farmers in a Mediterranean context.	Adamides, G., et al. (2020)
27	InTeGrate	AG	IT	All	USA	E-learning platform for a sustainable future, with a module for students on the adaptation of agriculture to climate change.	InTeGrate
28	AWA - AgriAdapt Webtool for adaptation	AG	IT	All	EUROPE	Herramienta web para la adaptación al cambio climático del sector agrario Europeo.	Herramienta Agri Adapt
29	Agrivoltaics	AG	STEC	Thermal stress	FRANCE - CHINA - USA	Photovoltaic panels installed at a sufficient height of the ground to allow cultivation.	Barron-Gafford, G., et al. (2019)
30	Aerofarms	AG	STEC	Water stress	USA	Vertical cultivation of vegetables for human consumption.	Aerofarms
31	Development of new varieties of cultivated plants	AG	STEC	Temperature change	FRANCE	Innovative plant variety testing methods for the introduction of new varieties better adapted to climate change.	Proyecto INVITE

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32	Heat alert system for workers in the agricultural and other sectors	AG	STEC	Heat waves	DENMARK	Climate change adaptation strategies for the EU's five main industries and their workers: manufacturing, construction, transport, tourism and agriculture.	Proyecto Heatshield
33	Heat alert system for workers in the agricultural and other sectors	AG	STEC	Temperature change	NORWAY	The GreenCap environmental control system provides energy-efficient climate control for industrial greenhouses where natural conditions are a challenge to production efficiency.	The Explorer
34	Adaptación al cambio climático en la Acuicultura	AG	STEC	All	INTERNACIONAL	Review of technological and non-technological solutions of aquaculture to climate change.	Galappaththi, E.K., et al. (2020)
35	Hoja Biosolar	AG	TEC	All	UNITED KINDOM - GERMANY	Microalgae bioreactor incorporated into panels to integrate into building facades.	Arborea Arup
36	Envira IOT	AL	IT	Floods	SPAIN	IoT system for small-scale flood detection through environmental parameters.	Envira IoT
37	ARANTEC	AL	IT	Floods	SPAIN	Cloud and mobile application that allows the monitoring of rivers and flows.	Smarty River
38	MIDAS: A New Integrated Flood Early Warning System for the Miño River	AL	IT	Floods	SPAIN	Intelligent early warning system for floods.	Fernández-Nóvoa, D., et al. (2020)
39	An Urban Flash Flood Alert Tool for Megacities—Application for Manhattan, New York City, USA	AL	IT	Floods	USA	Prediction system to determine which areas of the cities will be flooded in case of extreme rainfall.	Al-Suhili, R., et al. (2019)
40	Dynamic Real-Time Infrastructure Planning and Deployment for Disaster Early Warning Systems	AL	IT	Floods	SWITZERLAND	Dynamic infrastructure planner in the face of extreme natural events.	Zhou, H., et al. (2018)
41	Territorial early warning systems for rainfall-induced landslides	AL	IT	Floods	NORWAY - ITALY - GERMANY	Use of rain gauges and other sensors as monitoring instruments to measure the duration of intensity and weather models to forecast the expected amount of rain to issue a warning with a given delivery time.	Piciullo, L., et al. (2018)
42	Improving an Extreme Rainfall Detection System with GPM IMERG data	AL	IT	Floods	ITALY	Study of the accuracy of IMERG tools for accuracy in the detection of rainfall events and the prediction of the amount of water.	Mazzoglio P., et al. (2019)

