Deep Dive 'Climate Change, Research, and Innovation: Radical Options from Social Change to Geoengineering'

Final Report

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Foresight On Demand

Introduction & Approach

Climate change impacts are among the most significant contemporary threats to human society and natural ecosystems. There is scientific consensus that human-induced climate change (including more frequent and intense extreme events) has caused widespread adverse impacts and related losses and damages to nature and people, beyond natural climate variability[1]. However, recent developments such as the COVID-19 pandemic, the war in Ukraine, as well as insufficient global commitments to curb the climate crisis leave many open questions on the future success of climate mitigation[2] and adaptation[3], both in Europe and globally.

Current policies presently in place around the world are projected to result in between 2.5 and 2.9°C warming above pre-industrial levels (e.g. Climate Action Tracker, 2021). This would most likely trigger multiple climate tipping points and lock the Earth system on an uncontrollable and dangerous pathway to the climate crisis – a situation characterized by the threat of highly dangerous, irreversible changes to the global climate with severe implications to the nature and society.

This report discusses alternative scenarios on future developments related to climate mitigation and adaptation. It is part of the foresight project conducted by the "Foresight on Demand" Consortium on behalf of the European Commission, DG RTD to help prepare the 2nd Strategic Plan 2024-2027 of the

[1] IPCC, 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability, https://www.ipcc.ch/report/ar6/wg2/

[2] A human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs) (IPCC).

[3] The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC).

Horizon Europe Framework Programme for R&I. This report summarises the outcomes of the expert teamwork in the Deep Dive area "Climate change and R&I: from social change to geoengineering" conducted between June and October 2022.

The expert teamwork started with the exploration of the factors of change **(See Annex I)**, which provided a basis for the first workshop to construct the framework of the scenarios on alternative future states in 2040. This, in turn, provided a foundation to write four scenario narratives presented in this report. The second and third workshops were then organised to illustrate for each scenario a pathway from the present to 2040. The final workshop was organised together with the Horizon Europe Foresight Network and external climate change experts to assess the implications of the scenarios to stakeholders and R&I policy.

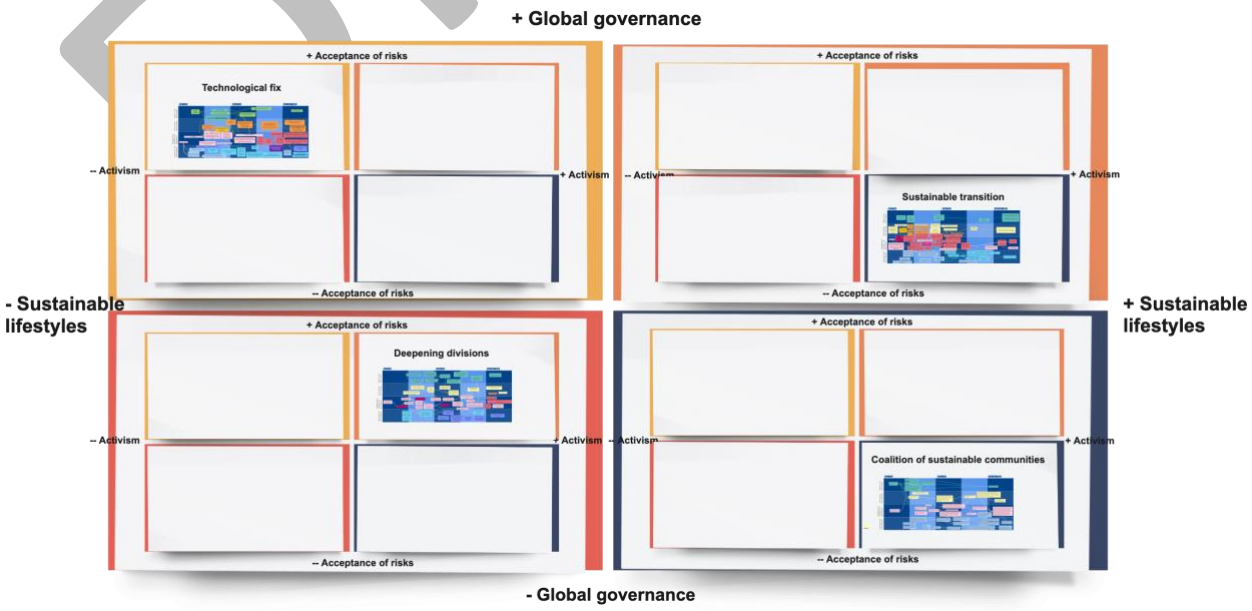
Scenarios

The four scenarios were developed to explore radical, but plausible, new research and innovation (R&I) activities in the second part of the framework programme (2024-2027) that could help curb the climate crisis between now and 2040. The method encouraged consideration of what practices need to be scaled down and ways to overcome existing sociotechnical lock-ins. Attention was paid to currently marginal and unexploited practices, either social or technical, which may gain momentum should climate impacts (see Annex I, Section 2.1 on the classification of impacts by IPCC) aggravate towards 2040, and current practices fall short of curbing the climate crisis. To have sufficient impact, such changes need to be large-scale and global, posing new challenges to all levels of governance from local to global.

To start with the scenario work, among the diverse factors of change, four key dimensions were identified:

- Global governance: Global governance of climate change
- Sustainable lifestyles: Sustainable lifestyles and consumption
- Acceptance of risks: Acceptance of risks in the experimentation of climate innovations
- Activism: Civil activism in its wide range of forms from legal to illegal

The figure below illustrates the key dimensions of each of the four scenarios, which are presented subsequently.



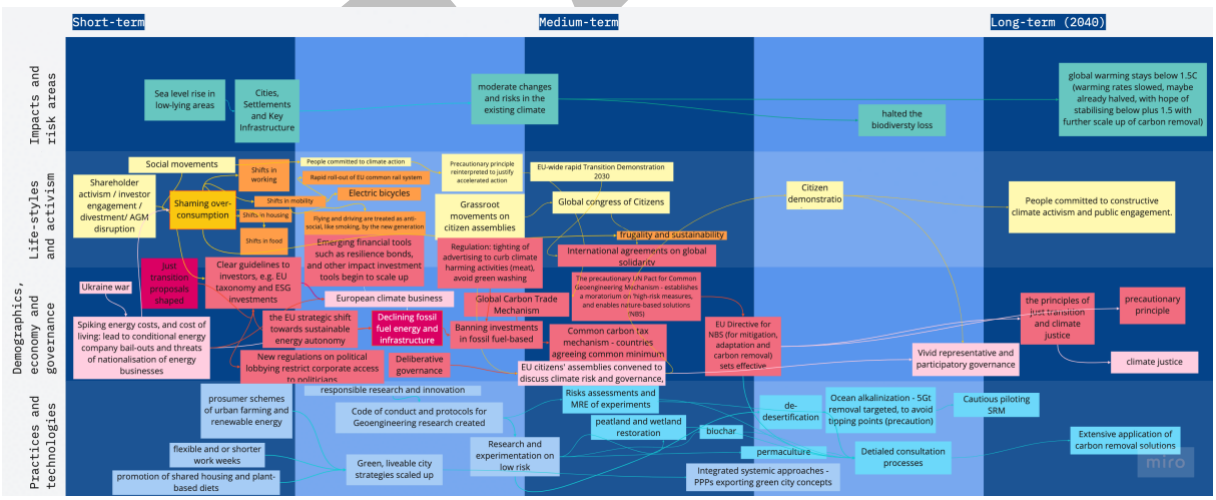
1. Sustainable Transition

Scenario dimensions

Strong global governance; Sustainable lifestyles; Adverse to risk-taking; Vigorous activism

In a nutshell

In the Sustainable Transition, the European Union is a global leader in climate policy, having successfully curtailed together with other countries the greenhouse gases and avoided the most catastrophic climate tipping points. It has also dealt with moderate climate impacts through successful adaptation. Europe is driven *by a strong engagement from civil society which has become institutionalised in citizen assemblies guiding decision-making towards sustainability and frugality with a strong emphasis on climate justice. Responsible research and innovation policy has incentivised testing carbon dioxide removal options, which has led to the implementation of nature-based solutions at a large scale across Europe. The reinterpretation of the precautionary principle is supported by the development of global frameworks and EU directives, as well as rigorous impact and risks assessments of pilots. These eventually lead to the adoption of less risky options across the Union and, as a by-product, to the lucrative exportation of climate innovations globally.*



Impacts and risk areas

In 2040, global warming stays **below 1.3°C** above pre-industrial levels and is expected to stabilise below plus 1.5°C. While this results in broadly moderate changes and risks in the existing climate, in some areas like coral reefs and glaciers impacts are severe. Hazards in Europe are visible in key exposure areas, as diverse as mountains, cities, and agriculture, occasionally affecting key infrastructure. Hazards include increased **heatwaves** that affect human health and the agricultural sector, which have been identified and necessary adaptation has taken place, resulting in low to moderate damages. Regional climate risk assessments are regularly employed to assess how much adaptation is necessary.

Demographics, economy and governance

High levels of mitigation and adaptation were driven by the EU's strategic shift towards sustainable **energy autonomy**, accelerated by the war in Ukraine in the early 2020s. These led to declining fossil fuel production and use, both of which were eventually banned at the beginning of 2030. Simultaneously there was an emergence of **European climate business** with global opportunities.

Sustained social change began to take hold in the 2020s. What started with the **shaming of overconsumption of multimillionaires** extended across society with shifts in working, mobility, housing and food cultures, demanding changes in infrastructure and urban planning. Guidelines issued for European businesses, such as the EU Taxonomy and environment, social and governance (ESG) focused investments have heavily influenced and steered businesses towards more sustainable practices for several decades. This has encouraged European climate business to grow and lead the global markets, supported by decades of joint research and development towards just transitions. The EU has been successful in **leading global governance efforts in climate policy** and major powers like the US and China have joined forces to push other countries to strengthen their commitments. The countries have also ratified the Global Carbon Tax Agreement and **the precautionary Global Pact for Common Geoengineering Mechanism**. The former aims to alleviate past injustices by using proceeds for restorative climate and development measures globally. The latter provides a forum to discuss geoengineering approaches transparently. All this is backed by international financial cooperation for mitigation, adaptation, and loss and damage compensation, ensuring also funds for developing countries, who are bearing the brunt of the climate impacts.

Within the EU, the institutional redesign has drawn heavily on the principles of just transition and climate justice, building-wide support for climate action. At the local level, **citizen assemblies** are a common way of engaging people. They start initially through local action but become part of official decision-making processes and spread globally to conduct just climate policy. These assemblies become institutionalised within the EU climate decision-making in the 2030s.

The so-called EU-wide **Climate Barometer+** is a deliberative policy tool which gauges European public opinion and is rarely ignored when decisions are made in terms of climate policy. It is employed Union-wide at regular intervals to gauge the public opinion and acceptability of climate policy. These include risk acceptance surveys of climate policy (strategy and implementation), and although the results are not legally binding, they nevertheless raise the level of compliance with policies across the Union. Acceptance of risk continues to be low, steering the options towards the “precautionary principle” and also screening out some climate solutions. This process leads to a **re-interpretation of the precautionary principle towards avoiding the most catastrophic climate tipping points and thus opening the door to experimentation** and testing of nature-based solutions alongside rapid emissions reductions.

Practices and technologies

Official climate policies have taken up many initiatives of civil movements, among others flexible and or **shorter work weeks, promotion of shared housing and plant-based diets**. Furthermore, the advances in responsible research and innovation to ensure the social acceptability of new practices and technologies have supported the rapid diffusion of prosumer schemes of urban farming and renewable energy micro-grids and mobility, for instance. During the 2030s, these trends lead to **integrated systemic approaches** building on synergies between adaptation and mitigation and broader sustainability and have resulted in green, liveable and walkable cities, and neighbourhoods. The fostering of climate business and the resulting European public-private partnerships are ‘exporting’ this know-how, widely requested across the world with supported social innovations and mechanisms of deliberative democracy for informed decision-making.

