
erc
European Research Council
Established by the European Commission
European Commission
Mapping ERC Frontier Research
Transformative change
for a sustainable future
2024

Table of Content

> ***No country, rich or poor, is immune to the devastation inflicted by climate change, biodiversity loss, land degradation and pollution.***
>
> António Guterres, UN Secretary General at the Convention for Biological Diversity COP16

Foreword

Across the world societies are seeking to tackle the interconnected challenges of climate change, the loss of nature and sustainable development. Both the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) have shown unequivocally that this will require profound transformation in our economic systems, political structures and cultural norms, supported by new technologies and innovations. Frontier Research is essential in understanding these global challenges and identifying transformative changes and their potential in order to address them.

Mapping Frontier Research is an initiative of the ERC Scientific Council which aims to demonstrate how curiosity-driven research supported by the ERC is contributing to our understanding of critical issues. This report, *Transformative change for a sustainable future*, draws on over 300 projects funded by the ERC over the last decade, which each contribute to understanding the profound transformation our societies need to respond, adapt, and thrive in the face of the crises of climate and nature. While the challenges we face are unprecedented, this research demonstrates that they also provide opportunities for societies to develop and flourish by protecting biodiversity and working with nature, generating innovation, and building new forms of social solidarity which foster healthy communities and strong and stable economic futures.

The report highlights the important role of the social science and humanities in generating new and creative ways of understanding the multi-crises we live in and in identifying pathways for transforming societies that can address trade-offs and enable just, sustainable solutions. It also demonstrates the importance of rethinking the kinds of knowledge we need to solve the problems ahead. Integrating knowledge from local, traditional, and Indigenous communities and from business and technology will be critical to move forwards and will in turn expand the horizons of frontier research through new collaborations. Researchers also emphasise the importance of multi- and interdisciplinary approaches that can integrate diverse perspectives, generate new methods, and deploy novel techniques, including through the use of AI, to support a holistic understanding of the transformative change ahead.

Frontier research is helping us to understand not only the challenges we face in tackling the climate and nature crises, but also the opening of new forward-looking perspectives on the many ways in which governments, businesses, communities and individuals are already creating solutions. Learning from this research will be vital as policymakers and practitioners seek to reach ambitious international goals and also ensure that local communities and businesses are supported through a just transition.

Harriet Bulkeley
Member of the
ERC Scientific Council

Eystein Jansen
Vice President
of the ERC Scientific Council

Introduction

The European Research Council (ERC), established by the European Union (EU) in 2007, is the premier European funding organisation for excellent frontier research. By giving researchers the freedom to pursue ambitious ideas without predetermined priorities, the ERC enables groundbreaking research with impact beyond science. This research provides knowledge and innovation that can inform and shape EU policies, from design to implementation.

In 2022, the ERC analysed the projects it funded under the EU's Horizon 2020 ('H2020') programme (2013-2020), as well as their relevance for key EU policies during that period. The study revealed that a significant proportion of research addressed pressing global challenges, with 14% of projects aligning with European Green Deal policies[1]. 29% of those projects tackled multiple policy areas, including climate change, the transformation of food systems, nature protection and restoration, and clean energy and transport.

The United Nations (UN) calls for a renewed commitment to the Sustainable Development Goals. To achieve those, scientific, technological and social innovations are essential. The Intergovernmental Panel on Climate Change (IPCC) has emphasised that effective solutions are available, but further climate action is needed to accomplish the transformational change that is essential for a sustainable, equitable world[2]. Solutions need to be scaled up and mainstreamed if climate action targets are to be met. Societies and economies will need fundamental changes to facilitate and accelerate the green transition.

The ERC Scientific Council therefore decided to analyse how **ERC-funded research could shed light on the concept of transformative change, what it entails, and its potential to create the conditions for nature, economy, and society to thrive in a sustainable future**.

This report presents an analysis of over 300 ERC-funded projects, their scientific scope, and their relevance to policy areas (Chapter 1). The following chapters (Chapters 2 to 6) showcase examples of projects in five thematic areas that illustrate **the diverse forms that transformative change can take, and how frontier research can inform policies in practice for sustainable transitions**. These chapters also highlight results from these projects, including **leverage points and factors that can facilitate or hinder a just green transition**, and recommendations by ERC grantees gathered through interviews.

In a nutshell

- Over 300 ERC projects help understand what transformative change is, and how it takes shape in various systems.
- Their results can inform the design and implementation of European Green Deal policies and how the Sustainable Development Goals can be achieved, through a just green transition.
- These ERC projects show that green transitions are already underway, transforming our existing systems and structures. In the race against the triple planetary crisis of biodiversity loss, climate change and pollution, they underline the urgency to act, and that both mitigation and adaptation interventions are useful and needed.
- ERC grantees emphasise the need to fully rethink systems - economic, food, or energy systems among others, and to develop multidisciplinary approaches that consider their complexity, while keeping in mind justice and equity.
- ERC frontier research can deliver a better understanding of global change and the multi-crises we live in. New and creative ways of thinking about these connections, across disciplines and involving multiple actors, can help identify pathways for transforming our societies.
- Many of the challenges identified by ERC projects in this portfolio are social, economic, cultural, and political. This is reflected in the large proportion of social sciences and humanities projects, which work on uncovering dynamics, causes and consequences of the just green transition.

Policy context

Climate change, biodiversity loss and pollution are existential threats that underline the need for concerted efforts while ensuring social justice and human rights. Just green transitions are therefore on the political agenda, aiming at fostering and accelerating transformation towards more sustainable pathways. This chapter provides an overview of the global framework and European policy context for this report.

Global framework

In 2015, the UN adopted the **2030 Agenda for Sustainable Development** 'to secure the rights and well-being of everyone on a healthy, thriving planet'. The Agenda provides a roadmap to 'transform our world' and achieve sustainable development in its economic, environmental and social dimensions, while fostering peaceful, just and inclusive societies[3]. This Agenda defines **17 Sustainable Development Goals (SDGs)**, each of which has a set of targets, that address a wide range of thematic issues including water, energy, climate, oceans, urbanisation, transport, science and technology, alongside objectives to end poverty and hunger and improve health, well-being, education and equality across the world. In September 2024, world leaders reaffirmed their commitment to the SDGs and adopted the Pact for the Future, which is designed 'to turbo-charge [their] implementation'[4].

The United Nations Framework Convention on Climate Change (UNFCCC), adopted in 1992, aims to stabilise greenhouse-gas concentrations 'at a level that would prevent dangerous anthropogenic (human induced) interference with the climate system.' It was followed, in 2015, by **the Paris Agreement**, which was a turning point, as the 196 signatory countries adopted a set of legally binding targets to combat climate change[5]. The implementation of the Agreement requires economic and social transformation, based on the best available science. It is supported by the Intergovernmental Panel on Climate Change (IPCC), the UN body for assessing the science related to climate change. The IPCC reports, starting with the special report on Global Warming of 1.5°C, call for transformation in our society to mitigate and adapt to climate change.

Building on the **Convention on Biological Diversity's** strategic plans, the Kunming-Montreal **Global Biodiversity Framework** was adopted in 2022[6].The framework seeks to preserve the diversity of life on Earth while promoting the sustainable use of natural resources and supports the achievements of the SDGs. Its implementation is supported by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (**IPBES**)[7], which gathers scientific evidence, in the form of assessment reports. The IPBES is preparing a thematic assessment focusing on the 'underlying causes of biodiversity loss, determinants of transformative change and options for achieving the 2050 vision for biodiversity'. It will be presented for adoption by the IPBES plenary in December 2024. IPBES has defined a set of leverage points for transformative change that the assessment will cover, which include behavioural, social, cultural, economic, institutional, technical, and technological dimensions, at both individual and collective levels.

Also in 2022, the UN Environment Assembly adopted a resolution calling for the establishment of a **science-policy panel on chemicals, waste and pollution prevention**. An ad-hoc Open-Ended Working Group has been mandated to prepare proposals for the science-policy panel.

The European Green Deal

At European level, the European Union (EU) and its Member States are signatories to the Paris Agreement. The EU strives to become the world's **first climate-neutral continent by 2050**, an economy with net-zero greenhouse-gas emissions, with the long-term objective to build a better, more sustainable future for all. This objective is set in **the European Green Deal**, which was adopted in 2019.

The European Green Deal is a comprehensive initiative to address climate change across policy areas. It is an opportunity to transform the EU into a resource-efficient and competitive economy, where no person and no place is left behind[8]. It includes a set of proposals to support sustainable development, encompassing policies and initiatives across various sectors and ensuring that the green transition is just and inclusive by:

- transforming our economy and societies;
- making transport sustainable for all;
- leading the green industrial revolution;
- cleaning our energy system;
- renovating buildings for greener lifestyles;
- working with nature to protect our planet and health; and
- boosting global climate action.

Policy and regulatory initiatives include the EU's biodiversity strategy for 2030[9], the EU strategy on adaptation to climate change[10], and the European Climate Law adopted in 2021[11]. In 2021, the EU also adopted the Zero Pollution Action Plan[12] and more recently the Net-zero Industry act and the Nature Restoration law[13].

Research and innovation in support of the EU Green Deal is crucial. The EU provides research funding to explore what transformative change would entail for climate and biodiversity. Beside ERC projects, which are funded by the EU without any predetermined priorities, the research and innovation programme funds projects under the 'Global challenges and European industrial competitiveness' pillar. It also launched a call[14], through which more than EUR 80 million has been invested in projects dedicated **to restoring biodiversity and ecosystem services at scale to enable transformative change**[15]. More recently, the European Biodiversity Partnership Biodiversa+, which is co-funded by the EU, launched a transnational joint research call on 'Biodiversity and Transformative Change'[16].

Following the 2024 European elections, the **political guidelines** of the European Commission President confirmed the Commission's commitment to the objectives of the Green Deal to create conditions for **sustainable prosperity and competitiveness in Europe**[17]. The guidelines propose, among others, a new prosperity plan that includes a Clean Industrial Deal to decarbonise and bring down energy prices; investments in the EU sustainable competitiveness so that businesses are productive and environmentally friendly; a new Circular Economy Act; a European affordable housing plan and a chemicals industry package.

A just and inclusive transition

At both international and European level, the importance of fostering a green transition that is also just is recognised. From a global perspective, a just green transition means addressing the disproportionate burden borne by **countries in the Global South**, as well as **Indigenous peoples and local communities (IPLCs)** worldwide, that are most affected by environment degradation and climate change. While historically contributing less to carbon emissions, these countries and communities often face the brunt of environmental degradation and extreme weather events. Ensuring a just transition is also a matter of intergenerational, economic and distributive justice. A just green transition entails not only supporting developing countries and climate vulnerable communities, groups and generations, but also addressing the **systemic inequalities** that perpetuate this vulnerability.

To support EU regions and Member States that rely heavily on carbon intensive activities, the European Commission has established the **Just Transition Mechanism**[18]. It also supports citizens who are most vulnerable to the transition, by providing access to reskilling programmes and employment opportunities in new economic sectors. Similarly, the Social Climate Fund[19] provides funding to Member States so that the most vulnerable people, such as households in energy or transport poverty, are directly supported during the green transition.

Against this policy background, the following chapter defines the scope for this report and the selection of the research presented.

Scope

This report showcases ERC-funded projects that explore transformative change towards a just green transition from various angles and some of their results. These projects examine the factors that facilitate or hinder the profound societal and economic transformations required to address the interconnected crises of climate change, pollution and biodiversity loss.

A wealth of ERC-funded projects contribute to our understanding of the impact of this triple crisis. Many have developed new technologies and innovations that can support climate mitigation and adaptation and address the environmental crisis. Several studies have confirmed the contribution of ERC-funded research in this regard:

- An ERC study of its funded research's representation on frontier, dynamic research areas showed significant impact in areas such as plant and crop genomics, ecology, forest dynamics, climate change, global precipitation change, and metal-halide perovskites for energy application[20].

- A report of the European Commission's DG Research and Innovation looked at the contribution of EU-funded research to the evidence base of the assessment reports of the Intergovernmental Panel on Climate Change (IPCC). Among those, ERC projects have contributed more than 850 publications that were cited in the reports[21].

- The 2022 ERC Mapping Frontier Research analysis of all H2020 ERC-funded projects showed that of the 6 707 projects analysed, 14% are relevant for climate policies and green solutions[22]. When looking at the contribution of ERC research to the advancement of scientific methods employed in the areas covered by the European Green Deal, substantial strides have been made, for example, in computational modelling, specifically in simulating sea-level changes and CO_2 fluxes. Significant developments have also been achieved in experimental methodologies, particularly in ecosystem modelling, CO_2 conversion and micro-nano-engineering, with a specific focus on enhancing the efficiency of solar cells and on developing advanced materials for energy applications.

- Finally, two ERC reports showcased projects relevant to two areas of the Green Deal policies. A first report on sustainable food production and consumption, highlights ERC-funded research that contributes to the advancement of sustainable food systems and the ten pathways of the EU Food 2030 strategy[23]. The second report presents ERC frontier research for biodiversity, its links with the EU Biodiversity Strategy 2030 objectives as well as project results that contributed evidence for three recent assessments of the last Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)[24].

Examples of ERC projects

- Solar power can help cut emissions and provide an alternative to fossil fuels. ERC grantee Michael Grätzel is pioneering a new generation of photovoltaic solar technologies that are highly reliable and cost effective. The record-breaking performance of his solar cells has real-world applications in sustainable electronics.
- Through combining their expertise, four ERC grantees have alerted the scientific community to what nutrient imbalances could mean for our planet and our species. Their findings could lead the world towards more accurate climate modelling, more equitable policymaking, and more sustainable food production.
- The work of ERC grantee Ülo Niinemets has shown that monitoring plant stress emissions could help us better understand atmospheric processes. This has led to a rethink on global climate modelling and has strengthened research into crop resilience.

Complementing previous analyses, this report focuses on projects that can help explain why, despite significant technological advances, our society is not more advanced on the path towards environmental sustainability. The project results also provide solutions or evidence that could be used by policymakers to lead to an overall shift in our society towards greener and more sustainable practices, from renewable energy to the use of natural resources, from new production modes to consumer behaviours.

The ERC projects highlighted in the following chapters aim to illustrate how transformative change can be put in motion in various ways and across sectors, and how to bring deep structural and systemic changes in the way societies operate, with an impact on the economic, social, environmental and institutional spheres.

1. ERC frontier research on transformative change: an overview

Over 300 projects were identified within the scope of this report. They were funded by ERC calls from 2014 to 2023 under the Horizon 2020 and Horizon Europe research and innovation framework programmes. As expected from the scope of the report, most of the projects are in the domain of social sciences and humanities.

Portfolio in numbers

312 projects

EUR 653 million Budget

22 Countries

34 projects Life Sciences

33 projects Physical Sciences and Engineering

245 projects Social Sciences and Humanities

Starting Grants **136 projects**

Consolidator Grants **103 projects**

Advanced Grants **43 projects**

Proof of Concept Grants **16 projects**

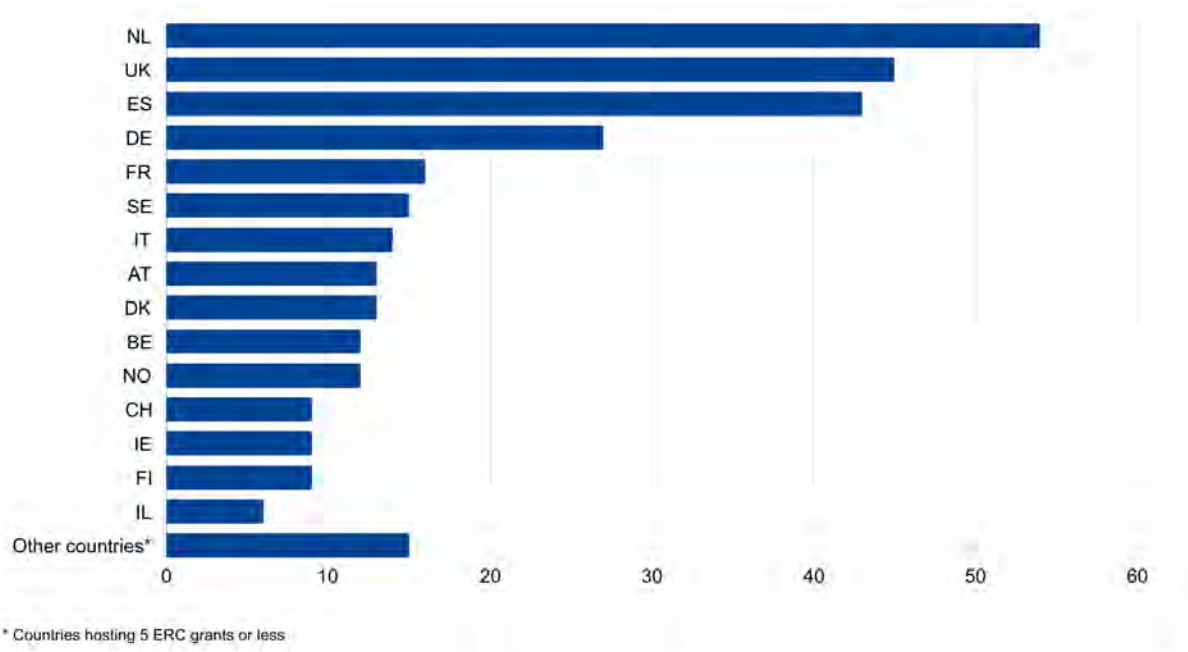
Synergy Grants **14 projects**

More specifically regarding the **scientific domains**[25], projects primarily focus on institutions, governance and legal systems (currently ERC panel SH2), human mobility, environment and space (currently ERC panel SH7, created in 2021) and the social world and its diversity (currently ERC panel SH3). In lesser numbers, projects address individuals, markets and organisations (ERC panel SH1), the study of the human past (ERC panel SH6) and cultures and cultural production (until 2023 ERC panel SH5).

In physical sciences and engineering, most projects fall within earth system science (ERC panel PE10), followed by product and process engineering (ERC panel PE8). In life sciences, projects mainly concentrate on environmental biology, ecology and evolution (ERC panel LS8), and biotechnology and biosystems engineering (ERC panel LS9). Additionally, there are 14 larger projects, led by more than one researcher, funded by Synergy grants.

In terms of **geographical distribution**, projects in this portfolio are hosted in 22 countries across EU Member States and associated countries. The countries hosting the highest number of grants are the Netherlands, the UK, Spain, and Germany, which host more than half of the projects in this portfolio. Additionally, seven countries – France, Sweden, Italy, Austria, Denmark, Norway, and Belgium – contribute significantly, accounting for approximately 30% of the projects. Other countries hosting grants are Czechia, Estonia, Finland, Greece, Ireland, Israel, Slovenia, Cyprus, Poland, Portugal and Switzerland.