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43	Enhancing the reliability of landslide early warning systems by machine learning	AL	IT	Floods	INDIA	Early warning system for rain-induced landslides based on machine learning.	Thirugnanam, H., et al. (2020)
44	Analysis of the Potential of IT System Support in Early Warning Systems for Flood Risk Mitigation	AL	IT	Floods	POLAND	IT system for the mitigation of the consequences with respect to extreme hazards consisting of the capture of information and warning to end users.	Goniewicz, K., & Burkle, F. (2019)
45	Geomorphology-Based Analysis of Flood Critical Areas in Small Hilly Catchments	AL	IT	Floods	ITALY	Geomorphological study at the scale of drainage basin combined with flood models for the evaluation of areas and their predisposition to floods.	Piacentini, T., et al. (2020)
46	Real-Time Early Warning System Design for Pluvial Flash Floods	AL	IT	Floods	COLOMBIA	A study that reviews the most important aspects of a flood early warning system and presents an architecture taking these aspects into account.	Li, H., et al. (2018)
47	Flash flood early warning research in China	AL	IT	Floods	CHINA	Long-term prediction methods based on regular statistics and flood mechanisms, real-time hazard indicators based on multiple data sources.	Li, H., et al. (2018)
48	A Belief Rule Based Flood Risk Assessment Expert System using Real Time Sensor Data Streaming	AL	IT	Floods	USA	Expert system based on belief rules (BRBES) that is developed on a Big Data platform to assess flood risk in real time.	Monrat, A.A., et al. (2018)
49	GEONICA	AL	STEC	Floods	SPAIN	Rain Alert	Geonica
50	Alert detection system to detect and mitigate health risks	AL	STEC	Increase in water-related diseases	SWEEDEN	Local anomaly detection and early warning system of the wastewater infrastructure towards the detection of events caused by extreme rainfall and / or human interaction on the network (European project SCOREWATER).	SCOREwater
51	UAV for early warning of landslides	AL	STEC	Landslides	ITALY	System that allows monitoring the areas of risk of slippage and studying the phenomena of slippage using unmanned aerial vehicles (UAVs) that allow early warning.	Bernardo, E., et al. (2021)
52	Landslide prediction with satellite rainfall data	AL	TEC	Heavy rainfall	ITALY - INDIA	Automatic calculation of precipitation thresholds that may induce the appearance of landslides.	Massimo, M., et al. (2018) Algoritmo CTRL-T algorithm

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53	THE NEST	BIO	NBS	Changes in precipitation patterns and types (rain, hail, snow)	GERMANY	Shelter for fauna and a tool for learning and social awareness. Increases biodiversity and wetland residence.	Animalesque
54	Urban green infrastructure strategy of Vitoria-Gasteiz	BIO	NBS	All	SPAIN	It is a comprehensive design solution with a double main objective: on the one hand to promote biodiversity in urban areas and on the other to use it to improve the quality of life and adapt to climate change.	Climate ADAPT Case Vitoria Gasteiz
55	Vrijburcht	BIO	NBS	All	THE NETHERLANDS	A privately funded climate-proof collective garden.	Climate ADAPT Case Vrijburcht
56	The Great Green Wall	BIO	NBS	Soil erosion	AFRICA	The Great Green Wall of the Sahara and Sahel (GGW) is a reforestation effort to halt land degradation across the African continent (Goffner et al., 2019).	Nature (2020) Goffner, D., et al. (2019) Greatgreenwall
57	Combating desertification, in the case of Alvelal	BIO	NBS	Soil degradation	SPAIN	Manage a territory from an agri-environmental point of view to prevent the problems arising from desertification.	Asociación Alvelal United Nations Convention to Combat Desertification
58	GUARDIAN	BIO	STEC	Forest fires	SPAIN	Guardian (UIA03-338) is a project aimed at increasing fire resilience in an area of the Túria Natural Park.	
59	WILD HOPPER	BIO	TEC	Forest fires	SPAIN	Drone with the capacity to extinguish fires in forests.	Wild Hopper project
60	Bioprotection of stone monuments	C	NBS	Changes in precipitation patterns and types (rain, hail, snow)	SPAIN	Bioprotection of stone monuments.	COE
61	Hyperion	C	IT	All	GREECE - ITALY - NORWAY - SPAIN	Reliable quantification of climatic, hydrological and atmospheric stressors.	Proyecto Hyperion
62	Modelling of indoor weather conditions	C	STEC	Temperature change	THE NETHERLANDS	Application of high-resolution regional climate models along with new building simulation tools to predict future outdoor and indoor weather conditions.	Proyecto CLIMATE FOR CULTURE
63	THERMOS	E	IT	Temperature variability	EUROPE	Thermal Energy Resource Modelling and Optimisation System.	Proyecto THERMOS
64	C3S Energy	E	IT	Temperature variability	EUROPE	State-of-the-art visualization tool, using high-resolution calibrated input data, to build the one that shows climate and energy variations across Europe.	WEMC Copernicus
65	Energy adaptation map	E	IT	Temperature variability	INTERNACIONAL	Collaborative web platform for monitoring case studies and projects in the field of adaptation to climate change in the energy sector.	Energy Adaptation Map