The EU climate policy portfolio also includes some less risky geoengineering options, which are heavily scrutinised through socially responsible research and innovation policy. This means that protocols and ethical guidelines developed in the late 2020s needed to be adhered to by public and private actors. Research funding is allocated to small-scale trials to gauge the potential impacts of different carbon dioxide removal techniques. The trials include compulsory risk and impact assessments, and their acceptability is also assessed through deliberative tools before they are piloted. The social and environmental impacts of any new geoengineering are assessed based on **the Directive for NBS (for mitigation, adaptation and carbon removal)**, which sets effective standards and mechanisms to prevent undesirable side-impacts.

Past the piloting and experimentation phase, as protocols have been accepted, these options are taken up. By **the new Common Geoengineering Mechanism, the EU is championing international pilots on ocean alkalinization and de-desertification** and directing significant investments in **biochar, extensive peatland and wetland restoration** across the EU and scaling up **permaculture and agroforestry** practices.

Lifestyles and activism

In Europe, people have become highly aware of the climate crisis and, even if they feel personally less vulnerable to changes, they stay **committed to climate action** through demonstrations, boycotts and witnessing and watching, as well as influencing through **consumer choice and shareholder activism**. These social movements have jointly contributed to the general outlook and preferences in lifestyles that emphasise frugality and sustainability, translating into shifts towards more sustainable mobility, housing and working.

2. Coalition of Sustainable Communities[4]

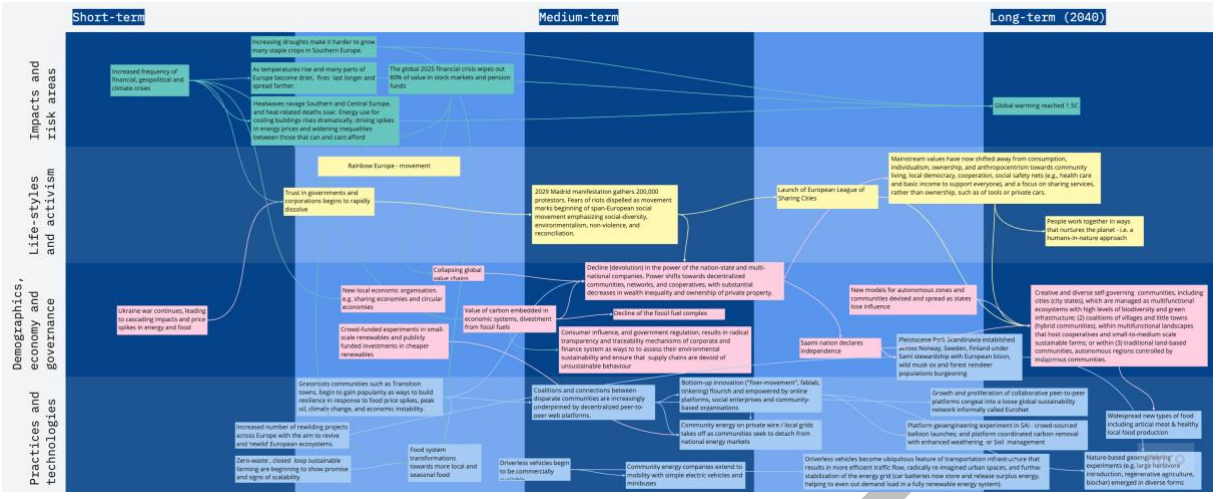
Scenario dimensions

Weak global governance; Sustainable lifestyles; Adverse to risk-taking; Vigorous activism

In a nutshell

Europe by 2040, there has been a dramatic decentralization of power, food and energy production. This has happened in conjunction with a shift in mainstream values away from consumption, individualism, ownership, and anthropocentrism towards community living, local democracy, cooperation, and sharing, rather than ownership, such as of tools or private cars. These changes in human values and social organization, have, together with technological change, facilitated much closer connections between people and nature.

[4] This scenario is heavily inspired and influenced by European future scenarios developed in Raudsepp-Hearne, C., G. D. Peterson, E. M. Bennett, R. Biggs, A. V. Norström, L. Pereira, J. Vervoort, et al. 2020. "Seeds of Good Anthropocenes: Developing Sustainability Scenarios for Northern Europe." Sustainability Science 15 (2): 605–17.



Impacts and risk areas

It's 2040, and the seeds of a new Europe are beginning to emerge following two decades of increased social conflict driven by interrelated **financial, geopolitical, and climate crises.** Between 2020 and 2040 global warming reached **1.5ºC** above pre-industrial levels and Europe experienced flooding, heat waves, and emerging diseases that generated substantial social disruption and social insecurity. A series of financial crises (the 2025 global financial crisis had a massive impact on stock markets and pension funds), combined with the tensions of economic reorganization (e.g., the loss of jobs), geopolitical tensions, and climate migration have led to **decreased trust in government, large companies, and financial institutions**.

Demographics, economy, and governance

The past two decades have therefore triggered a rapid change in many social practices and institutions. The national governments and multinational companies **are no longer dominant**. With some delay, but with growing influence, the diversity of **sustainable communities** has now emerged as a bottom-up-driven approach to address large-scale environmental challenges such as climate change and sustainable food production. Many of these communities were initially focused on **food system transformations**, because industrial food production underpinned so many of the risks and impacts described above, but also because food is so central to social capital and human health.

Initial successes around community organizations on food issues allowed trust in new **community councils** to grow. Communities began to support healthy food production and consumption practices and organize against **food multinationals,** encouraging more in-migration to provide the labour needed for sustainable, healthy agriculture. As climate migration continued to increase, these increasingly well-organized community forums also took on the integration of migrants into communities and were so effective that national governments began to rely on them to stabilize communities in the face of many challenging global and regional environmental issues. The importance of rural farming areas increased, and many people moved to the countryside to participate in increasingly important sustainable farming communities. By the time **the oil industry finally collapsed completely**, community councils were experienced and held power and the trust of communities, and the major shift in values towards community and environmental resilience was strengthened. These movements began to build on other existing citizen democracy movements in Europe, and combined traditions of grassroots politics and popular online-aided political movements and focused efforts on improving local places while sharing knowledge and skills across a broader region. Their coordination and collaboration were enabled by social media and computer-assisted technologies taming the

extremes of online dialogue and easing the technical difficulties of tasks such as organizing meetings and budgets.

Power now lies in these decentralized communities, networks, and cooperatives, with substantial decreases in wealth inequality and ownership of private property. Europe is witnessing a boom in **sharing** and **circular economies**. People are now emphasizing the importance of community, time, and collectives, and de-emphasizing private ownership and wealth creation. National governments and corporations still exist and function, but with less influence and new roles. Transparent regional and bilateral trade agreements have increased the participation and voice of smallholder farmers in local, regional but also international markets. Increased consumer awareness and power have imposed radical supply chain transparency through online tools such as databases, scorecards and traceability platforms.

Lifestyles and activism

The European identity is ever more pluralistic, and diverse and enables local communities to operate well with many different types of residents. In 2020, despite strong extreme right movements favouring isolation and imaginary pasts uncontaminated by people of colour, the movement for **'Rainbow Europe'** presented a positive vision of a fun, creative future that attracted many people. In 2030 massive mobilization (arguably triggered by the 2029 Madrid manifestation) across Europe of a movement for social diversity consolidated a generational shift, fusing the activist successes in women's rights, queer culture, and anti-racism, institutions enabling public participation in local and national decision-making, to develop social organizations that embraced diversity, encouraged experimentation and institutional pluralism. By emphasizing fun, non-violence, and reconciliation, this movement also developed new approaches to peacekeeping and conflict, these included radical reforms of the police and the creation of new networks of social problem solvers who worked to identify and address the causes of conflict.

Today, there are different types of communities across Europe. Some examples are (1) coalitions of cities (**city-states**), which are managed as multifunctional ecosystems with high levels of biodiversity and green infrastructure; (2) **coalitions of villages** and little towns (hybrid communities), within multifunctional landscapes that host cooperatives and small-to-medium scale sustainable farms; and (3) traditional land-based communities, autonomous regions controlled by **indigenous communitie**s. While certain aspects of life differ across these communities – e.g., technology, transport, currency, and religion – there is a mainstreaming of values around a relationship with nature, which has shifted from extractive and consumptive, to one of **humans-in-nature**, and this is reflected in land and natural resource use.

Practices and technologies

Initially, coalitions and connections between disparate communities were underpinned by decentralized **peer-to-peer web platforms**. Increasingly these platforms became focused on creating positive social and ecological impact and nurturing a vibrant community of young social activists and environmental enthusiasts who were willing to learn from each other and promote each other in creating a sustainable world together. The growth and proliferation of these platforms have now congealed into a loose, bottom-up-driven online global sustainability network.

The **rewilding of nature**, especially in urban areas, to make them greener and more connected to surrounding rural landscapes, is happening at rapid rates. Europe is now seeing multiple "bright spots" where ecological richness, diversity, and productivity are being regenerated and providing opportunities for people living there to achieve spiritual, and economic development.

The radical **decentralization of energy** production and distribution – together with the cost of renewables crossing a price threshold - has been a key catalyst of these social changes. But other technologies have contributed, such as **the democratization of driverless vehicles**. As these forms of transportation are now becoming ubiquitous, they are helping to free up enormous amounts of space in urban areas that had previously been used for parking areas and wider roadways than were needed, given the smaller number of vehicles on the road and more efficient traffic flow.

The decade between 2030 and 2040 saw a **rapid spread of innovation** occurring in these diverse communities, not through traditional top-down "breakthrough" approaches, but via the proliferation of **bottom-up elements such as Fablabs, tinkering, and MakerSpaces.** This approach to innovation has been mirrored in approaches to geoengineering (beyond those with a nature-based focus); for example, certain communities have **mobilized crowd-sourced stratospheric aerosol injection (SAI) balloon launches, and platform-coordinated carbon removal with enhanced weathering and soil management.**

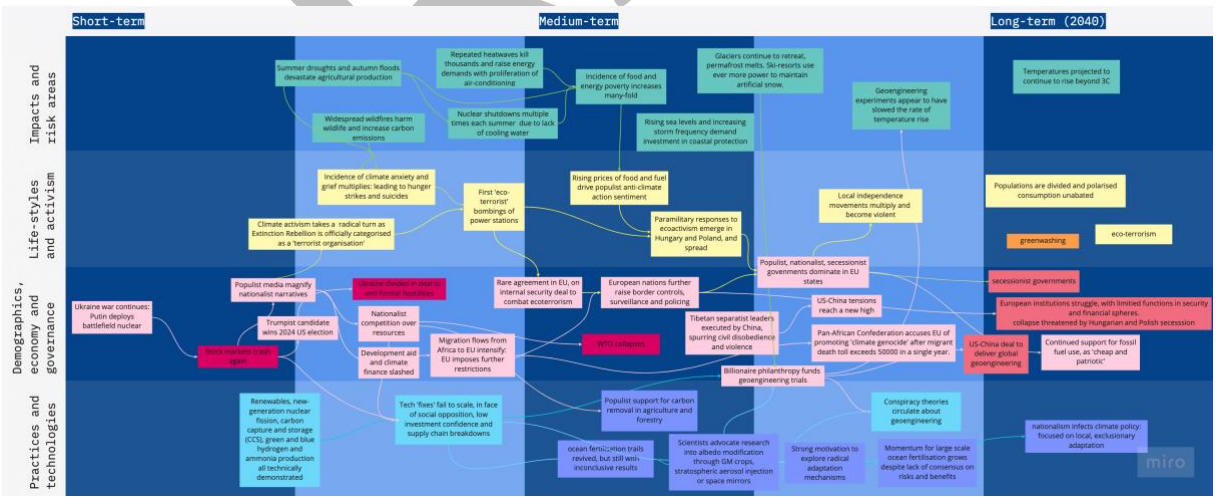
3. Deepening divisions

Scenario dimensions

Weak global governance; Unsustainable lifestyles; Open to risk-taking; Vigorous activism

In a nutshell

This scenario is based in an intensification of trends towards populism and nationalism. Putin's use of battlefield nuclear weapons in the grain-producing regions of Ukraine triggered price shocks and stock market collapses. Many countries swung towards authoritarian and isolationist leaders. The US elected a Trumpist successor in 2024. Neither public nor private sectors could sustain international collaboration on climate policy or technology.



