Digital Future Society

Reasons why artificial intelligence should be at the top of Spain's climate change agenda

A programme of

GOBIERNO DE ESPAÑA
VICEPRESIDENCIA SEGUNDA DEL GOBIERNO
MINISTERIO DE ASUNTOS ECONÓMICOS Y TRANSFORMACIÓN DIGITAL
SECRETARÍA DE ESTADO DE DIGITALIZACIÓN E INTELIGENCIA ARTIFICIAL

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Digital Future Society

About Digital Future Society

Digital Future Society is a non-profit transnational initiative that engages policymakers, civic society organisations, academic experts and entrepreneurs from around the world to explore, experiment and explain how technologies can be designed, used and governed in ways that create the conditions for a more inclusive and equitable society.

Our aim is to help policymakers identify, understand and prioritise key challenges and opportunities now and in the next ten years in the areas of public innovation, digital trust and equitable growth.

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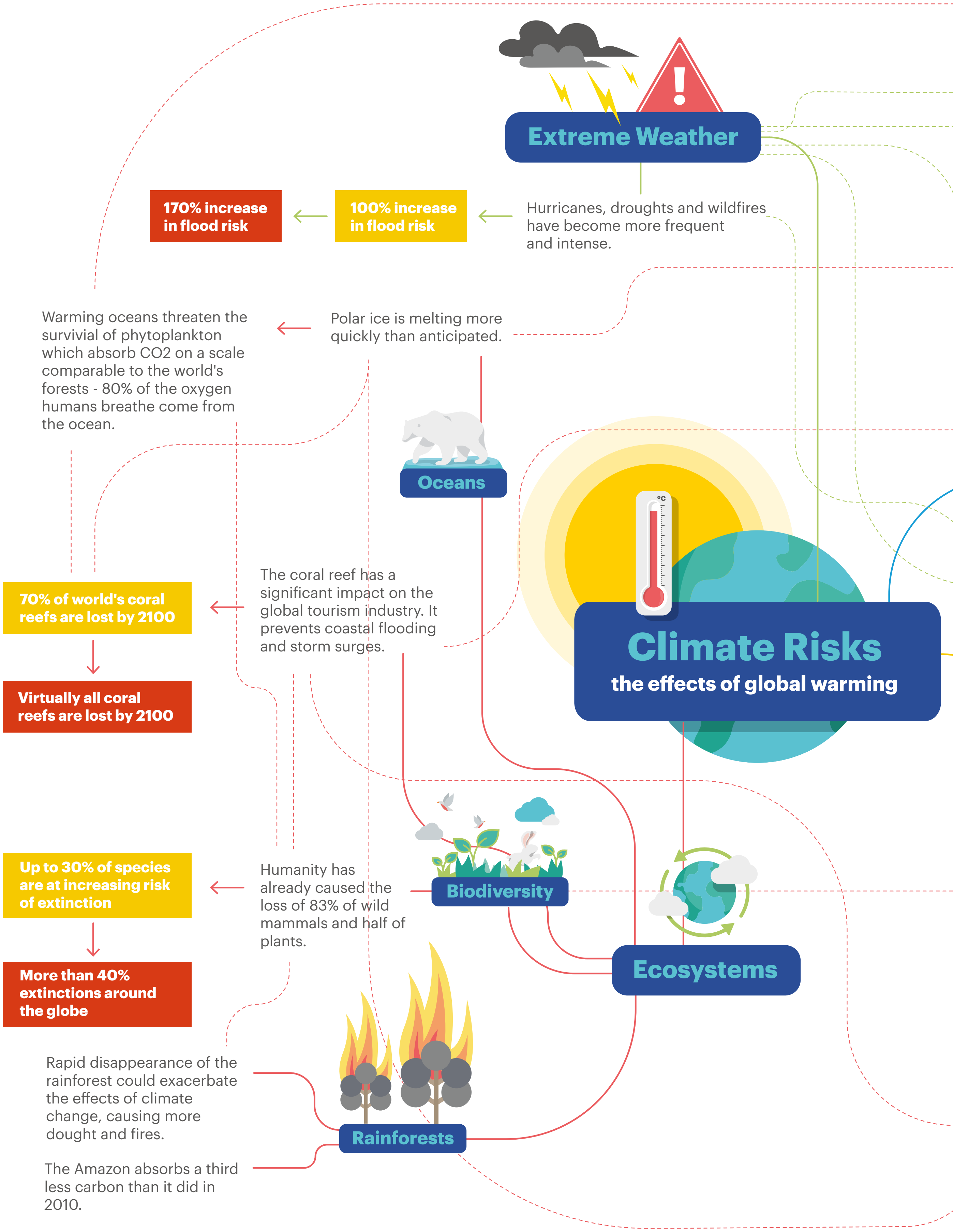
Extreme Weather
Hurricanes, droughts and wildfires have become more frequent and intense.
100% increase in flood risk
170% increase in flood risk
Polar ice is melting more quickly than anticipated.
Warming oceans threaten the survivial of phytoplankton which absorb CO2 on a scale comparable to the world's forests - 80% of the oxygen humans breathe come from the ocean.
Oceans
°C
Climate Risks
the effects of global warming
The coral reef has a significant impact on the global tourism industry. It prevents coastal flooding and storm surges.
70% of world's coral reefs are lost by 2100
Virtually all coral reefs are lost by 2100
Humanity has already caused the loss of 83% of wild mammals and half of plants.
Biodiversity
Up to 30% of species are at increasing risk of extinction
More than 40% extinctions around the globe
Ecosystems
Rapid disappearance of the rainforest could exacerbate the effects of climate change, causing more dought and fires.
The Amazon absorbs a third less carbon than it did in 2010.
Rainforests

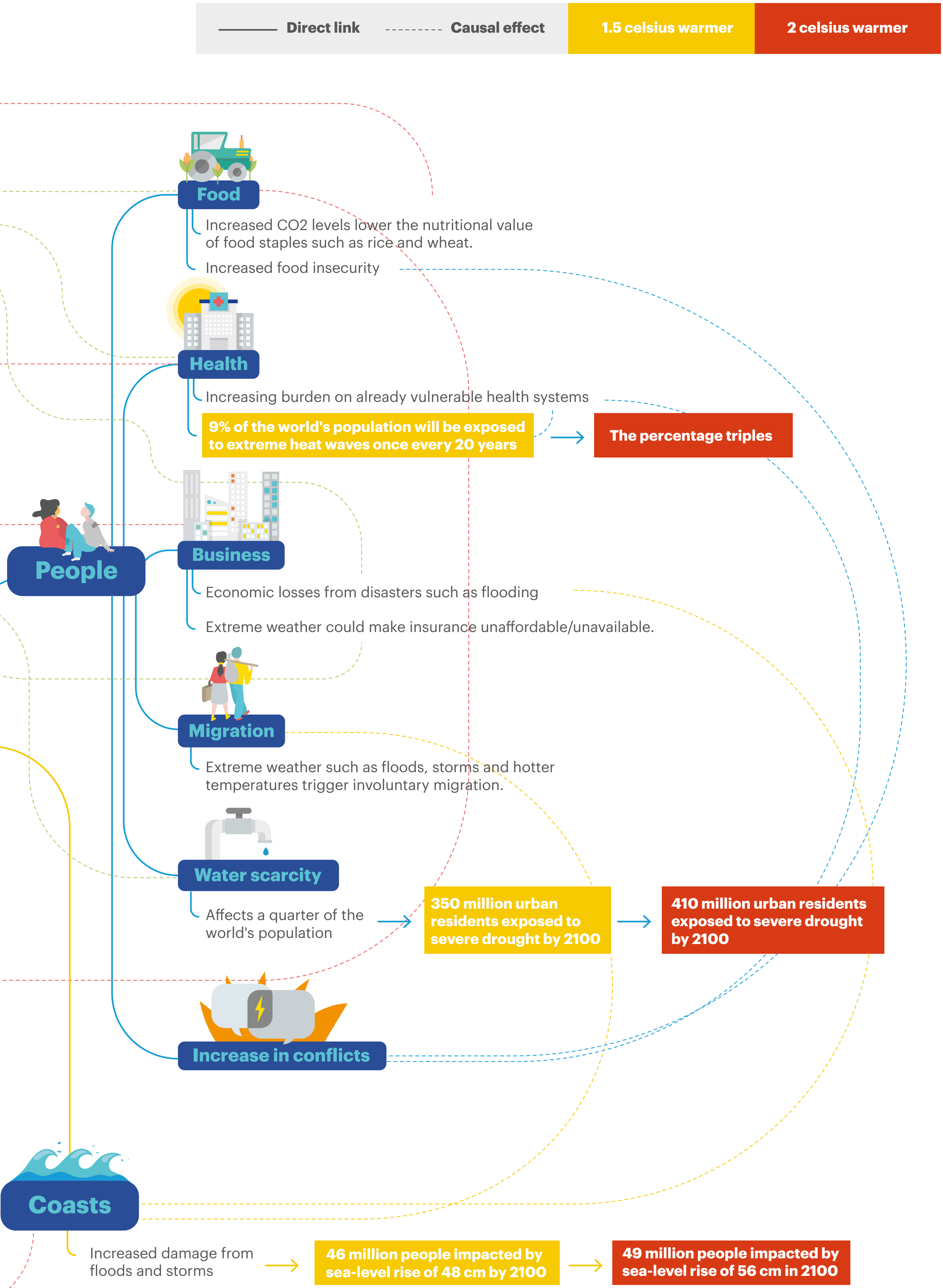

Figure 1: The complexity of the climate crisis and the interrelated nature of the effects of global warming. Image source: Digital Future Society. Data source: Intergovernmental Panel on Climate Change, IPCC 2007