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66	Écowatt	E	IT	Temperature variability	FRANCE	Web platform developed by La Réseau de Transport d'Électricité de France (RTE, operator of a transmission system) that provides the consumer with timely information on the state of consumption and forecast of cuts based on an "electricity climate" model. This initiative helps balance electricity supply and demand by managing fluctuations in production and forecasting demand peaks.	Ecowatt
67	Dynamic Line Rating	E	STEC	Temperature change	BELGIUM - BULGARIA - FRANCE - ITALY - USA - URUGUAY - VIETNAM	DLR is the ability to vary the thermal capacity of an overhead transmission or distribution power line (cable) dynamically and in real time, depending on the variation of environmental conditions (ambient temperature, solar radiation, and wind speed and direction). (IRENA, 2020).	Ouranos Cradden, L. C., & Harrison, G. P. (2013) IRENA (2020). Dynamic line rating. In Innovation landscape brief.
68	Earth-air heat exchanger	E	STEC	Temperature variability	INTERNACIONAL	Geothermal air conditioning method of summer ventilation and winter heating widely used in passive houses.	PAM Sakhri, N., et al. (2020)
69	PIANO KEY WEIR	E	TEC	Heavy rainfall	GLOBAL	Innovative design, with distinctive rectangular discharge tanks that look like the keys of a piano to increase the discharge capacity of spillways in reservoirs and dams.	
70	Agri-business incubator	FA	GOB	All	BULGARIA - ITALY	Agri-business incubator helps the local economy by creating new businesses, improving competitiveness and responding to the local agricultural market.	Proyecto IAGRI
71	Advancing Climate Risk Insurance Plus (ACRI+)	FA	GOB	All	BARBADOS - CHINA - GHANA - MOROCCO	Advancing Climate Risk Insurance Plus (ACRI+) is an initiative of the Munich Climate Insurance Initiative.	MCII
72	Climate Bonds Initiative	FA	GOB	All	INTERNACIONAL	Advancing Climate Risk Insurance Plus (ACRI+) is a Climate Bond initiative of the Munich Climate Insurance Initiative.	Climate Bonds
73	Forest Resilience Bond	FA	GOB	All	USA	The FRB is a public-private partnership that allows private capital to finance much-needed forest restoration (Beck et al., 2019).	Beck, M. W., et al. (2019)
74	Fonds de Prévention des Risques Naturels Majeurs (FPRNM)	FA	GOB	All	FRANCE	The Natural Risk Prevention Fund (FPRNM), known as the "Barnier Fund", created by Law No 95-101 of 2 February 1995 on strengthening environmental protection, was initially intended to finance compensation for the expropriation of property exposed to a significant natural hazard. Currently, the FPRNM finances investment actions. For example, grants allocated in the framework of the development of an action programme for flood prevention.	DREAL Grand Est
75	Grants for flood risk adaptation of existing buildings	FA	GOB	Floods	SPAIN	Public subsidies for the adaptation of buildings exposed to flood risk and the reduction of their vulnerability.	RD 1158/2020, de 22 de diciembre Consor Seguros, fecha de consulta 22-2-22