Demographics, economy and governance

In 2040 Europe stands divided. Populist, **secessionist governments** are in power in Poland, Italy and France (amongst others). **European institutions struggle** to exercise power and influence. In the wider world relations with Russia remain uneasy following the division of Ukraine; China-US military clashes continue in the South China Sea as China accuses the US of funding and arming Tibetan separatists, and tensions escalate between the EU and the Pan-African Confederation over the continued death-

toll amongst climate migrants seeking to cross the Mediterranean. Global climate governance is just one of the many casualties.

In this world, **competition over resources** dominates international relations, and free trade is a long-lost dream. European economies continue to falter as supply chains fragment. Populist movements verging on fascism are in ascendance in dozens of countries, while **local territorial defence and independence movements have become violent** in several cases. **Populations are divided and polarised**, with **consumption growing unabated**. Wealthy elites retreat into secure compounds and gated communities. And while some environmental activists are trying to build resilient self-sufficient eco-villages, others have embraced **violence**, especially in the face of authoritarian policing of protest and continued attacks on political freedoms.

Real and imagined threats of climate migrants and refugees from Africa continue to dominate political discourse. In every country, border controls are strengthened. Walls, fences and deportation programs proliferate. The Mediterranean and its coasts are more like a war zone than a holiday destination, with naval forces and drones deployed to deter crossings. But political myopia and **nationalism infect climate policy** – with more focus on **local, exclusionary adaptation** than mitigation. Populist movements combine ethno-nationalist prejudice with continued support for **fossil fuel use** – rhetorically described as **cheap and patriotic**.

Impacts and risk areas

Climate change is both a trigger and a consequence of fragmentation and deepening divisions. While biodiversity losses multiply as temperature rises reach 1.7ºC, climate scientists project temperatures rising further, **beyond 3ºC** above pre-industrial levels. Impacts are already widely felt, not only in coastal communities and those affected by vanishing glaciers and melting permafrost but more widely and especially in the form of prolonged heatwaves, massive wildfires and droughts during summers followed by autumn flooding. These conditions have **devastated agricultural production** and exacerbated pressures on electricity systems: droughts causing **nuclear shutdowns** due to lack of cooling water (as well as reducing hydropower production), whilst demands for energy rise with the widespread use of air-conditioning. Energy and food prices have spiralled, fuelling **food and energy poverty**; undermining livelihoods, harming health and well-being for many, and fragmenting communities. Public health suffers from growing health inequality.

Rising prices have also fuelled **populist anti-EU and anti-climate** action sentiment. Public sentiment, powered by populist media, is further **polarised** by more **radical climate activism** using cyberattacks, blockades and violence against property to attack fossil power stations, airports and other targets (including geoengineering research facilities). Most states deploy anti-terror powers against climate activists, and **paramilitary responses** (tacitly ignored by state authorities) including assassination and kidnapping of activists have spread from the extractive frontiers of the global South to some European countries.

Practices and technologies

Scientists and technologists have demonstrated most of the suite of new climate technologies anticipated in 2020, including new-generation nuclear fission, carbon capture and storage (CCS), green and blue hydrogen and ammonia production, CCS has been linked not only to industrial processes but also to bioenergy (BECCS) and capture of CO_2 directly from the atmosphere (DACCS). But none of these technologies has reached scale as **supply chains, social licences, and investment flows have all been disrupted** and undermined by international and national conflicts.

As a result, governments are pursuing local adaptation, and carbon removal through agriculture and forestry, using natural resources; but climate scientists are now widely and urgently advocating and researching more radical and controversial technological approaches including **ocean fertilisation** for carbon removal, and large-scale **albedo modification** through GM crops, **stratospheric aerosol injection** or **space mirrors**. Trials of some of these technologies have attracted **billionaire philanthropy backing and entrepreneurs eager to scale up their application**. Even though some scientists say the trials indicate that such technologies could slow down global temperature rise if implemented at scale, others debate the validity of small-scale short-term trials. More widely suspicion and conspiracy theories abound on social media, multiplied by disinformation efforts by hostile states. As a result, many people believe droughts and floods are a product of such 'Green-finger' geoengineering rather than a reason for such experiments.

Lifestyles and activism

For the wealthy, lifestyles remain luxurious, and most citizens still aspire to enjoy such high levels of consumption and mobility. Products with green and 'sustainable' labels are scarce and expensive, even though widely considered to be mainly greenwashing. In our divided society though, anti-consumerist riots and looting, involving the destruction of merchandise or property are not uncommon. Climate activism takes multiple forms. For some, **climate grief** is expressed through the embrace of religious faiths, and some engage in non-violent protests such as hunger strikes. Conventional NGOs continue to lack influence in polarised political debates, and more radical forms of activism have proliferated including demonstrations and mass arrests, hacktivism and cyber-attacks, and even **eco-terrorism**, sabotage and bombing.

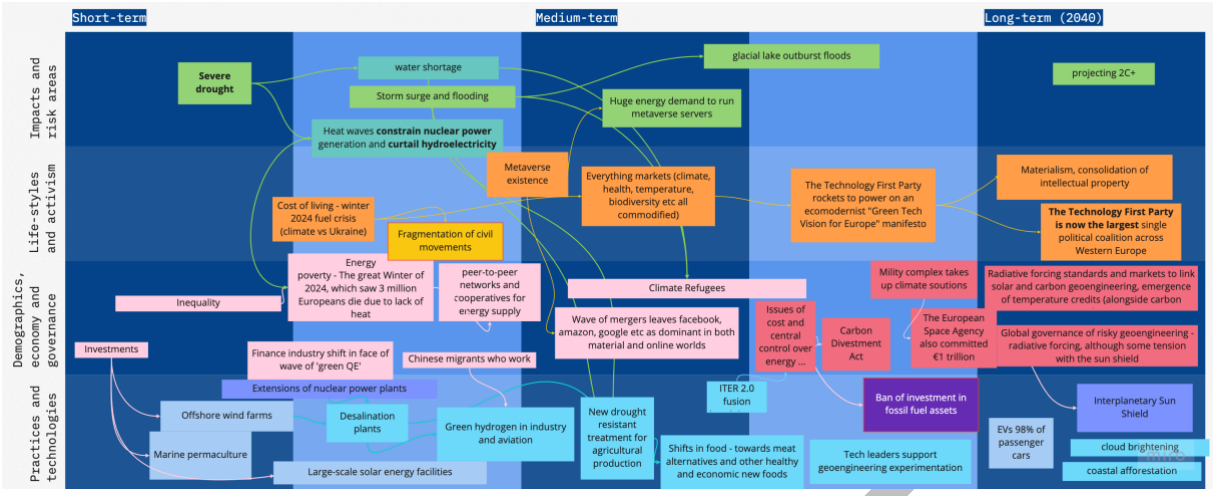
4. The Technological Fix

Scenario dimensions

Strong global governance; Sustainable lifestyles; Open to risk-taking; Weak activism

In a nutshell

In this scenario, technology operates to save humanity from the impacts of climate change. Technology companies and mega-corporations are the biggest drivers of change, with promises of great future breakthroughs such as fusion power, sentient robots, and fully automated smart homes promised as soon as mid-century. A highly technical form of neo-liberalism has taken over and shifted to 'eco-liberalism' framed around pervasive markets. Most of civil society and participatory democracy face disillusionment. Policymakers have turned to technology fixes and market mechanisms supported by businesses benefiting from high carbon prices and climate tech subsidies.



Impacts and risk areas

Although Europe has banded together via the European Commission as well as interstate coordination involving coalitions of individual countries, climate change continues to ravage the continent in 2040 as temperature rises reach 1.6ºC, and climate scientists project temperatures rising further, **beyond 2.5ºC** above pre-industrial levels. **Storm surges and flooding** are frequently inundating large parts of the Netherlands and other low-lying parts of Western Europe. The Arctic parts of Russia, Norway, Finland, and Sweden continually see numerous **glacial lake outburst floods and the advanced melting of permafrost**, some incurring billions of dollars of damages. Most famous of such events are the 2029 avalanche resulting flood that decimated large parts of Rundvassbreen, an outlet glacier of Blåmannsisen, and one from Flatbreen, an outlet glacier of Jostedalsbreen, and the permanent closure of the Trans-Siberian railway. **Severe drought** has also affected crops severely with Greek olive farmers, French winemakers, and Spanish vegetable growers all seeing record-high rates of **crop losses, fires, and unemployment**. Heat waves continue to **constrain nuclear power** generation in France and **curtail hydroelectricity** generation in Norway, Eastern Europe, and Iceland, due to unexpected melting of snowpack and seasonal alterations in river flow and precipitation patterns. For the first time ever, London faced a severe **water shortage** in 2039 due to unusually warm temperatures and the complete draining of the Thames River, which ran dry for four months. European leaders plan to meet in 2040 to discuss a "Common Treaty for **Climate Refugees**," estimated to surpass 100 million in 2035. The European Fuel Poverty Observatory also estimates that 40% of households across the continent are either in severe or chronic **energy poverty.**

Practices and technologies

Europe remains a hub of hopeful innovation and technical fixes to these challenges, with scores of notable inventions patented and commercialized over the past two decades. French biologist Jean-Luc Picard famously developed his **drought-resistant treatment** for agricultural production in 2031, one that entered into widespread use within the sector by 2035. Artificial meat and advancements in other cultured products have buttressed large **changes in diet**, with 40% of Western Europe now self-identifying as either vegetarian or vegan. Six of Europe's largest offshore wind farms as well as seventeen **nuclear power** plants (expected to retire in the 2020s) were instead given **license extensions** and now power the four largest desalination facilities in the world, supplying water to one-third of continental Europe and (via a transboundary sharing agreement) Israel. Large-scale solar energy facilities have been built and operated via Desertec in Northern Africa (Morocco) which exports power to Germany and France, Gobitec in Asia (Mongolia to China), and Ameritec being built in Desert Valley. The European Space Agency also committed €1 trillion to deploy an **Interplanetary Sun Shield** at the Lagrange Point between the Earth and Sun, with construction already occurring in high orbit and

completion of a moon colony (which will provide materials, robotics, and resources for the Shield) expected to occur by 2042. The Sun Shield is competing with an American proposal to deploy a Dyson Dot also at the same Lagrange point, with construction commencing in 2044. As a result, the Americans, the Europeans, and the Chinese have all greatly bolstered their **space forces,** and significant advances in a new space economy are endlessly discussed in the media. In the Mediterranean, localized deployment of **cloud brightening** and **coastal afforestation** have begun to regenerate and restore degraded seascapes and marine areas. **Hydrogen** has achieved widespread use within industry, and 98% of Europe's passenger car fleet is now fully battery electric, and hydrogen aircraft flying most short and medium-range flights within Europe. **Marine permaculture**, especially seaweed farming, is widespread off the coast of Scotland, Ireland, Iceland and Greenland.