Projects by country

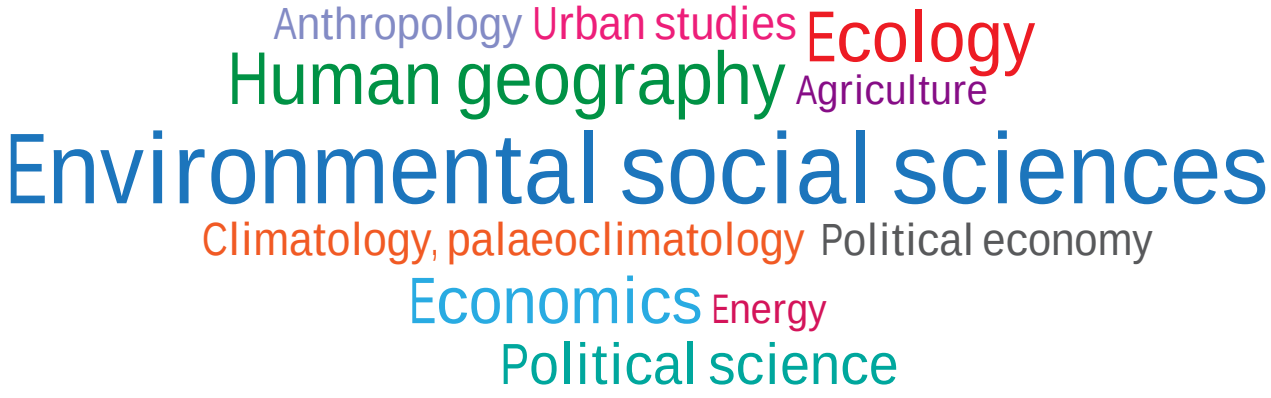


* Countries hosting 5 ERC grants or less

Scientific landscape: disciplines, topics and geographical spread

Mapping Frontier Research (MFR), an internal ERC classification system, provides further insights into the main scientific disciplines and topics of this group of projects[26]. The word clouds below show the main disciplines and topics addressed by ERC projects in this portfolio. It should be noted that many projects on transformative change combine or work across disciplines, and address research questions spanning several topics and systems.

In terms of **disciplines**, environmental social sciences, human geography, ecology, economics and political sciences are the most represented. Climatology and palaeoclimatology, urban studies, anthropology and political economics are also well accounted for in the portfolio.



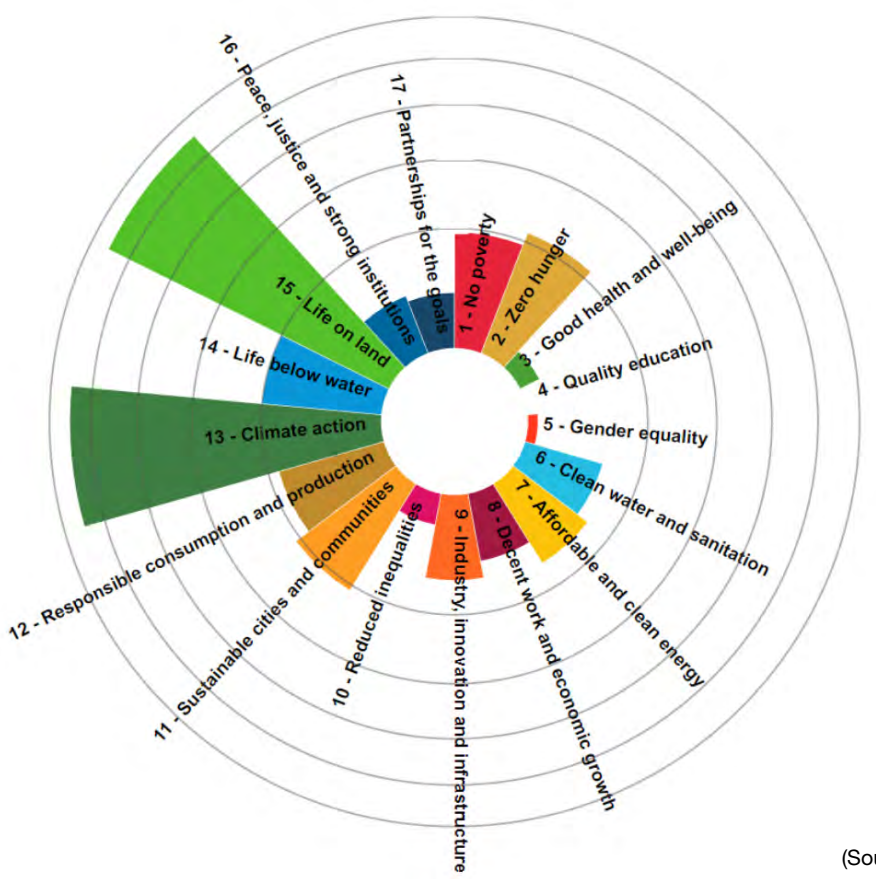
In terms of the **main topics** addressed by the projects, climate change impact, adaptation, and mitigation as well as sustainability, are naturally the most prominent ones. Other topics widely covered by this portfolio include biodiversity and conservation biology; policy; governance; resilience (environmental, social, economy and psychological); climate, ocean, atmosphere and icesheet dynamics and evolution; ecosystems and community ecology; resource management; land use; and sustainable growth.

Policy landscape: relevance to SDGs and EU Green Deal policies

This section gives an overview of how the projects in this portfolio are linked to, firstly, the Global Sustainable Development Goals, and then to the policy areas of the European Green Deal. Many ERC projects in this report cover several dimensions of the green transition, study complex systems or work across sectors (e.g. energy, water and agriculture). They are consequently seen as relevant for several goals and policies, with strong overlaps between some objectives.

The chart below illustrates the **contribution of this group of projects to the 17 SDGs**. It was drawn up using an internal European Commission IT tool (CORTEX) by analysing the research projects' relevance to the Sustainable Development Goals. The tool relates projects descriptions and results (e.g. publications) to SDGs. One project can be linked to one or more SDGs.

ERC projects relevance to SDGs



(Source: CORTEX)

A closer look at the data shows the co-occurrence of several SDGs for many projects. For example, many projects linked to SDG 13 (Climate action) are also relevant to one or more other SDGs, with the strongest link with SDG 15 (Life on land), but also connections with SDGs 14 (Life below water), 12 (Responsible consumption and production), 11 (Sustainable cities and communities) and 6 (Clean water and sanitation).

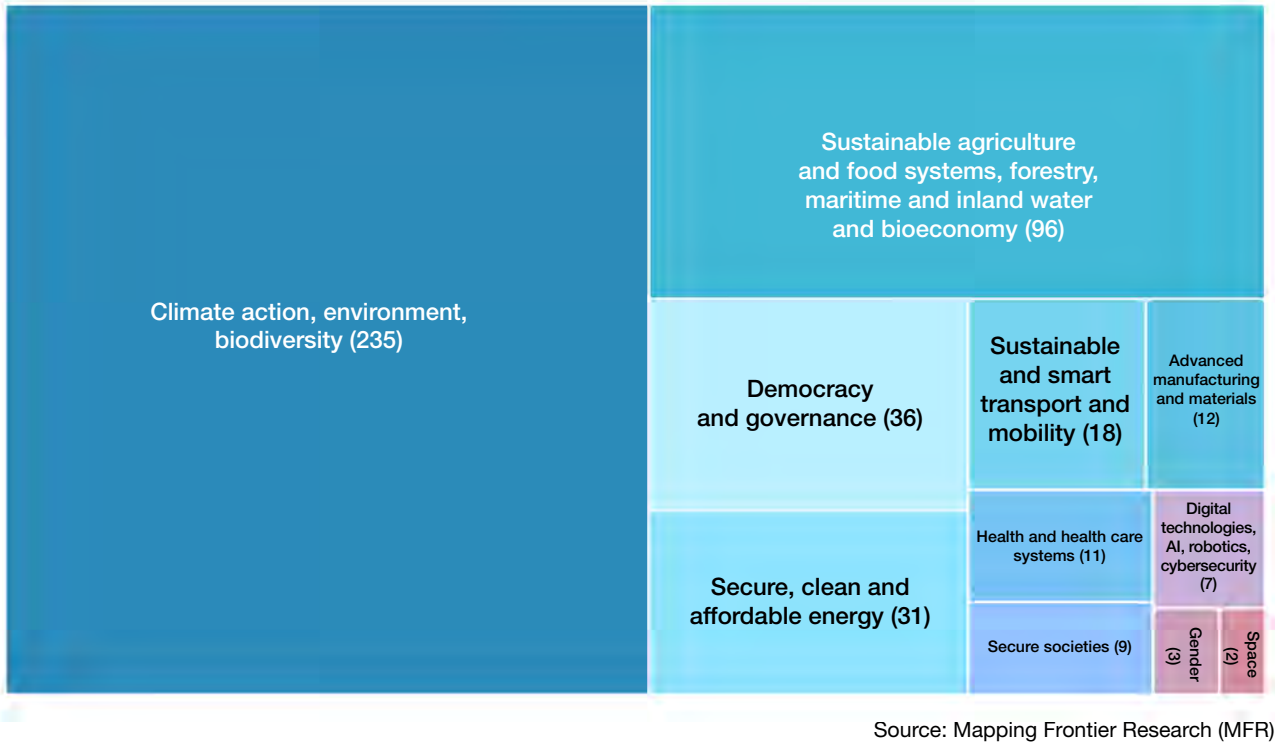
Many projects relevant for SDG 14 (Life below water) are also relevant to SDGs 13 (Climate action) and 15 (Life on land). A small group of ERC projects address coastal management through various lenses from managing the risks for flooding and sea-level rise to fisheries and environmental coastal management.

Projects relevant for SDG 2 (Zero hunger) are often relevant to SDG 1 (No poverty), 13 (Climate action), 15 (Life on land) and 12 (Responsible consumption and production), highlighting a group of projects working on land use and food systems.

This distribution of projects guided the structure of the following thematic chapters.

Further insights are provided using the **ERC Mapping Frontier Research (MFR)** internal classification, which gives a picture of how the projects in this portfolio align with EU policy objectives as defined in the H2020 and Horizon Europe framework programmes for research and innovation. The objectives reflect the policy areas covered by the European Green Deal as well as those relevant to the research policy.

ERC projects links with EU policy priorities



Source: Mapping Frontier Research (MFR)

Examples of ERC grantees at the interface between science and policy

Many researchers provide evidence-based advice to inform local, national, EU or international policies. Below are a few examples of grantees working at the crossroads of science and policy:

- **Jörn Birkmann** is Director of the Institute of Spatial and Regional Planning at the University of Stuttgart, Germany. He focuses particularly on issues of sustainable development, urban planning and climate change adaptation as well as risk and vulnerability reduction. He is Coordinating Lead Author for the IPCC's Sixth Assessment Report AR6.
- **Vanesa Castán Broto** is a Professor of Climate Urbanism at the Urban Institute, University of Sheffield. She is a Lead Author for the Intergovernmental Panel on Climate Change (Working Group II, Vulnerability, Impacts and Adaptation).
- **Joyeeta Gupta** is a professor of environment and development in the Global South at the University of Amsterdam. In 2024, she was appointed as a Co-chair of the United Nations Group of Ten High-level Representatives of Civil Society, Private Sector and Scientific Community to Promote Science, Technology and Innovation for the Sustainable Development Goals.
- **Phoebe Koundouri**, Professor at the Athens University of Economics and Business and the Technical University of Denmark, President of World Council of Environmental and Natural Resource Economists, Chair of the United Nations' SDSN Global Climate Hub. She acts as an advisor to the UN, G20, World Bank, European Commission, EIB, EBRD, OECD, WHO, and many others, including international and national governments and private companies.
- **Victoria Reyes-García**, ICREA Research Professor at the Institute of Environmental Sciences and Technology of the Autonomous University of Barcelona (ICTA-UAB), Spain is a coordinating lead author of the IPBES assessment on transformative change. Her work focuses on the relevance of Indigenous and local knowledge systems to understanding and addressing the environmental and climatic crises.

- **Johan Rockström**, from the Potsdam Institute for Climate Impact Research, Germany, is an internationally recognised scientist on global sustainability issues, who led the development of the new Planetary Boundaries framework for human development in the current era of rapid global change. Besides research that has been widely used to guide policy, he provides strategic scientific guidance and is a consultant for several governments and business networks.
- **Sebastian Villasante**, from the University of Santiago de Compostela, Spain, is engaged with the Global Tipping Points reports (2023 and 2025) and is a coordinating lead author of the IPBES assessment on transformative change. He studies marine and coastal ecosystem services, the governance of the oceans, climate change and poverty alleviation.

2. Leverage points for sustainable transitions

The urgent need for climate action and combatting nature loss has prompted international and European organisations to call for transformative change towards more sustainable societies. ERC projects in this report encompass a wide range of approaches, from theoretical frameworks to concrete case studies and policy recommendations. This chapter focuses on projects that shed light on three possible leverage points for a just, green transition: institutional aspects and governance; social and behavioural factors that could help with the adoption or mainstreaming of greener behaviours; and financial and fiscal aspects.

2.1. Institutions and environmental governance

The selection of projects below focuses on governance and institutional aspects. They look at factors, drivers and scenarios that could lead to more efficient environmental governance, balancing interests and avoiding backlash against policies. They also highlight the need to better understand how stakeholders and citizens receive and engage with policy proposals and their implementation.

The ProblemShifting project investigates the **trade-offs that can occur between equally important environmental goals**. Rakhyun E. Kim and his team at the University of Utrecht, Netherlands, look at how environmental treaties influence each other and how decisions made under one treaty can have unintended negative effects at scale, including on the environment. With over 1 000 international environmental treaties in force, preliminary results show that these 'green-green' conflicts are more common than we realise and can undermine the green transition.

Through a survey, Kim's team developed a database of problem-shifts, covering aspects such as climate change, biodiversity, wetlands, desertification, chemicals, hazardous waste, ozone depletion, marine pollution, plastics, space, and fisheries[27]. The database will support a comprehensive mapping of problem-shifting between international environmental treaty regimes. The team is studying under which conditions problem-shifting happens, how some treaty regimes proactively counter the risk, and the systemic effects of this phenomenon beyond treaties. The aim is to develop proposals to ensure that global environmental efforts have a net positive impact.

> *When identifying leverage points, we often focus on synergies and how to scale them up. I believe addressing critical trade-offs or conflicts - what I call 'problem shifts' - is equally important. If these conflicts are not addressed, we face the risk of paralysing the entire environmental treaty system.*
>
> Rakhyun E. Kim, ERC project ProblemShifting

Some reflection points highlighted by the team include the role of institutions, and the need to define clear boundaries of what is acceptable in the pursuit of the green transition and what cannot be compromised. Kim also stresses the need for the green transition to have a mission-oriented approach that includes a clear overarching objective shared by all institutions involved through an inclusive, transparent and participatory process.

> *At the most fundamental level, we need to promote systems thinking or holistic approaches. We need to think of policies that contribute to an overall sustainability goal, not to individual goals, to goals that seem most pressing in the moment or goals that focus on a single political mandate without considering the bigger picture.*
>
> Rakhyun E. Kim, ERC project ProblemShifting

Urgent action is needed to address the nature and climate crises. This requires ambitious policy actions, with the associated risk of policies being 'pushed back' e.g. via protests and social mobilisations. Backlash has been observed in recent years, which can weaken policies or lead to their being reversed.

Focusing on climate policy in industrial democracies, the BACKLASH project aims to understand **why societies sometimes accept costly public action, while at other times turning against a particular policy**. Backlash can arise because of economic factors (e.g., perceptions of costs), cultural factors (e.g., perceptions of what climate policy symbolises about oneself and society), or the complex ways in which policy expectations interact with peoples' everyday lives. But exactly when backlash occurs is complex, and not easy to predict[28].

James Patterson's team, also at the University of Utrecht, Netherlands, empirically studies policy backlash in a variety of industrial countries building on the conceptual framework they designed[29]. Preliminary results tend to show that extreme forms of backlash are uncommon but, when backlash occurs, it can be very impactful and can set back policy progress in many ways[30]. Studying how and why opposition arises helps to understand how to advance ambitious climate policy and to find ways for policymakers to proactively address the concerns that people may have in their real-world contexts.

> ***We should think about climate policy as much more than just setting targets. It is also about seemingly mundane aspects that are crucial to making low-carbon options viable in peoples' lives. Climate policy might mean thinking outside the box in other ways, such as creating positive conditions that make people feel more secure and able to take on the more demanding changes***.
>
> James Patterson, ERC project BACKLASH

According to Patterson, a key opportunity could be to support timely and in-depth learning and exchange among policymakers, politicians and researchers about policy responses to avoid backlash. Policymakers and politicians almost everywhere are confronted with the challenge of advancing ambitious climate policy while avoiding backlash. At the same time, there is a wealth of policy and practical experience that provides the opportunity to develop new innovative policy approaches.

Among ERC projects that have a particular focus on **ocean governance**, the MARIPOLDATA project, led by Alice Vadrot from the University of Vienna, studied the political aspects of marine biodiversity data, and global and national policies and practices of monitoring the oceans. Her second project, TwinPolitics, aims to understand the socio-technical challenges of a digital twin of an ocean (DTO) and its use in national and international contexts. Its aim is both to develop methodological approaches to address these challenges and to ensure the effective use of DTOs.

2.2. Mainstreaming green behaviours

Transformative change for a just green transition will not only require adequate governance and institutional practices, but also profound adaptations at the citizen level. Technology-based solutions (e.g. hybrid or electric cars) and the internalisation of environmental costs have been given a great deal of attention, but behavioural change is equally needed. The green transition requires social coordination and a substantial mobilisation towards greener behaviours. Several ERC projects investigate the conditions that may enable or hinder the adoption of individual (or minority) behaviours by larger groups.

By studying the role that social norms, observability, and individual vs. collective responsibility play in displaying voluntary climate actions (e.g. changing to renewable energy), the GREEN TIPPING project will offer innovative strategies to instigate transformative shifts. Drawing from the literature on ecological tipping points, Alessandro Tavoni, from University of Bologna, Italy, proposes **social tipping points and behavioural interventions** that can accelerate a 'cascading dynamic of self-enforcing change'. These are based on social psychology concepts such as pluralistic ignorance and conditional cooperation.

> ***We still need supply side interventions in the form of traditional policy but given that those that need to abide by these policies are humans, and considering our social and behavioural proclivities, it is very important to push from the demand side as well.***
>
> Alessandro Tavoni, ERC project GREEN TIPPING

Identifying key promoters of such change can inform communication policies, which in turn can lead to the exponential adoption of more sustainable practices and consumer choices. Led by Lorraine Whitmarsh, University of Bath, UK, the MOCHA project explores life events that can trigger a **shift towards greener behaviours**. Her research shows that climate-relevant behaviours are often habitual rather than intentional, and to break certain habits, one must change contexts (via legislation, incentives, etc.) and link behaviour to identity.

Focusing on particular social groups offers a more granular understanding of the conditions and motivations that can lead to coordinated actions. Led by Sander Thomaes at the University of Utrecht, the GREENTEENS project considers the situation of **youth** to be unique in terms of vulnerability to climate change, concern, and motivation towards sustainable conduct. Drawing from adolescent behavioural change theories, the researchers propose the sustainability-motive alignment principle to guide sustainability-promoting policies. These can be greatly improved by incorporating environmental education into the national curricula of all Member States. Along these lines, the researchers put forward ways to tailor these policies to overcome typical constrains in these groups, e.g. resistance to authority and/or lack of appreciation for or connection to nature.