Climate change is one of the most significant challenges of our time. It represents an existential threat to natural habitats and human communities alike all over the world. Overlooking the negative effects of climate change will seriously undermine all future actions and the ability to drive change and prosperity. The World Economic Forum's annual Global Risks Report has climate action failure at the epicentre of the top long-term global risks they identified.[1]

Around the world, artificial intelligence (AI) researchers and practitioners are currently pooling resources towards solving the issues that are feeding the climate emergency. In this regard, major topics emerging in relation to climate extremes include climate datasets post-processing, Earth system modelling, forecasting, and climate impacts. Climate change is now a field that is continuously pushing boundaries through the development and evolution of, both in terms of sophistication and maturity, existing computer science tools and data heavy analytical capabilities. This, together with the drive to ensure AI works on societally relevant issues, is creating a unique global opportunity to leverage digital capabilities for climate change.

As well as a critical social and ecological need, there now exists a vertical alignment of political will and ambition to act against the growing climate emergency. To comply with the Paris Agreement, and achieve the 2030 targets it set out, the world must reduce greenhouse gas (GHG) emissions by 25-55% compared to 2018 levels, to limit global warming to 2°C-1.5°C.[2] This is the decade of climate action and, accordingly, there is a need for global action backed up with regional, national and local responses.

Spain, together with many of its European partners, has the political leadership and commitment needed to develop and enforce policies to promote and deliver effective change when it comes to the climate crisis. From the UN and through the EU to Spain and its regions, cities and towns, ambitious policies and plans designed to mitigate the ever-increasing effects of climate change are now in place. Furthermore, Spanish climate change research has a solid reputation with high levels of success, enjoying access to European funds and strong visibility in the international arena. The Barcelona Supercomputing Centre is a prime example of this.

Therefore, as this report will show, this time for action also presents Spain with a unique opportunity.

So, what does it mean to put artificial intelligence at the top of your climate change agenda? To fulfil such a commitment means understanding the field, creating the right conditions for it to develop and having the political will to enable change through policy making, aligned strategy and dedicated budgets. It also requires building on international alignment as well as already existing efforts and initiatives, supporting the development of technical knowledge and promoting multiple levels of national and gender-balanced talent.

[1] World Economic Forum 2020

[2] United Nations Environment Programme 2019

Furthermore, it requires an assurance that all other relevant parts of your government are aligned when it comes to strategy, funding and dedicated budgets and requires work on strengthening the private sector's engagement and commitment.

Finally, on top of all this, putting AI at the top of your climate change agenda means generating meaningful debate and reflection on ethical and social impact aspects and, most importantly, enabling public understanding, participation and support of your efforts.

2. The urgency and the opportunity

The United Nations Sustainable Development Goals, the European Green Deal and Covid-19 recovery plan, and the recently announced Spanish climate change related strategies show that, through the merging of the digitalisation, decarbonisation and climate resilience agendas, urgency and opportunity have been coupled together in a unique manner.

United Nations Sustainable Development Goals

The UN's 2030 Agenda for Sustainable Development offers a blueprint for peace and prosperity for people and the planet and has been adopted by all UN Member States. In particular, the Agenda's 17 Sustainable Development Goals (SDGs) provide an urgent call for global action to address the societal challenges of our time.

Of particular relevance here are SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), SDG 14 (Life Below the Water) and SDG 15 (Life on the Land) as they relate to the climate emergency and the effects it is having on the planet. These goals add to the global framework for action on climate change mitigation, but require concerted effort, innovation and applied solutions if they are to be more than mere ambitions.

Figure 2: SDGs relevant to the climate crisis. Image source: Digital Future Society.

Digital Future Society

European Green Deal and the recovery plan

The European Green Deal is the EU's roadmap for a sustainable, thriving economy. It is a growth strategy that aims to transform the EU into a modern, resource-efficient and competitive economy that decouples economic growth from resource use. The strategy also includes reducing Europe's net greenhouse gas emissions by at least 55% compared to 1990 levels, by 2030. This is directly in line with the objectives of the United Nations Framework Convention on Climate Change's Paris Agreement and puts climate neutrality at the heart of the European Green Deal.[3] There is now a comprehensive legislative framework in the EU that supports this commitment and a range of measures and initiatives designed to mitigate the climate emergency by reducing greenhouse gas emissions, adapting to the impacts of climate change, and embarking on the wide-ranging economic and societal transition that is needed.[4]

As an explicit example of Europe's commitment, the first strategic and regulatory climate action initiatives under the Green Deal are:

- The European Climate Law, which aims to put the 2050 climate-neutrality pledge into EU law[5]
- The European Climate Pact, which aims to raise societal awareness and promote citizen engagement into practical climate action[6]
- The European Climate Target Plan, which proposes to increase the commitment to reduce net greenhouse gas emissions by at least 55% compared to 1990 levels, by 2030 through a defined responsible roadmap and concrete policy actions[7]

In parallel, and as an urgent response to the challenges and social and economic damage stemming from the Covid-19 pandemic the European Commission, the European Parliament and the EU leaders announced a recovery plan that represents the largest stimulus package ever announced — supported by the EU's long-term budget and the NextGenerationEU (a specifically created and temporary instrument). The aim of the assigned 1.8 trillion EUR is to support rebuilding an EU that is "greener, more digital and more resilient". Climate change concerns are core to this package and its associated rebuild activities.[8]

[3] United Nations Framework Convention on Climate Change 2020

[4] European Commission 2020a

[5] European Commission, n.d. b

[6] European Commission, n.d. c

[7] European Commision, n.d. a

[8] European Commission, n.d. d

Spain

In 2019, while hosting the United Nations Climate Change Conference (COP25) in Madrid, the Prime Minister of Spain, Pedro Sánchez, pledged that Madrid would be the capital for action and commitment to the fight against the climate crisis and would loudly champion the science and the urgency of addressing these issues.[9]

Spain's ministry responsible for climate change issues is the Ministry for Ecological Transition. Created in 2018, it develops policy to mitigate climate change, prevent pollution, evaluate environmental impact and support the use of clean tech. The ministry also promotes the adaptation of more sustainable consumer habits and seeks to protect natural heritage and biodiversity, among other ecological features.[10]

In 2020, the Ministry for Ecological Transition circulated draft legislation to support Spain's 2050 climate neutrality goal, adding Spain to a small number of other countries to legislate the target.[11] Towards climate neutrality, the government proposed interim targets including the 23% reduction of emissions from 1990 levels by 2030, doubling the proportion of electricity coming from renewable energy sources to at least 70%, and introducing energy efficiency measures to reduce consumption by at least 35%, focusing on retrofitting existing buildings and homes.[12]

These targets are also designed to have a positive effect on the economy and create jobs and opportunities within Spain. The government forecasts that the plan will generate more than 200 billion EUR in investment and will create up to 350,000 new jobs every year, boosting economic growth by 1.8% on business-as-usual.[13, 14]

[9] Harbour and Planelles 2019

[10] Government of Spain 2018

[11] Climate Home News 2019

[12] Ministry for Ecological Transition and the Demographic Challenge 2020a

[13] Ibid.

[14] Ibid.

3. The merging of the digitalisation and climate change action agendas

The global, European, and Spanish contexts described illustrate the ongoing merging of the digital and climate change agendas. This intertwining of agendas should inform forecasting and attempts to predict the future. The best example of this combined digital and green transition is the EU's current digital transformation plan: Shaping Europe's Digital Future. It focuses on three areas: technology that works for people, a fair and competitive economy, and an open, democratic and sustainable society.[15] The approach aims to improve every citizen's daily life with technology and assist businesses to start, grow and innovate as well as helping the EU reach climate neutrality. It acknowledges that Europe must work towards a digital transition that works for everyone and simultaneously, through digital technologies, fights climate change and assures a green transition.[16]

Shaping Europe's Digital Future stresses the role technology will play in the digital and green transition. It nominates energy networks, precision farming, mobility and transport, smart buildings, green data spaces and the power of data as priority areas of work to achieve the transition.[17] These are all areas where AI is playing a transformative role as the case studies presented later demonstrate.