Demographics, economy and governance

Europe remains a global leader in climate governance, succeeding the United States in 2028 as President of the World Bank and becoming the premier negotiator for climate mitigation thereafter. The landmark 2031 Treaty between the EU-China pledges to cut emissions by 90% by 2040, well before China's Five-Year Plan had initially promised. In return, Europe now has 250 million **Chinese migrants who work on green technology** and clean industrial systems, notably solar energy, hydrogen, and batteries. Populations in Europe have therefore begun to rise, due to the influx of immigrants and the positive spillover effects of innovation. Crowdsourcing business models have begun to flourish as well, especially among **peer-to-peer networks and cooperatives**, such as the newly formed Mondragon Energy Cooperative in 2039, which now controls 24% of the **European electricity supply** across seven countries. Innovations have not diffused equally, however, with many youths and students, those having to rent rather than own their homes, and the elderly still reliant on fossil fuels or in substandard housing. **Markets** and **market fixes** have become cemented as preferred solutions around the world, driven by **eco-libertarians** and a new philosophy that blends tougher ecological modernization with neo-liberalism. As a result, very large and active markets exist not only for carbon credits but also for water credits and biodiversity credits. Influenced by this philosophy, and also driving a complete realignment of infrastructure, is the role of central banks, who created a regional **carbon currency** and then a global **carbon coin** in 2028 and 2034, respectively. This financial innovation was driven by finance rather than social movements and is now coordinated by the **Central Carbon Bank**.

Lifestyles and activism

Given the severity of highly visible impacts and risk areas, climate change and technical solutions to it have become a defining local, national, and regional political issue. **The Technology First Party is now the largest** single political coalition across Western Europe, following national victories in German, Denmark, and the UK (following a disastrous 20 years of Conservative leadership). Their "Green Tech Vision for Europe" has wide appeal across all constituencies. The great Winter of 2024, which saw 3 million Europeans die due to lack of heat, created a "heating first" agenda that prioritized energy affordability and adequacy rather than sustainability, and significantly slowed down social movements against big technology. Convinced that social change can only occur from the top-down through policy change, the election of Prime Minister Greta Thunberg to preside over the European Commission has launched a new wave of youth climate activists, including the very influential **"Net Zero Now!" organization** which has more youth subscribers than the Girl Scouts and Boy Scouts combined. The 2037 **Carbon Divestment Act**, implemented as EC.1031.121, also restricts any financial institution from investing in fossil fuels, an act that resulted in the stranding of more than $110 trillion in fossil fuel assets around the world. Technology companies and **mega-corporations** are the biggest drivers of change, with promises of great future breakthroughs such as **fusion**, **sentient robots**, and fully **automated smart homes** promised as soon as mid-century.

Implications for Research and Innovation Policy

Each of the four scenarios entails future developments from today until 2040 with respective threats and opportunities to stakeholders, and also potential implications to R&I policy. In general terms, a continuation of business as usual will risk sliding into the *Deepening Divisions* scenario, or at best constitutes a high-stakes gamble with the socially harmful *Technological Fix* scenario; and will fail to open up the new political and social possibilities in the Coalition of Sustainable Communities and *Sustainable Transition* scenarios. In particular, the participants of the implications (final) workshop found the most plausible the *Deepening Divisions* scenario. If we are to avoid its worst implications such as the spread of disinformation, policy securitisation and the corporate capture of regulatory processes, strengthening participatory governance and civil society is crucial. It is also urgent to develop common governance frameworks for the effective and safe experimentation and scaling up of a wider set of climate innovations. The participants of the implications workshop and the expert team analysed each of the scenarios identifying key developments and related threats and opportunities to different stakeholder groups including business, civil society, science and technology and governance actors. These provided then a basis to formulate implications to R&I policy (for details on the implications of each scenario, see Annex II) strengthening climate innovation including both technological advances and social innovation to mitigate and adapt to climate change. In what follows, the implications are summarised and grouped by the key domains used in the scenario work:

Business and markets

- Research and develop transdisciplinary R&I management and policy processes to scale up climate business that combine the representation and deliberation of different stakeholder groups, and carefully navigate the challenge to meaningfully bring together powerful and marginalized stakeholders.
- Accelerate and coordinate European public-private investments via incentives and mission-based innovation platforms to strengthen European climate tech leadership and transition towards sustainable consumption.
- Establish innovation programmes to create and orchestrate climate innovation ecosystems among civil society, startups, universities, industry and other stakeholders.
- Invest in inclusive open-access technology and infrastructure as platforms for climate innovation.
- Support research to better understand the implications of market-based policy instruments and business strategies for just transitions and social and environmental goals as well as alternative pathways like degrowth or managed sufficiency.
- Research and accelerate measures for corporate disclosure of climate-related information and investor accountability for climate impacts to transform financial markets.

Civil society

- Ensure both social and environmental goals are horizontally embedded in climate research and governance.
- Expand civil society initiatives and roles for sub-national actors to strengthen and scale up community-based climate innovation.
- Foster experimentation of reflexive policy institutions across scales in the EU to demonstrate how public opinion can be part of institutions (e.g., citizen assemblies) and make climate policy more relevant and socially acceptable.
- Invest in commons, public spaces, open access, and strategies for inclusion in open access technology and infrastructure as platforms for climate innovation and profit.
- Search for synergies among global civil society efforts and corporate climate leadership.

- Involve climate activists as stakeholders in research agendas.

Science and Technology

- Pursue a broad portfolio of different options to diversify the chances of climate innovation breakthroughs. Develop and improve carbon removal techniques.
- Get ahead of the game with governance for geoengineering research. Develop comprehensive and transparent R&D policy on geoengineering with public engagement throughout the research, development and deployment phases; and consider also broad and long-term impacts.
- Hedge future risks by investing in challenge-based science and technology programs. For instance, implement mission-driven innovation programs to promote transformative climate innovation
- Develop novel techniques and governance for fair nature-based solutions (NBS) with a focus on assessing the environmental, economic and social effects of the implementation of NBS over spatial and temporal scales.
- Publicly funded climate change research programmes should include end users and focus on production methods that are diverse, sustainable and widely accessible, such as agroecology. Commit to broad support for public sector food and agricultural R&D that encourages climate innovations that are not driven solely by profit, e.g., public plant-breeding programmes (including open-source seeds).
- R&I strategies focused on energy transitions that have: a high involvement of different types of actors (e.g., NGOs, municipalities, trade unions) that will become increasingly important as renewable energy systems become more distributed and decentralised; a systems perspective to understand the need for complementary innovations, especially in later phases of energy transitions; a reflexive and learning-focus to continuously adapt policies to changing circumstances.
- Reform intellectual property regimes to deliver public benefits and wide sharing of climate innovations.

Government and policy

- Foster enhanced global climate cooperation through the EU's international development policy, support international governing institutions and foster global civil society institutions.
- Research politics and psychology of climate populism. Research climate technology agendas in party politics and how to avoid radical agendas. Inoculate against disinformation with education and awareness raising.
- Develop at the global level a precautionary framework and mechanism for managing geoengineering and establish a forum to discuss geoengineering approaches transparently.
- Develop mechanisms for (climate) migrant integration.
- Research how the security/defence industry influences climate change governance. Research de-escalation, disarmament, and non-proliferation mechanisms for peace and global climate governance.
- Research regulation, incentives and biz-models for climate tech; policies to rein excessive corporate influence in regulatory processes and scientific discourse (e.g., in the food and agriculture sector).

General (cross-cutting)

- Assess and consider the diverse social, economic and environmental risks involved in experimentation in climate innovations (including the likelihood of deterring action on

mitigation) as well as the consequences of lack of experimentation that could, in turn, reduce the options and delaying climate mitigation and adaptation.

- Emphasise research on managing degrowth and just transition. Invest in the implementation of the just transition agenda to facilitate collaboration across society.
- Research new forms of polycentric and resilient governance for climate mitigation and adaptation.
- Invest in and give more space for transformative and transdisciplinary research approaches at the science-society interface (such as real-world laboratories, and T-labs) that contribute to building capacity to support societal change.

Annex I: Factors of change

Table of Contents

1 INTRODUCTION TO FACTORS OF CHANGE

Climate change impacts are among the main threats to human society and natural ecosystems. In connection to climate change, the Strategic Plan 2021-2024 for Horizon Europe, the EU's 9th multiannual framework programme for research and innovation, defines the key strategic orientations for the first four years:

- The European Union has stated its ambition to substantially reduce greenhouse gas emissions by 2030 and to become **climate neutral by 2050** and turn into a more sustainable bio-based, climate-neutral, circular, non-toxic and competitive economy.
- Horizon Europe investments plan to help deliver on the different dimensions of the European **Green Deal**, the European Union's new growth strategy.
- **Investments** are planned to be aligned with strategic priorities such as the European Union's Climate Action, the New Industrial Strategy for Europe, Renovation Wave Strategy[5], European Strategy for Energy System Integration, European Hydrogen Strategy, Offshore Renewable Energy Strategy and Circular Economy Action Plan.
- Through these investments, the European Union aims to contribute to digitally transforming the EU industry and to make the EU climate-neutral by **transitioning all economic sectors**. This should boost the role of the European Union as a solution provider for the benefit of all and position Europe as a technological and industrial leader in the green transition.

[5] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

Recent developments, in particular, the Covid-19 crisis and the war in Ukraine as well as **insufficient global commitments** to curb the climate crisis leave many open questions on the future success of climate mitigation and adaptation, both in Europe and globally. Current policies presently in place around the world are projected to result in about 2.7°C warming above pre-industrial levels (see Figure 1), which would be a devastating climate breakdown.

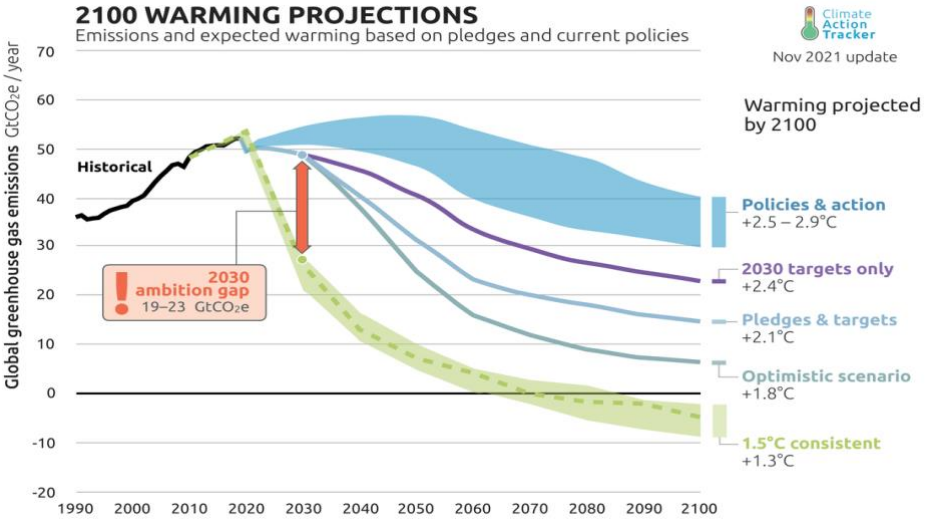


Figure 1. 2100 Warming projections. ref. Climate Action Tracker (2021)[6]

2 CURRENT AND FUTURE DEVELOPMENTS

As existing measures seem to prove to be insufficient to curb global warming and its impacts, especially on the most vulnerable societies and ecosystems, demand for a wider set of climate practices may rise. This section identifies related current and future developments in subsections: i) climate impacts, risks and vulnerabilities, ii) game-changing socio-economic responses and iii) unexploited technological alternatives to curb the climate crisis.

2.1 Climate impacts, risks and vulnerabilities

2.1.1 Climate impacts

Increasing global warming levels translate into climate change impacts on nature and society observed as changing patterns (trends) and extreme events with aggravating frequency, duration, intensity and spatial extent, in some cases possibly reaching even the tipping points. Table 1 summarises some of the key climate impacts identified by (IPCC, 2021b), see also Annex I for more details.