> ***Effective education for youth aligns with their heightened sensitivity to status, social justice, and respect. Teenagers want to be able to have their voices heard, create their own solutions, and stand up for what they care about.***
> Sander Thomaes, ERC project GREETEEENS

Analysing the adoption of greener behaviours as a function of the technology or service in question can provide useful strategies. For instance, Charlie Wilson (SILCI project, University of East Anglia, UK) investigated disruptive low-carbon innovations (e.g. car sharing networks, car-free communities, and net zero energy buildings), and in particular the attributes valued by actual and potential users, and the mechanisms of social influence affecting their diffusion. Likewise, Kirsten Gram-Hanssen (eCAPE project, Aalborg University, Denmark) and Sonja Haustein (URGENT, Technical University of Denmark) investigate smart home technologies and sustainable transport respectively, with a focus on the personal, social, technical and spatial factors affecting their adoption.

2.3. Finance and taxation

How can finance and taxation be leveraged for climate action and biodiversity protection? This section highlights projects that look into carbon pricing, the financing of green and environmental policies.

With an interdisciplinary approach, from transition studies to engineering, political science, and economics, the TRIPOD project studied how the various goals of energy policies interact, affect each other and the transition to a renewable energy system. Led by Johan Lilliestam, currently at the Friedrich-Alexander University Erlangen-Nürnberg, Germany, the project aimed to identify potential policy conflicts and develop solutions. Their results highlighted a conflict between energy efficiency and renewable energy policies and suggested that focusing on the delivery of a zero-carbon energy supply first is essential, if progress cannot be achieved in parallel.

Regarding **energy market liberalisation and renewable energy policies**, the team's results suggest that carbon pricing is not well suited to triggering a system transformation in the energy market. Lilliestam argues that while renewables need high support in initial deployment phases, their costs decrease over time. The main market-based instrument, carbon pricing, starts low and increases over time, the exact opposite of what would be needed. Today, the main barrier to the expansion of renewables is not cost, but infrastructures and institutional reforms. These aspects are not addressed by carbon pricing schemes. While carbon pricing has led to incremental emission reductions, it may not be the instrument that triggers the necessary investments in zero-carbon technologies.

> ***The energy transition as all transitions will happen as a long, iterative process. We need to take a long-term view. But we also need to kick start this process quickly, because it can become an economic opportunity for Europe. I believe the energy transition will benefit European citizens, consumers and companies. It will cost us investments, but it won't cost us money.***
> Johan Lilliestam, ERC Project TRIPOD

Finally, the project concluded that market-based policies have not played a big role in decarbonisation. On the contrary, public policies developed in response to crises can act as catalysers to accelerate an energy transition that is already underway, as they help invest in structural changes and make them permanent.

The GREENFIN project addresses the financing challenge of the green transition. Led by Bjarne Steffen, at ETH Zürich, Switzerland, the team has published **an analysis of the investments needed for low-carbon infrastructures** in Europe until 2035[31]. They quantify the investment needed, and highlight power plants, electricity grids and rail infrastructure as the most critical areas in need of investment. Their results suggest that sustainable finance policies should consider the context, financing needs and structures of the technologies and sectors in need of funding. The team now works on deriving more effective policy design based on these findings.

> ***Green financial policies – i.e., policy interventions to re-direct finance flows – hold great potential if they are utilised smartly in an effective policy mix. In particular, green state investment banks can have a catalysing function.***
>
> Bjarne Steffen, ERC project GREENFIN

They have also estimated the cost of capital and its drivers for various low-carbon technologies. This is available, from the IEA Cost of Capital Observatory[32]. The overall investment need increases, because many green energy technologies are more capital-intensive compared to fossil fuel-based solutions (e.g. renewables vs. gas-fired power plants). Many transition technologies are comparably new, without any existing financing track record – making them very costly to finance (high risk markups in cost of capital), or completely unbankable. In some cases, not only is more investment is needed, but also different types of finance: other financiers, other structures (e.g., more project finance than corporate finance), and an evolving role of the state. Opportunities exist and the types of investors interested in green infrastructure investments is increasing in connection with Environmental, Social, and Governance (ESG) principles and stakeholders' interests.

The GRETA project applies an integrated methodology to reach the double aim of meeting environmental targets while simultaneously striving for a more equitable distribution of the associated burdens and benefits across diverse segments of society. Lassi Ahlvik, University of Helsinki, Finland, argues that well-designed **tax policies** can mitigate adverse distributional effects in consumption and labour markets in a way that is considered fair. They can also incentivise reductions in greenhouse-gas emissions and positively influence labour supply.

> ***While people share the broader worry that climate change is an important challenge, they often oppose concrete climate policy proposals. There should be more research to understand what people consider to be fair and acceptable climate policies. The economics angle helps to understand the human factor, complementing the engineering perspective where it is already clear what we need to do.***
>
> Lassi Ahlvik, ERC Project GRETA

In line with this, the theoretical part of the project proposes **a green tax reform that creates sufficient incentives to cut emissions, generates public revenue for the green transition, and ensures that costs are fairly distributed across society**.

In the empirical part, in the Finnish context, the project will first estimate the inequalities within- and across-income that were created by the sudden rise in electricity prices, taking into account individual-level emission semi-elasticities. The sudden energy price increases resulting from the war in Ukraine serve as a natural experiment for future, potentially stricter, climate policy interventions. The team will then study the contribution of energy price spikes to inequality through their different impacts on business owners and workers. Finally, they will analyse fairness perception through a large-scale survey, linking responses to administrative data. Ahlvik and his team also use Finnish government data to simulate how the EU Social Climate Funds could be allocated in Finland to support the most vulnerable people in the green transition, in a way that is considered fair.

Other ERC projects studying finance in the context of the just green transition include the IMPACT HAU project that explores the **cultural and ethical dimensions of the rapid growth in 'sustainable' and 'ethical' finance**. Led by Marc Brightman at the University of Bologna, Italy, this project focuses on various types of bonds like green bonds, sustainability bonds, social bonds and development impact bonds, to find out who is behind this trend, what their motivation is and how they impact local populations and environments.

Focusing on nature protection and restoration, the Ecospace project led by Lars Hein at the Wageningen University, Netherlands, developed and tested methods for mapping and **accounting for ecosystem services** at large scales (e.g. a province) and examined how policy options can be analysed with such models. Ecosystem services were modelled aligned with the System of Environmental Economic Accounting - Ecosystem Accounting approach, which could be used in support of developing 'natural capital accounts' for analysing the effects of changes in ecological capital in a manner that is consistent with national accounting.

The ReDirect project studied the theory and practice of approaches to conservation using **payments for ecosystem services** (PES). The team led by Adrian Martin, from the University of East Anglia, UK, successfully designed, established, and monitored a PES system where communities in a montane rainforest in southwest Rwanda were offered cash transfers, contingent on their performance in relation to a set of conservation indicators. The Ecospace and ReDirect projects were funded by the seventh framework for research and innovation (2007-2013).

Other projects studying leverage points

- LEVER will investigate values as leverage points for sustainability transformation, and propose an integrated theory of transformative research.
- LESTRA studies how sustainable transitions can be facilitated and accelerated through better practices of 'learning-by-doing' and 'doing-by-learning'.
- REBOUNDLESS will explore the mechanisms of the rebound effect triggered by sustainable design strategies, with an aim to enable the 'reboundless' design of sustainable systems.
- LO-ACT assesses low-carbon action in the world's fastest-growing cities in Asia and Africa, that are seeking to cooperate in a new understanding of global environmental politics and urban governance.
- GlobalGoals proposed four areas of change that could strengthen the SDGs and accelerate sustainable development. The project 2024 conference led to the adoption of a statement on 'Reinvigorating the Sustainable Development Goals'[33].
- FinanceCC focuses on institutional investors and the role they can play in encouraging companies to intensify their efforts in combatting climate change. Preliminary results showed that companies financial value seems linked to carbon emissions. The project now aims to determine how widespread this link is, what its determinants are, and how it affects corporate behaviour.

3. A just green transition

Justice and equity are key components in building an environmentally sustainable society. While some countries (China, India and Brazil), classified by the UN as developing countries, are currently among the highest greenhouse-gas emitting countries[34], developed countries have historically contributed disproportionately to CO_2 emissions. Meanwhile, the greatest impact of climate change, biodiversity loss and pollution is felt by nations in the Global South and by Indigenous peoples and local communities around the world, who are particularly vulnerable to its effects. The climate and nature loss crisis not only deepens global North-South inequality but also reflects intergenerational injustice and disparities within societies, where the well-off are better equipped to adapt, leaving vulnerable communities and future generations disproportionately exposed to harm. It demands urgent action to address these overlapping inequalities for a more equitable and sustainable future.

While justice and equity are crosscutting issues addressed by almost all the projects presented in this report, this chapter highlights projects that explore the potential for just transformative change through environmental and climate litigation, human rights and activism.

3.1. Environmental and climate litigation

Environmental and climate litigation is increasingly used as a mechanism to address the adverse effects of energy and other development projects, including the adverse effects of 'green' transition projects. Litigation can play an important role in addressing injustices related to the green transition, but it also comes up against barriers, as identified by the projects below.

The Curiae Virides project, led by Liliana Lizarazo-Rodríguez, Vrije Universiteit Brussel, Belgium, explores **the progressive transformation of human rights litigation into ecocentric litigation**, focusing on the ability of existing judicial and non-judicial mechanisms to provide justice to victims of development projects and regulatory measures, including green ones[35].

> ***The green transition will not take place if the main direct ecological risks, hazards and harms inherent to the value chains that aim at its realisation are externalised to other countries with less institutional capacity to avoid or mitigate them.***
>
> Liliana Lizarazo-Rodríguez, ERC project Curiae Virides

The socio-ecological impacts associated with development projects (including green ones) reveal how addressing planetary boundaries such as climate change may result in adverse effects. Frequently, local impacts of green development projects are overlooked, and the broader benefits are also frequently not visible in the places where the impacts occur. For instance, green development projects may result in actions that release more waste, pollute water sources, and displace Indigenous and local communities, who often do not benefit from these clean technologies and may not even have access to clean and affordable energy. Hence, while it is important to achieve the objectives of decarbonisation, the multiplicity of transnational ecological conflicts generated around them show that the acceleration of this transition is not straightforward.

> ***Access to justice for transnational impacts caused by the operations of global value chains needs to be central in the agenda of policymakers.***
> Liliana Lizarazo-Rodríguez, ERC project Curiae Virides

To ensure the green transition is a just transition, a comprehensive approach is needed to assess the effectiveness of the mechanisms available to affected persons to claim environmental justice when the policies or the due diligence of companies are not enough to prevent, redress or compensate for harms. Courts play an important role in this. However, affected persons face multiple barriers to obtaining an effective remedy in courts or through mediation mechanisms. Guaranteeing an effective and opportune remedy when the green transition generates adverse impacts on people and the planet, is a necessary part of the transition agenda.

A central challenge to courts is the availability of reliable data and access to information, which plays a crucial role in the way in which conflicts are identified and analysed, people become aware of the possibility to claim protection of their rights and territories, and court outcomes are understood and implemented. Court outcomes also unveil the limited role and space that courts have to understand and decide on transnational ecological conflicts, because they frequently claim lack of territorial jurisdiction (when the impact occurs in third countries) or material jurisdiction (when sustainability topics do not fall under the topics they must decide upon). Therefore, there are limits to the responses offered by traditional state-based jurisdictional solutions to address the transnational nature of these problems. New forms of extra-territorial and supranational regulation are required to address these issues and to provide a remedy for victims of transnational ecological risks, harms and hazards.

> ***Courts may be emerging as central actors for the formulation of policies to keep the Earth functioning within the planetary boundaries and with a healthy balance between intergenerational justice and intra-generational justice. However, it is uncertain how courts are prepared to solve these wicked problems.***
> Liliana Lizarazo-Rodríguez, ERC project Curiae Virides

Policymakers cannot ignore global claims for environmental justice, and the need to establish solid mechanisms for affected victims on other continents. It is therefore important to assess the potential and limits of litigation in addressing global and complex concerns, even if these issues could in principle be better solved by policymakers, who have more democratic representativeness and more access to scientific advice to assess this complex phenomenon in a comprehensive manner, Liliana Lizarazo-Rodríguez concludes.

The TransLitigate project, led by Phillip Paiement, Tilburg University, Netherlands, examines **how litigating lawyers develop cases related to climate change, biodiversity loss, land conflicts and pollution from extractive industries**. It also evaluates how lawyers and civil-society organisations negotiate tensions in climate governance, including the position of marginalised communities and interest groups, as well as the potential negative consequences that the energy transition poses for biodiversity protection. Through these analyses, the project seeks to identify **how litigation can be used to achieve a more just energy transition**.

> *The green energy transition is a unique opportunity to shift out of exploitative economic practices and build global economic relations premised on equity. If we do not rise to this challenge, there can be no successful green energy transition. We will simply have shifted to new types of our familiar, unsustainable exploitation of cheap nature and cheap labour.*
>
> Phillip Paiement, ERC project TransLitigate

The transition has been largely facilitated by market-based governance mechanisms (subsidies, public funding for infrastructure projects, green taxation, etc.), which can lead to conflicts among interest groups. Economically marginalised or disempowered groups – Indigenous peoples, smallholding farmers, labour unions, racial and ethnic minorities, and women – often find themselves 'left out' of green transition planning, either unaffected by it or placed in a worse position than prior to the green transition.

> *The green transition is not meeting the challenge of radically rethinking how we structure our global economy but simply shifting to new manifestations of familiar forms of resource and labour extraction for the benefit of Global North economies, their consumers and capital holders.*
>
> Phillip Paiement, ERC project TransLitigate.

Paiement underlines two main trade-offs that require negotiation in the pursuit of a just green transition. First, there is a renewable energy-biodiversity trade-off. The renewable energy transition consists of a massive infrastructural project, which competes with the protection of habitats that are crucial for biodiversity protection. This trade-off can be navigated through prioritising different strategies of renewable energy development (focusing on projects in built-up areas or degraded landscapes, technologies with a lower environmental impact). But most notably, reducing energy consumption offers the most effective strategy for navigating this trade-off. In limited instances, it can also be converted into a win-win scenario (e.g. transforming offshore wind farms into marine conservation reserves). The second trade-off is in land use decisions. Large areas of land are required for solar and wind energy facilities, mines are developed for rare earth materials needed for electrifying our transport systems, and forests are increasingly relied upon as carbon sinks. Each of these land uses can come into conflict with other communities that rely on these lands for other purposes. Recognising the land-use implications of the energy transition is essential for avoiding human rights violations.

Paiement also points to the need for more data for advancing knowledge about the potential of litigation to promote a just green transition. More precisely, an overview of transnational and international legal frameworks of business and human rights norms and their implications for public and private actors involved in the energy transition. As we increasingly see home-state legislation with transnational reaches, there are a myriad of ways in which accountability regimes are being developed to protect the legal interests of marginalised actors. However, there are still considerable knowledge gaps between these regimes and the economic activities bound up in the green energy transition, Paiement concludes.

The PROPERTY(IN)JUSTICE project, led by Amy Strecker, University College Dublin, Ireland, studies the role of international law in facilitating spatial justice and injustice, focusing **on land-related property rights, international human rights, environmental and cultural heritage law**.

> *It is important that the green transition does not repeat historical patterns of land dispossession and landscape destruction under the guise of 'sustainability.*
>
> Amy Strecker, ERC project PROPERTY(IN)JUSTICE

While tackling climate change requires replacing fossil fuels with renewable energy, the chosen forms of such a transition can have a serious impact on the human rights and landscapes of local communities, such as mining for minerals used in electric car batteries, solar panels, and wind turbines.

In prioritising certain renewables and minerals, it is important not to lose sight of what is being made invisible. Carbon tunnel vision (focusing on reducing emissions to the detriment of other forms of planetary health) can tend to overlook culture and place attachment, wildlife and habitat loss, and human health and well-being. This leads to the broader societal question of how we define growth, and who it serves. Energy demand has been one of the principal causes of the polycrisis, but climate measures intended to address this overrun, such as carbon credit offset schemes, have also commodified and monetised land use in a global marketplace, with little consideration for its local impact.

> ***To be legitimate, land-use decisions need to be democratically grounded, and yet the scale at which change needs to occur has created a perceived need for green growth and a race for rare earth minerals.***
> Amy Strecker, ERC project PROPERTY(IN)JUSTICE

The lack of cohesion between different areas of international (and EU) law hinders a just green transition because some legal norms, such as those on trade and investment, carry more weight in policy and decision-making than others, such as human rights relating to the environment and culture. This can create an inequity whereby ecological integrity and local cultural conditions are often rendered invisible or inferior to a particular 'strategic' development, which is in turn compounded by a lack of access to justice for communities contesting unjust forms of land-use development. A just green transition needs to take account of the social and cultural consequences of policies and not rely entirely on technical expertise.

The PROPERTY(IN)JUSTICE project therefore advocates for a more place-based understanding of land across international law. In concrete terms, this means limiting the idea of land as abstract property (for 'improvement' or 'development') and instead emphasising the social, cultural and environmental values of land as a lived-in landscape. The aim is to render these values more visible in law, and ultimately to lead to more socially just land-use decision-making, especially in areas involving international investment. Environmental democracy needs to be mainstreamed. Procedural environmental rights are already enshrined in several international treaties (such as the Aarhus Convention, the Escazú Agreement, and the European Landscape Convention), but their implementation needs to be augmented rather than diminished.

Other projects on climate and environmental litigation

- UEPP explores the potential of the legal principle whereby a person should not be unjustly enriched at another's expense to solve broad societal issues, including climate change.
- YOUTHCLIMATEJUSTICE provides a large-scale transnational examination of youth justice in the climate crisis.

3.2. Justice and activism

Grassroots movements are contributing to advancing a just green transition by empowering communities to demand equitable climate action and ensure that the benefits of sustainability are accessible to all.

The main goal of the EnvJustice project, led by Joan Martinez Alier, Autonomous University of Barcelona, Spain, was to develop the **Environmental Justice Atlas** (EJAtlas), a unique, open-access database on the main ecological conflicts and their cultural expressions. Based on the analysis of these conflicts, the project developed a theory of ecological distribution conflicts and explored the efficacy of grassroots protests versus institutional forms of contention.

> ***To understand the political opportunities or obstacles to a transition to a different energy system, one must look at the socio-ecological grassroots movements, which are not always NIMBYs (not in my backyard), they are often NIABYs (not in anyone›s backyard).***
>
> Joan Martínez Alier, ERC project EnvJustice

The EJAtlas is an interactive platform containing more than 4 000 environmental justice conflicts across the globe, which can be searched by country, extractive company, commodity (including some "new" commodities in high demand for the electrical energy transition) and protestors/activists. It is an impressive tool for research, teaching and advocacy. Since it also includes media such as songs, protest banners, videos and documentaries, it can serve as an important resource for the arts and environmental humanities.

Martínez Alier's research shows that **an important leverage point for a just green transition is the growing grassroots movements advocating for environmental justice** around the world.