AI's role in the fight against the climate crisis is becoming increasingly visible. This is due in part to the role that computational sciences have been playing and will continue to play in understanding, forecasting and mitigating climate change. Initiatives like Destination Earth exemplify this in a very clear and transformative manner. It is easy for the workings and existence of AI to lay masked in the background of technological applications and hidden from the users, even during simple everyday interactions. Currently, applying AI to the mitigation of climate change is still in the early days, despite the level of potential it shows. There is much to do to further understand the opportunities it presents and mature the application further, but also to understand the impacts and ethical questions that surround AI.

[15] European Commission 2020d

[16] Ibid.

[17] European Commission 2020f

Destination Earth (DestinE)

DestinE is a bold new initiative that supports the EU's Green Deal and the EU's digital plan. DestinE's main objective is to create a "very high precision digital model of the Earth to monitor and simulate natural and human activity, and to develop and test scenarios that would enable more sustainable development and support European environmental policies".[18] The implementation will start gradually in 2021 and is planned to last for 7 to 10 years. DestinE will monitor the health of the planet according to agreed indicators, be able to perform high precision and dynamic simulations of the Earth's natural systems, improve modelling and predictive capabilities and support EU policymaking and implementation. Furthermore, it will reinforce Europe's capabilities in simulation, modelling, predictive data analytics, AI and high-performance computing.[19] Overall, DestinE can also support efforts to speed up the green transition and help plan for major environment degradation and disasters at the global level.

[18] European Commission 2021b

[19] Ibid.

4. AI's global role in the fight against climate change

Recent decades have seen a proliferation of research into and the application of algorithmic solutions to automate tasks and solve problems commonly associated with intelligent human behaviour. Collectively, this field falls under the broad label of artificial Intelligence. Specifically, there has been a surge in machine learning and, in particular, deep learning – an evolution and subset of machine learning.

Machine learning programs use algorithms to learn and improve from experience, applying the learnings to make decisions and improve outcomes. They use accessible data to make informed decisions and process the data in a way that would be too onerous to program manually. Machine learning has improved classical data analytics, forecasting and optimisation tasks. It has also paved the way towards solving some of the hardest open problems in the field of AI including computer vision, natural language processing, and autonomous planning and acting.

Computer vision, for example, involves using machine learning to analyse digital images or video. Computer vision is now able to automate tasks that require a high-level of visual understanding, similar to that of humans, with self-driving vehicles representing an excellent example of its use.

These revolutionary successes come from one particular paradigm of machine learning known as deep learning.

Deep learning's foundations date back to the 1950s as perceptrons, the foundational blocks of deep learning, were first conceived in 1958. Despite this, however, it was not until circa 2012 before deep learning applications took off thanks to the following infrastructure improvements:

1. Improved computing due to specialised processing units such as Graphics Processing Units (GPUs) and, more recently, Tensor Processing Units (TPUs), multicore technology and, to a lesser extent, the advent of cloud computing

2. The creation of curated datasets with thousands of labelled examples, such as ImageNet and the development of data labelling infrastructure such as that of Amazon Mechanical Turk. This type of infrastructure allows human-in-the-loop feedback (HITL), which is human interaction to validate, fine-tune and retrain a machine learning model

Figure 3: Captcha is a high profile example of a dataset labelling infrastructure.

Image source: Digital Future Society. Data Source: Strickland, n.d.

Therefore, while AI has been around for decades, recent developments in digitisation and datasets, processing speeds, and advancements in the underlying technologies have made it a much more accessible technology. AI has now moved out of academia with all major tech companies, fuelled by enormous and detailed datasets from devices, sensors and satellites, incorporating it into their products. Whereas formerly data use was limited by the ability to analyse it, AI systems can now process large amounts of data easily. In fact, the more data there is available for processing, the more accurate the analyses will be. AI systems can even aggregate and incorporate different datasets and types of data to further refine models and make even more accurate predictions or decisions, depending on the purpose of the system. The extremely complex nature of the climate crisis, due to the huge number of variables involved, makes AI a valuable tool that could help manage it effectively.

The widely known paper Tackling Climate Change with Machine Learning, written as a global call for action to the machine learning community, presents key contributions machine learning can make both as "one part of the solution" and also as "a tool that enables other tools across fields". The paper offers some key examples of how machine learning (ML) can contribute:[20]

> **"ML can enable automatic monitoring through remote sensing (eg by pinpointing deforestation, gathering data on buildings and assessing damage after disasters). It can accelerate the process of scientific discovery (eg by suggesting new materials for batteries, construction and carbon capture). ML can optimize systems to improve efficiency (eg by consolidating freight, designing carbon markets and reducing food waste). And it can accelerate computationally expensive physical simulations through hybrid modeling (eg climate models and energy scheduling models)."[21]**

The paper positions AI as a tool to complement existing actions against climate change rather than as a standalone solution. Linking, for example, the creation of carbon accountability markets and AI's ability to map and predict those markets as a key driver for increased efficiency. With ambitions to limit global warming to 1.5°C or even 2°C requiring a shift from incremental to exponential action, incorporating AI into existing strategies represents a much-needed step in the right direction.[22]

Another area where the support of AI can make a big difference is building retrofitting. This area is an excellent example of the added value AI can offer to standard mitigation strategies. Retrofitting offers a robust solution in its own right, with regulation requiring new buildings to have proper insulation offering a potential 40% saving on heating energy consumption.[23] Using AI in the retrofitting process and machine learning to automate building heating could then increase efficiency a further 10–15%. The DEXMA and Orpheus case studies presented later show that Spanish technology and innovation is already driving efficiency in this way.

[20] Rolnick et al. 2019

[21] Ibid.

[22] Falk et al. 2019

[23] Mackay 2008

5. Issues and considerations when working with AI

It is worth noting that, as well as the positive applications AI can offer climate change action, there is also scope for AI supporting the polluting coal infrastructure. It could, therefore, help prolong the life of fossil fuels and other polluting infrastructures. Perhaps the most obvious issue is that the **computational power needed to run AI is itself a climate change issue.** Today, training machine learning models mainly occurs through the use of cloud computing, using data processing centres and services such as Amazon Web Services, Microsoft Azure or Google Cloud, to name a few. These services can facilitate machine learning solutions thanks to the large computational resources they offer but, at the same time, they consume exceptional amounts of energy.

According to a recent study, training a cutting-edge deep learning model requires computational resources comparable to five times the amount of CO2 a car will consume in its lifetime.[24] In 2016, the world's data centres made up about 3% of the world's total electricity consumption, 40% more than the consumption of the whole of the UK for the same year. This consumption is expected to double every four years, although not all of the demand can be attributed to AI applications.[25, 26]

In Spain, the MareNostrum 4 Power9 cluster at the Barcelona Supercomputing Center (BSC) ranked sixth on energy efficiency in the Green 500 supercomputers in the world.[27, 28] The cluster primarily runs AI models non-stop and uses an enormous amount of electricity and computing power. For these reasons, some emerging lines of work seek to, as far as possible, dispense or alleviate these large centralised systems by making use of distributed learning and perimeter computing. This has given rise to a new discipline, Edge machine learning, with projects seeking more sustainable systems already underway in Spain such as, the machine learning on the edge (MLoE) project, for example.[29]

Edge computing enables data to be pre-processed in the sensor network. This saves power consumption for data storage and communications as only data that is relevant to the centralised system needs to be transmitted. The challenge of reducing energy requirements is leading the current green artificial intelligence revolution that sees many algorithms being redesigned and the design of new algorithms prioritising low consumption to comply with new restrictions.[30]

Furthermore, there are other risks and issues to consider when working with AI, and challenges to overcome in system design and development.

[24] Strubell et al. 2019
[25] Danilak, 2017
[26] Gartner Inc. 2017
[27] BSC-CNS 2020
[28] Top500.org 2019
[29] Fontenla Romero 2020
[30] Pruhs, 2019

The challenge of evidence-based climate policymaking is the need **to understand causal inference** (drawing a conclusion about a causal connection based on the conditions of an occurrence of an effect) to estimate the counterfactual effect of enacting different policies.

Another problem is **reward hacking,** where an AI system finds a solution for a problem using a logic that apparently solves the problem from the point of view of an intelligent system but does so by using unexpected and undesired shortcuts or out-of-the-box solutions that pervert the spirit of the system designer's intent. For example, a system designed to keep fire-free zones that receives a reward each time its inspection detects no fires, might choose to avoid fires rather than fight them. Systems must behave as intended and so must be designed to avoid proposing solutions to the problems they face that do not fulfill the ultimate purpose of their task.[31]

AI systems also need to improve their **ability to handle the uncertainty** inherent in problems such as climate change, for example facilitating flexible energy forecasting, as well as improve their ability to better **quantify the uncertainty** of the predictions they make.[32]

Another issue relates to integrating climate models at different scales. This will require an improved understanding of how to integrate machine learning models as defined at different resolutions and ontologies. An example of this is integrating climate modelling with agricultural production models, which is known as a **hierarchical world model.**

AI systems also need to improve transfer learning, which involves the use of a model designed for a given task as a starting point to develop a model in another related task. For example, a model developed to forecast energy demand for a specific building could be transferred and used as a starting point to model forecasts for new buildings. Therefore, AI systems must be designed to be able to adapt to different domains and handle different conditions, such as changes in the distribution of input variables, robustly. This is known as **covariate shift.**[33] Adapting systems to different regions will require progress in how to transfer learning in this way.