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76	Map of financial stress derived from the CC	FA	GOB	All	EUROPE	The assessment of financial stress derived from climate change involves estimating the possible losses caused jointly by physical and transition risks with the aim of assessing the resilience of corporations and banks in the medium and long term.	Alogoskoufis, S., et al. (2021)
77	InVEST	FA	IT	All	USA	InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) is a software for mapping benefits of urban nature.	Hamel P., et al. (2021) Natural Capital
78	Pilot projects for the adaptation to the risk of flooding of infrastructures and buildings	FA	STEC	Floods	SPAIN	Pilot projects for the adaptation of various types of buildings and infrastructures subject to flood risk.	Consorcio de Seguros
79	Supply Chain Digitalization	IS	STEC	All	INTERNACIONAL	The digitalisation of the supply chain will lead to greater transparency and allow companies to minimise their own operational risk, as well as effectively identify and remediate partners at risk.	
80	OFF GRID ELECTRIFICATION STRATEGY	IS	STEC	All	SPAIN - SWEEDEN - GERMANY	To power manufacturing sites mainly through on-site production, i.e. to be largely self-sufficient with regard to power.	Bautista., J.A. et al. (2020)
81	Closed water circuits and valorisation in mining	IS	STEC	Water stress	FINLAND	Closed water circuits and recovery of waste in mining.	ITERAMS (2020). Kinnunen, P., et al. (2021)
82	Circular water use systems in industrial estates	IS	STEC	Droughts	SPAIN	Industrial water recovery for cooling towers, boilers and demineralized uses.	Proyecto ULTIMATE
83	Shallow water tanker	IS	TEC	Droughts	GERMANY	BASF presents innovative tanker for low-water transport on the Rhine. The design makes an essential contribution to the security of supply and competitiveness of the local grid, as well as a significant increase in transport volumes with little water compared to conventional tankers.	BASF
84	CoolAnt – Natural Air Cooler	IS	TEC	Thermal stress	INDIA	Terracotta hive structure designed as a cooling system.	Ant Studio
85	LIFE ALGAECAN	IS	TEC	Water stress	SPAIN - ESLOVENIA	Wastewater treatment from the fruit and vegetable processing industry based on the cultivation of heterotrophic microalgae.	Proyecto LIFE ALGAECAN
86	Local-provincial vulnerability guide to improve adaptation to health.	SA	GOB	All	CANADA	Regional/local plan for the analysis of health risks and vulnerabilities. Targeted adaptation at the neighbourhood level.	

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87	Vegetation walls	SA	NBS	Increased air pollution	UNITED KINDOM	Plant walls of young birch trees in streets of intense traffic against the ultrafine material caused by the combustion of vehicles.	
88	UrbClim	SA	IT	Heat waves	BELGIUM - SPAIN	Heat stress adaptation system in Antwerp (Belgium) based on a high-resolution 100-m urban climate model to map on a microscale (neighbourhoods, streets) heat waves and thermal stress (UrbClim).	De Ridder, K., et al. (2015)
89	Calculation of the map of Madrid of the Wet Bulb Globe Temperature with microsensors	SA	IT	Temperature change	BELGIUM	High-resolution daily computation and mapping of wet Bulb Globe Temperature values 2 meters, which should always be below 25°C to have no effect on health.	
90	iSCAPE living labs	SA	IT	All	EUROPE	The iSCAPE project (Improving the Smart Control of Air Pollution in Europe) aims to integrate and advance the control of air quality and carbon emissions in European cities in the context of climate change through the development of sustainable and passive air pollution remediation strategies, policy interventions and behavioural change initiatives. The project channelled through the concept of Living Labs, addressed the problem of reducing air pollution at target receptors with an innovative SME-led approach, focusing on the use of 'passive control systems' in urban spaces.	Proyecto iSCAPE Living Labs iSCAPE
91	ARBOCAT	SA	IT	Increase in vector-borne diseases	SPAIN - USA	Platform of mathematical models that predict the risk of local outbreaks of arboviral infectious diseases that may spread in Catalonia based on the control of a series of variables including climatic, ecological and socioeconomic information particular to the region.	ArboCat
92	Toolkit for citizen awareness	SA	IT	All	USA	A digital tool (toolkit) to use social networks, communicate about the effects of climate change on health.	
93	Health Equity Zones (HEZ)	SA	STEC	All	UNITED KINDOM	Community workshops help residents assess their strengths and vulnerabilities associated with climate change and identify strategies to reduce climate risks. After an initial workshop, each team studies their own communities and developed a range of initiatives ranging from training and outreach on disaster preparedness, to tree planting and homeowner education. The needs and priorities of communities drive these efforts and generate a number of diverse initiatives. Encourage and equip neighbours and community partners to collaborate in creating healthy places for people to live, learn, work and play.	Rhode Island, Health Department of Health
94	UKCIP's Adaptation Wizard	SA	STEC	All	UNITED KINDOM	App for adaptation in health to climate change.	UKCIP