> ***Look at grassroots movements for environmental justice worldwide, cooperate with them, and denounce the repression against them.***
>
> Joan Martínez Alier, ERC project EnvJustice

According to Martínez Alier, the potential power of grassroot movements to push for the transition to be just should be further explored by sociologists, anthropologists, and political ecologists, and support should be provided to these movements and the NGOs supporting them. Furthermore, scientists should advocate for precautionary principles, and post-normal scientific approaches to address the 'manufacturing of uncertainty' as it is happening in relation to climate change.[36] Do they assume that a green transition is achievable without a degree of economic degrowth?' Martínez Alier concludes.

Similarly, projects such as EcoIslam, led by Leonie Schmidt, from the University of Amsterdam, Netherlands, and ClimaSoNo, led by Andreas Pondorfer of the Technical University of Munich, Germany, offer a global perspective on the social norms that drive climate-friendly behaviours in more than 10 countries, and how the climate change movement is developed, negotiated, and contested.

Other projects on environmental justice and activism

- ToxicExpertise provides the first systematic social scientific study of the global petrochemical industry in relation to corporate social responsibility and environmental justice, responding to calls for the democratisation of science to make it more transparent and accountable.
- RIVERHOOD examines the new water justice movements fighting to revitalise rivers.

3.3. Equity and Global North-South justice

Addressing climate change and nature loss is a matter of justice, as the Global South bears the greatest impacts despite having historically contributed less to the crisis. There are vast differences within the Global South, with rapid and emerging economies like China, India and Brazil that are today among the world's largest emitters of CO_2, compared to the Least Developed Countries (LDCs), which face the greatest vulnerabilities and limited capacities to respond. Similarly, within the Global North, there are substantial differences, with some countries possessing far greater wealth and technological capacity than others.

Through the DecentLivingEnergy project, led by Narasimha Rao at the Institute for Applied Systems Analysis (IIASA), Austria, now at Yale University, US, set out to **understand and quantify the energy needs and climate change impacts of eradicating poverty and providing decent living standards for all**.

It is a general concern that poverty eradication will substantially increase the global greenhouse-gas emissions. However, in reality, there is no good understanding of what the energy need, and thus the emission impact, of poverty eradication would actually be. The DecentLivingEnergy project provides concrete answers to this question, based on empirical **analysis of basic energy needs and the development of decent living standard indicators** that quantify material requirements on a household, community and national scale. These indicators recognise the universality of the human condition but also allows for its customisation to cultural and context-specific conditions. Using the indicators as an anchor, the project developed a methodology to link the related material consumption to energy demand throughout the economy, and derived, for the first time, the energy demand for eradicating poverty in India, Brazil and South Africa, and the potential to reduce this demand growth through climate-friendly development policies.

The project has made important contributions that could help push forward the just green transition. It has identified concrete strategies for, and synergies between, eradicating poverty, improving well-being and reducing emissions that could be implemented by governments in low- and middle-income countries to meet the basic energy needs of citizens in an energy efficient manner. The decent living standard indicators could also be used at international level. It is recognised in the UN Framework Convention on Climate Change that the share of global emissions originating in developing countries will grow for them to be able to meet their social and development needs.

The decent living standard indicators could be used in this context, as they provide a credible way of identifying and quantifying the basic level of consumption and energy growth needed that could be exempted from the responsibilities of climate mitigation.

As Rao points out, existing access to energy projects is often not ambitious enough. Some projects suggest very small-scale solutions, e.g. providing people with a lantern with a small LED on it. However, providing energy access to meet decent living standards should involve scaling up solutions and thinking more broadly about energy access solutions that caters to the aspirations of people, not just light bulbs and phone chargers. This could be an off-grid system to provide people with energy access, such as a solar panel to support basic needs such as a refrigerator, a fan and or a small, efficient air conditioner, or powering a school or a healthcare facility. There is also a need to scale up institutional capacity to mainstream climate considerations into various aspects of development policy. There are synergies between development priorities and climate priorities, and government departments have the analytical tools to analyse these synergies.

> ***It is important for policymakers to consider that there are fewer trade-offs than previously thought between enhancing human well-being and mitigating climate change. There are so many untapped synergies between pursuing more equitable development pathways and climate mitigation and a lot of win-win solutions. It is a matter of political will.***
> Narasimha Rao, ERC project DecentLivingEnergy

An important aspect for politicians to consider is that they have the possibility to increase the well-being of many with fewer resources. For politicians making choices with a limited budget, it makes more sense to direct resources towards the shared basic need for infrastructure as you can increase the wellbeing of more citizens. At the same time, it is reducing energy needs: when you have shared networks you have fewer resources per capita than if you have private resources per capita.

Inequality is a defining challenge of the 21st century that impacts the well-being of people around the world. Oceans play an important part in this as they provide food, jobs, and space for recreation, amongst other vital services. The EQUALSEA project, led by Sebastián Villasante of the University of Santiago de Compostela, Spain, examines how anthropogenic stressors, such as climate change

and biodiversity loss, affect the well-being of millions of people and coastal communities, who rely on the ocean. The project focuses on coastal fisheries and Indigenous knowledge in the Amazon, woman-run shellfisheries in Galicia, Spain, and fishing communities in West Africa.

> ***By definition transformative change is complex and practical solutions may have unintended consequences. But there is massive scientific evidence showing that we need to do something radical to change views (ways of thinking, knowing), structures (ways of organising, regulating and governing) and practices (ways of doing, behaving and relating). Each of these three dimensions can be key entry points for promoting and accelerating transformative change. This is not easy as it entails both behavioural changes and political will for long-term thinking beyond the next election. – Sebastián.***
>
> Sebastián Villasante, ERC project EQUALSEA

EQUALSEA is creating the largest database **with international case studies and ongoing initiatives to identify positive examples** with transformative potential of the oceans and people. This includes projects from governments, the research community, private and public sectors and NGOs. These examples are generating a positive impact not only on the environmental dimension of the ocean, but also in terms of social equity. The database contains examples related to small-scale fisheries but also aquaculture, tourism, marine protected areas, Indigenous peoples and local communities, and initiatives based on art. It also documents the potential negative and positive impacts of these initiatives, such as in the case of deep-sea mining or conflicts and trade-offs with wind energy generation. The database is a powerful tool for assessing potential green solutions and their overall impacts. It has also provided scientific evidence for the IPBES assessment of transformative change. Furthermore, the project is creating **the Ocean Equity Index** to identify multiple critical drivers that induce social tipping-point dynamics and transformative changes across space and time. The index will be an essential tool for policymakers worldwide and can contribute to monitoring progress towards ocean equity.

> ***The common denominator shared by these promising examples of initiatives in the database is universal values shared by the actors such as dignity, compassion and equity. In fact, the projects that have these common values are those that are the most transformative around the world.***
>
> Sebastián Villasante, ERC project EQUALSEA

Villasante co-authored the *2023 Global Tipping Points Report*[37]. It shows that humanity is currently on a disastrous trajectory, but it also highlights that emergency global action can harness positive tipping points and steer us towards a thriving, sustainable future. The report points out that bold, coordinated policies could trigger positive change in cascade across multiple sectors including energy, transport, and food, for the benefit of citizens, the economy and the natural world. In line with this conclusion, the EQUALSEA project is documenting positive tipping points under the development of their global database on transformative initiatives towards ocean equity and sustainability. Villasante is also co-author of the Global Tipping Points Report to be published in 2025. In the report, positive tipping points will be operationalised, and the extent to which these are referenced in law and policies in 10 to 15 large countries around the world will be analysed.

There is an urgent need to reconsider the relationship between humans and nature in countries where economic growth is required to fight extreme poverty. In developing countries, economic development typically takes place in parallel to an increase of natural resources being extracted and energy consumption increasing. The negative externalities this growth creates, through the degradation of the world's forests and oceans, pollution, and climate change, will have a global impact. The MANANDNATURE project, led by Robin Burgess, London School of Economics and

Political Science, UK, researched **natural resource management and energy use in developing countries**, with a focus on forest and ocean conservation.

Unless better protection for both forests and oceans are secured, we are losing out on a very cost-effective means of promoting the green transition, Burgess underlines. For the transition to be just, countries need to be able to exploit these resources sustainably as a means of raising living standards. Conservation policies can help to maintain carbon stores whilst also allowing economic development to move forward.

As Burgess points out, the main drivers of both deforestation and ocean exploitation are private firms. Therefore, finding ways to conserve these natural resources requires a very careful consideration of political economy. Firms must be given sufficiently strong incentives not to engage in illegal deforestation and illegal fishing, whilst still allowing legal and sustainable exploitation of these resources to continue.

The most relevant outcome of MANANDNATURE was to show, that policies intended to protect these ecosystems can be successful. The bottom line is that with sufficient political will and strong incentives, conservation can be effective even in low institutional capacity settings.

Showing what policies are effective can guide the scaling-up of solutions. Mainstreaming the solutions will require other governments to learn from what successful interventions have achieved. This is all about forcing private companies to consider the negative externalities they are creating. In simple terms, it requires much stronger penalties for illegal deforestation, illegal fires and illegal fishing.

> *To achieve the just green transition, we need to use the full policy arsenal at our disposal. 'Whatever it takes', meaning that we should not leave any policy measure off the table. We should be considering a whole range of different measures to confront climate change.*
> Robin Burgess, ERC project MANANDNATURE.

The concept of a just green transition can be interpreted in many ways, yet often the discussion around a 'just transition' in developed countries often centres narrowly on the mitigation side – reducing greenhouse-gas emissions. The CCLAD project, led by Lisa Vanhala, University College London, UK, broadens the concept. Transformative change is always contextually defined: the world's poorest countries and communities are among those that are already going through transitions, witnessing the impacts of climate change on their homes and homelands and the natural environment around them.

The project raises important questions about the **types of action that can be taken at international and national level to make these imposed transitions more 'just'**. Focusing on two scales (international and national) of governance of climate change loss and damage, the project reveals some of the less visible ways in which political progress is thwarted at international level, while also highlighting the challenges and opportunities faced by national policymakers face across the Global South.

> *In both subtle and overt ways, the governance of climate change loss and damage has been blocked and stagnated by arguments over definitions, processes and technicalities. Throughout the global climate negotiations, voices from developing countries have been directly and indirectly marginalised, minimised and silenced. The culture of agreement-making and unmaking needs to change dramatically and every policy maker has a role to play. This takes visionary leadership.*
> Lisa Vanhala, ERC project CCLAD

The CCLAD project has identified different kinds of barriers to the just green transition as concerns **helping the most vulnerable countries and communities adapt to climate change and address loss and damage**. Many observers of global climate governance would identify the lack of finance and technical support and the lack of data and knowledge on climate hazards and vulnerabilities as critical barriers. The project confirms those challenges but also reveals how some of the more mundane aspects of international agreement-making and implementation act as barriers to progress. The project has identified how various tactics have been used to shape the nature of agreements, including the construction of ambiguous agreements; multiple modes of forum-shifting and delay tactics; performances of inclusion and knowledge politics, i.e. debates about what counts as relevant knowledge and who is seen as a holder of knowledge. These tactics have proven surprisingly effective, and many mainstream theories of international climate governance would not necessarily identify these more subtle, stealthy modes of power politics.

The CCLAD project's research on national policymakers makes clear that it is not always those that face the most severe and existential impacts that take national policy action on loss and damage. Instead, national institutional frameworks and governing paradigms allow some civil servants and politicians to identify climate risks and consequent loss and damage more clearly. The project team's forthcoming book Governing Climate Change Loss and Damage: The National Turn (Cambridge University Press) identifies new institutional linkages that allow countries to better address issues such as climate-related internal displacement and shows how different forms of knowledge – from local and lived experience to historic disaster data – can supplement a lack of systematic information in policymaking processes. In doing so, the book shows the way to more effective governance of loss and damage now and in the future.

The loss and damage issue presents several complex dilemmas for policymakers. One challenge is how to make informed decisions and implement them effectively in the face of uncertainty and limited data on climate hazards, local vulnerabilities, and their intersections. Additionally, prioritising policy interventions becomes difficult when technical and financial resources are scarce, particularly as extreme weather events intensify and awareness grows of slow-onset hazards and their widespread human and ecosystem impacts. Designing processes, institutions, funding mechanisms, and technical support systems that are inclusive of those most affected by climate change, who are often also politically marginalised, adds another layer of difficulty. Finally, engaging in a global governance system where the poorest developing countries face systemic disadvantages further complicates the issue.

Vanhala highlights two points that would help to scale up existing solutions. Firstly, greater representation of the loss and damage issue within the IPCC's reports, specifically on ways to address different types of loss and damage and efforts to address the 'evidence deserts' in terms of science of climate change loss. Secondly, policy-science engagement efforts by a wide range of UN agencies would help to ensure an evidence-informed and more coherent approach to tackling the tricky issue of climate change loss and damage.

Other projects on equity and justice

- REPAIR calls for reparations to address major global development challenges focusing on reparations for infectious disease outbreaks, climate change, and toxic environments.

3.4. Indigenous peoples and local communities

Indigenous peoples and local communities play a critical role in climate change and nature loss mitigation and adaptation, as their knowledge systems offer insights into environmentally sustainable practices. It is essential not only to incorporate this knowledge to inform climate solutions but also to safeguard their human rights and protect their cultural heritage.

The LICCI project, led by Victoria Reyes-García, Autonomous University of Barcelona, Spain, documented how Indigenous peoples and local communities (IPLCs) understand, live with and

respond to climate change impacts. IPLCs have nature-dependent livelihoods, steward large shares of biodiversity-rich areas and are disproportionately affected by climate change impacts. Yet, their experience, knowledge and needs receive inadequate attention in climate research and policy. IPLCs should, however, be recognised as legitimate and important custodians of environmental knowledge. For a green transition to be just, new usable knowledge on how to tackle transitions must be co-created. IPLCs provide holistic, relational, place-based, culturally grounded, and multi-causal understandings of climate and environmental changes, largely focused on processes and elements that are relevant to local livelihoods and cultures.

> *Science and technology alone cannot provide simple and uncontested answers to the environmental crisis because they do not tackle the underlying causes. We need to change the way in which usable knowledge is generated, shared, and governed and to look for alternative ways of organising human-nature relationships. Across disciplines, the scientific community needs to partner with societal actors from governments, business, and civil society to engage in the co-creation of knowledge and action.*
>
> Victoria Reyes-García, ERC project LICCI

To bring the plurality of legitimate perspectives into dialogue and decision making, the team collected primary data in 179 communities across 37 countries, including more than 5 000 participants representing 49 cultures and nationalities. Alongside this unique field work, the project generated two related Proof of Concept projects, ICCION enabling IPLCs to effectively participate in climate change science and policy in a network; and RIDaGoP, which developed a toolkit contributing to more ethical data governance and indigenous data sovereignty in open-data research. Altogether, these three projects underpin the importance of iterative and reflexive approaches to planning, implementing, monitoring, evaluating, and reviewing transformative change initiatives.

> *We can learn a lot from Indigenous peoples and local communities, but we need to learn how to listen. We have to reorganise the way we produce knowledge and ensure that knowledge systems, other than science, are recognised.*
>
> Victoria Reyes-García, ERC project LICCI

Other projects on Indigenous Peoples and local communities

- INCLUDE studied deforestation in the Argentinean Dry Chaco in the Salta province, the Chaco Salteño.
- IEK-CHANGES studies Indigenous environmental knowledge (IEK) changes over time, and their ecological impacts at a unique research site in the Bolivian Amazon.
- COSMOVIS explores what the global environmental initiatives of the future will look like, and how scientists, shamans, priests and other Indigenous holders of animistic knowledge can collaborate in regions of climatic vulnerability.

4. Redefining prosperity: post-growth, circular economy, sustainable use of resources

The strain on planetary boundaries and the negative environmental impact of current predominant production and consumption modes are forcing societies to re-evaluate our provisioning and economic systems. Projects presented in this chapter offer perspectives on what are the barriers and possibilities for changes to economic and production systems in view of generating transformative change towards a just green transition.

4.1. New economic paradigms: post-growth

Post-growth perspectives argue for the need to significantly rethink and change our economic system to reduce the negative environmental impact of current production and consumption methods. Post-growth theories advocate for the transformative potential and the fundamental need to transition to an economy that is not growth-dependent, that moves beyond traditional measurements of well-being, and whose main objective is ecologically sustainable and equitable societal development. They are intrinsically linked to claims for justice, equity, democracy, and decolonisation. They aim to provide answers to the main question of how we can reduce carbon emissions at the same time as ensuring decent living standards for all, globally.

Post-growth approaches differ from green/clean growth approaches in their view on what is needed for a truly transformative change towards a just green transition. Green or clean growth theories and policies rely on the possibility to decouple economic growth from unsustainable resource use and carbon emissions. To the contrary, post-growth theories are critical of the feasibility of obtaining environmental sustainability, while upholding economic growth as an objective.[38] They point out that there is no empirical evidence to suggest that fully decoupling from resource use can be achieved on a global scale, and that fully decoupling from carbon emissions is highly unlikely to be achieved at a rate rapid enough to prevent global warming over 1.5 or 2°C. They consider that green growth is likely to be a misguided policy objective, and that policymakers need to look towards alternative strategies to promote truly sustainable transformative change.[39]

The REAL project, led by Julia Steinberger, University of Lausanne, Switzerland, Jason Hickel and Giorgos Kallis, both at the Autonomous University of Barcelona, Spain, develops post-growth societal transformation strategies. Based on increasing empirical evidence that it is impossible to

sufficiently mitigate climate change while pursuing economic growth, the project investigates the **potential and viability of post-growth solutions**. It analyses the changes in policies, politics and provisioning systems that are necessary for a just post-growth transition that can ensure well-being for all on a global scale.

In an interview, the project team stresses that the world faces a double crisis, an ecological, but also a profound social one, characterised by high levels of inequality. Addressing this double crisis is the objective of the REAL project and should be the objective of progressive social movements: to understand the ecological and social crisis together. There is a need to address the deep inequalities that lie at the heart of green growth visions. This is what is meant with Global North-South convergence: energy levels will need to rise in the Global South to meet decent living standards, while it must decrease in the Global North.[40]

Started in 2023, the REAL project develops equitable North-South scenarios, models provisioning systems and well-being scenarios within planetary boundaries, and viable post-growth policy proposals. It also studies which political movements and communities can help advance post-growth transitions.

In the same interview, the team notes that postgrowth transitions would represent such a huge change, that is difficult for people and even analysts to imagine it happening in today's liberal democracies, where you can only achieve marginal changes. This is exactly the reason why the project aims to work and advance on these pathways.[41]

The PROSPERA project, led by Mario Pansera, Universidad de Vigo, Spain, similarly argues for the **need to decouple innovation from the economic growth paradigm**. Science, technology, and innovation are considered the engine of economic growth. However, as the pursuit of endless economic growth has proven to be ecologically unsustainable, the project argues for the need for new narratives, including the concept of innovation.

> ***There is an obsession with innovation and technological development. In reality, we are innovative perhaps 1% of our time, while the remaining 99 % of our time we spent on caring and maintenance. However, society does not value maintaining and caring enough. That is why we need science-technology policies focused more on maintenance.***
>
> Mario Pansera, ERC project PROSPERA

PROSPERA explores **under which conditions science, technology and innovation can flourish without being tied to the need for economic growth and investigates what policies, infrastructures and organisational forms are needed**. Pansera also stresses that justice is the main issue in relation to climate change.