Something else that needs considering is that, to avoid unacceptable mistakes during the learning period, continuously learning systems (especially online reinforcement learning) require an improved understanding of **safe exploration.** For example, a swarm of drones learning how to monitor and manage crops for precision agriculture could fail to dodge each other or even damage crops depending on the actions they take in certain situations, such as when deciding how to treat a blight on the crops.

To **avoid creating systems that perpetuate social inequities** or only allow for a few logic types, AI requires interdisciplinary discussion that includes diverse perspectives. The current gender imbalance and the skew of talent working in AI being from an IT, maths and physics background may act as an echo chamber. A more diverse talent pool would broaden and assist the development of AI. The same applies to the need to understand and analyse the short and long-term impact of AI on its context of use, particularly when outside of controlled environments, and closer to domestic and social situations.

[31] Amodei et al. 2016

[32] Davey 2018

[33] Stewart 2019

In one way or another, the topics mentioned in this section relate to the relatively new field of trustworthy artificial intelligence that faces challenging aspects regarding privacy, robustness, transparency or ethics.[34] With **privacy,** AI systems must protect raw data as well as new information generated through interactions with them. They must also respect agreements with data owners and regulatory laws, such as the EU General Data Protection Regulation that establishes the principles that sustain a transparent, precise and fair AI to prevent discrimination based on race, health or sex.[35] **Robustness** will ensure that AI systems can cope with errors and handle new situations or attacks. Finally, **transparency** is highly related with the concept of **Explainable AI**, an emerging field that attempts to improve effective decision-making systems by incorporating insights on the data, variables and decision points a system used to make a decision or recommendation.[36, 37] This is one of the concerns of the European Commission and its High Level Expert Group on Artificial Intelligence, which is in charge of delivering the guidelines for the Strategic Plan in AI for EU.[38] The plan includes recommendations on future AI-related policy development and also the ethical, legal, social and socioeconomic challenges that Europe and the world will have to face.[39]

Advances in artificial intelligence through the development of new reliable methods will allow Europe to become a leading global innovator in rights-based, ethical, safe and cutting-edge AI. As an example of the importance of these aspects, TAILOR, the network of research centres for foundations of trustworthy AI, was created in late 2020 under funding from the H2020 program with an overall budget of 12 million EUR.[40] This network, with the participation of several Spanish centres and universities, will increase the joint AI research capacity of Europe, helping it take the lead in trustworthy AI. The Commission's proposals in the next EU multiannual financial framework Horizon Europe (2021–2027) will also open the door to investment in research and innovation in this field.

What these issues clearly highlight is a requirement for leadership on a global level at the intersection of the climate emergency and AI. To take advantage of the opportunities offered by AI while also successfully dealing with the issues and challenges it poses will require skilled direction.

[34] European Commission 2019a

[35] European Union 2016

[36] Gilpin at al. 2018

[37] Guidotti et al. 2019

[38] European Commission 2021a

[39] European Commission 2018

[40] TAILOR 2021

6. Spain's AI-friendly public sector

Spain, as well as other Mediterranean countries, is in a geographical area that is highly sensitive to the climate-related challenges that lay ahead.

Climate change consequences for Spain

According to Price Waterhouse Cooper's (PWC's) 2015 report, El Cambio Climático en España 2033 (Climate Change in Spain, 2033), the consequences of climate change in Spain in the medium-term include:

- increased heatwaves, floods and droughts
- disruptions in the agriculture, livestock and forestry sectors due to increased diseases and fires, and changes in crop seasonality
- disruption of the tourist industry
- afflictions of coastal areas due to increased storms, and salinisation of adjacent areas due to rising sea levels

The report estimates that during the period 1990 to 2033, Spanish GHG emissions will:

- Under the hypothetical trend scenarios that involve no further actions taken other than those already implemented when the report was published, grow between 72%-83%.
- Under the scenarios that include the full implantation of all planned measures, have a slower rate of growth of between 4%-16%.
- Under the scenarios that include innovation and technological development allowing Spain to make a firmer commitment to reducing emission, decrease between 7%-17%.[41]

However, Spain has a relatively good position when it comes to its ability to apply AI to climate change mitigation and adaptation. Spanish researchers and companies currently have access, even if with limitations, to funding, AI talent, support through governmental programmes and policies, and a governmental commitment to climate neutrality and digital transformation.

[41] PwC España 2015

The Spanish government is showing leadership through policies and strategies pursuing AI technologies and climate change agendas.

The two ministries responsible for overseeing the governance of AI in Spain are:

- The Ministry of Economic Affairs and Digital Transformation. Specifically, the Secretary of Digitalisation and Artificial Intelligence, created in January 2020, handles the ministry's AI-related affairs having a mandate to articulate policies and initiatives that can lead the digitalisation of society and the economy while promoting and regulating digital services and the digital economy.[42]

- The Ministry of Science, Technology, Innovation and Universities. In 2019 the ministry published the Spanish Research, Development and Innovation (RDI) Strategy for AI, as other countries have done in recent years. As the strategy acknowledges, AI will most likely be responsible for "the rapid transition to a new society and economy".[43]

The ministry responsible for climate change adaptation and mitigation is:

- The Ministry for Ecological Transition and the Demographic Challenge. Created in 2018 (at the time only as the Ministry for Ecological Transition), the ministry evokes the transition towards a new industrial, economic and social model that is more sustainable and climate neutral.[44, 45]

The 2025 Digital Spain strategy, released at the end of July 2020 by the Ministry of Economic Affairs and Digital Transformation, supports the objectives of these three ministries. It offers an ambitious plan to invest in Spain's ongoing digital transformation, aligned with the digital policies defined by the EU's Shaping Europe's Digital Future plan. The strategy has a five-year timeframe and a budget of 140 billion EUR.

2025 Digital Spain seeks to lead and support a productive and structural transformation of the state, economy and society in Spain and has AI as a common element to most of its 10 strategic axes, similar to the priorities of the ministries mentioned above. Overall, the strategy aims to transform Spain into a global reference for the data economy, developing and supporting AI as an innovation and economic growth accelerator while remaining inclusive and sustainable.[46]

In total, 5 of 2025 Digital Spain's 10 strategic axes closely relate to AI and the climate emergency:[47]

1 **Digital connectivity** – Reference is made to the importance of supercomputation for climate change modelling with Spain as a part of Europe's supercomputational backbone.

[42] Ministry for Territorial Administrations 2020

[43] Ministry of Science, Innovation, and Universities 2019

[44] Ministry for Ecological Transition and the Demographic Challenge 2020b

[45] Ministry for Territorial Administrations 2020

[46] Government of Spain 2020d

[47] Ibid.

4 **Cybersecurity** – Over the next 5 years there, will be an emphasis on training 25,000 new cybersecurity, AI and data specialists strengthening Spain as one of Europe's business capacity centres. Cybersecurity is core to any data or AI strategy and infrastructure.

5 **Digital transformation of the public sector** – The digitalisation of public services should provide more streamlined and sustainable services, but also services that are more personalised to the needs of each citizen.

7 **Accelerate the digitalisation of the production model across strategic sectors** – The strategy aims to accelerate the digitalisation of strategic economic sectors while reducing the sectors' carbon footprints. This will facilitate coordination mechanisms, help build efficiencies and create synergies.

9 **Data economy and AI** – The overall objective is to assure that by 2025, at least 25% of Spanish companies will have data and AI at the core of their business model. This includes sectors such as health, agriculture and environment.