Impacts	Description
Heat and Cold	Frost Cold spell Extreme heat Mean air temperature
Wet and Dry	Hydrological drought

[6] https://climateactiontracker.org/global/temperatures/

	Aridity Landslide Heavy precipitation and pluvial flood River flood Mean precipitation
Wind	Sand and dust storm Tropical cyclone Severe windstorm Mean wind speed Fire weather Agricultural and ecological drought
Snow and Ice	Hail Heavy snowfall and ice storm Lake, river and sea ice Permafrost Snow, glacier and ice sheet
Coastal and Oceanic	Ocean acidity Marine heatwave Coastal erosion Coastal flood Relative sea level Snow avalanche
Other	Air pollution weather Atmospheric CO2 at surface Radiation at surface

Table 1. Summary of the key climate impacts (IPCC, 2021b)

2.1.2 Climate risks and vulnerabilities

The climate impacts cause diverse risks to ecosystems, biodiversity, society and its sectors. See Table 2 on how IPCC (2021) has categorised them.

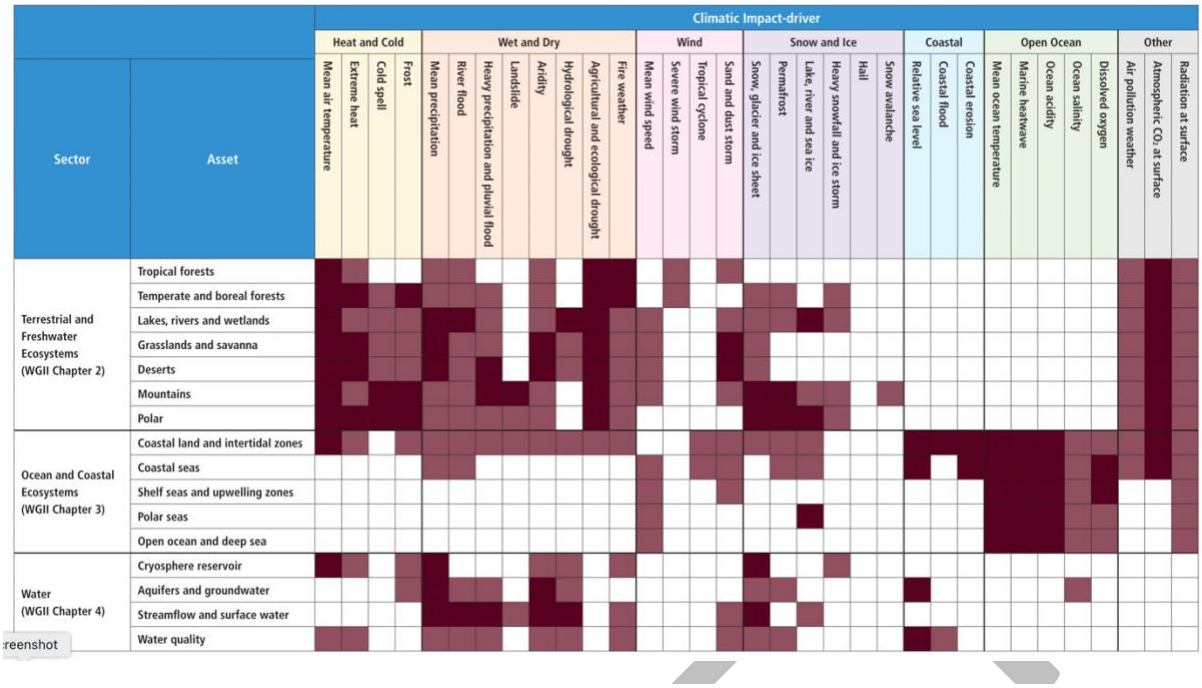
Risk areas	Description/examples
Terrestrial and Freshwater Ecosystems	Tropical forests Temperate and boreal forests Lakes, rivers and wetlands

	Grasslands and savanna Deserts Mountains Polar
Ocean and Coastal Ecosystems	Coastal land and intertidal zones Coastal seas Shelf seas and upwelling zones Polar seas Open ocean and deep sea
Water	Cryosphere reservoir Aquifers and groundwater Streamflow and surface water Water quality
Food, Fibre and Other Ecosystem Products	Crop systems Livestock and pasture systems Forestry systems Fisheries and aquaculture systems
Cities, Settlements and Key Infrastructure	Cities Land and water transportation Energy infrastructure Built environment
Health, Well-being and Communities	Labour productivity Morbidity Mortality Recreation and tourism
Poverty, Livelihoods and Sustainable Development	Housing stock Farmland Livestock mortality Indigenous traditions

Table 2. Risk areas (sectors and assets) affected by climate change.

IPCC (2021) possesses the risks of climate-impact drivers on sectoral assets globally (Figure 2) and in Europe (Figure 3).

Figure 2. Climate Change Information for Sectoral Impact and for Risk Assessment Globally



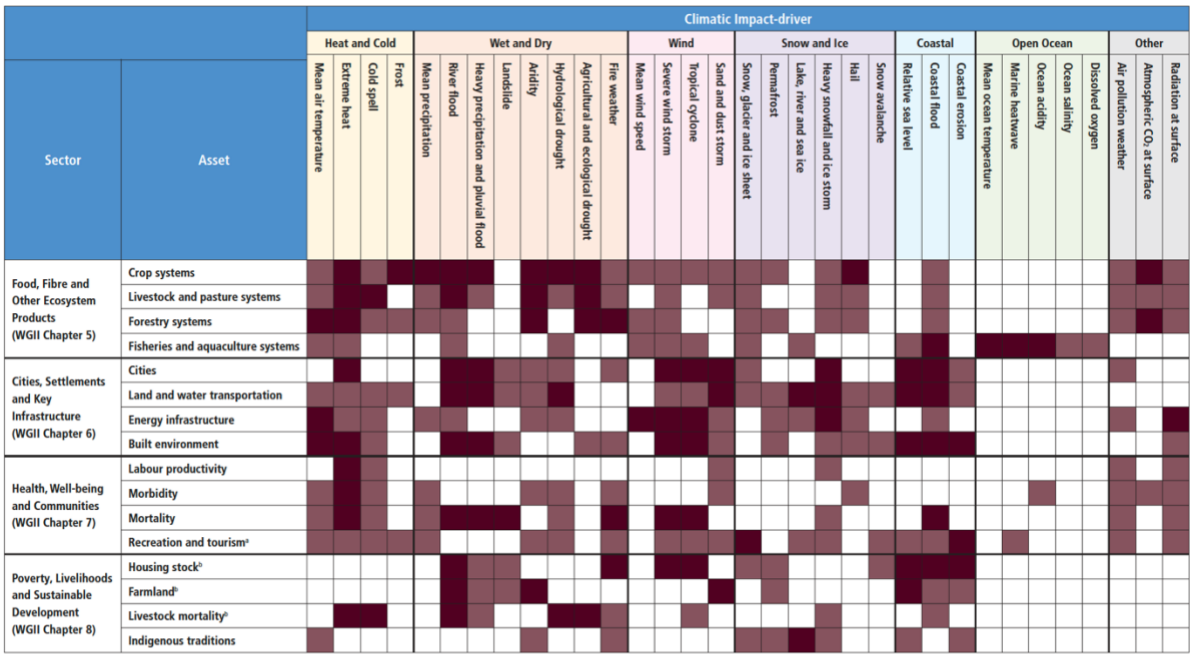
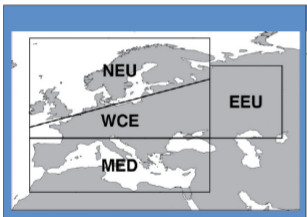


Figure 3. Climate Change Information for Regional Impact to Europe and for Risk Assessment.

Table 12.7 | Summary of confidence in direction of projected change in climatic impact-drivers in Europe, representing their aggregate characteristic changes for mid-century for scenarios RCP4.5, SSP2-4.5, SRES A1B, or above within each AR6 region (defined in Chapter 1), approximately corresponding (for CIDs that are independent of sea level rise) to global warming levels between 2°C and 2.4°C (see Section 12.4 for more details of the assessment method). The table also includes the assessment of observed or projected time-of-emergence of the CID change signal from the natural interannual variability if found with at least *medium confidence* in Section 12.5.2.



Region	Climatic Impact-driver																												
	Heat and Cold				Wet and Dry									Wind				Snow and Ice						Coastal and Oceanic					Other		
	Mean air temperature	Extreme heat	Cold spell	Frost	Mean precipitation	River flood	Heavy precipitation and pluvial flood	Landslide	Aridity	Hydrological drought	Agricultural and ecological drought	Fire weather	Mean wind speed	Severe wind storm	Tropical cyclone	Sand and dust storm	Snow, glacier and ice sheet	Permafrost	Lake, river and sea ice	Heavy snowfall and ice storm	Hail	Snow avalanche	Relative sea level	Coastal flood	Coastal erosion	Marine heatwave	Ocean acidity	Air pollution weather	Atmospheric CO_2 at surface	Radiation at surface
Mediterranean (MED)	●	●	●		○		5						6	7					●				○		2		○		●	
Western and Central Europe (WCE)	●	●	●					4									●		●				○		2		○		●	
Eastern Europe (EEU)	●	●	●														●												●	
Northern Europe (NEU)	●	●	●		○	1											○		●				○	8	2,3		○		●	

1. Excluding southern UK.
2. Along sandy coasts and in the absence of additional sediment sinks/sources or any physical barriers to shoreline retreat.
3. The Baltic Sea shoreline is projected to prograde if present-day ambient shoreline change rates continue.
4. For the Alps, conditions conducive to landslides are expected to increase.
5. Low confidence of decrease in the southernmost part of the region.
6. General decrease except in Aegean Sea.
7. Medium confidence of decrease in frequency and increase in intensities.
8. Except in the northern Baltic Sea region.

● Already emerged in the historical period (*medium* to *high confidence*)
● Emerging by 2050 at least in scenarios RCP8.5/SSP5-8.5 (*medium* to *high confidence*)
● Emerging after 2050 and by 2100 at least in scenarios RCP8.5/SSP5-8.5 (*medium* to *high confidence*)

High confidence of decrease | Medium confidence of decrease | Low confidence in direction of change | Medium confidence of increase | High confidence of increase | Not broadly relevant

2.2 Societal factors of change

2.2.1 Lifestyles/consumption

Lifestyles	Description/examples
Materialism	Societies based on individual material gain, here-and-now-thinking
Prosumerism	Microgrid communities, urban farming communities
Frugality	Anti-consumerism, consume less goods
Optimism	Overly optimistic beliefs in tech or social transformation. Climate delay has emerged as the new denial for personal change.
Shifts in housing	Change temperature settings, shared common spaces, smaller apartments, multi-generational housing, daylighting (IPCC, 2021a)
Shifts in food	Keep calories in line with health guidelines, meat alternatives, vegetarian/vegan diets (IPCC, 2021a)
Shifts in working	Change dress codes, change work times, short work weeks (IPCC, 2021a)
Shifts in mobility	

Climate grief	A wider loss and anxiety related to the overall effects of climate change, related to eco-anxiety, ecological grieving[7]. At the moment, numerous Finns – and other Nordic people – suffer from "winter grief" (talvisuru), loss of traditional winters because of climate change[8].
Religion	
Nationalism	Ethnonationalism, resistance to migration, fossil fascination (Malm and Zetkin Collective)
Prejudice and discrimination	
Everyday denial	Kari Norgaard's work is still valid

Table 3. Factors related to lifestyles and consumption.

2.2.2 Activism

Climate anxiety and perception of government inaction have triggered, for instance, the 'Fridays for future' movement, which contributes to the emergence of global conscience on the climate and biodiversity crisis and the need for justice.