> ***We often neglect that climate change is not just an environmental problem that can be fixed with technical solutions, it is a problem of justice. Climate change is probably the biggest injustice in human history, because a small percent of society, the 1% richest, is jeopardising the life of the remaining 99%. Therefore, climate change is primarily about justice and rediscovering a sense of democracy.***
>
> Mario Pansera, ERC project PROSPERA

To obtain transformative change, Pansera underlines the fundamental need to rethink the role of organisations in the production of science and innovation to obtain a more sustainable and just way of organising our economies, to explore the sense of democracy in the production circle, and to address issues of justice and power relations. Furthermore, Pansera highlights the clear need for democratic and participatory economic and production planning, envisaging the role of people, workers, local communities, care and social reproductive work, and non-human nature.

Marija Bartl, of the Amsterdam Law School, Netherlands, leads the project N-EXTLAW, which has the goal **to achieve a non-extractive, sustainable economic model**. Bartl and her project team are rethinking legal frameworks to support sustainable economic practices and seek to build a community of people and organisations to create concrete social change together.

Bartl highlights the relentless focus on profit extraction as one of the major reasons for the environmental deterioration and the concomitant social problems (such as inequality and displacement). She points out how, in this context, alternative economic models, such as doughnut economics or postgrowth, have only gained modest political traction, and the scaling-up of these models meets difficulties, including accessing financing, detrimental consumption behaviours and legal barriers.

N-EXTLAW theorises that by creating an appropriate legal framework, non-extractive and sustainable economic activities can be promoted, or can at least operate in a level playing field. These activities are usually more environmentally friendly, less profit-oriented and more sharing by design, distributing capital across the production line. However, this also makes them appear risky to investors, as they do not promise major returns on capital.

Therefore, Bartl stresses that several parallel interventions are necessary. First, we need to provide ready-made legal forms for more distributive types of economic activity, such as steward ownership or (the transition to) workers ownership. Secondly, we have to remove obstacles for financial institutions and investors to provide credit to sustainable economic activities and entities. Third, public procurement should be at the centre of the legal reorganisation as it combines financing streams with public goals. Finally, the promotion of national agencies for social economy in each Member State could be a key measure to promote a required level of environmentally responsible economic activity and investment.

> ***There is evidence that social economy entities can be more innovative and resilient because they can invest in greener technology, since they don't have to pay shareholders.***
> Marija Bartl, ERC project N-EXTLAW

Bartl underlines that there is a need to broaden the understanding of profitability, and to challenge the narrow focus on traditional profit metrics. For examples, prioritising decent worker compensation generates demand, and this contributes to economic resilience. Examples such as steward-owned companies show that businesses not driven by immediate profit still achieve innovation and growth, often outperforming competitors. Contemporary neoliberal capitalism creates a sort of 'dead weight' profit that feeds financial markets instead of reinvesting in productive sectors. A healthier, reinvestment-focused economy, with happy and well-compensated workers, is key to sustainable growth.

Focusing on agrifood systems, the UNMAKING project, led by Giuseppe Feola, University of Utrecht, Netherlands, explored **the potential of grassroots initiatives in challenging and changing environmentally destructive practices** deeply ingrained in capitalist societies, and how this creates space for alternatives at individual and social-ecological level. The project found that amidst increasing compelling evidence of the simultaneous unsustainability and continued reproduction of a capitalist economy, it is misguided to assume that transformation can happen by merely constructing supposed 'solutions', be they technological, social or cultural. There is instead a need to better understand how existing institutions, forms of knowledge, practices, imaginaries, power structures, and human-non-human relations can be deconstructed for the service of sustainability transformation. The project identified processes of 'unmaking capitalism' in agrifood grassroots initiatives and demonstrated how they are concretely entangled in the construction of post-capitalist realities[42].

The Fair Limits project, led by Ingrid Robeyns, University of Utrecht, Netherlands, explored the concept of limitarianism, that is, the view that there should be upper limits to how many valuable goods each person should have. As justice is a cardinal value when it comes to how we want to organise our societies, Fair Limits **investigated whether justice requires us to put limits on how many ecological resources a person should have access to, and how the distribution of financial resources is related to a just transition**.

> ***There is a widespread view that market mechanisms are the way to make sure the transition is fair, e.g., by having a carbon tax. However, we overlook the normative premisses in these proposals, whether, given massive economic inequalities, a carbon tax is the fairest mechanism. There are other mechanisms, such as rationing, that should be taken much more seriously.***
> Ingrid Robeyns, ERC project Fair Limits

At the same time, putting limits to the amount of personal (ecological and economic) resources that a person can have, is not something that is implementable in the short run. It is rather what philosophers call 'a regulative ideal'. Policy changes only come at the very end of a chain of events; new ideas and a different perspective are needed first. That is what the Fair Limits project contributed to: a new way of looking at the question of the **distribution of economic and ecological resources from a fairness perspective**. The project notes that an important thing for policymakers to do when considering how to support a just green transition is to always question the underlying normative and ontological assumptions of their policy proposals.

Other projects on economic systems

- MaSES is bridging the gap between societal demand and ecological limits by introducing a new concept of social-ecological sufficiency.
- CLIMGROW studies to what extent concerns about economic growth, ranging from pro- to anti-growth, hamper social-political support for ambitious climate policy, and how this can be amended.
- RethinkingWork will study the role that national systems of labour law play in the emancipation of work from productivism on a finite planet. The project will start in 2025.

4.2. Circular economy and new production models

The circular economy is commonly defined as a model of economic production and consumption that strives to maximise the productivity of materials, and in so doing reduces waste and raw-material intake[43]. It is considered an important building block of the European Green Deal, as it is expected to reduce pressure on natural resources and create sustainable growth and jobs[44]. The Circularity Gap Report 2024 shows, however, that the vast majority of extracted materials entering the economy are virgin, with the share of secondary materials declining steadily since the Circularity Gap Report began measuring it: from 9.1% in 2018 to 7.2% just 5 years later in 2023[45].

The projects highlighted below provide insights into the possibilities, the limits, and the transformative potential of the circular economy as a means to obtain environmental sustainability.

Experimenting with circular service business models, such as companies shifting from selling to leasing products or introducing lifelong warrantees to extend product lifetimes, lies at the heart of the Circular X project, led by Nancy Bocken, Maastricht University, Netherlands. In a context of increasing pressures on resources and the climate, the project cooperates with organisations, from small start-ups to large multinationals, to help them develop and experiment with the circular business paradigm.

As discussed in one of the project's publications, the current linear economy is unsustainable, and the transition towards a circular economy inevitable. Empirically, the circular economy has shown a significant potential to decrease environmental impacts. On the other hand, to meet global goals such as those of the Paris Agreement, the demand for resources needs to be reduced, even with the implementation of (circular) technical processes in manufacturing. This does not negate the circular economy's contributions to environmental sustainability, which alone is not enough[46].

Companies need a business case or clear policy incentive for pursuing circular economy models, but both are often lacking. By providing circular business-model tools and methods, the Circular X project supports companies in their circular economy transition, while also normalising circular innovations for business and the wider public. Benefits include cost savings, finding new revenue streams, or simply being a first mover in this area.

To support the advancement of a circular economy, the project identifies that there is the need for widespread policy support, as well as education. Circular X is rolling out executive education on circular economy, but this education should start much earlier and be consistent, from primary school onwards. Advancing a circular economy also requires policy makers to be ambitious and bold in their circular economy policies as it is a massive transition that requires policies to help slow, close, narrow and regenerate resource loops.

The WasteMatters project, led by Olli Pyyhtinen, Tampere University, Finland, studies waste. It develops a new methodology, more-than-human ethnography, to **explore four kinds of waste: food waste, plastic waste, waste incineration ash, and nuclear waste**. Across sites in Finland and Sweden, the project follows waste streams across society and maps waste flows focusing on the processes of sorting, discarding, reappropriating, transporting, processing, and (re)valuing.

According to Pyyhtinen, waste defines all aspects of social life and society as a whole. It is a wicked problem that requires constant action without being completely solvable[47]. One of the most important barriers to sustainable waste management, according to a project publication, lies in the premise of the so-called 'waste-as-resource paradigm' that prevails in the circular economy. The premise for a circular economy is the finitude of resources and therefore minimising their extraction; approximating the life cycles of human-made stuff with natural processes; and envisioning such an achievement through the technology-aided perpetual (re)production of closed loops[48]. However, there are significant challenges to this ambition in terms of feasibility and ethics. In terms of scalability, circular economy solutions are rarely sustainable, if even possible, if implemented at a global scale. Secondly, circular economy practices have first and foremost become a business

model for developed economies, in which waste is used by wealthy countries to make money from overconsumption at the expense of poorer countries, contributing to global inequality[49]. While the article is critical of the transformative potential of the circular economy ideal of transforming waste into resources, Pyyhtinen nonetheless points out that he has trust that the circular economy has the potential to bring about a decrease in natural resource extraction by prolonging the lifespan of usable matter. A crucial question that is yet to be answered is to what degree, to what magnitude and for how long this is effective[51].

Other projects on circular economy and new production models

- INNORES studies the disruptive side effects of waste from three kinds of innovation: nuclear waste, microplastics and data waste.
- COSMOLOCALISM studied how to create a sustainable economy through the digital commons.
- DECYCLE studies the regulatory frameworks that make it possible to revalue waste materials as a resource for city-regional development, using an institutional urban political ecology approach.

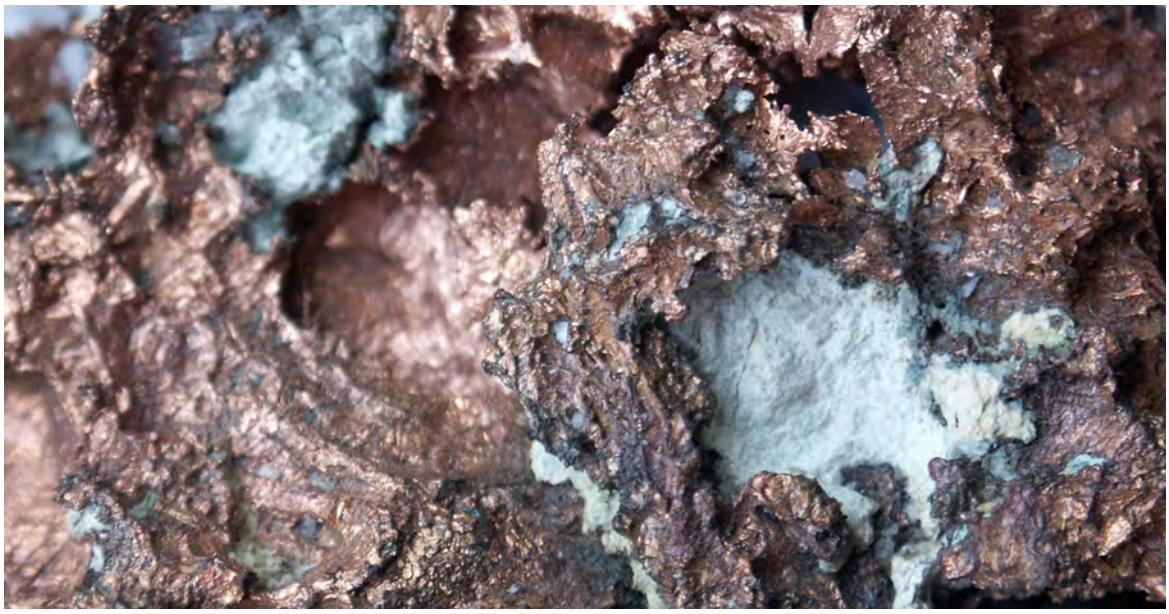
4.3. Raw materials

Raw-material extraction plays a crucial role in the development of sustainable energy solutions in industries such as electric vehicles, renewable energy, and advanced technologies. However, the extraction and processing of these materials have significant environmental and social impacts, often concentrated in the Global South. These effects remain largely invisible to consumers in the Global North.

> ***The green transition isn't just about reducing emissions; it's about reducing 'omissions' - the social and environmental disruptions that remain unseen. Real solutions emerge not from technological fixes, but from engaging with the complexities of places and people, acknowledging that the future is open, uncertain, and plural. We need to move beyond a linear vision of progress and foster conversations between disciplines and communities to create transitions that are truly just and sustainable.***
>
> Cristobal Bonelli, ERC project World of Lithium

The Worlds of Lithium project, led by Cristobal Bonelli, University of Amsterdam, Netherlands, examines **how transition strategies from fossil fuel transport to electric mobility powered by lithium-ion batteries are deployed in three key countries**: Chile, the world's largest lithium supplier; China the largest producer of lithium-ion batteries; and Norway which plans on being the world's first 'zero-emission' mobility country. From an anthropological perspective, the project follows the route of lithium along its supply chain in these countries. It carries out a transnational documentation of knowledge and practices through which scientists, grassroots communities, policymakers, and lithium-ion battery producers respond differently to ecological transformations and disruptions.

The project reveals how reducing CO_2 emissions through the technological replacement of fossil-fuel-based transport by electric mobility (relying on lithium-ion batteries) urgently requires addressing how to reduce the social and material unattended effects that the emission reduction project itself is generating.



> ***Opportunities lie in interdisciplinary, experimental collaborations that integrate diverse knowledges and publics to develop more inclusive and just transitions. A leverage point is to foster these collaborations as a way to move beyond the limitations of isolated technological fixes and towards a more complex and planet-wide response.***
>
> Cristobal Bonelli, ERC project World of Lithium

Led by Stefan Giljum, Wirtschaftsuniversitat Vienna, Austria, the FINEPRINT project underlines that there is an urgent need to transform our production and consumption patterns and creates knowledge to help reduce the global impacts of raw-material use. The project has mapped and analysed the **material footprints and related environmental and social impacts of consumption around the globe** using new methods assessing the environmental impacts of the extraction of a wide range of raw materials and by tracking material flows along global supply chains. The project has developed a comprehensive open database on mine-specific production and an interactive global map, where users can analyse mining land-use data and the locations of the mine-specific production data [52]. Giljum and his team found that both industrial and artisanal mining are intensifying across the tropical biome, driven by rapidly increasing demand for mineral resources. While direct deforestation concentrates only in a few countries, industrial mining causes indirect deforestation in two-thirds of tropical countries. To preserve tropical forests, the direct and indirect deforestation impacts of mining projects should be fully considered and addressed[53].

GRIP-ARM, led by Jewellord Nem Singh, International Institute of Social Studies, Netherlands, and University of Sussex, UK from January 2025, is a systematic, comparative study of **critical raw materials and economic development**, bringing political science perspectives together with natural resource geography and international political economics. It examines the globalised supply and demand for critical minerals such as niobium, rare earths elements, uranium and nickel from the point of mineral extraction through processing, manufacturing and recycling. It provides a closer scrutiny of mining both as a strategy for industrialisation and as an integral part of contemporary efforts towards a sustainable supply of raw materials. GRIP-ARM is at the interface of critical minerals governance, global supply-chain restructuring and the new geopolitics of energy transition. According to Nem Singh, energy transition pathways will have to be forged at the national level, and, with this recognition, it is possible to clearly see potential winners and losers in the climate crisis. As electric vehicle sales accelerate and bigger wind turbines are built, mineral producers and countries with strategic advantages in clean energy technologies are likely to play a wider role in ensuring the resilience of global supply chains[54].

> *The future path for the Global South has yet to be written. Political leaders must turn crisis into opportunity by designing new energy systems and alternative economic growth strategies beyond the carbon-intensive industrial model of the past century.*[55]
>
> Jewellord Nem Singh, ERC project GRIP-ARM

The CLIFF project, led by Joyeeta Gupta, University of Amsterdam, Netherlands, investigates the role of **big investors in leaving fossil fuels underground (LFFU), the Global North-South implications of LFFU, and the necessary measures to equitably allocate and accelerate the responsibilities of shareholders and stakeholders in energy transformation**.

To halt climate change, the 2015 Paris Agreement implicitly requires leaving fossil fuels underground, which will affect big investors: fossil fuel firms, shareholders, debt financiers and governments. CLIFF examines the changing equity dimensions and geopolitics of fossil fuel resources, reserves, investment, and their related financial streams. It investigates the key political, legal, and social institutions and bottlenecks in shifting to a fossil-free future, and how the related financial streams can be made coherent. CLIFF explores solutions to these bottlenecks, the role of countervailing powers globally, and whether analysing these issues might lead to a new definition of development, of state and interstate responsibility, and of how governance should be organised.

In a recent policy brief, the project team advocates for a paradigm shift towards a just and inclusive energy transition by addressing the obstacles posed by current market dynamics. The brief highlights that subsidies artificially inflate the market value of fossil fuels, thus impeding the transition to renewable energy sources and that merely investing in renewables and focusing on emissions is insufficient without concurrently implementing supply-side measures targeting fossil fuel production. It stresses that policies must actively discourage the extraction and use of fossil fuels while incentivising renewable energy production and consumption. Furthermore, the policy brief advocates for the importance of the concept of "True Zero", which foregoes emissions altogether as opposed to the current notion of Net Zero, which implies offsetting emissions through carbon credits and creative accounting practices. Instead, a genuine commitment to achieving True Zero emissions is required, with tangible actions and policies.

Another project on raw materials

- AFREXTRACT studies how resource extraction industries propelled environmental transformation across Africa, most notably between 1950 and 2020.

5. A healthy planet

A healthy planet is key to ensuring human health and for human activities to thrive, from green energy production to sustainable food systems, from tourism to developing sustainable urban living and working environments. Many ERC projects address the challenges caused by climate change, pollution and biodiversity loss.

Projects focusing on **oceans and seas** study marine ecosystems conservation, ocean pollution, ocean modelling and monitoring, the sustainable use of oceans, and fisheries. Other topics include sustainable ocean governance, ocean equality and ocean-based economic development, and a global assessment of the role of marine life in societal development. As far as **life on land** is concerned, ERC research covers the study of ecosystems, from forests to agroecosystems to freshwaters and urban ecosystems and new solutions to protect or restore ecosystems' functions and services.

Many projects address environment conservation practices and their interactions with climate change and earth systems, as well as food and energy production and the impact on populations in terms of health, hunger and nutrition, and economic livelihoods and jobs. Land-use and natural resources management, including water management, are recurrent topics, along with the trade-offs that policymakers may have to consider when setting goals for green transitions that are also just and supported by citizens.

This chapter focuses on projects that study the challenges and opportunities faced by policymakers when addressing **pollution**, aim to protect and **restore ecosystems** and develop the **sustainable food systems** of the future. The final section presents a set of projects studying these aspects with a focus on green transition and climate action in **coastal areas**.

5.1. Addressing pollution

Pollution harms both human health and ecosystems health. This chapter reviews ERC projects which propose solutions to monitor pollution levels and assess their impacts on health and the environment, and ways to address pollution within the broad context of global change. Beyond the projects presented below, ERC grantees' work on new production methods, the circular economy and waste management presented in Chapter 4 could also support a transition towards toxic-free environments, including in urban environments (Chapter 6).