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95	AirQon	SA	STEC	Temperature change	THE NETHERLANDS	Sustainability and health of events in public spaces and reduction of emissions.	UIA
96	SMARTCITIZEN	SA	TEC	Increased air pollution	INTERNACIONAL	Low cost sensors for measuring air quality (PM10, PM2.5, PM1), meteorological (humidity, atmospheric pressure, temperature), greenhouse gases (eCO2, TVOC), light, noise.	Proyecto BGG
97	Rapid E	SA	TEC	Increased air pollution	SWITZERLAND	Laser fluorimetry for real-time detection of bioaerosols. It allows identification and quantification based on the libraries created in the cloud. At first it was developed for the real-time identification of pollen and was therefore the first alternative system to expert counting by a botanist.	Šikoparija B., (2020) Sauliene I., et al. (2019) Kawashima, S., et al. (2017) Sindt, C., et al. (2018)
98	AerosolSense™ Sampler	SA	TEC	Increase in vector-borne diseases	USA	This sampler specifically adapted to aerosol virus sampling is sold as a solution in the monitoring and detection of new pathogens, such as SARS-CoV-2. It is advertised as a tool for the detection of pathogenic microorganisms in indoor air and therefore allows to improve indoor safety protocols (e.g. large museums, spaces where many people congregate, etc.) The cartridges with the collected samples must be sent to a laboratory that processes the samples by PCR.	Thermofisher
99	ARANET CO2 sensors	SA	TEC	Increased air pollution	USA	Use of carbon dioxide measurement sensors to report on the level of ventilation in enclosed spaces.	Washington Post
100	HEPA / HVAC	SA	TEC	Increased air pollution	USA - UNITED KINDOM	Installation of portable HEPA filters or HVAC filtration systems.	
101	CO_2 indicator in large spaces	SA	TEC	Increased air pollution	JAPAN	Screen that shows in real time the concentration of CO2 in concerts and other large spaces (airports, theatres, art galleries ...), with the aim of reducing the risk of potential contagion of coronavirus (and other respiratory viruses, seasonal for example, such as influenza or rhinovirus).	Asahi
102	SAFEWAY	T	IT	Heavy rainfall	EUROPA	GIS-based infrastructure management system for optimized response to extreme events in ground transport networks.	
103	PANOPTIS	T	STEC	Landslides	SPAIN	Increasing road resilience through the combined use of multi-sensor technology and climate models.	Sevilla de la Llave, I., et al. (2020)
104	RESIST	T	TEC	Landslides	SPAIN	Prototypes (UAVs) for contact inspection of critical transport structures (bridges and tunnels).	Proyecto RESIST
105	PROSNOW®	TU	IT	Thermal stress	FRANCIA - SUIZA - ITALY - AUSTRIA	Weather and climate prediction system applied to snow management in ski resorts.	PROSNOW