Activism	Description/examples
Witnessing and watching	Documenting injustices or unsustainable practices
De-legitimation	Challenging the veracity of accepted information
Demonstrations and mass arrests	Making visible discontent and dissatisfaction, even with possible incarceration
Social movements	Creating a sustained effort at calling for change
Permanent resistance	Interfering with unsustainable practices for a long period of time
Occupation and sit-ins	Interrupting the normal order and business as usual
Boycotts	Disrupting markets and profits for private sector firms
Labour strikes	Mass refusal of employees to work until demands are met
Hunger strikes	Refusing to eat food until demands are met (often undertaken by prisoners)
Trespassing	Challenging property rights and attacking media attention
Blockades	Physically stopping access to a project or location
Sabotage	Destroying or tampering with unjust structures
Hacktivism	Using the internet, computers, or software to challenge hegemony

[7] https://www.bbc.com/future/article/20200402-climate-grief-mourning-loss-due-to-climate-change

[8] https://www.sciencedirect.com/science/article/pii/S2542519621002783

Destruction of merchandise or property	Destroying products or other valuable assets
Mass riots or looting	Organizing massive public demonstrations to incite overreactions or enable looting
Terrorism	Perpetrating low intensity conflict and acts of violence
Assassination and kidnapping	Undertaking targeted, ruthless acts of murder or violence
Bank robbery	Expropriating money or financial resources from industrialists
Military and paramilitary action	Implementing sustained armed campaigns
Bombing	Detonating incendiary devices to injure or kill or destroy property
Shareholder activism	Investor engagement / divestment/ AGM disruption
Tax withholding	
Astroturfing	And other forms of fake counter-protest. Astroturfing is the practice of masking the sponsors of a message or organization (e.g., political, advertising, religious or public relations) to make it appear as though it originates from and is supported by grassroots participants.
Disinformation	

Table 4. An inventory of anarchist, civil disobedience, and guerrilla tactics for climate protection. source: (Sovacool & Dunlap, 2022)

2.2.3 Demographics and economy

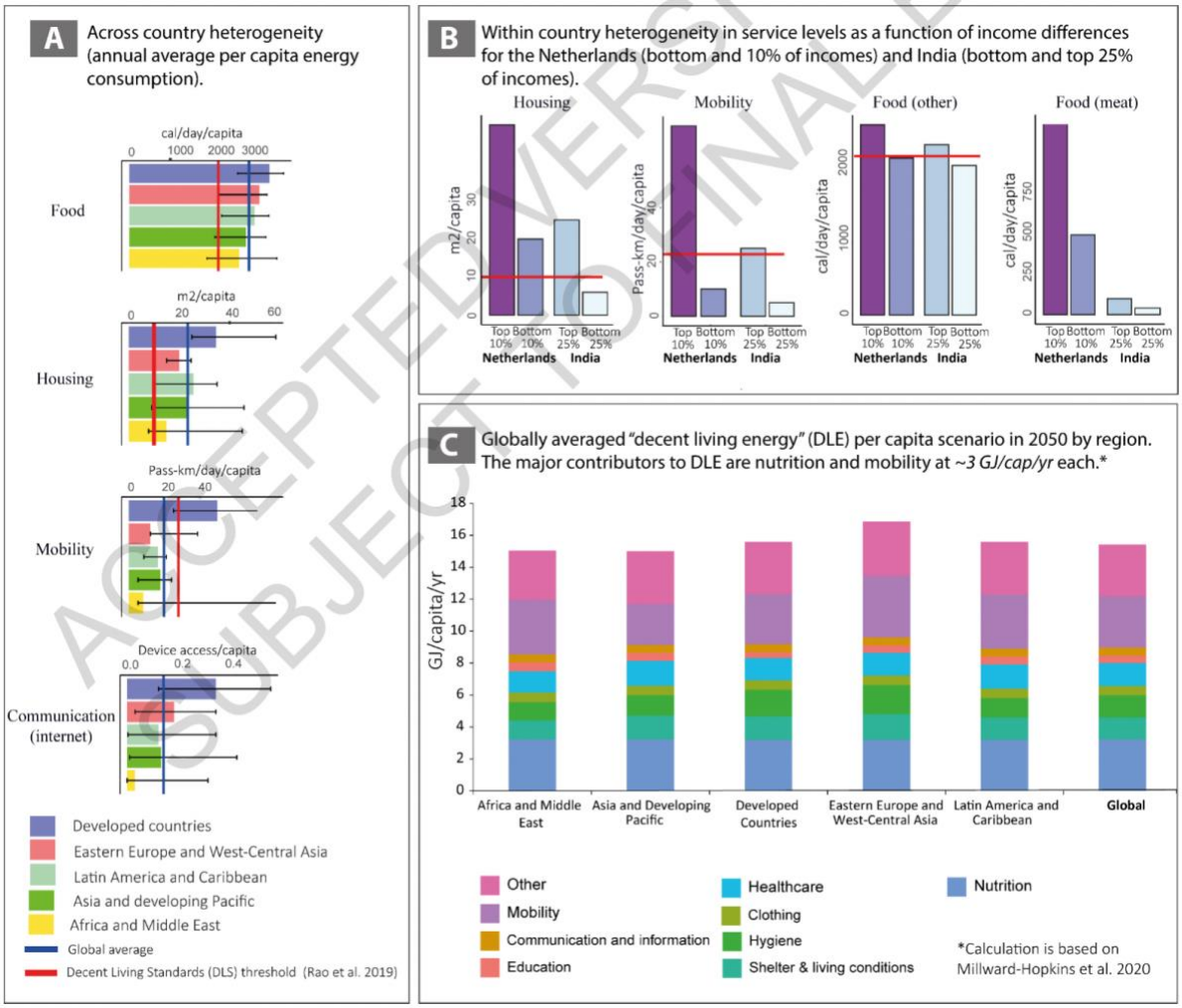


Figure 4. Heterogeneity in access to and availability of services for human well-being within and across countries. Ref. (IPCC, 2021a)

Variation in service levels across countries within a region are shown as error bars (black).

Demographics and economy	Description/examples
Investments	Average annual modelled investment requirements for 2020 to 2030 in scenarios that limit warming to 2°C or 1.5°C are a factor of three to six greater than current levels, and total mitigation investments (public, private, domestic and international) would need to increase across all sectors and regions (medium confidence) (IPCC, 2021b).
Stranded assets	Typically understood to be a productive investment which is no longer economic or legal to use as a result of climate mitigation regulation or taxation. So, we hope that coalmines, airports and fossil-fuelled power stations will be stranded. Climate change may leave some assets unused (e.g., in summer 2022 London subway during the heatwave)[9].

9 https://doi.org/10.1016/j.oneear.2019.11.012

Path dependency	Gas infrastructure beyond 2050
Business models	Eco-friendly business models
Circular economy	
Overproduction	
Growth	Economic growth, especially in developing countries
Competition for scarce resources	Some mitigation options can increase competition for scarce resources including land, water and biomass, e.g., the large-scale or poorly planned deployment of bioenergy, biochar, and afforestation of naturally unforested land.
International financial cooperation	To address inequities in access to finance and the costs of, and vulnerability to, the impacts of climate change.
Country indebtedness	
Population growth	
Energy poverty	800+ M no access to electricity, half in Africa
Inequality	Exacerbated social inequalities may lead to either lack of willingness or ability to participate in transitions or trigger social movements.
Migration	Refugees
Economic elites	The global wealthy. According to a 2020 report[10] from Oxfam and the Stockholm Environment Institute, the wealthiest top 1% were responsible for 15% of global emissions, nearly twice as much as the world's poorest 50%, who were responsible for just 7%.
Just transition	Job creation and retraining targeted a transition of workers from climate damaging to climate sustaining industries. with attention also to effects of transition on communities and consumers - for example by targeting home efficiency retrofits (done by redeployed, retrained workers) on the homes of those in fuel poverty, and/or prioritising those in communities previously dependent on fossil industries.
Climate justice	Equitable sharing of benefits and burdens of mitigation, increasing resilience to the impacts of climate change, especially for vulnerable countries and communities, and equitably supporting those in need.
Universal basic income	e.g., https://www.ubilabnetwork.org/blog/why-is-a-basic-income-good-for-the-environment

Table 5. Factors related to demographics and economy.

[10] https://www.sei.org/wp-content/uploads/2020/09/research-report-carbon-inequality-era.pdf

2.2.4 Governance

Governance	Description/examples
Political myopia	Short political cycles, and lack of broad political agreement on alternative paths seem to keep us on the path to the climate crisis.
Global Carbon Reward	Compensate fossil fuels not burned[11]
Emission trading systems	Carbon price, international framework
Pooling funds	International pooling in new areas (similar to ITER)
Global commons	Protect the global commons, including indigenous cultures and atmospheric commons.
Global governance of geoengineering	The planet lacks a fair and appropriate governance structure providing a framework on who is entitled to carry out geoengineering projects in the name of the planet and what their responsibility is.
Participatory mechanisms	Engagement of citizens in the public decision-making.
Regulatory environment	
Capacity building	
Responsible research and innovation	
Voting and representation systems	FPTP vs PR; sortition
Citizens assemblies	And other forms of deliberative citizen involvement.
Institutional design and reform	e.g., Commissioner for the future; Chamber of the Seventh generation
Walkable cities	Removing road space from cars, and allocating it to walking and cycling with dedicated routes and infrastructures, densifying urban neighbourhoods to reduce journey lengths etc.
Carbon Border Adjustment Mechanism	CBAM[12] is a climate measure that should prevent the risk of carbon leakage and support the EU's increased ambition on climate mitigation, while ensuring WTO compatibility. The CBAM will equalise the price of carbon between domestic products and imports and ensure that the EU's climate objectives are not undermined by production relocating to countries with less ambitious policies.

Table 6. Factors related to governance.

[11] https://en.wikipedia.org/wiki/Global_Carbon_Reward

[12] https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3661

2.3 Unexploited alternative practices and technologies

This subsection aims at identifying the development of, until today, largely **unexploited** climate practices and technologies, because of their perceived risks or feasibility, the risk referring to the probability and impact of an event. We look for **new perspectives to climate** research, development and deployment (RDD), incl. existing underexploited safe bets (e.g., reforestation), future breakthroughs (e.g., carbon capture, use and storage) and questionable alternatives (like some risky geoengineering[13] options, e.g., solar radiation management), see Table 7 and 8 for further clarification of the categories.

Social change related practices	Existing safe bets (below overshoot)	Future Breakthroughs (overshoot)	Questionable alternatives (beyond overshoot)
	Civil movements	Sustainable lifestyle	Ecoterrorism
	Shifts in organising the work (change dress codes, change work times, short work weeks)	Shared housing (shared common spaces, multi-generational housing)	Isolation (retreats to radical eco-villages)

Table 7. Social change related practices.

	Existing safe bets (below overshoot)	Future Breakthroughs (overshoot)	Questionable alternatives (beyond overshoot)
Current social acceptance	High	Medium	Low or varying
Current market competitiveness (price)/efficiency	High	Low	Low/Medium/High
Market offer (available resources and production capacity)	Medium	Low	Medium
Technological maturity	High	Low	Low/Medium/High
Examples of current efforts in scale	Wind energy Solar panels Electric vehicles	Nuclear fusion	Nuclear fission

[13] Geoengineering proposals fall into at least three broad categories: i) Reducing the levels of atmospheric greenhouse gases, e.d. greenhouse gas removal (GGR) through large-scale manipulations: e.g., carbon capture and storage (CCS), ocean fertilization or afforestation using non-native species; ii) Exerting a cooling influence on Earth by reflecting sunlight, e.d. solar radiation management (SRM): e.g., putting reflective particles into the atmosphere, putting mirrors in space, increasing surface reflectivity, or altering the amount or characteristics of clouds. SRM sits closer to adaptation strategies (building resilience to climate change impacts) in that it is inherently a partial solution, e.g. oceans continue to acidify (Sovacool, 2021); iii) Other large-scale manipulations designed to diminish climate change or its impacts: e.g., constructing vertical pipes in the ocean that would increase downward heat transport. Ref. https://www.ametsoc.org/index.cfm/ams/about-ams/ams-statements/statements-of-the-ams-in-force/geoengineering-the-climate-system/

Examples of possible new efforts in scale	Plant-based meat substitutes Cycling infrastructure Whitening of rooftops	Bioenergy with carbon capture and storage (BECCS), Direct air capture Enhanced weathering	Solar radiation management Ocean fertilisation

Table 8. Types of technological solutions to possibly scale up.