In July 2020, The Ministry of Economic Affairs and Digital Transformation also announced the creation of the Artificial Intelligence Advisory Board. Comprised of Spanish experts, the board's purpose is to provide advice and recommendations and contribute to the implementation of the National Strategy for Artificial Intelligence, taking as a starting point the 2019 Spanish RDI Strategy for AI.[48, 49]

For the most part, the Ministry of Science, Technology and Innovation's Spanish RDI Strategy for AI focused on identifying priority areas for AI innovation and infrastructure and to measure progress in these areas. The strategy did recommend the use of AI as a lever to achieve the UN's SDGs, five of which,) — SDG 7 (Affordable Clean Energy), SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), SDG 14 (Life Below the Water) and SDG 15 (Life on the Land) — have particular relevance here.[50]

Beyond the national strategy, Spain's autonomous regions have been consulting with experts and developing their own AI strategies. Such plans are at different stages of development. For example, the Artificial Intelligence Strategy of the *Generalitat Valenciana* (Valencian Regional

[48] Government of Spain 2020e

[49] The Spain Journal 2020

[50] Ministry of Science, Innovation, and Universities 2019

Government) was presented in December 2019 and has been developed with three objective characteristics: to design an AI that is “competitive”, “focused on people and the planet’s sustainability” and “inclusive”.[51, 52] Catalonia launched its 10 million EUR Catalonia.AI strategy and programme in 2020.[53, 54] The Basque Country is working on an advanced strategy draft that is yet to be launched.[55]

[51] Generalitat Valenciana 2019a

[52] Generalitat Valenciana 2019b

[53] Government of Catalonia 2020

[54] Pueyo Busquets 2020

[55] Euskadi.eus 2020

7. Spain has good access to AI expertise and talent

Spain is in the top 20 countries for AI talent, with AI experts in Spain comprising 2.6% of a 2018 survey of 36,500 LinkedIn profiles.[56] Furthermore, 8% of the Spanish pool of experts surveyed in the 2018 Global AI Talent survey had made an outstanding contribution to AI, placing Spain in the top 10 countries in terms of relative quality.[57]

Spain achieves these numbers by retaining its own top talent while also attracting talent from elsewhere. A survey of attendees across multiple AI conferences, which looked at where AI experts studied and where they worked, showed that Spain was a net importer of talent, with AI talent moving to Spain at a higher rate than Spanish talent was moving away.[58]

In terms of gender, the Global AI Talent Report 2019 reported that 26% of conference papers from Spain were written by female authors. While this may seem low, it represents the most gender-equal country in the survey, with the next closest countries, Taiwan, and Singapore both at 23%, and is significantly higher than the global mean of 18%.[59]

Spain also hosts a unit of the renowned European Laboratory for Learning and Intelligent System (ELLIS) network in Alicante, which includes “the very best European academics” in the field.[60] This unit is led by Nuria Oliver and enjoys a strong focus on talent and exchange of researchers with other ELLIS units.[61]

When it comes to access to talent and the exchange of researchers, it is worth mentioning the European Digital Innovation Hubs (DIHs), designed with the digital transformation of European companies in mind. Each hub’s objective is to support “companies [to] improve their processes, products and services through the use of digital technologies”, organised around highly specialised thematic areas in an ecosystem of research centres and industry.[62] Several of the already fully operational DIHs in Spain focus on AI and sustainability.[63]

Of the professionals interviewed for this report, most senior staff in the field had a higher education background, although not necessarily, in computer sciences. Physics and mathematics backgrounds are also prevalent. Around the world, about 28% of self-reported AI experts on LinkedIn had formal training in computer sciences, the others coming from related disciplines such as, indeed, physics and mathematics.[64]

[56] Kisser and Mantha 2019

[57] Ibid.

[58] Ibid.

[59] Ibid.

[60] ELLIS Society, n.d.

[61] Torre Juana OST 2020

[62] European Commission 2021c

[63] European Commission 2020b

[64] Kisser and Mantha 2019

Spain also has a relatively high ratio of industry led AI contributions compared to those from academia. With 28% of AI contributions coming from industry and 72% coming from academia, industry is contributing towards AI in Spain much more than it is in other countries.[65] For example, in China, 90% of all high impact research comes from academia. All countries see the most impactful AI coming from academia rather than industry with France's 30% of impactful research coming from industry representing the highest contribution of all.

Although academics interviewed for the report were more likely to have the impression that Spain is a hostile environment to innovation and excellence in AI and other fields, the businesspeople interviewed for this report did not see talent as a major bottleneck for their projects. Most of the academic complaints related to a lack of funding and brain drain while, seemingly, businesses see AI as an exciting area where many people want to work.

[65] Kisser and Mantha 2019

8. There are multiple sources of funding available to Spanish projects

Government and public funding comes in many forms such as grants, subventions, deductions, loans, guarantees and equities, prizes and public contracts. This funding can also be made available by different levels of governments and public institutions. However, when it comes to AI and climate change in Spain, the EU is a major source of funding at transnational, national, regional and local levels.

European funding, therefore, plays a major role in sustaining both AI academic research for excellency projects and providing seed funding for AI start-ups. In many cases, Spanish funding complements this.

While there is funding available, the landscape is very competitive, and applying with at least the potential of success is a resource-intensive process. Applications can be out of reach for many without guidance, networks, proven traction, or the offer of clear innovation with significant benefits.

European Commission funding programmes

Recently concluded, Horizon 2020 (H2020) was the EU's Framework Programme for Research and Innovation. It was the biggest European funding programme to date, with almost 80 billion EUR of funding available over seven years between 2014 and 2020. Funding through H2020 focused on three key areas: excellent science, industrial leadership, and societal challenges with funding allocated through several different subprogrammes.[66]

There were four main types of European Research Council grants, which were particularly important for research. These were: starter, consolidator, advanced and synergy grants, with endowments between 1.5 million EUR and 2.5 million EUR. The ERC also adjudicates smaller proof-of-concept grants with endowments of 150,000 EUR.[67]

The ultimate and largest H2020 call, assigned a 1 billion EUR budget, is of particular relevance here. The European Green Deal Call, launched in September 2020 as a response to the Covid-19 derived crisis aims to support Europe's recovery "by turning green challenges into innovation opportunities".[68]

[66] European Commission, n.d. e

[67] European Research Council 2017

[68] European Commission 2020c

With its first work programme announced in February 2021, Horizon Europe, the new research and innovation framework for 2021-2027, started a roll-out of over 100 billion EUR of funds.[69] In this program, sustainability, ecology and attention to climate change are essential priorities present in a direct way (tackling climate change represents 35% of budgetary target) and in a transversal way throughout the program.[70] Specifically, within *Pillar 2* of the program (Global Challenges and European Industrial Competitiveness), research and innovation is grouped into 6 clusters of activities:

1. Health
2. Culture, Creativity and Inclusive Society
3. Civil Security for Society
4. Digital, Industry and Space
5. Climate, Energy and Mobility
6. Food, Bio-economy, Natural Resources, Agriculture and Environment[71]

Clusters 5 and 6 are directly related to climate change and sustainability, and cluster 4 is central to AI and other information and communication technologies (ICT). However, the concern to impact any of the SDGs is present in all clusters with certain SDGs specifically marked as objectives of the activities. Similarly, data and AI related topics, considered key enabling technologies, are spread all over the clusters.[72]

On the other hand, the program defines five missions as a set of interdisciplinary actions to solve pressing challenges in society within a certain timeframe and budget. There will be hundreds of pilots launched in search of innovative solutions for each of these missions during the coming years. Four of these missions, again, are related to climate change and natural ecosystems. These are:

- Adaptation to climate change including societal transformation
- Healthy oceans, seas, coastal and inland waters
- Climate-neutral and smart cities
- Soil health and food[73]

There are also significant funding opportunities in the Digital Europe Programme — an EU initiative to support the digital transformation of society, "focused on building the strategic digital capacities of the EU and on facilitating the wide deployment of digital technologies". This includes the Digital Innovation Hubs mentioned earlier and has 9.2 billion EUR of funding in place between 2021 and 2027.[74, 75]

[69] European Commission 2021e

[70] European Commission 2019b

[71] European Union 2020

[72] Ibid.

[73] Ibid.

[74] European Commission 2021d

[75] European Commission 2021f

Funding in Spain

The Spanish Strategy for Science, Technology and Innovation 2021–2027 was announced in September 2020.[76] One of the main points worth mentioning is the new public commitment "to double the sum of public and private investments in research and development" compared to 2018 levels. Doing so would mean investments of 2.12% of GDP by 2027.[77] As a direct consequence of the effects and consequences of the Covid-19 pandemic, the strategy is divided into two phases:

- The first phase, 2021–2023, will focus on the health sector as well as on strong investment to support the ecological transition and digitalisation, aligned with the EU strategy.
- The second phase, 2024–2027, will aim to strengthen the national foundations and enable a knowledge-based economy.[78]

Two of the six strategic sectors of action are of particular relevance here. They are:

- Climate, energy and mobility: fight against climate change, decarbonisation, mobility and sustainability
- Food, bio-economy, natural resources and environment: from biodiversity to the smart and sustainable agri-food chain and the study of water and oceans.[79]

Additionally, for the period 2021-2023, there will be some relevant funding allocated through the National Strategy for AI. The strategy includes "a public investment of 600 million EUR between 2021 and 2023" and an additional 330 million EUR available through the national budget "for artificial intelligence and the data economy".[80]

In one way or another, it is reasonable to expect numerous financing opportunities for projects on climate change and AI.