Led by Matthias Rillig, of the Free University of Berlin, Germany, the Gradual Change project set out to study **the effects of environmental change, including drivers of global change, on ecosystems with a focus soil biodiversity**, in particular fungi. The project tested the effect of environmental changes on soils, using new experiments that delivered those changes gradually as they would appear in nature (rather than abruptly as in most experiments). For the first time, experiments combined and tested several factors of change at the same time to try and replicate the multiple changes affecting ecosystems in the real world. Their results have implications for our understanding of the effects of global change as well as how we approach global change when designing nature conservation or remediation plans or for the design of environmental impact assessments.

The project showed that the rate of change indeed matters and can change the outcome of experiments. A less expected outcome suggests that the sheer **number of factors of change** affecting soil determines the impact on soil properties and functions rates -such as decomposition, soil aggregation and biodiversity- independently of the nature of the factors combined[56]. Not only is the number of factors important, but factor dissimilarity is also key for predicting joint effects that would not have been observed when testing the effect of one factor on its own.

This new research design now provides a window of opportunity to assess the effects of a very large number of factors experimentally, and it could be applied to other disciplines. These results could also inform the **design of environmental impact** testing, where new substances are usually tested on their own as a new factor.

> ***Our results point to the need to experimentally test new chemical compounds in combination with several other factors to assess their potential impact. But there is of course a trade-off to be found between thorough testing for environmental and health effects, and reasonable testing scenarios that would not suffocate progress.***
> Matthias Rillig, ERC project Gradual_Change

In the context of biodiversity and ecosystem restoration and bioremediation, if the number of factors drives changes in ecosystems, it could be inferred that every factor that can be reduced or removed should lead to a positive impact. Conversely, if many factors affect ecosystems in combination, there may be a need to develop a range of restoration management practices to address one ecosystem. This is currently being tested in follow-up studies.

The project results also led to **microplastics** being established as a new type of pollutant in soils and a factor in toxicity and global change biology. The team showed that many of the impacts of microplastics on soil ecosystems could be understood by looking at them as particles, and especially at their shape.

> ***Environmental change is complex, and it comes with very many factors, from climate change to chemical pollutions. New factors and their effects are regularly discovered, like microplastics. But in the end, it's all global change, human-caused global environmental change, that we need to address and understand as a multifactor phenomenon.***
> Matthias Rillig, ERC project Gradual_Change

The ATLANTIS project, led by Francesca Verones at the Norwegian University of Science and Technology, develops models for **quantifying impacts on species diversity and ecosystem service losses in marine ecosystems within the life cycle assessment (LCA) framework**, a tool used to support environmental decision-making. While LCAs cover some impacts on oceans, such as climate change and eutrophication with some models, the impacts of marine plastic debris and marine invasive species were not included, and this is what the project aims to remedy.

The project worked on integrating plastic pollution in LCAs: the team already published a framework for **marine plastic litter impact** and a model to disentangle marine plastic impacts on ecosystem quality. The team also worked on **data-deficient species**, species for which insufficient data is available to define whether they are at risk of extinction, thereby addressing a research gap that will be useful for their models. Their results suggested that more than half of these species could actually be threatened. The project is now developing a model to **assess the impact of invasive species** that are carried by both shipping (through ballast water and hull) and rafting on waste particles. A first effect factor model has been developed.

The project applies a holistic approach to quantify the impacts of a large number of human pressures on marine environments. Once finalised, their model could support policymakers and businesses to evaluate whether a planned marine activity, process or product is sustainable, and what their impact is on oceans and seas.

How do smoke particles from biomass burning interact with clouds and affect rainfall, the climate and public health? The PyroTRACH project aimed to detect, monitor and understand the impact of burned biomass aerosols coming from wildfires or heating in densely populated urban environments, such as in Athens, Greece. The project led by Athanasios Nenes, from the Foundation for Research and Technology Hellas, tracked particles from biomass burning from emission to final deposition in the atmosphere, and after multiple days of residence. The team also assessed their toxicity across time. Their results show that biomass burning is highly toxic, and even if highly diluted, particles can cause adverse health effects if breathed in.

Finally, a study in the Athens region showed that the urban population is significantly exposed to airborne carcinogens, a pollution type that largely comes from wintertime domestic wood burning in fireplaces, wood stoves and pellet burners. While wood burning and its impact on air quality can be highly dangerous for health, it is still seen in a positive light as a natural activity and, in the context of the green transition, a renewable energy source.

Other projects focusing on pollution

- CoSense4Climate develops new types of sensors, methods and models to precisely localise and quantify the emission sources of greenhouse-gases and air pollutants in cities at high resolution.
- EcoWizard aims to understand the chronic effects of engineered nanomaterials on organisms and species interactions to predict their toxicity and assess the effect of long-term exposure.
- HEAL studies air pollution caused by the combustion of fossil fuels and its impact on human health and the workforce. It aims to develop tools for assessing the trade-off when designing climate and air-quality management policies.
- OSPAPIK studies contemporary arts created by Indigenous peoples to better understand how waste and debris are perceived, and the impact of pollution and waste on the relationship people build with the ocean and space.

5.2. Ecosystem protection and restoration

Biodiversity is threatened by a variety of factors. The five main drivers of biodiversity loss are changes in land and sea use, climate change, invasive species, pollution and direct exploitation of natural resources. The projects presented in this chapter study these factors and possible solutions to protect, manage or restore ecosystems in the context of global change, including extreme weather conditions.

As climate change is pushing ecosystems beyond known boundaries, the FutureNature project proposes a **new approach to nature conservation**, by which restoration would not be planned to reproduce past conditions, but **to ensure that ecosystems are functioning and future-proof**, i.e. resilient to the climate conditions they will face in the future. Koenraad Van Meerbeek, KU Leuven, Belgium, works on natural grassland ecosystems in Europe, which are expected to experience a warmer climate and more frequent extreme droughts.

His research aims to test the use of **functional assisted migration** for conservation. His controlled climate change experiments will test how the relocation of non-invasive plant species can shape new resilient grassland communities. Van Meerbeek underlines the long-term benefits of this strategy if it proves successful, but this approach also faces controversy linked to the risk of introducing species that may become invasive. Before assisted migration can be implemented in conservation practices, scientific evidence is needed, beyond a sound hypothesis, opinion papers and anecdotal evidence, to make sure assisted migration works.

> *Our current approaches are not sufficient to slow or halt biodiversity loss. We need new approaches, and we need to implement changes fast, but still, as a scientist I think it's more important to have proof before we act.*
> Koenraad Van Meerbeek, ERC project FutureNature

If functional assisted migration proves to work, this approach could be used in other ecosystems. It would also represent a paradigm shift in how we think about conservation, with a focus on ecosystem functions rather than on species preservation. To address global change, Van Meerbeek advocates for both climate change mitigation and adaptation in parallel, as two important parts of the solution.

> *Climate change adaptation is not only necessary in agricultural and urban ecosystems that are human dominated, but also in natural ecosystems because the natural capacity to adapt and respond to climate changes is not large enough to cope with the changing conditions.*
> Koenraad Van Meerbeek

With the FLUFLUX project, Gabriel Singer, University of Innsbruck, Austria, focused on the conservation and restoration of biodiversity at the scale of river networks. The project results help better understand the consequences of habitat fragmentation in freshwater ecosystems for biodiversity and ecosystem functioning. They can also support the restoration of river ecosystems, for instance by helping identify critical locations where dam removal or other restoration measures would have a more positive effect.

Singer and his team chose the particular river system of the Aoos/Vjosa river, which flows through Albania and Greece, as one of their case studies and the project outcome points to the need to **plan conservation and restoration at a larger spatial scale**. This has implications for policymakers and conservation managers as projects will consequently involve more stakeholders, which could make them more difficult to debate. Projects will also potentially become more prone to facing opposition. This approach also requires **desired outcomes to be designed for broader regions**, rather than focusing on smaller, strongly protected areas located within landscapes that are heavily used for human activities.

> *All this clearly calls for conservation and restoration projects to be planned more in concert "with" people, i.e. with outcomes that foresee and support spatial co-existence of nature and people.*
>
> Gabriel Singer, ERC project FLUFLUX

River networks are important for their biodiversity and ecosystems services, which sustain regions, as well as for water, which carries organic matter and nutrients. They also have a role in the Earth's carbon cycle. One of the trade-offs identified by the project is between **freshwater ecosystem protection and the transition of energy systems** towards renewable energy, including hydropower. While the installation of river dams has negative effects on biodiversity and sometimes on the climate system, the conservation of rivers can be seen as a missed opportunity for renewable energy. Finding a balance between competing interests is a challenge. Stakeholders must work together to find common ground and accept limitations in order to develop concrete implementation plans.

> *We need to search for solutions that do not exacerbate climate change or biodiversity loss, but address both simultaneously. Policymakers should facilitate this search, identifying ways for renewable energy development while supporting nature conservation and ecosystem restoration with a plan and guidance at a large spatial scale.*
>
> Gabriel Singer, ERC project FLUFLUX

An indirect, positive consequence of the project and other scientists' work at the Vjosa river sites was the media attention on the river's understudied but valuable ecosystem. This visibility and increased awareness, beyond scientific results, led to the Albanian government declaring the Vjosa River a national park in 2023.

Rachael Garrett at the University of Cambridge, UK, studies tropical forests, which are rapidly disappearing across the world. She examines the **supply-chain policies of companies selling products associated with deforestation** (such as soybeans, cattle, palm-oil and cocoa), **and how they can drive native forest ecosystem conservation** (or not). With her FORESTPOLICY project, she defined and tested the criteria for effective zero-deforestation commitments by companies, such as commitments to not source from suppliers that deforested their land, and the development of supplier lists based on certifications that verify zero-deforestation and/or reforestation on properties (e.g. Rainforest Alliance certification)[57]. They found many inherent limitations, as supply-chain policies can only tackle a very limited part of the food and land system and their goals are fairly incremental (tackling deforestation as a symptom, not a root cause). She concludes they have insufficient scope or ambition for transformative change. Instead, she argues that we need to talk about engagement with local communities and directing finance to enabling conditions to make existing policies work and redesigning economies to tackle root causes of problems.

Garrett stresses the challenges of studying and triggering systemic changes: structural change is more difficult to study for scientists and, for policymakers, more difficult to adopt and implement. She suggests that the solution may lie in **re-centring supply-chain policies on equity and care principles and choosing approaches that engage local communities, with a focus on awareness, norms, and culture**. The team also frequently communicates the need for structural changes in national policies in the regions they study, Indonesia and west Africa, as they can tackle the root causes. They advocate for landscape-level approaches to help understand local needs and plan different types of interventions. Above all, they stress the need to engage local communities in solutions[58].

> ***Our research highlights how the existing suite of policies tend to result in intractable tensions between different goals and a lack of focus on what really matters – systems change. Land users and traditional and Indigenous communities can help in driving attention towards solutions that already exist but aren't being scaled up and out due to systemic barriers.***
>
> Rachael Garrett, ERC project FORESTPOLICY

Other projects on ecosystem protection and restoration

- REACT studies natural regeneration as managed by farmers, how it develops over time and what benefits it brings, with the aim of defining the optimal social-ecological conditions for ecosystems restoration across sub-Saharan Africa.
- WaterSmartLand will identify optimal land management scenarios for implementing nature-based solutions such as wetlands and riparian buffer strips to reduce agricultural nutrient runoff from catchments.
- RELATE explored human-nature relationships, with a focus on the role played by biodiversity on physical and mental well-being. The resulting BIO-WELL tool can help measure how nature-based health interventions or conservation efforts benefit human well-being, other species and wider ecosystems.
- PLaNT aims to understand the barriers to the development of climate-smart marine spatial planning, in Antarctica and globally, and how to plan for sustainability and equity.

5.3. Rethinking food systems and natural resource management

The ERC projects in this chapter explore solutions to make food systems more sustainable and resilient. They look at agricultural and fishery practices as well as alternative ways of subsistence, such as foraging, and how they can adapt and develop within nature's boundaries to provide nutritious food for all. The projects address the many factors affecting global food systems including land-use, natural resource and water management, trade-offs with nature protection, justice and equity aspects, and local populations' livelihoods, health and jobs. Some of these projects work on the nexus between biodiversity, water, food and climate that is currently being discussed as part of the IPBES Nexus assessment, which will be presented for adoption by the IPBES plenary in December 2024. These research projects aim to support the development of the food systems of the future, which are respectful of nature and for the benefit of local populations.

Led by Carole Dalin, at the Centre National de la Recherche Scientifique (CNRS) and Ecole normale supérieure (ENS) in France, the FLORA project aims to **quantify the environmental impact and sustainability of global food systems, focusing on both environmental and human health outcomes**. The team investigates the key drivers of these impacts on biodiversity, climate and water resources, and seeks solutions to enhance sustainability and health. Their initial findings indicate that our food systems are not aligned with the goals of improving environmental and human well-being, confirming the need for a profound transformation.

Dalin's approach involves examining various aspects of food systems – greenhouse-gas emissions, water, land and fertiliser use for agricultural production, as well as nutritional quality and accessibility of food supply, to identify synergies and trade-offs. By considering multiple factors simultaneously, the project aims to prevent negative consequences that could arise from isolated solutions. For example, increased fertiliser use in cropland since the 1960s, has boosted food production but also caused environmental damage such as soil degradation and water pollution.

A coordinated global effort using transdisciplinary methods is essential to understanding and addressing these trade-offs. The challenges faced by policymakers include balancing dietary recommendations and potential interventions (e.g., taxing sugar, carbon, or red meat) that may be perceived as going against individual freedoms.

In addition, policies need to change across the entire food system, including agriculture, food distribution and trade, to ensure a systemic approach. The project emphasises the importance of reallocating subsidies, informing consumers, and making holistic policy adjustments to achieve sustainable and healthy food systems.

> ***Something to keep in mind: research shows that it is possible to transform our food systems so that they fit in the boundaries of our living planet, and with the benefits of improved human health, livelihoods and well-being.***
> Carole Dalin, ERC project FLORA

The SOS.aquaterra project aims to identify **measures that are socio-economically feasible to meet future food demand while respecting key planetary boundaries in food production**: water, land, nutrients and biosphere integrity. The project is led by Matti Kummu, Aalto University, Finland, who does not consider these planetary boundaries independently, but recognises the interactions, feedback and potential trade-offs between their processes. With his team, he has developed an **integrated food system model** that enables a systemic understanding of the entire global food system, including trade. This model will be used to estimate, for the first time, the combined potential of conventional measures (diet change, food-loss reduction, yield-gap closure, trade) and future innovations (e.g. vertical farming and alternative protein sources) to meet future food demand within a safe operating space.

The project's key results so far include the establishment of a new planetary boundary for freshwater change. The project team supported the estimation of food production capacity within planetary boundaries through diverse strategies, demonstrating comprehensive approaches to enhancing global food security and sustainability. They have shown the potential to increase circularity and avoid food-feed competition in livestock and aquaculture production by increasing the use of food system by-products in animal feeds, with the potential to provide food for a billion people. Currently, the team is assessing the potential to increase crop production sustainability, without altering yields, by implementing regenerative agriculture practices such as agroforestry, no-tillage farming, cover cropping, and organic farming, with the possibility of combining these practices in different locations.

According to Kummu, a drastic transformation of the food system is necessary if we are to secure food for future populations while staying within safe operating spaces such as planetary boundaries. But there are also windows of opportunity for a green transition in food production: in circularity; systemic changes in how and where food is produced; and in food consumption. The challenge for policymakers is to ensure the foundations of an integrated, sustainable food system (taking into account social, economic, environmental, and health factors) in a specific region at a specific time. This is a very complex puzzle that also needs to take into account how to make the transformation just and fair for all groups.

> ***The current food system is very complex and increasingly global, making changes difficult to implement in practice. It would require an integration of environmental sustainability, economic feasibility, social acceptance, and supportive policies, among other actions.***
> Matti Kummu, ERC project SOS.aquaterra

Developing sustainable food systems is a key to addressing malnutrition across the world. Several ERC projects focus their research on this issue. Among them, Christina Graham's FAIRFISH project at the University of Lancaster, UK, focused on the ecological and socio-cultural determinants of the **contributions that small-scale fisheries make to human health**. Results indicate that fish-based food strategies have the potential to substantially contribute to global food and nutrition security. At the same time, the danger of the emergence of an eco-precariat is highlighted, resulting from a process of stigmatisation and separation from previous livelihood activities.

With the FORESTDIET project, Laura Rasmussen from the University of Copenhagen, Denmark, is rethinking food security for populations living close to forests in Africa. **Forests provide nutritious wild food, but access to this free or affordable food is jeopardised** by efforts to provide food security when they involve deforestation for agricultural land use. Results highlight the need for a more integrated approach between agriculture and forest land-use planning to address malnutrition,

which takes into account the benefits of local forest diets. The project also developed a 'Forest and Trees Toolkit' proof of concept to reduce malnutrition in Africa.

The CLOCK project developed a **new adaptation framework for fisheries management** under climate change and shifting fish stocks. A set of case studies demonstrates how to integrate theory and a participatory process to increase fisheries' social, ecological and institutional resilience to climate change. Regarding network structures, the project findings indicate that fishers who depend on several marine species, communicate with other fishing groups and/or have trust in institutional actors within the small-scale fishery, are more likely to engage in livelihood diversification. The project was led by Elena Ojea, University of Vigo, Spain.

Among other solutions, models and early warning systems are being developed with ERC grants that could help planning and agricultural management. Sonia Seneviratne (MESMER-X project, ETH Zürich, Switzerland) developed a climate or **earth system model emulator** that can quickly give an initial assessment of how climate extremes might evolve on a regional scale under particular global warming and emissions pathways. It enables better consideration of feedback from climate extremes (heat, fires and droughts). The Emerald project, led by John Goold, Trinity College Dublin, Ireland, developed and tested an innovative **soil fertility monitoring and forecasting method** that could be used to plan land use as well as food and emergency responses.

With rising temperatures, new insects that are considered pests in the food chain or carry tropical diseases have settled in southern Europe. The solution developed by the REVOLINC project could help in **fighting insects while reducing the use of biocides** that pollute the environment. Their results showed that the boosted sterile insect technique may enable three groups of insects to be controlled efficiently and reduces the biocide used by 6 000 times and make its application more specific. Jérémy Bouyer, CIRAD, France, who led the project, has created a start-up, MoSITouch, to commercialise the product developed with the ERC grant. MoSITouch recently received an award from Bpifrance as a French Tech Deeptech.

Other projects focusing on food systems

- ConFooBio studied conservation conflicts relating to the prioritisation of biodiversity over food security and agriculture, and vice versa.
- EPIFISH studied the role of epigenetics in fish domestication and selective breeding. A proof of concept now explores epigenetic markers to improve the Nile tilapia's breeding practices, which promises a sustainable alternative to some traditional fisheries.
- PERENNIAL explores the feasibility of transitioning from annual crops to perennial grains for agriculture.
- VITALGREENHOUSE investigates sustainability practices in greenhouse agriculture from the perspectives of growers, workers and environmental groups.