1.1.1 Scalable existing safe bets

Here we seek to identify possible safe bet technologies that could be developed and deployed further in scale. IPCC (2021) provides a summary on the potential of technologies to reduce net emissions and related costs (Figure 5).

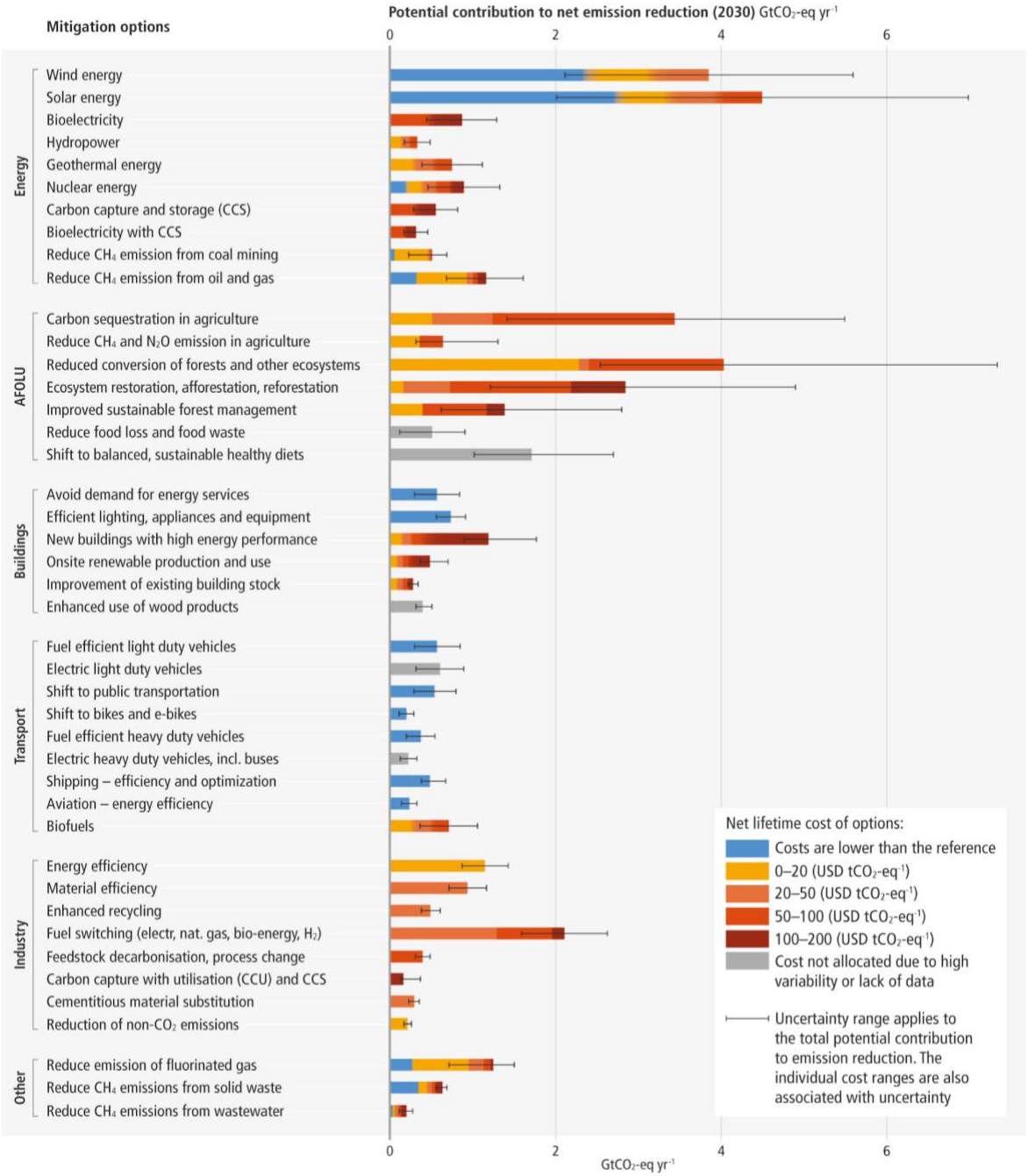


Figure 5. Overview of mitigation options and their estimated ranges of costs and potentials in 2030. Costs shown are net lifetime costs of avoided greenhouse gas emissions. Costs are calculated relative to a reference technology (IPCC, 2021).

Table 9 provides examples some safe bet technologies that could be scaled up. Also, the drawdown[14] project provides a number of examples of such technologies.

Safe bet technologies	Description/examples

[14] https://drawdown.org/solutions/table-of-solutions

automation of re-/afforestation	Planting trees or vegetation to absorb carbon dioxide growth. However, current evidence of using drones for reforestation is mixed.[15]
De-désertification (adaptation techniques)	There is no standard technical solution to control desertification; every place and every situation requires specific solutions. The most frequently used methods are dune fixing, windbreak arrangement, reforestation, maintaining the natural vegetation, agro-forestry and improving soil fertility.[16]
Sustainable fuels	Sustainable biofuels, low emissions hydrogen, and derivatives (including synthetic fuels) can support mitigation of CO2 emissions from shipping, aviation, and heavy-duty land transport but require production process improvements and cost reductions.[17]
Land permaculture	Land-based permaculture, and peasant agriculture - techniques of intensive, high carbon storing land management that run counter to the imaginaries of global agribusiness. While some NGOs and global South activists promote peasant permaculture, there are huge cultural obstacles to it.
Marine permaculture	Marine permaculture is the ocean farming of kelp and seaweeds and can counteract ocean acidification, climate change and loss of biodiversity. Seaweed and kelp can also be a source of biofuel, feed for cattle and could provide food security for millions.[18]
Peatland/wetland restoration	reversing carbon losses from drained wetlands and peatlands by blocking drains and rewetting.
Carbon capture and storage	Technologies or solvents that extract, capture, transport, and store carbon dioxide released from fossil fuel combustion or industrial processes such as cement manufacture. Technically well demonstrated, but not yet successfully commercialised.
Energy storage devices other than batteries	e.g., pumped storage, compressed air storage, seasonal heat storage
Combined heat and power generation technologies	Poorly deployed outside of locations with district heat networks.
Deep geothermal power	
Sustainable food innovations	A sustainable, and transformed, food system, is at the core of a better future. New food initiatives are interesting because they

[15] https://eandt.theiet.org/content/articles/2022/01/tree-planting-drones-could-help-restore-the-world-s-forests/

[16] https://wikiwater.fr/e13-soil-arrangement-technologies

[17] IPCC 2021

[18] https://whatsyour2040.com/marine-permaculture/#:~:text=It%20turns%20out%20that%20kelp,provide%20food%20security%20for%20millions

	connect the technological, social and environmental domains so profoundly. They include new structures to connect consumers and producers (farmers markets, online platforms), innovative farming systems (urban gardening, permaculture, artificial meat), initiatives to cut food waste (recycled food leftovers from restaurants), and initiatives that underpin protein shifts (new and old forms of proteins, e.g., legumes or insects, that shift us away from meat-based diets).
Grazing ecosystems	Replacement of the current unproductive northern ecosystems by highly productive pastures which have both a high animal density and a high rate of biocycling. Moreover, grazing ecosystems in the Arctic promote climate cooling through series of ecological effects.[19]

Table 9. Safe bet technological solutions.

2.3.1 Future breakthroughs

Future breakthrough technologies	Description/examples
Soil carbon sequestration or enrichment	Growing cover crops, leaving crop residues to decay in the field, applying manure or compost, using low- or no-till systems, and employing other land management techniques to improve soil structure (Sovacool, 2021).
Biochar	Biochar is obtained from pyrolysis, i.e., the thermal degradation of organic material in the absence of oxygen. Added to soils, biochar is a means to increase soil carbon stocks as well as improve soil fertility and other ecosystem properties (Sovacool, 2021). As an agricultural technology, biochar is probably in the former category (safe bet). But we don't know enough about carbon storage and permanence to deploy at scale. And there are emerging biochar-based systems that are still short of readiness to deploy. e.g., some Xprize entries.
Bioenergy with carbon capture and storage (BECCS)	Harnessing specific energy crops (e.g., perennial grasses, or short-rotation coppicing) or increased forest biomass to replace fossil fuels as a source of thermal energy, and capturing the CO2 produced and storing it underground. Most real-world emanations of BECCS involve only partial CO2 capture on biofuel fermentation, with the CO2 then injected into oil wells to enhance production.
Direct air capture (DACCS)	Involves a system where air from the atmosphere flows over a contactor that selectively removes the CO2, which is then released as a concentrated stream for disposal or use, while the sorbent is

[19] https://pleistocenepark.ru/

	regenerated, and the CO2-depleted air is returned to the atmosphere (Sovacool, 2021)
Hydrogen and ammonia in industry	Blue (CCS) or green (renewable electricity) hydrogen and ammonia fuels for high temperature uses
Ocean alkalinization	Deploys physical or chemical mechanisms to accelerate the geochemical processes that naturally absorb CO2 at slow rates. The big question marks here tend to be about governance, given norms regarding ocean pollution and dumping. Accelerated weathering: Chemical reactions to form carbonate or silicate minerals Adding alkalinity to the ocean would not only increase CO_2 uptake by the ocean, but it would also counter seawater acidity generated by excess anthropogenic CO_2. Considering that mineral weathering and ocean alkalinity production are the primary mechanisms whereby nature is consuming and storing CO_2, investigating this approach seems worthwhile.[20]

Table 10. Future breakthrough technologies.

2.3.2 Questionable alternatives

Here we seek to identify possible questionable technologies that for some reason have not been the subject of efforts in scale – often labelled as 'last resorts' but depending on the perceived urgency their deployment could be even imminent.