The Ministry of Economic Affairs and Digital Transformation offers tax deductions for research and development activities; technological innovation activities; acquisition of advanced technology in the form of patents, licenses, know-how and designs; and obtaining the certificate of compliance with the quality assurance standards of the ISO 9000 series, GMP or similar (not including those expenses corresponding to the implementation of said standards).[81]

Enisa is a state-owned company under the management of the General Directorate of Industry and SMEs. It offers alternative financing to entrepreneurial Spanish SMEs, is a major funder in Spain and was mentioned repeatedly during interviews for this report. Enisa has loaned 1,000 million EUR across over 6,600 businesses. Some notable funding instruments from Enisa include *Enisa Jóvenes Emprendedores* (Enisa Young Entrepreneurs), *Enisa Expansion* (Enisa Expansion) and *Enisa Desarrollo* (Enisa Development).[82]

[76] Government of Spain 2020a
[77] Government of Spain 2020b
[78] Ibid.
[79] Government of Spain 2020b
[80] Government of Spain 2020c
[81] Ministry of Science and Innovation, n.d.
[82] Enisa 2020

Furthermore, loans for innovation and entrepreneurs are available through some banks. CaixaBank has MicroBank that specialises in microcredits, with 50,000 EUR loans available for businesses. There has also been a recent surge of crowdfunding initiatives, such as la Bolsa Social, Capital Cell, CrowdCube and Startupxplore.

Lastly, other foundations drive the development of projects too. One of them is the *Fundación Biodiversidad* (Biodiversity Foundation) created in 1998, and today part of the Ministry for the Ecological Transition and the Demographic Challenge, which manages its own financial support for projects in several fields, including climate change and environmental quality.[83]

Since 2014 the BBVA Foundation has also been offering an interesting aid programme to areas including, among others, ecology and conservation Biology, digital economy and society, and Big Data. All of these areas have room for projects on the application of AI.[84]

[83] Fundación Biodiversidad, n.d.

[84] Fundación BBVA, n.d.

9. AI can help the private sector be more efficient and climate-friendly

There are a number of ways that Spain's main export and industrial sectors can benefit from AI applications and climate change adaptation, as shown in figure 4 at the end of this section. The 2025 Digital Spain strategy articulates these opportunities repeatedly as they are core to the strategy itself. However, unless the private sector can grasp the opportunity and understand how and where AI can transform and improve its business and productive models, 2025 Digital Spain will likely only see limited success.

Tourism is Spain's largest export earner with international tourists spending 92 billion EUR in 2019.[85] Spain is the second most visited country in Europe but as it is a popular holiday destination thanks to its warm weather and beautiful beaches, cities and landscapes, the Spanish tourism industry is dependent on climate and geography. Spanish tourism, therefore, is vulnerable to the effects of climate change.[86]

AI applications related to tourism include using remote sensing to monitor the rise in sea level; modelling expected climate changes to identify areas at risk of flooding, heatwaves or wildfires; improving heating and cooling efficiency through automatic controls, and identifying and prioritising buildings for retrofitting.

The automobile industry is Spain's biggest industrial export.[87] Artificial Intelligence can help design and operate engines to improve efficiency, provide proxies for complex aerodynamics models used in vehicle design, and improve processes for manufacturing lighter vehicle parts.[88] AI can also help improve Electric Vehicles (EVs) by modelling and scheduling charging, integrating EVs into the electric grid, and developing and optimising EV batteries.[89, 90] More efficient petrol vehicles and EVs will contribute to climate change mitigation.

Agriculture and farming is worth more than 49 billion EUR per year to the Spanish economy.[91] AI and precision agriculture can support a transition to less resource-intensive methods, monitor emissions, anticipate the impact of climate change on crops and inform crop diversification.

[85] Ministry of Industry, Commerce and Tourism 2020

[86] Moreno 2019

[87] Harvard Growth Lab 2017

[88] Climate Change AI 2020

[89] Frendo et al. 2020

[90] Climate Change AI 2020

[91] European Commission 2020e

Clean energy is an area where Spain is a world leader both as a technology exporter and as an energy producer. It is mainly energy from wind, but with significant solar and nuclear power as well. There is a lot of potential here. Artificial intelligence can: help improve energy supply and demand forecasts, improve electricity scheduling algorithms, control storage and flexible demand, design real-time electricity prices that reduce CO2 emissions, aid the design of better solar batteries and solar panels, adaptively control the orientation of solar panels and turbines, aid the design of better nuclear reactors, perform predictive maintenance of renewable infrastructure, help manage and oversee the electric grid and more.[92]

Spain's petroleum exports are about 1.3% of world exports. As the world transitions to cleaner energy, demand for petroleum oil is likely to fall. By aiding with the forecast of long-term demand, AI can help inform the economy's transition away from fossil fuels. AI can also help accelerate research into biofuels, as a possible way of transforming the industry.

Spain's large metal industry can utilise AI to reduce GHG emissions from industrial heating, ventilation and air conditioning (HVAC) systems and other control mechanisms via adaptive control, provide consumers information about the carbon footprint of products, and use predictive maintenance on industrial equipment. Specific to metal, AI can help time and energy-intensive powder-coating processes to use renewable energy and help discover climate-friendly alternatives to the current GHG and pollution intensive processes of steel production.

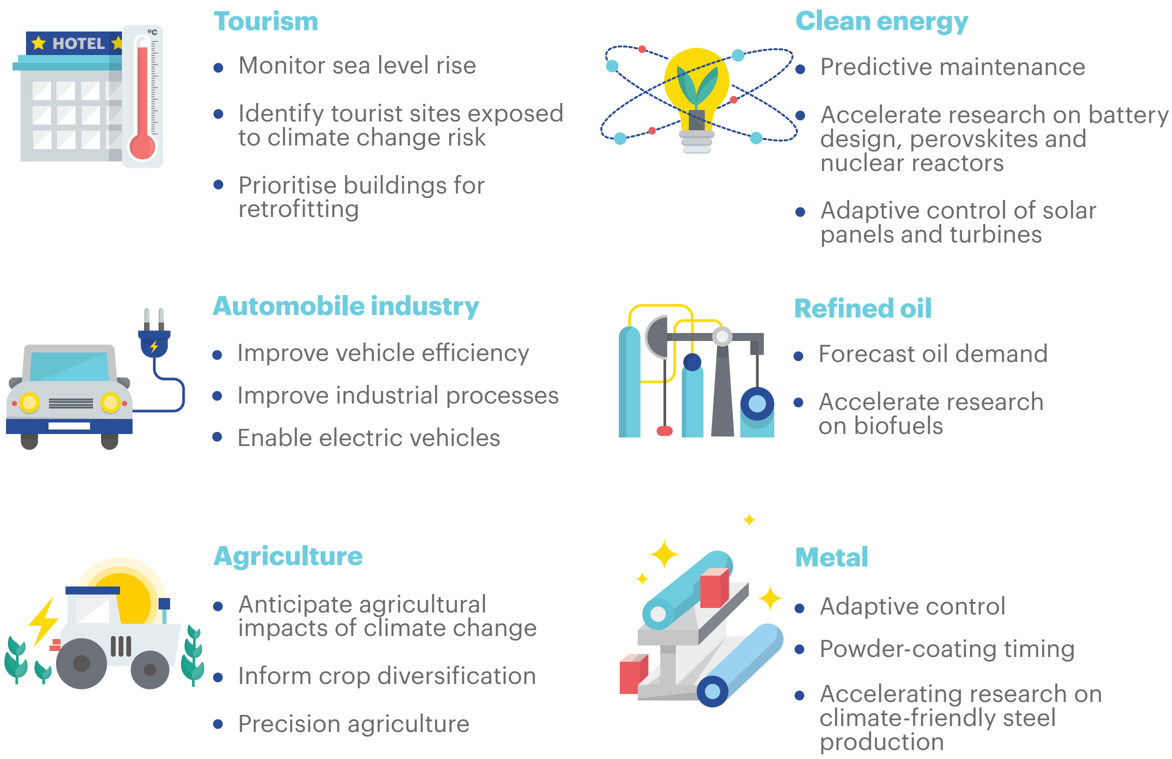

Figure 4: Main Spanish sectors and related AI+CC technologies. Image source: Digital Future Society. Data source: Climate Change AI 2020

[92] Climate Change AI 2020

10. It is already happening: five projects in Spain you need to know about

This section showcases Spanish projects that are addressing climate change adaptation and mitigation using AI:

- **AI for Understanding and Modelling the Earth System (USMILE)**, an international research effort using state-of-the-art hybrid machine learning to improve climate models
- **Orpheus**, formerly known as Maichinery, a start-up developing automatic control of buildings based on machine learning to improve heating efficiency
- **DEXMA**, a scale-up business developing data science solutions for energy consumption efficiency
- **Low carbon at work (LOCAW)**, an example of an interdisciplinary, international, medium-size research project leveraging traditional AI to produce policy recommendations
- **Artificial Intelligence for Ecosystem Services (ARIES)**, a semantic system approach to applying AI to improve our understanding of environmental interactions.

These projects have been selected as they are representative of the range of scopes and capabilities currently working at the intersection of AI and climate change in Spain. They also showcase AI that is investigated, developed and funded within Spain, including through international partnerships, academic projects and start-ups.

Each case study includes:

- A summary of the project and the people involved
- The project's expected impact, based on track record if it has already been deployed, and its potential to scale
- What the project means for Spain.