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106	ECOARTISNOW	TU	TEC	Temperature change	ITALY	More efficient and quieter snow cannons.	Proyecto EcoArtiSnow
107	UVOX-Redox technology (demEAUmed)	TU	TEC	Water stress	SPAIN - GERMANY	The pool water treatment line consists of UV disinfection, ozonation and advanced oxidation by hydroxyl radicals lead to the inactivation of all pathogens and microorganisms in the water and the oxidation of (micro)contaminants.	DemEAUmed UVOX
108	RESILENCE BY RENOVATION	URB	GOB	Heavy rainfall	THE NETHERLANDS	Urban soil treatment to increase permeability and decrease wastewater management from river water (Renovation of dikes in the Netherlands).	TUDelft
109	Growing Fresh and Clean Air	URB	NBS	Increased air pollution	INTERNACIONAL	Phytofiltration in buildings.	Wbdg
110	PHUSICOS	URB	NBS	Avalanches	EUROPA	Nature-based solutions to reduce the risk of the effects of climate change in mountain areas.	Phusicos
111	RESILIO	URB	NBS	All	THE NETHERLANDS	Resilience nEtwork of Smart Innovative cLImate-adapative rOoftops.	Uia
112	SUPERMANZANA BARCELONA	URB	NBS	Increased air pollution	SPAIN	New program of resilient urban spaces with more prominence for users and that promotes local commerce.	Superilles
113	Ebroresilience	URB	NBS	Floods	SPAIN	Measures aimed at minimizing the risk of flooding in the Ebro axis, either by giving more space to the river, or by facilitating the opening of alternative flood channels, or through temporary reservoirs to capture excess flow.	Consor seguros
114	THERMAFY	URB	IT	Temperature change	UNITED KINDOM	Thermal analysis and construction management tools integrated into smartphones.	ThermaFY
115	RESCCUE	URB	IT	Cyclones, hurricanes and typhoons	EUROPA	A toolkit geared towards end users (city managers and urban service operators) will have the ability to be deployed in different types of cities, with different pressures from climate change.	Proyecto RESCCUE
116	EAVOR - Loop®	URB	STEC	Temperature variability	CANADA	Closed-loop geothermal system in the form of underground resistance.	Eavor
117	Water Square	URB	STEC	Rainfall and/or hydrological variability	THE NETHERLANDS	Estanques de recogida de aguas pluviales. Cuando el tiempo lo permite, los estanques pueden utilizarse como anfiteatros, canchas de baloncesto y voleibol o pistas de skate.	Public space
118	CONFLUENCE PARK	URB	STEC	Floods	USA	Holistic design of water management in buildings.	Lake Flato Flato Architects
119	CARBON CURE	URB	STEC	Temperature change	USA	New composition of reinforced concrete with captured carbon dioxide.	Carbon cure
120	THE URBAN VILLAGE	URB	STEC	All	DINAMARCA	Nueva visión de cómo diseñar, construir y compartir nuestros hogares.	Effekt

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121	HOLEDECK	URB	STEC	Cyclones, hurricanes and typhoons	SPAIN	New slab of lightened slabs.	Issuu Alarcón + Asociados
122	BIOHM	URB	TEC	Temperature change	UNITED KINDOM	Insulation for buildings implementing biomaterials.	Biohm
123	SMOG FREE TOWER	URB	TEC	Increased air pollution	THE NETHERLANDS	Local solution to clean the air in specific areas of the city by capturing carbon from the environment.	Studio Roosegaarde
124	Raindrop	URB	TEC	Water stress	THE NETHERLANDS	Rainwater collector vessel in single-family homes and low-density residential typologies.	Raindrop
125	MADE OF AIR	URB	TEC	Temperature change	GERMANY	Carbon positive panels.	Madeofair
126	Wind catchment towers	URB	TEC	Temperature change	MIDDLE EAST	Cooling and natural ventilation through wind collection towers.	Sangdeh, P. K., & Nasrollahi, N. (2020) Guggenheim
127	Phase Change Materials	URB	TEC	Thermal stress	INTERNACIONAL	Phase change materials, commonly known as PCMs, are products that store and release thermal energy during melting and freezing processes.	PCM

5.2 Multidisciplinary team that carried out the study

Xavier Martinez Lladó is Chemical Engineer graduated from the Polytechnic University of Catalonia (2003), Postgraduate in Environmental Management (2003), with a PhD in Environmental Chemistry from the same university (2008). His main research focus is separation technologies, especially membranes, for water treatment and the recovery of valuable compounds. Currently, he is responsible for the water, air and soil unit of Eurecat, focusing on the coordination of R+D+I projects on water, air and soil technologies in the private and public sector, working with top-level companies in the water sector but also with companies from other sectors where separation technologies have a key role in their industrial processes: food, chemistry, mining, etc. He is co-author of more than 25 peer-reviewed publications and has directed 2 doctoral theses. He also has extensive experience in coordinating research and innovation projects at regional and European level.