5.4. Focus on sustainable coastal areas

Coastal areas are at the crossroads of land and sea and can host a wide range of ecosystems. They also host large populations in coastal cities, whose economic activities rely on the local ecosystems, from fisheries to tourism. Moreover, these areas are confronted with sea-level rises and related flood risks. The ERC projects in this chapter aim to provide new approaches and solutions to coastal area management from diverse perspectives. They also show how local climate action can be put in place in these areas.

What drives the behaviour of populations when confronted with sea-level rises and extreme flood events? This is the topic of the COASTMOVE project led by Jeroen Aerts, from Stichting VU, Netherlands. It focuses on human adaptation in coastal areas, in particular when faced with the choice of migrating to safer areas. The project aims to integrate global coastal flood risk within an agent-based model, that includes behaviours of not only households in the coastal zone, but also governments and the private sector (e.g. insurance companies). Drivers include environmental, socio-economic and demographic ones.

The project also surveyed people around the world to understand their motivation to migrate, and to locally adapt (or not). The model will help identify trade-offs between investments in coastal adaptation and protection (e.g. with dikes or by elevating houses) and migration away from low-lying coastal areas. The model will help simulate environmental risk for the period 2020-2080 as well as the effect of adaptation and migration policies under different risk scenarios. The model was already tested for French coastal areas and showed that projections of coastal migration due to sea-level rises are most sensitive to migration costs and whether the government has installed coastal flood protection.

The GLOBCOADEV project, led by Alex Armand, New University of Lisbon, Portugal focuses on the **impact of water pollution on economic development** in coastal areas. Combining a wide array of micro-level datasets, ranging from household surveys to satellite imaging, and applying advanced micro-econometric techniques, it aims to assess the effect of coastal water contamination on local economic development (including fisheries) and human health, in particular early-childhood development as driven by nutrition. The project will also investigate the side-effects of, among other things, changes in political attitudes, the insurgence of violence, and rural-urban migration

Combining environmental history and natural sciences, the DUNES project provides an innovative global history of coastal dunes. Led by Joana Freitas, University of Lisbon, Portugal, it focuses **on**

the origins, reasons and means of dune afforestation, and how the creation of new landscapes impacts local communities and ecosystems. While coastal dunes were long considered threats that needed to be stabilised, they are now rebuilt and reinforced as nature-based solutions to protect the infrastructures and activities developed on the shore and are being restored to foster endemic biodiversity. Understanding the long-term relations between dunes and people and their narratives can support holistic coastal management. Past examples were collected in a Coastal History Open Archive, which can help stimulate environmental citizenship and inform coastal scientists and managers. The project results are gathered in the book *A Global Environmental History of Coastal Dunes*[59].

The TRADITION project investigates the **historical ecology of fisheries in Brazil and their legacy in present-day food security and poverty alleviation**. Over the past two years, André Colonese and his team at Autonomous University of Barcelona, Spain, and University of York, UK, have worked with local communities, particularly small-scale fishers, to understand their perceptions of environmental change and to explore pathways for a more sustainable use of coastal and ocean resources. This allowed them to understand the key drivers of socio-ecological changes that underpin today's challenges, including the impact of early political subsidies on fisheries, and the effects of industrialisation, urbanisation, and market forces on food systems, local diets and overall health.

> ***For the green transition to be truly successful, it must go beyond political and economic interests, focusing instead on the needs of the most vulnerable populations.***
> André Colonese, ERC project TRADITION

According to Colonese, for a sustainable ocean governance, policymakers need to balance economic development - based on the sustainable use of marine resources - with environmental protection, in particular to preserve critical ecosystems like coral reefs and mangroves. Policymakers also need to navigate between short-term socio-economic gains and long-term sustainability goals, while considering social equity and the needs of traditional and local communities. André Colonese advocates for a systems approach that integrates all types of knowledge - transdisciplinary scientific knowledge, local, and traditional - to promote economic development, social equity and environmental sustainability. Cultural heritage in particular holds great potential to inform pathways for future sustainable socio-ecological scenarios.

> ***Strengthening the ocean knowledge-policy-society interface, institutionalising transdisciplinary science, and enhancing capacity-building are essential steps in effectively addressing the ocean crisis.***
> André Colonese, ERC project TRADITION

Another project on coastal areas

- BEFOREtheFLOOD tests how Neolithic coastal communities around the Mediterranean constantly re-adapted to dynamic environmental processes over time by modifying their environment and developing new technologies and social interactions.

6. Sustainable urban development and infrastructures

This chapter presents projects with a focus on cities and infrastructure, including key sectors such as building, manufacturing, energy and transport. By integrating nature-based solutions and sustainable practices, these projects aim to enhance sustainable water management in cities, promote the use of renewable energy, and develop environmentally sustainable transport systems. The chapter also highlights inclusive and accessible approaches to urban planning, ensuring that green transitions not only protect the environment, but also create equitable opportunities for all citizens.

6.1. Sustainable water systems

In a context of climate change, water management is of critical importance, including in urban areas. Cities face increasing pressure from water scarcity, rising water demand and flooding in connection to extreme weather events. Effective water systems help reduce vulnerabilities, improve resilience and are crucial part of sustainable urban development.

The Water Futures project is led by four principal investigators: Marios Polycarpou, University of Cyprus; Dragan Savić, University of Exeter, UK; Barbara Hammer, Bielefeld University, Germany and Phoebe Koundouri, Athens University of Economics and Business, Greece and Technical University of Denmark. The project aims to **design the next generation of urban water systems** in the face of significant challenges such as climate change, economic instability and population growth and in a context where cities are expected to house 80% of the global population by 2050. The goal is to design sustainable systems that are efficient across social, economic and technical dimensions. These systems must be equitable, ensuring fair access and pricing, and protection from climate-related risks, for all segments of the population.

The main challenges pointed out by Phoebe Koundouri for advancing the green transition lie in breaking down silos between different scientific disciplines and in engaging all relevant stakeholders in a meaningful way. Interdisciplinary collaboration is of the essence and the project draws from socioeconomics, water informatics, AI and electrical engineering, among other disciplines. A further critical aspect is to co-design solutions involving all stakeholders, including scientists, policymakers, civil society and businesses. This inclusive approach ensures that the solutions proposed are viable, validated, and accepted by all those involved, making the green transition more equitable and effective.

> ***What we need is a systems approach. One that involves interdisciplinarity and cohesion and engaging everybody. For change to be massively deployed, we need the critical mass of scientists, of stakeholders, and of policymakers.***
> Phoebe Koundouri, ERC project Water Futures

Another major barrier is the lack of readiness in the labour market, with 85% of the skills needed to implement policies such as the European Green Deal currently missing. Without addressing these gaps and fostering collaboration between science and society, progress will be limited, Koundouri underlines.

Despite these challenges, there are also significant opportunities for change. Interdisciplinary work is becoming more prominent, with policy frameworks such as the Sustainable Development Goals (SDGs) and the European Green Deal reflecting a more integrated approach. However, the pace of change is insufficient, given the urgency of global challenges. More needs to be done to accelerate progress. Policymakers face the dilemma of prioritising and securing the necessary budgets for transformative change. Without cooperation and financial commitment, even the best policies will fail to have an impact. Scaling up solutions requires substantial financial investment, and a major overhaul of education to reskill and upskill the workforce.

Koundouri's key message to policymakers is to build strong partnerships with scientists, just as they do with other key stakeholders. Trust and collaboration are crucial elements for refining policies, attracting necessary financing, and accelerating the implementation of impactful solutions. The need for this collaboration is urgent, as action is required immediately to address the scale of the challenges ahead.

Water systems need **water-treatment technologies** that are sustainable, robust, energy-efficient and that can reduce the pollution created by the release of toxic chemicals in the environment. The Electron4water project, led by Jelena Radjenovic, Catalan Institution for Research and Advanced Studies, Spain, focused on the removal of 'forever chemicals' (perfluorinated and polyfluorinated alkyl substances, PFASs), which are extremely persistent in the environment and the human body. The project was successful in developing a nanostructured material for a chemical-free water purification technology. The project invented graphene sponge electrodes, which have demonstrated electrochemical inertness to chloride and can, at the same time, degrade PFASs. The system has several advantages and scale-up possibilities: low cost, modularity, the possibility to be powered by renewable energy, and, most importantly, the ability to treat both complex waste streams and simpler ones such as tap water. The project team is further developing and upscaling the concept with an ERC Proof of Concept Grant GRAPHEC.

6.2. Transport

Sustainable and inclusive green transport solutions are needed for reducing global greenhouse-gas emissions and pollution, in particular in urban areas.

Over the last few years, many cities have undertaken ambitious proposals aiming at reducing car use and creating a more sustainable, equitable and healthy transportation system. Most of them, however, have been met with strong opposition. At the same time, mayors, and other elected leaders worldwide, who have pushed for ambitious built-environment-based travel-demand policies, have later been vindicated by re-election. This would suggest the existence of an 'active travel backlash paradox', where loud opposition movements might be concealing a high rate of policy acceptance by the silent local citizen majority[60]. The ATRAPA project, led by Oriol Marquet, Autonomous University of Barcelona, Spain, examines what are the determining factors of the dissonance between public opinion creators and the perception of lay citizens, thereby enabling policymakers to implement progressive environmental traffic policies.

Other projects on transport

- MAGnUM creates a consistent set of interrelated dynamic and multimodal traffic models able to capture driver behaviours at different urban scales, and to apply this variety of models to design efficient and green traffic management strategies.
- CriticalMaaS develops new behavioural models of traveller and supplier trends that will be used to study emerging practices, transition steps and critical mass concepts, with a view to innovating transport modelling.

6.3. Energy

As stressed by the IPCC, the climate change crisis is a shared global challenge and is to a large extent an energy challenge. As energy accounts for over two-thirds of global greenhouse-gas emissions, sustainable energy must be at the heart of any solution[61].

The ICEBERG project, led by Anthony Papavasiliou, National Technical University of Athens, Greece, aims to **break down the current barriers to renewable energy integration**. By mobilising untapped flexibility at all layers of the energy network the project aims to meet ambitious sustainability targets through infrastructure upgrades, without compromising the quality of electric power service.

It optimises electric power grids by moving beyond conventional approaches that focus solely on large-scale power plants. It integrates numerous small, flexible resources, such as electric vehicles, along with distributed and unpredictable renewable sources like solar and wind power, into electrical grids at a large scale. Advanced algorithms are being developed to coordinate these resources and manage their fluctuations, ensuring that the secure operation of the power grids is not compromised.

The project also gives an insight into electricity markets. The algorithms developed within the project enabled the team to demonstrate that, by coordinating the provision of energy and reserves, electricity markets can save up to approximately EUR 2 billion per year compared to current operating paradigms in Europe. Furthermore, the project highlighted that merging the provision of energy and reserves may encounter institutional challenges, since it requires a tighter coupling of operations between various market players in the existing power industry.

> *A green transition requires increased coordination between stakeholders that have traditionally been accustomed to doing things independently of each other. The green transition will also cost money, and this creates winners and losers. Sometimes the losers of the transition are powerful Member States or organisations that resist disruptive but needed change in the policy arena.*
>
> Anthony Papavasiliou, ERC project ICEBERG

With increasing temperatures and heatwaves becoming more common, the use of energy for cooling purposes is growing rapidly. The ENERGyA project led by Enrica De Cian, Ca´Foscari University of Venice, Italy, developed an interdisciplinary and scalable research framework integrating data and methods from economics with geography, climate science, and integrated assessment modelling to provide new knowledge about heterogeneity in energy use across countries, sectors, socioeconomic conditions and income groups. De Cian assessed the **broad implications that adaptation-driven energy use can have on the economy, the environment and human welfare**. As temperatures rise, more and more people will need to use air conditioning, which in turn will impact the climate. Since air conditioning is the main mechanism that increases households' electricity use and expenditure, this also means that a significant portion of the population will be unable to pay for energy services adequately, contributing to energy poverty. As climate change makes indoor cooling essential for the health and safety of a growing number of people, sustainable energy solutions are urgently needed.

Other projects on energy systems

- MANIFEST develops a new scientific understanding of the feasibility of decarbonising the electricity sector, focusing on both launching low-carbon electricity in developing countries and sustaining the growth of renewable electricity already in place in front-runner countries.
- ELECTRIC CHALLENGES studies how to design optimal regulatory and market-based solutions to achieve the least-cost transition toward a low-carbon economy.
- SOLSPACE develops a novel strategy to improve the delivery of global clean energy services through the use of ultra-lightweight orbiting solar reflectors.
- eCAPE contributes with the development of a new theory to understand and promote a low-carbon transition, and to ensure that this transition does not indirectly become a driver of gender and social inequality.
- illicitLABOUR pioneers a study of the linkages between climate change mitigation and illicit economies in the photovoltaic sector and the resulting implications for ecological governance.

6.4. Buildings and bio-based materials

Buildings play a crucial role in climate change, as they significantly impact energy consumption, carbon emission, and resource use.

Moving from the current reliance on non-renewable materials from the geosphere to renewable and fundamentally cyclical materials of the biosphere, can establish foundations for thinking about alternative sustainable building practices[62]. The goal of the ECO-METABOLISTIC-ARC project, led by Mette Ramsgaard Thomsen, The Royal Danish Academy of Fine Arts, School of Architecture, Design and Conservation, is to **rethink sustainable building practices through bio-based materials** in response to the increasing global crisis of material depletion. It introduces a new world of bio-based materials that are fundamentally different from current building materials because of their complex heterogeneity, unpredictable behaviours and limited lifespans. As the project underlines, the industrialisation of construction and modernism brought about the idea that architecture was somehow permanent. However, we are already living in buildings that must be maintained. Bio-based materials open up to a more participatory way of looking at buildings[63].

The project proposes a holistic eco-metabolistic framework that allows for carbon-neutral, renewable and materially optimised design solutions. It employs a research-by-design method to investigate three bio-based material perspectives (glulam, bio-polymer composites and bioluminescent bacteria), and instrumentalises them through three advanced computational modelling networks for the predictive modelling, adaptive fabrication and environmental sensing of bio-based materials.

The project points out that, as living materials, bio-based materials require continuous care. In the same way as people water their plants, inhabitants of buildings made of bio-based materials will nurture their home, and therewith fully participate in its life, which fundamentally changes ideas of ownership and participation[64].

Other projects on buildings and nature-inspired materials

- HELIOS: develops innovative materials that act as a “skin” on surfaces to passively cool urban areas without consuming energy.
- ARCHI-SKIN: develops a sustainable, self-healing, eco-friendly bioactive protective coating system for engineered materials, inspired by fungal biofilms, to protect surfaces while conserving energy and water.
- Materials-GRoWL evaluates the environmental impacts of construction materials in the Global South and creates a framework for sharing knowledge on sustainable material use.

6.5. Greening cities and inclusion

Urban greening is essential for enhancing well-being in urban environments. It can improve air quality and promote biodiversity. At the same time, it is crucial to ensure that these initiatives are inclusive and accessible to all citizens.

Urban greening projects are transforming neighbourhoods into better places with more parks, bike lanes, gardens, and other green infrastructures. However, these amenities also create new real estate value, attracting investors and high-income residents, and thereby push poorer people to greyer and climate-displaced neighbourhoods. This phenomenon of **social inequity production by green gentrification** was at the heart of the project GREENLULUS, led by Isabelle Anguelovski, Autonomous University of Barcelona, Spain,

The project investigated the conditions under which urban greening projects in distressed neighbourhoods redistribute access to environmental amenities for historically marginalised groups in 40 cities across Europe, the United States, and Canada. The team conducted a broad study of the cities on the scope and magnitude of green gentrification using demographic, real estate, development and green spatial data. The relationship between greening and gentrification was confirmed in the majority of the cities studied.

To promote change, GREENLULUS introduced **policy tools for a more equitable green transformation** that does not leave anyone behind. These tools focus firstly on anti-displacement prevention (e.g. property-tax breaks for low-income residents, taxes on empty luxury units to avoid speculation); and secondly on zoning tools (including percentage of new built developments reserved for social housing, protection of community gardens, participatory planning of greenery, etc.).

With a follow-up ERC Proof of Concept grant for the ClimateJusticeReady project, the researchers support actionable policy and planning tools for greater urban climate justice. It is implemented in collaboration with the cities of Barcelona and Boston, supporting their efforts for just and equitable green cities.

6.6. City management and urban planning

City planning is vital when addressing climate change: urban areas are major contributors to greenhouse-gas emissions and are particularly vulnerable to its impacts. Urban planning can enhance resilience, reduce emission, and promote sustainable development, making cities more resilient.

Climate change and urbanisation are transforming life globally, with direct impacts on each other, yet they are rarely studied together across disciplines. The Urbisphere project coupling dynamic cities and climate is led by Jörn Birkmann, University of Stuttgart, Germany, Andreas Christen, University of Freiburg, Germany, Nektarios Chrysoulakis, the Foundation of Research and Technology Hellas, Greece and Sue Grimmond, University of Reading, UK. Urbisphere forecasts the **feedback between weather, climate, and urban environments**. By leveraging new synergies among four disciplines - spatial planning, remote sensing, modelling, and ground-based observations - the project integrates city dynamics and human behaviour, including human vulnerability, into weather and climate forecasts. The emphasis is on understanding within-city activity patterns and their scalability to global urban contexts. The project is providing important insights into how cities will impact climate change and how the impacts of climate change will influence cities, including vulnerable groups.

More than half the world's population currently lives in cities. This number is expected to reach two thirds by 2050. As cities already account for 75% of global resources and energy use, and it is important to improve efficiency, sustainability and resilience. In this context, the CoCi project, led by Dirk Helbing, at the Federal Institute of Technology in Zürich, Switzerland, explores **whether a decentralised, participatory approach is more effective and sustainable than a fully centralised model**. It also examines how distributed co-creation processes can be effectively coordinated and elevated. Building on the smart city paradigm, the project argues that organising societies for greater resilience requires more decentralised solutions rooted in digitally assisted self-organisation. This approach aligns with sustainability goals and fosters enhanced democratic participation. By embracing decentralisation, diversity and combinatorial innovation, it is possible to cultivate a co-created, co-evolving urban life. In this new paradigm, **the principles of co-creation, co-learning, and co-evolution are key success criteria**[65].

6.7. Urban agriculture

Urban agriculture can be an important aspect of the green transition in cities, as it contributes to reducing greenhouse-gas emissions, enhances local food security, and promotes biodiversity within cities. It can also foster community resilience and sustainable practices.

The URBAG project, led by Gara Villalba, Autonomous University of Barcelona, Spain, investigates how green infrastructures can be a source of sustainable food, reduce environmental impacts, and promote a more efficient use of resources in urban regions. The project explores what combinations of urban, peri-urban agriculture and green spaces result in the best performance in terms of local and global environmental impact.

The project's innovation lies in integrating the life cycle impacts of the resources required for green infrastructures, with an understanding of how those green infrastructures impact the urban atmosphere interactions. URBAG has introduced an assessment framework focusing on vulnerability to steer the implementation of nature-based urban solutions (NbS). Effective planning of NbS can accelerate the green transition by maximising the positive effects and minimising the negative ones, while also ensuring the efficient use of resources for their implementation and maintenance. The prioritisation of NbS based on a spatially differentiated understanding of social and ecological needs, breaks with the common paradigm in green infrastructure planning (to assess and maximise net ecosystem service benefits). It operationalises spatial justice from a human and more-than-human perspective in a concrete manner that has shown relevant for strategic spatial planning.