Figure 5: Map of Spain showing where the case studies are based. Image Source: Digital Future Society.

Case study #1: AI for Understanding and Modelling the Earth System (USMILE)

AI for Understanding and Modelling the Earth System project (USMILE) is an international and interdisciplinary six-year research project to develop hybrid models combining physics and machine learning to improve current climate modelling and projection capabilities.

Roadmap and technology

USMILE is funded by a 10 million EUR synergy grant from the European Research Council (ERC) and led by four international researchers: Gustau Camps-Valls from the Image Processing Lab of the University of Valencia, Spain; Veronika Eyring from The German Aerospace Center (DLR); Pierre Gentine from Columbia University in the City of New York, USA; and Markus Reichstein from the Max Planck Institute.[93] The six-year project started in September 2020 and is divided into four main areas of work.

The Spanish principal investigator, Gustau Camps-Valls, previously received an ERC grant for the project Statistical Learning for Earth Observation Data Analysis. That project, which in many ways was a precursor to USMILE, developed advanced machine learning and causal inference algorithms to process and understand remote sensing satellite observational data and models.[94] USMILE's four main areas of work are:

1. **Land and atmosphere modelling:** Improve land and atmosphere modelling of key essential climate variables, such as biomass, land/air humidity and temperature. The purpose of this work is to achieve a forward leap in modelling precision and uncertainty quantification. It will go from existing models that work at a resolution of $100km^3$ to models working at a resolution of $30m^3$.

2. **Machine learning hybrid models:** Develop data-driven machine learning hybrid models that include built-in physical constraints. This novel paradigm should improve and speed up the most complex climate models. These models could be less expressive than usual machine learning models, to make sure that the model predictions obey certain physical laws. This area of research builds interdisciplinary expert knowledge into the models, which are then adjusted automatically based on data obtained from more complex physical models.

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[93] European Research Council 2019

[94] SEDAL, n.d.

3 **A new climate model:** Develop and validate a new climate model by comparing the inferred causal graph among the variables with the one derived from observations. A second validation test will assess the new model's capabilities to deal with climate extremes and anomalous events like droughts, hurricanes and heatwaves.

4 **Explainability models:** Develop explainability models, aiming to find precursors of extreme events (teleconnections) that will help develop early warning systems and better forecast the future climate from current observations.

Impact and potential to scale

USMILE is explicitly global in scale, and the results will be useful worldwide. The project's most immediate impact should come from an improvement in climate change projection, which will assist with adaptation, specifically through the development of early warning tools to anticipate extreme events.

Beyond its immediate impact, USMILE will push forward the state-of-the-art on hybrid modelling, causal inference and explainability, and could potentially result in more generally useful insights. For example, there is reason to believe the work on physical models will result in novel machine learning architectures that could apply to other fields of science and engineering.

The first two areas of work involve developing new algorithms that build upon the latest advances in deep learning and physical knowledge and represent a useful incremental advance. While the last two are quite ambitious and, therefore, may raise questions of viability, the novelty of the methods employed and the interdisciplinary approach make it particularly promising from a value-of-information perspective.

What this means for Spain

USMILE reinforces the University of Valencia as a strong research institution, working at the cutting edge of machine learning. Besides, ERC synergy grants are prestigious and an indication of remarkable talent. Furthermore, an initial ERC grant for a Spanish team/university also leads the way for future grants and further international collaboration and impact.

Case study #2: Orpheus

Orpheus, formerly known as Maichinery, is an early-stage start-up from Girona working on hardware and software solutions to monitor, regulate and optimise energy use in public buildings. The system uses sensors to receive information and has a dashboard for monitoring and reporting. After installation, it has a 15-day training period while it calibrates itself to the building, and then continuously learns afterwards. The system learns each action differently and governs with a unique handcrafted system. To maximise the impact of the project, Orpheus focuses on public buildings that rely on outdated heating systems.

Roadmap and technology

Cofounded by two AI engineers and launched in 2019, Orpheus has since expanded to a team of six. The system has been installed in 10 buildings, with a goal of 500 by 2023. The start-up has received financial support from Enisa's Jóvenes Emprendedores programme, in the shape of a 90,000 EUR loan and has also participated in two accelerator programmes, Ship2B and EIT Innoenergy.

Orpheus's primary product is the virtual concierge platform under the same name Orpheus that works with long-range sensors that can be attached to any surface, and long-range thermostat actuators (control mechanisms). It typically only takes two hours to set up the platform and sensors. The Orpheus platform collects data from the sensors and takes actions to control the temperature automatically or alert the owners of anomalies. The system has adaptive control over actions, such as turning on the thermostat in the morning, turning it off at night, maintaining the target temperature or alerting the owner of humidity anomalies, etc.

To prevent extrapolation to situations the system does not understand, it ranks the situations it faces against the situations it has faced in the past. If it decides the current situation is anomalous, the system reverts to its default programming instead of making a novel decision. For example, if the temperature outside is unusually cold, and the system has not trained with similar temperatures, it will turn on the heating as pre-programmed by the customer and learn from the action instead of taking autonomous action. This is an example of safe exploration.

The Orpheus platform is a practical example of task-based AI innovation and the opportunities that exist for current AI research and AI products. It utilises adaptive control to calibrate the temperature, safe exploration to decide when to let the AI system take decisions instead of resorting to the default configuration, and few-shot learning that calibrates the system in a short time.

[96] MacKay 2008

Impact and potential to scale

Improving heating and cooling efficiency is one of the most effective levers for climate change mitigation.[96] While retrofitting buildings with better insulation is generally the first step to reduce the heating and cooling footprint of a building, heating, ventilation and air conditioning (HVAC) controls can still play a part to further optimise energy usage. The Orpheus team estimates a 10-15% decrease from heating and cooling emissions in buildings with their system.

They plan to expand their product to control illumination and other aspects within the building. However, in terms of emissions, it is expected that heating and cooling efficiency gains will vastly dominate.

The Orpheus team's focus is on developing a scalable product that is compatible with a broad range of buildings and requires minimal installation and configuration. This is favourable in the short-term when compared with more traditional solutions such as insulation, which require a large upfront installation cost.

Currently, Orpheus is working with local clients, with plans to expand nationally.

What this means for Spain

Orpheus's history and product is an example of Spain's increasingly dynamic start-up culture, which enables people to turn their expertise into products.

The support they received is a recipe for success that other Spanish innovators can follow. In particular, the accelerator programmes the team participated in have been critical for their success. Through them Orpheus was able to build a network that they have successfully leveraged for mentorship and funding.

Case study #3: DEXMA

DEXMA is a medium-sized software company based in Barcelona using control application and predictive methods to offer data science-based products for demand-side energy consumption efficiency management. It has approximately 50 staff members and has served 4,000 organisations in over 30 countries.

Roadmap and technology

DEXMA was created in 2007 by a team of computer engineers. After experimenting with different verticals, the team set up as energy efficiency software specialists in 2010. Currently, with its existing client database, DEXMA monitors about 100,000 buildings.

The company's first product, DEXMA Analyse, was a data visualisation interface offering statistics and analysis of energy consumption patterns in real-time for commercial and industrial organisations. It has since added two more products, DEXMA Detect and DEXMA Optimise.

DEXMA Detect is a product that leverages DEXMA's existing client database to create accurate insights and predict potential efficiency gains for new clients. The system clusters similar clients together and collates their data including a site's consumption patterns, weather and geographic data to detect the areas that offer the greatest energy savings.

DEXMA automates the energy audit process with AI, segmenting a business's property portfolio and deciding which sites have the most potential for energy savings. It uses non-intrusive load monitoring (NILM) AI models to disaggregate data consumption virtually and remotely and use AI-informed models to calculate savings.

DEXMA Optimise is an anomaly detection product that uses a neural network to flag unusual energy consumption automatically. Using a year's existing energy consumption data and sensors (datapoints) placed around the building, DEXMA Optimise trains an AI model for that building. It incorporates temporal features (time, day of the week) and optional additional information (weather and holiday information), to create a statistical model that estimates the expected range of consumption. It retrains the model automatically every month and alerts the company when an anomaly is detected, understanding that not all differences are anomalies and knowing when to alert the company.

Rather than breaking new ground in terms of AI development, DEXMA is leveraging state-of-the-art AI models to help organisations worldwide reduce their climate impact.

DEXMA has a sizable research and development (R&D) department and has been involved in 13 energy efficiency projects over the last five years. To support its R&D efforts, DEXMA has received over 800,000 EUR from the EU's Horizon 2020 programme. To access funding to scale and internationalise, DEXMA also received support through *Spain's Centro para el Desarrollo Tecnológico Industrial, CDTI* (Industrial Technology Development Centre), as well as additional support through the EU's Eurostars programme.