Laura del Val Alonso holds a PhD in Geotechnical Engineering from the Polytechnic University of Catalonia (UPC), a Master's Degree in Hydrogeology from the Vrije Universiteit (VU) in Amsterdam, and a Degree in Environmental Sciences from the University of Alcalá (UAH) in Madrid. She began her professional career executing and managing international projects in the water sector for IGRAC, UNESCO's centre in Delft. Subsequently, she joined the UPC as a predoctoral researcher. The objective of her thesis was the application of new methodologies for the characterization of coastal aquifers. During the realization of her thesis, she continued to collaborate with UNESCO as an external consultant in projects related to transboundary aquifers. Once she obtained her PhD degree, she joined as a postdoctoral researcher at the University of Barcelona, where she worked in geothermal energy exploration. She is currently working as an advanced researcher in Eurecat's soil and groundwater line, on issues related to groundwater pollution treatment and sustainability.

Carmen M. Torres Costa is a chemical engineer from the University of Santiago de Compostela (USC, 2006) where at the end of her degree she worked as a researcher in the Environmental Modelling Group until 2010. He obtained a PhD in Chemical, Environmental and Process Engineering at the Rovira i Virgilli University (URV, 2013). She has been a researcher hired in the Environmental Analysis and Management group (URV, 2013-2021), and since 2016, she is an associate professor in the Department of Chemical Engineering of the URV. She is currently a researcher at the Eurecat Foundation in the Sustainability Area, within the WAS (water, air and soil) technical unit.

Irene Ràfols is An Architect by the Polytechnic University of Catalonia (UPC) with a Master's Degree in Engineering and Production Integrated (UPC). It is currently the Head of the Innovation and Product Development Department at Eurecat. Has 15 years of experience in R&D projects having participated in European (h2020) and National (Challenges, CIEN, Cervera) Projects. His experience focuses on the development of innovative products for different sectors from concept to industrialization, specializing mainly in products for the construction sector. Its knowledge of materials is based on polymeric materials, composite materials and high performance concretes. She is the inventor of 4 patents. She has also worked as an architect in the rehabilitation of buildings.

Nil Álvarez is a researcher in the climate change line of the Eurecat Foundation, where he participates in projects of ecosystem restoration, nature-based solutions, ecosystem services, bioeconomy, sustainable tourism, climate resilience, ecology, sustainable agriculture and governance. He has a degree in Environmental Sciences from the Autonomous University of Barcelona and has always worked in the field of research and development both in universities (Autonomous University of Barcelona, Universidad dos Açores, Aberdeen University and Manchester University), as well as in research centres (The James Hutton Institute and the Institute of Agrifood Research and Technology).

Mireia Plà Castellana is a Researcher in the Water Air Soil (WAS) unit of Eurecat. Geologist, by the Autonomous University of Barcelona (UAB), and with a master's degree in land engineering and Physical Engineering, with a specialization in Underground Hydrology, from the Universitat Politècnica de Catalonia (UPC). Currently, he is finishing his thesis in chemometrics and creation of algorithms for the detection of contaminants in different water matrices (drinking and residual) using spectrophotometry sensors. She has worked as a researcher at the UNESCO Chair in Sustainability of the Universitat Politècnica de Catalonia in projects for the creation and construction of natural systems for the improvement of water quality in agriculture and the wine industry, and as a technician in the R&D department in technological projects to control water quality. She is currently involved in projects to develop algorithms for the control of chlorine concentration in the urban water distribution network, chemical speciation and metal recovery, and soil decontamination.

Eloy Hernandez Researcher of the R&D Group of the Applied Artificial Intelligence unit. He studied Technical Engineering in Management Informatics at the University of Lleida (UDL) and also holds the Certificate of Pedagogical Aptitude from the Institute of Education Sciences (ICE) of the University of Lleida. Eloy has more than 12 years of experience as a programmer of web platforms and resource planning and management (ERP) applications for companies in the nuclear energy sector and the administrative field. He has worked as a researcher in projects oriented to the analysis and visualization of data applied in IoT and Big Data architectures. Currently involved in projects related to data analytics, predictive models, efficient resource managers, interoperability and IoT such as the B-WaterSmart, iBathWater and Glomicave projects.