Villabla and her team find that main barriers to implementation of greening and local agriculture include the high water requirements and the potential increase in greenhouse gas emissions from land-cover change and fertilisers usage, and the complexity of managing trade-offs between land use for agriculture versus conservation of nature. Significant opportunities arise such as enhancing urban resilience through better integration of green infrastructures in urban planning, particularly by optimising the placement and types of vegetation in urban landscapes.

> ***Policy frameworks that incentivise the expansion of green infrastructure, promote sustainable agricultural practices, and support community involvement can serve as critical leverage points. Opportunities lie in cost-effective solutions demonstrated through case studies, such as cool roofs that increase rooftop albedo.***
>
> Gara Villalba, ERC project URBAG

Siloed approaches are still at the forefront of most planning, design and management decisions, with a single challenge addressed by a single solution. This common practice hampers the flourishing of nature-based approaches, which by definition are multi-functional, and more adaptive to diverse and changing societal needs. More holistic approaches are needed to unleash nature-based solutions full potential, Villalba concludes.

Conclusion

This report presents a portfolio of over 300 **ERC projects on transformative change for a just green transition**. It complements previous analyses of how ERC-funded research contributes to the European Green Deal with a focus on research that can help us understand what transformative change entails and how it can deliver the solutions needed to address the triple crisis of biodiversity loss, pollution and climate change.

The report provides an overview of the scientific landscape covered by these ERC projects and demonstrates their connections to the objectives of the **17 Sustainable Development Goals and EU policy priorities**.

Examples of projects are showcased, mainly from the social sciences and humanities domain. These projects offer different perspectives on drivers and challenges, grouped in five thematic areas: **leverages for a green transition; the just green transition; rethinking prosperity; a healthy planet; and sustainable urban development**. Their results propose specific solutions and provide in-depth insights on the factors that can drive the systemic and structural changes needed for more sustainable and fair societies.

The ERC supports researchers with long-term grants, which are evaluated without any predefined policy priorities. This type of funding allows researchers to think differently about global challenges and their interconnections - across disciplines, systems, economic sectors, and among societal actors.

While many projects see green transitions in progress, they also point to the urgent need to fully rethink our economic systems. They generate knowledge that can inform policies from design to implementation.

Frontier research provides a space for agile minds and innovative approaches to tackle the complexity of environmental and climate challenges, and can unlock the transformative change needed for nature and society to thrive.

Acknowledgments

We acknowledge colleagues from the ERCEA Scientific Department (Alejandro Aparisi Rey, Veronika Czakó, Carmen Garcia Fernandez, Inés Marín Moreno, Annekathrin Jaeger, Inés Marín Moreno, Fabio Marques dos Santos, Jana Šifta, Vittorianna Tasco), for their work on this report, which was led by Noélie Auvergne and Anne Nielsen from the Scientific Impact and Feedback to Policy (F2P) Sector in the ERCEA.

We would like to thank Harriet Bulkeley, and Eystein Jansen, members of the ERC Scientific Council, for their guidance and enthusiasm leading up to the publication of this report. We would also like to thank Eleni Zika, Head of the F2P sector for her guidance, and the ERCEA F2P network for their feedback and support, with thanks also to Katarina Henning, as well as Inge Ruigrok and Eilish Brault from the Communication Unit. Finally, we would like to thank colleagues at the European Commission DG Research and Innovation (R&I), Directorate B Healthy Planet/Unit B3 Climate and Planetary Boundaries and the Joint Research Council team of portfolio 1 for our exchanges and their collaboration and valuable feedback.

Under the Horizon Europe programme, the European Commission has delegated a new task to the ERC Executive Agency (ERCEA) to identify, analyse and communicate policy-relevant research results to Commission services. The ERCEA has developed a Feedback to Policy (F2P) framework for ERCEA to guide these activities, adapted to the specifics of the ERC as a bottom-up funding programme. This report is part of a series aiming to highlight the relevance of ERC-funded frontier research, for addressing societal, economic and environmental challenges, and thus its contributions towards key EU policy goals. This F2P series does not offer any policy recommendations.

More information: https://erc.europa.eu/projects-statistics/mapping-erc-frontier-research

Methodology

- A set of keywords and phrases was developed to identify ERC projects relevant to transformative change for a just green transition, with the input and feedback of ERCEA and European Commission colleagues.
- These keywords were used to identify ERC projects funded under the Horizon 2020, and Horizon Europe framework programmes, using a European Commission internal text mining tool (CORTEX, data as of May 2024). Additional projects were identified via the ERCEA internal classification system Mapping Frontier Research (MFR) (data as May 2024).
- ERCEA scientific officers reviewed the list of projects to select those that fit the scope of this report. This resulted in a list of 312 projects covering all scientific domains.
- Using the European Commission's internal tool (CORTEX), projects were clustered according to their relevance to the 17 Sustainable Development Goals. Based on this clustering, thematic chapters were defined and projects were selected as examples in each chapter. Projects were selected based on how advanced they were, whether they had produced tangible research outputs and based on their relevance to transformative change. The report showcases projects from 20 countries, with some coming from host institutions that host multiple grants in this domain.
- Finally, interviews were conducted with a few ERC grantees leading the research, either online or by email. These interviews formed the basis for some of the outcomes and quotes presented in this report.

Further reading

The ERC published feedback to policy reports derived from thematic portfolio analyses, outlining how ERC's projects contribute to major EU policy priorities:

- Frontier research for the European Green Deal | ERC (europa.eu)
- Frontier research for Food 2030 | ERC (europa.eu)
  European Commission: European Research Council Executive Agency, Mapping ERC frontier research sustainable food production and consumption, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2828/106806
- Frontier research for biodiversity | ERC (europa.eu)
  European Commission: European Research Council Executive Agency, Mapping ERC frontier research biodiversity, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2828/42652
- Frontier research for democracy | ERC (europa.eu)
  European Commission: European Research Council Executive Agency, Mapping ERC frontier research – Democracy, Publications Office of the European Union, 2024, https://data.europa.eu/doi/10.2828/548275

Two European Commission reports describe the contribution of EU-funded projects, including ERC projects, to the knowledge bases of IPCC and IPBES reports:

- Informing global climate action - Publications Office of the EU (europa.eu)
  European Commission: Directorate-General for Research and Innovation, Mugabushaka, A. and Rakonczay, Z., Informing global climate action – Contribution of the Framework Programmes (FP7 and H2020) to the knowledge base of recent IPCC reports based on openly available data, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2777/928125
- Linking research to global biodiversity policies - Publications Office of the EU (europa.eu)
  European Commission: Directorate-General for Research and Innovation and Mugabushaka, A., Linking research to global biodiversity policies – How did the EU research funding contribute to recent IPBES reports?, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2777/703327

The European Environment Agency (EEA) recently published a report on Just sustainability transitions:

- Just sustainability transitions – From concept to practice
  European Environment Agency, Just sustainability transitions – From concept to practice, Publications Office of the European Union, 2024, https://data.europa.eu/doi/10.2800/6238023

Endnotes

1 https://erc.europa.eu/projects-statistics/mapping-erc-frontier-research/frontier-research-european-green-deal
2 https://www.ipcc.ch/2023/03/20/press-release-ar6-synthesis-report/
3 https://www.un.org/sustainabledevelopment/development-agenda/
4 https://www.un.org/en/summit-of-the-future/pact-for-the-future
5 https://unfccc.int/process-and-meetings/the-paris-agreement
6 Kumming-Montreal Global Biodiversity Framework: https://www.cbd.int/gbf
7 Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES): https://www.ipbes.net/
8 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
9 The EU's biodiversity strategy for 2030 : https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en
10 EU strategy on adaptation to climate change: EU Adaptation Strategy - European Commission
11 https://climate.ec.europa.eu/eu-action/european-climate-law_en
12 EU Zero Pollution Action Plan: https://environment.ec.europa.eu/strategy/zero-pollution-action-plan_en
13 https://www.consilium.europa.eu/en/press/press-releases/2024/06/17/nature-restoration-law-council-gives-final-green-light/
14 https://research-and-innovation.ec.europa.eu/research-area/environment/biodiversity/biodiversity-research-policy_en#:~:text=The%20EU's%20research%20and%20innovation,achieving%20climate%20neutrality%20and%20adaptation.
15 https://rea.ec.europa.eu/news/rea-projects-helping-restore-europes-forests-freshwater-sources-coasts-and-wetlands-2024-07-10_en
16 https://www.biodiversa.eu/
17 https://commission.europa.eu/document/download/e6cd4328-673c-4e7a-8683-f63ffb2cf648_en?filename=Political%20Guidelines%202024-2029_EN.pdf
18 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/finance-and-green-deal/just-transition-mechanism_en
19 https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/social-climate-fund_en
20 ERC Annual report 2022 and 2023
21 ERC Annual report 2022, https://op.europa.eu/en/publication-detail/-/publication/c4573b42-c1e7-11ec-b6f4-01aa75ed71a1/language-en
22 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
23 Mapping ERC Frontier Research, Sustainable Food production and consumption: https://erc.europa.eu/projects-statistics/mapping-erc-frontier-research/frontier-research-food-2030 (2023)
24 Mapping Frontier Research, Biodiversity: https://erc.europa.eu/projects-statistics/mapping-erc-frontier-research/frontier-research-biodiversity (2023)
25 The evaluation of applications to ERC grants is conducted by peer review panels organised in three domains: Life Sciences (LS), Physical sciences and engineering (PE) and Social sciences and humanities (SH) described in ERC panel structure: https://erc.europa.eu/sites/default/files/2023-03/ERC_panel_structure_2024_calls.pdf. NB: The descriptions for panel SH2 and SH3 have evolved since H2020. ERC panel SH7 panel was created and used from 2021.
26 To note than PoC grants are not included.
27 Problemshifting database: www.problemshifting.directory
28 BACKLASH project website: https://backlashproject.eu/
29 BACKLASH project conceptual framework: https://direct.mit.edu/glep/article/23/1/68/113509/Backlash-to-Climate-Policy
30 BACKLASH: Anisimova, K.V., Patterson, J.J., 2024. Public responses to hard climate policies in OECD member countries: prevalence of contention at the post-adoption stage. Climate Policy 1–18. https://doi.org/10.1080/14693062.2024.2409806
31 GREEFIN project: Investments needed for low-carbon infrastructures in Europe, https://www.nature.com/articles/s41558-022-01549-5
32 https://www.iea.org/reports/cost-of-capital-observatory
33 Statement: "Reinvigorating the Sustainable Development Goals https://globalgoalsproject.eu/globalgoals2024/
34 See https://edgar.jrc.ec.europa.eu/report_2024
35 The project team has analysed approximately 2 700 cases occurring within a 22-year timeframe and the outcomes in terms of access to (environmental) justice. Based on this, the project has obtained a deep understanding of the variables that intervene when green projects (among others) are seen as unjust: the fragmentation of economic operations in global value chains, overlapping (and sometimes disconnected) legal systems, and a growing awareness of rights and ecosystem values, which triggers conflicts that often escalate into legal disputes.

36 Post-normal science was developed in the 1990s by Silvio Funtowicz and Jerome R. Ravetz. It is a problem-solving strategy for when facts are uncertain, values in dispute, stakes high and decisions urgent, conditions often present in policy-relevant research. In those situations, PNS recommends suspending temporarily the traditional scientific ideal of truth, concentrating on quality as assessed by internal and extended peer communities. Funtowicz, S. O. & Ravetz, Jerome R. (1991). A New Scientific Methodology for Global Environmental Issues. In Robert Costanza (ed.), Ecological Economics: The Science and Management of Sustainability. Columbia University Press. pp. 137-152; Funtowicz, S. O. & Ravetz, J. R. (1992). Three types of risk assessment and the emergence of post-normal science. In Sheldon Krimsky & Dominic Golding (eds.), Social Theories of Risk. Praeger. pp. 251-274; Silvio O. Funtowicz, Jerome R. Ravetz,Science for the post-normal age, Futures, Volume 25, Issue 7, 1993, Pages 739-755.
37 2023 Global Tipping Points Report: https://report-2023.global-tipping-points.org/
38 Tim Jackson, Jason Hickel, Giorgos Kallis, Confronting the dilemma of growth. A response to Warlenius (2023), Ecological Economics, Volume 220, 2024. https://www.sciencedirect.com/science/article/pii/S092180092300352X. Aljoša Slameršak, Giorgos Kallis, Daniel W. O'Neill, Jason Hickel, Post-growth: A viable path to limiting global warming to 1.5°C, One Earth, Volume 7, Issue 1, 2024, Pages 44-58, Pathways towards Post-Growth (Julia Steinberger, Jason Hickel, Giorgos Kallis) (youtube.com) Best of #BeyondGrowth 2023 - Jason Hickel, https://www.youtube.com/watch?v=xszUWnSEJig, Federico Savini, Post-growth, degrowth, the doughnut and circular economy: a short guide: https://planetamateur.com/2022/11/07/post-growth-degrowth-the-doughnut-and-circular-economy-a-short-guide/
39 Hickel, J., & Kallis, G. (2019). Is Green Growth Possible? New Political Economy, 25(4), 469–486. https://doi.org/10.1080/13563467.2019.1598964
40 Pathways towards Post-Growth (Julia Steinberger, Jason Hickel, Giorgos Kallis), Pathways towards Post-Growth (Julia Steinberger, Jason Hickel, Giorgos Kallis) (youtube.com) (Last consulted 17.10.2024)
41 Pathways towards Post-Growth (Julia Steinberger, Jason Hickel, Giorgos Kallis), Pathways towards Post-Growth (Julia Steinberger, Jason Hickel, Giorgos Kallis) (youtube.com) (Last consulted 17.10.2024)
42 https://cordis.europa.eu/project/id/802441/reporting
43 Federico Savini, Post-growth, degrowth, the doughnut and circular economy: a short guide: https://planetamateur.com/2022/11/07/post-growth-degrowth-the-doughnut-and-circular-economy-a-short-guide/
44 https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
45 https://circulareconomy.europa.eu/platform/en/knowledge/circularity-gap-report-2024
46 Tomohiko Sakao, Nancy Bocken, Nabil Nasr, Yasushi Umeda, Implementing circular economy activities in manufacturing for environmental sustainability, CIRP Annals, Volume 73, Issue 2, 2024, pages 457-481.
47 Olli Pyyhtinen receives €2 million from ERC for a sociological study | Tampere universities (tuni.fi)
48 Stylianos Zavos, Olli Pyyhtinen, The limits of waste as a resource: a critique and a proposition towards a new scalar imagination for the circular economy model, Cambridge Journal of Regions, Economy and Society, 2024;, rsae013, https://doi.org/10.1093/cjres/rsae013
49 Stylianos Zavos, Olli Pyyhtinen, The limits of waste as a resource: a critique and a proposition towards a new scalar imagination for the circular economy model, Cambridge Journal of Regions, Economy and Society, 2024;, rsae013, https://doi.org/10.1093/cjres/rsae013
51 Stylianos Zavos, Olli Pyyhtinen, The limits of waste as a resource: a critique and a proposition towards a new scalar imagination for the circular economy model, Cambridge Journal of Regions, Economy and Society, 2024;, rsae013, https://doi.org/10.1093/cjres/rsae013
52 https://www.fineprint.global/visualisations/
53 Stefan Giljum, Victor Maus, Nikolas Kuschnig, Sebastian Luckeneder, Michael Tost, Laura J. Sonter, Anthony J. Bebbington, A pantropical assessment of deforestation caused by industrial mining, PNAS, Issue 119 (38), 2022. Moritz Kramer, Tobias Kind-Rieper (WWF), Raquel Munayer (adelphi),Stefan Giljum (WU), Rens Masselink (Satelligence), Pia van Ackern (adelphi), Victor Maus, Sebastian Luckeneder, Nikolas Kuschnig (WU), Felipe Costa (WWF), Lukas Rüttinger (adelphi), Extracted Forests: Unearthing the role of mining-related deforestation as a driver of global deforestation, WWF, Vienna University of Economics and Business (WU), Satelligence and adelphi. https://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/Wald/WWF-Studie-Extracted-Forests.pdf
54 Nem Singh, J. T. (2023). Recentring industrial policy paradigm within IPE and development studies. Third World Quarterly, 44(9), 2015–2030. https://doi.org/10.1080/01436597.2023.2216140 https://www.tandfonline.com/doi/full/10.1080/01436597.2023.2216140#d1e607
55 Nem Singh, J. T. (2023). Recentring industrial policy paradigm within IPE and development studies. Third World Quarterly, 44(9), 2015–2030. https://doi.org/10.1080/01436597.2023.2216140 https://www.tandfonline.com/doi/full/10.1080/01436597.2023.2216140#d1e607
56 https://www.nature.com/articles/s41467-024-52511-2#Abs1
57 FORESTPOLICY criteria for effective zero deforestation commitments https://www.zerodeforestationimpacts.com/insights-from-our-work/
58 FORESTPOLICY: Garrett, Rachael, Joice Ferreira, Ricardo Abramovay, Joyce Brandão, Eduardo Brondizio, Ana Euler, Daniel Pinedo, Roberto Porro, Emiliano Cabrera Rocha, and Oscar Sampaio. 'Transformative Changes Are Needed to Support Socio-Bioeconomies for People and Ecosystems in the Amazon'. Nature Ecology & Evolution
59 A Global Environmental History of Coastal Dunes https://www.routledge.com/A-Global-Environmental-History-of-Coastal-Dunes/deFreitas/p/book/9781032329253?_ga=1862398909.1721952000&srsltid=AfmBOoqNZ81JsM19KFlvlbGWVkwBcD5Mq03NhfEZklV-2kEYBeUjCtSb
60 https://webs.uab.cat/atrapa/
61 Post by Dr Hoesung Lee, Chair of the Intergovernmental Panel on Climate Change, and Dr Fatih Birol, Executive Director of the International Energy Agency, Energy is at the heart of the solution to the climate challenge, https://www.ipcc.ch/2020/07/31/energy-climatechallenge/. Last consulted on 24.10.2024
62 Thomsen, Mette & Tamke, Martin. (2022). Towards a transformational eco-metabolistic bio-based design framework in architecture. Bioinspiration & Biomimetics. https://www.researchgate.net/publication/359641751_Towards_a_transformational_eco-metabolistic_bio-based_design_framework_in_architecture
63 https://erc.europa.eu/projects-statistics/science-stories/bio-based-architecture-sustainable-living
64 https://erc.europa.eu/projects-statistics/science-stories/bio-based-architecture-sustainable-living
65 https://cordis.europa.eu/project/id/833168/reporting

Luxembourg: Publications Office of the European Union, 2024

Title: Mapping ERC Frontier Reseach: Transformative change for a sustainable future
Contact: Noélie Auvergne Email: ERC-FEEDBACK-TO-POLICY@ec.europa.eu

PDF: 978-92-9215-133-1 • doi: 10.2828/5997136 • JZ-01-24-003-EN-N

Contact:
ERC-Info@ec.europa.eu
ERC-FEEDBACK-TO-POLICY@ec.europa.eu
https://erc.europa.eu/

Publications Office
of the European Union