Questionable alternative technologies	Description/examples
Ocean fertilisation	Phytoplankton form the basis of the marine food web and are naturally limited by the availability of certain elements such as nitrogen, phosphorous and iron in the ocean. Ocean Fertilization approaches aim to add these limiting elements to the upper sunlit layers of the ocean to stimulate phytoplankton growth and photosynthesis. During these processes phytoplankton fix CO2 in their biomass, thereby increasing the carbon uptake of the upper ocean. When the phytoplankton die and their biomass sinks into the deep ocean, the fixed carbon can be stored at depth for 100 years and more.[21] Risks: Ocean fertilisation, if implemented, could lead to nutrient redistribution, restructuring of ecosystems, enhanced oxygen consumption and acidification in deeper waters.
Artificial Upwelling	Phytoplankton (small marine algae) form the basis of the marine food web and are limited by the availability of certain elements

[20] https://www.oceannets.eu/ocean-alkalinization/

[21] https://www.oceannets.eu/ocean-fertilization/

	(nutrients) such as nitrogen, phosphorous and iron in large parts of the ocean. These regions are referred to as ocean deserts. Enhancing the upward transport of nutrient-rich deep waters using pipes or wave pumps (**artificial upwelling**) has a fertilizing effect and can make the waters of ocean deserts more productive. Through the stimulated growth of phytoplankton, more CO_2 can be fixed in their biomass, which increases the carbon uptake of the upper ocean. When the phytoplankton die and their biomass sinks into the deep ocean, the fixed carbon can be stored at depth for 100 years and more.[22]
Space mirrors	Placing scatterers or reflectors of some kind in space to reduce the amount of sunlight entering Earth's atmosphere. Surface based brightening (i.e., albedo modification via human settlements): Enhancing the reflectivity of the built environment, crops or deserts at large scale buildings, roads, or other structures to cool the global temperature (Sovacool, 2021).
Stratospheric aerosol injection	Dispersing aerosol particles through high-altitude jets (e.g., sulphur) into the lower stratosphere, where they would reflect a small portion of incoming sunlight back to space, cooling temperatures.
Cirrus cloud thinning	Instead of reflecting incoming sunlight, this approach reduces cirrus cloud cover to facilitate the release of outgoing radiation.
Marine sky or cloud brightening	Coordinating fleets of ships to spray sea water into the air below marine clouds, thereby increasing the reflectivity and longevity of clouds.
Surface based brightening (i.e., albedo modification)	Enhancing the reflectivity crops, sea or deserts at large scale to cool the global temperature. Modifying human settlements could have positive impacts locally but likely to be too small to have impact on the global climate.
New-generation nuclear fission	Thorium, molten salt, SMRs etc - maybe just feasible in the time longer scales

Table 11. Questionable future technologies.

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Annex II: Key scenario developments and R&I implications

1. Sustainable transition

Domain	Development (probability: low, medium, high)	Related opportunities	Related threats	Implications to R&I policy today
Business	Business drives change towards sustainability and is supported by financial incentives and regulation towards carbon neutrality. New green business opportunities emerge (medium)	Scaling up green tech development and implementation beyond Europe and become a major export product	Emergence of green technology does not take place	Support for transdisciplinary R&D policy with support for scaling up
Civil society	Grassroots sustainability movements spread from within the Union to global scale and become institutionalised into climate policy decision making (medium)	Stronger cohesion in the EU, vibrant civil society and strong backing of EU climate policy and trust in institutions	Civil society movements fail to capitalize on their scale and remain a fractured and local	Foster experimentation of reflexive policy institutions across scales in the EU to demonstrate how public opinion can be part of institutions and make climate policy more relevant.
Science and Technology	Active R&D engagement and policy by the EU provide regulation for early experimentation of carbon removal approaches	Possibilities of combining R&D policy on carbon removal approaches to the EU's climate portfolio	Public opinion does not support geoengineering testing and thus preventing its progress towards testing and utilisation	Develop comprehensive and transparent R&D policy on geoengineering with public consultation throughout the development phase
Gov´t and policy	Strong global EU climate policy leadership supported by reflexive, deliberative democracy inside the Union (low)		Global governance structures deteriorate, and multilateralism is replaced by increasing animosity	Continue foster global cooperation through the EU's international development policy, support international governing institutions and foster global civil society institutions

General (cross-cutting)	Sustainable transition takes places across society with a diverse climate policy portfolio supported by strong mobilisation of society with global scaling up (low)	Rapid employment of a just transition agenda can bring down emissions while ensuring social support for climate policy	Transition does not scale up across society	Investment in the implementation of the just transition agenda to facilitate collaboration across society

2. Coalition of Sustainable communities

Domain	**Development (probability: low, medium, high)**	**Related opportunities**	**Related threats**	**Implications to R&I policy today**
Business	Power, size and influence of multinational companies declines (low)	Productivity increases, advance of public good takes precedence over advancing short-term interest of company shareholders, income more equally distributed, environmental impacts severely reduced and more easily controlled	Economic development of many merging markets slows down dramatically, jobs lost as multinational companies devolve, recession and economic slowdown	Stronger policies needed to rein excessive corporate influence in regulatory policies and scientific discourse (e.g., in the food and agriculture sector)
	Bottom-up innovation ("fixer-movement", FabLabs, tinkering) flourishes and is empowered by online platforms, social enterprises and community-based organisations (medium)	Innovation ecosystem that is nimble, dynamic adaptive and more effective to tackle challenges emerging.	The innovation capacity of this bottom-up approach could remain disconnected to and unable to confront the global challenges set by climate change and the Anthropocene	Academic innovation funds to nurture bottom-up and co-produced (university, industry, other stakeholders) innovation ecosystems. Investment for inclusion in open access technology and infrastructure as platforms for innovation and profit.

Civil society	Power rests to larger extent in decentralized communities, networks, and cooperatives, with substantial decreases in wealth inequality and ownership of private property. (low)	Rewilding of urban areas to make them both greener and more connected to surrounding rural landscapes.	Not all communities take collaborative, progressive approach. Instead, a more tribal, insular and militaristic movements take over	Similar as above. invested in commons, public spaces, open access, and strategies for inclusion in open access technology and infrastructure as platforms for innovation and profit.
Science and Technology	Widespread new types of local food production, especially in and around cities, including artificial meat (medium)	Can reduce systemic risks related to disruption of distant and highly concentrated global value chains. Reduced carbon emissions. Regenerated ecosystems	Initial prices surge initially (driven by rising age among farmers, difficulty to get in new younger farmers, breaking of international price competition) causes insurmountable public backlash and food insecurity	1) Commit to broader support for public sector food and agricultural R&D that encourages innovations that are not driven solely by profit, e.g., public plant-breeding programmes (including open-source seeds). 2) Public research programmes should be inclusive of end users and focus on production methods that are diverse, sustainable and widely accessible, such as agroecology.
	Decentralization of energy production and distribution (medium)	Diversifying national and regional energy mixes from highly centralised infrastructure (typically dependent on fossil-fuels or large hydro-electric schemes) to more diverse and local	Increased burden on producers and less regulated trading markets increases transaction costs of producers, and end-user prices. Lack of accountability on decentralized producers. Together this	R&I strategies focused on energy transitions that have: a high involvement of different types of actors (e.g. NGOs, municipalities, trade unions) that become increasingly

		renewable energy options, will underpin resilient energy systems	causes energy crisis to be exacerbated.	important as renewable energy systems becomes more distributed and decentralised; a systems perspective to understand the need for complementary innovations, especially in later phases of transitions when renewable energy technologies diffuse widely; a reflexive and learning-focus so as to continuously adapt policies to changing circumstances.
Gov´t and policy & General (cross-cutting)	Large (macro-scale) sustainability transition emerges from the bottom-up following experimentation at the micro-level, the formation of new coalitions, and the destabilization of existing regime.	Deep transformation stretching across how power, food and energy is produced and consumed. Shift in mainstream human values and social organization, occur together and in tandem with technological change.	Top-down barriers to change quell transition. Enabling factors to drive deep transformation not strong enough	Ramp up space for transformative and transdisciplinary research approaches at the science-society interface (such as real-world laboratories, T-labs) that contribute to building capacity to support societal change.

3. Deepening divisions

Domain	Development (probability: low, medium, high)	Related opportunities	Related threats	Implications to R&I policy today

Business	Investment inadequate (med)	Increased reliance on state investment (easier to ensure ESG conditions)	Broader economic instability	Research into regulation, incentives and biz-models for climate tech that don't rely on markets.
	Food and energy sectors badly impacted by climate change (high)	Driver for energy efficiency and dietary change	Social instability	Research options for managing degrowth and just transition
	Security/military/ policing complex grows (med)	New logic for climate investment	Authoritarian enforcement	Governance to detach from security / defence influence
Civil society	Activism increasingly disruptive (med)	High awareness of climate issue. New spaces for action.	Authoritarian reactions. Polarisation	Involve activists as stakeholders in research agendas now
	Social organisations increasingly engaging on climate (high)	New social-environmental alliances	Political polarisation if climate seen as left / woke issue only	Ensure social & environmental goals are linked in research plans and governance
Science and Technology	Emphasis on NBS for adaptation and carbon removal (med)	Address biodiversity issues in tandem	Undermine biodiversity by focus on carbon. Social injustice in land grabs.	Develop techniques and governance for just NBS
	Scientific calls for geoengineering (med)	Galvanise mitigation action	Co-option to justify continued fossil exploitation	Get ahead of the game with governance for geoengineering research
Gov´t and policy	Populism spreads (high)	Democratise decision making, with e.g. citizen assemblies	Social and political polarisation Resistance to immigration	Critical to research politics and psychology of populism. And tools for migrant integration
	Inter- and intra-national tensions raised (med)	Effective devolution of power. Climate as possible 'peace-building' issue	Secession and state disintegration, possible (civil) wars and genocides.	Research de-escalation, disarmament, non-proliferation tools.
	Nationalist development of fossil fuel reserves (high)	(Re)deploy fossil fuel industry expertise to support CCS, Hydrogen etc.	Continued non-climate impacts (air pollution, oil-spills etc)	Developing and improving carbon removal techniques.

General (cross-cutting)	International institutions and cooperation weak and fragmented (high)	Reduced international trade and growth	More conflict. More suffering of migrants and refugees. Destabilisation of states.	New forms of polycentric governance.
	Disinformation persistent (high)	Regulate / nationalise social media platforms	Destabilisation of democratic processes / elections	Education and other tools to inoculate against disinformation.

4. The Technological fix

Domain	**Development (probability: low, medium, high)**	**Related opportunities**	**Related threats**	**Implications to R&I policy today**
Business	American Big Tech (FAGMA) becomes a key climate driver with climate tech acquisitions in Europe, R&I investments and heavy lobbying to shift the markets. (medium)	A shift toward low carbon business in general and scaling up climate tech.	Investments in technology are not enough to curb climate crisis. No clear decoupling of economic growth and climate impact, no behavioural changes in consumption patterns.	Greatly and immediately accelerate European public-private investments in climate R&D, and steer and coordinate (via incentives or mission-based innovation platforms) to ensure European climate tech leadership and that markets evolve towards sustainable consumption.
Civil society	Global civil society movements are weakened and co-opted by big tech firms and government. (low)	Co-opted movements would have greater access to resources and larger visibility within corporate social responsibility programs Joint civil society-industry partnerships with entirely new actors and structures could also emerge	Civil society is no longer able to act independently or as a check on Big Tech and Big Government plans Governance patterns become infused with for-profit motives and an emphasis on markets and financialization	Integrate and coordinate global civil society efforts with corporate climate leadership Expand of voluntary initiatives and a role for sub-national actors

Science and Technology	Investments in science and technology increase substantially, making energy, transport, buildings, and climate change the largest single source of revenue (high)	Accelerated patterns in intellectual property and new, unforeseen "serendipitous" inventions Greatly improved performance, scaling, and commercialization of many niche innovations (e.g., desalination, hydrogen, renewables, agriculture and food)	Reliance on technology and supply-push ignore other forms of social change such as behaviour or direct action Consolidation of intellectual property and power in a few corporate firms and actors, widening the disparity between rich and poor (within and between countries)	Implement mission-driven innovation programs to promote transformative R&DD Pursue a broad portfolio of different options to diversity the chances of innovation breakthrough
Gov´t and policy	Ecomodernist technology party rises to leadership in the EU (low)	Scaling up green tech development and implementation	Policy co-opted by big green tech. Missing degrowth options, social aspects and precautionary principle	To research (green) technology agendas in party politics and how to learn from but avoid radical agendas
General (cross-cutting)	Recognition that future climate pathways need some level of non-state involvement (e.g., private sector, civil society, even if in compromised form) (high)	Spillovers from innovation into other non-climate areas (aerospace, medical life sciences) Co-benefits extending beyond climate action such as jobs, resilience, and improved domestic security	Risks of centralization and consolidation of power Tensions between climate action (a public good) and private sector motives (private goods)	Hedge future risks by investing in challenges-based science and technology programs rather than technology or disciplinary based ones