Aitor Corchero is a senior researcher and R&D project manager in the R&D&I Group in Applied Artificial Intelligence of the Eurecat Technology Center. He studied Computer Engineering at the University of Mondragón (MUN) and has also obtained a Master's Degree in Computer Science at the University of Lleida. He has over 10 years of experience as a data scientist and semantic web. Specifically, he has expertise in semantic web technologies, data analytics (machine learning/data mining and deep learning), decision support systems (rule-based reasoning and case-based reasoning) and cognitive artificial intelligence for a wide range of domains including water and energy management of construction efficiency management and physical and logical security systems (detection and remediation systems of botnets). In addition, he is involved in the domain of water (OGC®, ICT4Water Cluster), semantic web (IoT Schema.org) and IoT partnerships (AIOTI, BDVA). Currently, he is leader of the AIOTI water management action group and also leader of the "Standardization and Interoperability" action group of the ICT4WATER cluster. In addition, Aitor has been involved and led from EUT more than 20 EU projects covering the FP7, H2020 and LIFE programs.

Carles Ibañez Martí is Scientific Director of the Center for Climate Resilience and Coordinator of the Climate Change Line of EURECAT. PhD in Biology (Cum Laude) from the University of Barcelona (1993). Author of 130 publications in international scientific journals and book chapters, and of numerous technical and informative publications. He has participated as a lecturer in more than 100 international congresses on ecology, water resources, climate change and sustainability. He has directed 14 doctoral theses and numerous master's theses. He is Associate Editor of the scientific journal "Estuaries & Coasts". He has been an expert reviewer of the IPCC's fifth report. Visiting Researcher at the Socio-ecological Synthesis National Centre of United States (University of Maryland). He is a member of the Advisory Council on Sustainable Development of the Government of Catalonia.

Queralt Plana Puig holds a PhD in Water Engineering from Université Laval (Québec, Canada) in the Department of Civil Engineering and Water Engineering, since 2020. She previously obtained a degree in Chemical Engineering from the University of Barcelona in 2010, complemented by a master's degree in Environmental Engineering from the Polytechnic University of Catalonia in 2013, and another master's degree in Water Engineering from the Université Laval in 2015. During his professional career, he has dedicated himself to the on-line monitoring and modelling of wastewater treatment plants and rivers, and the analysis of long data series. The work carried out has led to scientific publications and participation in national and international congresses (5 articles in indexed journals and > 10 congresses). She currently works as an advanced researcher at Eurecat in the Water, Air and Soil Unit of the Sustainability Area, on issues of modelling of environmental processes and on wastewater and drinking water treatment technologies.

Xavier Rodó is responsible for ISGlobal's CLIMATE (Climate and Health) Program (ORCID ID: 0000-0003-4843-6180). Founding director of the Catalan Institute of Climate Sciences (IC3) and former director of the LRC-Parc Científic de Barcelona. MSc in Engineering, BSc in Biological Sciences, completed his PhD in 1997 (Univ. Barcelona) on simulation of extreme ecosystems under climatic forcing. Visiting researcher at the Univ. Princeton and the Univ. California at San Diego, and associate scientist at the Center for Ocean-Land-Atmosphere Studies (COLA-IGES) in Maryland. Specialized in population ecology, climate dynamics and climate impact modelling. He taught ecology, advanced statistics, climate dynamics and sustainability and led/participated in more than 50 research projects. He has mentored 20 postdoctoral researchers. Co-President of CLIVAR-Spain (-2007), SSC of MEDCLIVAR-ESF, Contributing Author and Expert Reviewer of AR4-GTII and Expert Reviewer of AR6 (IPCC 2007, 2021). Scientific Committee Member of the Drought Integration Group of the World Climate Research Program (WCRP) and the ISIMIP Health Impact Models for IPCC AR6. Member of the editorial board of PLoS NTD, Scientific Reports, PLoS Climate. He is part of the World Meteorological Organization's expert panel on the effect of climate and air quality on the COVID-19 pandemic. Expert in the Health Group of the Union for the Mediterranean.

Joan Sabat is an architect, Director of SaAS architecture and sustainability, president of the *Association Low Impact Mediterranean Architecture* (LIMA), Director of the Building Department of La Salle Barcelona, URL (1197-2012), founding partner of the sustainable architecture group of the COAC and member of the committee of experts of the Association Architecture and Sustainability (ACA)