Local support has come through *Catalonia's Acció: Nuclis and Comunitats de l'energia* (Energy Communities) programme that assisted DEXMA in gaining Horizon 2020 funding through the SME Instrument Programme.[96]

Impact and potential to scale

With DEXMA installed in 100,000 buildings internationally, its assessments and recommendations have a significant influence over energy usage, and therefore GHG emissions, around the world. DEXMA's impact, however, is indirect as it works via providing information, recommendations and warnings that the building managers then follow up on.

Companies like DEXMA can play an important role in motivating building owners to take the necessary steps to make their buildings more efficient. The DEXMA project DREEAM, targets a 70% energy demand reduction based on technology recommendations, financial capacity, tenant preference, energy systems including energy demand reduction, renewable energy generation, energy storage and dynamic control.[97]

What this means for Spain

DEXMA is an example of a Spanish company working internationally in the fiercely competitive energy efficiency industrial sector. It has succeeded in penetrating this market using software services, while focusing on climate change reduction as a company goal.

It showcases how, through innovation and scale-up funding from European, national and regional programmes, Spanish start-ups can innovate and succeed in a competitive environment.

DEXMA is now preparing to connect with new and emerging initiatives and programmes such as the DataHub, and other coordinated projects that the Spanish and European governments may put forward to promote sustainability in companies.[98]

[96] Acció, n.d.

[97] DEXMA 2020

[98] Datahub 2020

Case study #4: Low Carbon at Work (LOCAW)

LOCAW is an interdisciplinary project that used agent-based modelling to understand behaviour patterns around energy and materials consumption, waste generation and management, and work-related mobility in the workplace.[99]

Roadmap and technology

LOCAW involved seven research organisations: University of A Coruña, Spain (main coordinator); Umeå University, Sweden; West University of Timisoara, Romania; University of Surrey, UK; Macaulay Land Research Institute, UK; University of Groningen, Netherlands; and the Center for Inter-University Research on Environmental Psychology of Sapienza University of Rome, Italy.

In total there were 42 researchers working on the project, with Ricardo García Mira, from the University of A Coruña, as the main coordinator.

The LOCAW project involved six case studies of organisations within heavy industry, the public sector and private service. The project then analysed unsustainable and sustainable behaviours and practices in those workplaces to identify the factors that determine these actions. These were then put into an agent-based model to clarify interactions and provide insights into the conditions required to achieve a transition to a low-carbon Europe. These insights fed the design of an agent-based model that is an abstract simulation involving components that interact in specific pre-programmed ways. An example is a model of how likely a person is to decide to follow a specific climate-related recommendation, such as using public transport instead of commuting by car.

The agent-based model was developed to test the assumptions derived from the empirical research as well as to dynamically test policies that could contribute to effective change in everyday practices.

The model involved the design of agents that interact with one another and react in predetermined ways, according to parameters inferred by the previous interdisciplinary research. For example, interventions either restricting or making car use less attractive through an agents' model, where the agents are people deciding whether or not to use their vehicles based on their personal sensibility to policies and the decisions of their peers. These sensibilities went into the model based on previous surveys, discussion groups and organisational documentation.

Internally, the agents are modelled using a decision tree and learn their behaviour automatically based on the data collected in surveys. This approach has a very distinct advantage of being highly interpretable, facilitating later examination and modification by domain experts.[100]

[99] Low Carbon at Work 2020

[100] Domeisen et al. 2018

The project received almost 1.5 million EUR in funding from the European Union's seventh Framework Programme.[102]

Impact and potential to scale

While this research did not break new ground in AI, that was not the goal of the project. LOCAW is a very interesting example of how to integrate research insights originating from computer models into decision making.

For example, their decision trees illustrate what factors individuals are more sensitive to when deciding whether to follow a recommendation. They found, for example, that biospherism, worrying about the environment for its own sake, is a more important factor than altruism when deciding whether to commute by car. This finding can then be used to help tailor public transport campaigns that appeal to a wider audience.

The LOCAW models have to be finetuned at regional level, but the methods developed can be repeated elsewhere. The LOCAW methodology provides a systematisation of a complex modelling process that allows understanding of the emergent effects that arise from the interaction of the simultaneous implementation of different policies.

The models are currently influencing policy. LOCAW reached an agreement with one of the case study organisations, the University of A Coruña, to work together to implement specific measures to support transitions to sustainable practices in the University, like hiring procedures that value biospherism, thus having a direct impact.

LOCAW tools provide active insights and a way for people to think through the impacts of different environmental policies. However, conclusions can arise by virtue of the assumptions baked into the model and the previous interdisciplinary research conducted to collect the data needed to adjust the model. This means it can be difficult to ascertain the counterfactual impact of LOCAW, especially from their agent-based models.

Regardless, LOCAW remains as a remarkable example of socially aligned interdisciplinary research.

What this means for Spain

The LOCAW initiative not only shows remarkable research talent, but also a willingness from Spanish public institutions and private companies to collaborate in order to test out different environmental policies. There is a willingness to invest in environmental issues that Spain should foster and develop. One particular strength of this project is its interdisciplinary nature, as it involves psychologists, which can be a fruitful bed for further collaboration.

[102] Cordis 2020

Case study #5: Artificial Intelligence for Ecosystem Services (ARIES)

Based on a simple user query, ARIES builds all the elements involved in the interaction between nature and society. It then connects them into a flow network to create the best possible models for each element and interaction. The result is a detailed, adaptive and dynamic assessment of how nature provides benefits to people and society.

ARIES chooses ecological process models where appropriate, turning to simpler models where process models do not exist or are inadequate. It is not a model but rather a creator of models and collections of models.

There are two components to ARIES:

- A semantic database of datasets and model components that employs rule-based AI to build data flows from user queries automatically, choosing between alternate solutions using automatic and hand-designed criteria.
- An infrastructure to design and host interactive sustainability simulations to study complex phenomena such as hydrological models, which can be used as dynamic components in the model building framework above.

Roadmap and technology

The ARIES project started in April 2007 at the University of Vermont, USA, supported by a 1 million USD grant from the US government's National Science Foundation. A prototype of the model building system was developed over the following year, and a functional prototype was made available online in 2012.

Eventually the team moved to the Basque Centre for Climate Change (BC3), where the technology has continued developing ever since. The team is small with the ARIES team recently expanding from 10 members to 19.

The core functionality of ARIES involves a semantic engine. Users can upload databases and models implementing a typed input/output relation. Users can later query the system by introducing the type of output they want, specified in their own declarative language, called k.IM.

The inference engine resolves how the different databases and models can be pieced together to obtain the input specified by the user, and select one of them based on handcrafted automated criteria. The criteria accounts for some objective and subjective metrics (eg the amount of data available or the data quality, respectively) and the inference engine returns the composite model that scores highest under this criteria.

Beyond that, the broader system k.LAB is an infrastructure designed to host interactive simulations – abstractions of physical systems that interact with one another in predefined ways to model more complex phenomena.

ARIES can, for example, be used for flood risk early warning systems, which is relevant for climate adaptation to manage the expected increase of flooding events.[102, 103]

Some future plans for the project include:

- Augment the selection criteria with machine learning. This is likely to be a direct trade-off between transparency and efficiency of the inference engine.
- Work with some states to implement using the ARIES technology, a System of Environmental Economic Accounting (SEEA), following the UN's standards.[104]
- Expand the system to work on other problems.

Impact and potential to scale

Unusually for an academic project, ARIES is focused on designing a product.

The system they have developed can be thought of as a transparent and automatic way of combining curated models and data collection. In this sense, it does not replace but rather augments current modelling efforts.

This puts it in a unique position, where capacity for impact is tightly joined to ability to convince and coordinate a community to develop models together.

Semantic models and expert systems similar to ARIES were extensively researched and ultimately abandoned in the last century. However, there is significant value in infrastructure hosting expert-designed and reusable ecosystem model components. Furthermore, the situation has changed a lot since expert models were last considered in the 90s.

ARIES technology has garnered a moderate amount of support and interest from government, academia and industry. This is a promising sign. However, the project is quite limited in resources and bottlenecked on talent. Additional financial support would help to hire engineers and social managers that would help them create a thriving open-software community.

ARIES is a tool that could be useful beyond its original scope of application and that may improve scientific efforts in a wide array of disciplines. From a climate change perspective, it is expected that this initiative can provide insights related to climate change mitigation and adaptation.[105]

[102] Balbi et al. 2015

[103] Balbi et al. 2016

[104] SEEA, n.d.

[105] See Balbi et al. 2015 for an example of where the ARIES tool is used to find out how to implement carbon sequestration agricultural practices with small impact on yield and Aries 2020 for more examples.

What this means for Spain

ARIES is an example of a project that started elsewhere but was then able to move forward in the environment and resourcing Spain is able to offer. By design, ARIES is attempting to create a community of practice around its technology, that if successful will position the BC3 as an international reference in ecosystem services. There is also a chance for the technology to flourish beyond its scope and have an even greater impact, which is a hallmark of an important project.

The degree of flexibility and ongoing support provided by the Basque Government has been critical and will continue to be critical for the further development of this technology.

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