European Commission

S&T&I FOR 2050

Science, Technology and Innovation for Ecosystem Performance – Accelerating Sustainability Transitions

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Report

Research and Innovation

S&T&I FOR 2050: Science, Technology and Innovation for Ecosystem Performance – Accelerating Sustainability Transitions

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Manuscript completed in May 2023

PDF	ISBN 978-92-68-04712-5	doi: 10.2777/100029	KI-03-23-253-EN-N

Luxembourg: Publications Office of the European Union, 2023

EUROPEAN COMMISSION

S&T&I FOR 2050

Science, Technology and Innovation for Ecosystem Performance – Accelerating Sustainability Transitions

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Europe and the world are facing sustainability and environmental challenges of unprecedented complexity, scale and urgency (SOER 2020). The European Green Deal is Europe's response to these systemic challenges. It aims at ambitious actions and measures to position Europe firmly onto a path towards sustainability and as a world leader in the implementation of the UN Agenda 2030 and its Sustainable Development Goals. The **pandemic and geopolitical shifts** also add to the urgency of acceleration of transitions and transformative resilience.
The vision of a clean planet by 2050 guides the Green Deal and related strategies. Science and technology via technological and social innovation (S&T&I) have to play a central role to achieve this.

As highlighted by Roco and Bainbridge's renowned 2003 book on converging technologies, human performance has long been a dominant pursuit and driver of progress in science and technology. As notions of performance are still guiding STI research, discussions on its nature are relevant and shape STI directions. Human needs and performance are inextricably linked to challenges related to the health of the planet. Considering that, a debate is warranted to **shift the attention from human performance to a more inclusive performance of flourishing ecosystems**. For the project, the combination of these aim is comprised in the term *"**ecosystem performance**",* as opposed to prevailing human performance in traditional R&I perspectives

The aim of S&T&I For 2050 is *the identification and mapping of future scientific and technological developments that can radically improve ecosystem performance.* This shall provide *reflections towards the 2nd strategic plan of Horizon Europe (HE), in its broad direction to support the Sustainable Development Goals."*

The project started with **identifying the most dynamic STI areas worldwide**, based on the free to use academic search engine, Microsoft Academic, as the primary source of data. It contained information on around 254 million documents, including around 89 million peer-reviewed academic papers and around 61 million patents. In the analysis we came up with a list of 1000 dynamically growing STI topics over a 10-year period until 2020, from which we **identified 130 STI directions clustered in 21 domains** for our forward looking exercises (Delphi and scenario development).

In parallel, an **understanding of what Ecosystem Performance encompasses**, was developed. Based on literature review, the analysis showed that there is a broad range of approaches which very much depend on the world view on the relation between humans and nature and humans' role in the flourishing of planetary ecosystems and responsibility for planetary health. Clustering led to **three perspectives** that built the basic for further analysis

Perspective 1: Protecting & Restoring	
Notion of ecosystems	Distinctive nature sphere interacting with the human sphere (natural capital)
Motivation to promote ecosystem performance	Costs and benefits of (in-)action regarding limiting effects on the environment
Proposed attitude towards ecosystems performance	Manage the impact of human activities to reach a desired target

Perspective 2: Co-shaping socio-ecological systems	
Notion of ecosystems	Complex adaptive socio-ecological systems with no clear boundaries
Motivation to promote ecosystem performance	Steer system dynamics towards long term survival
Proposed attitude towards ecosystems performance	Move specific socio- ecological systems towards more beneficial dynamics

Perspective 3: Immersing & Caring within hybrid collectives	
Notion of ecosystems	Pluriverse of hybrid entities with agency emerging out of relations to each other
Motivation to promote ecosystem performance	No other choice for humans, ethics of care

Proposed attitude towards ecosystems performance	Negotiate with other inhabitants of critical zones to allow all to flourish on their own terms

To **identify future scientific and technological developments that can radically improve ecosystem performance**, we **consulted the most cited researchers in a two-round Dynamic Argumentative Delphi survey.** Participants were selected based on relevance and number of citations of their publications in Scopus. **Invitations reached 130 000** individuals asking them 1st to prioritise top STI directions in their domain and 2nd the most significant harm that STI could inflict on the capability of planetary ecosystems to flourish. In the first round there were 1 637 respondents out of which 638 participants contributed to the second round of the survey. Results were mapped in Future Sheets[1] for each domain with 3-5 most voted STI directions examples of technological/science applications are provided. Furthermore, each Future Sheets includes a list of potential significant harms that STI could inflict on the capability of planetary ecosystems to flourish.

In several online-workshops with foresight and domain experts and stakeholders, and based on the Delphi results, **six Case Study topics** were identified. These topics represent a selection of the dynamic areas that promise to improve ecosystem performance by STI. The case studies **illustrate new thinking and build narratives on different lines of R&I development** that can inform programming and implementation of Horizon Europe and help to evaluate projects and policy decisions. They **explore different scenarios related to the different perspectives** on, and understandings of society-nature interactions, their pre-conditions, and implications.

CASE STUDY	SCENARIOS
DATA AS REPRESENTATION	P1. To the maxx P2. Radical responsibility P3. We, the life
LAND USE FUTURES	P1. Efficiency and optimisation of land use P2. Towards effective multiple use of land P3. Land use adapting to nature
LAW FOR NATURE	P1. Rights for Nature, without Justice P2. Rights of Nature, Missing the Forest for the Trees P3. Rights and Justice with Nature
MICRO-NANO COSMOS	P1. Cleaning up Micro- and Nano-Cosmos P2. Reflexively and anticipatory aligning with Micro- and Nano-cosmos P3. Caring humans within Micro- and nano-Cosmo - from predation to adaptive and caring humans' roles
REGENERATIVE ECONOMY - ACCELERATING TRANSITIONS TO REGENERATIVE ECONOMY	P1. Smart eco-efficient markets decoupling growth from environmental degradation P2. The circular economy pathway toward a regenerative economy P3. Conversion to a deeply symbiotic economy
SOIL TO SOUL	P1. Eyes on the prize P2. Cultivating each other P3. Full circle of life

There has been a **shift in the expectations of development in S&T&I since the turn of the centuries**, when nanotechnology, biotechnology, information technology, and cognitive science (NBIC) were identified as converging scientific and technological fields, which would create new opportunity for enhancing human performance. Now, **societal challenges have shifted towards global threats for human health and planetary health.** This shift becomes evident in the mapping of the most dynamic STI directions at present. Now more STI domains specifically address ecosystem performance than two decades ago. Among the most dynamic domains we find ecology & environmental health, environmental planning & environmental engineering, agriculture science & agriculture engineering besides artificial intelligence, biotechnology, nanotechnology, data sciences. The results of the Delphi survey provided an abundance of 400 STI directions within the 21 domains, showing the potential to contribute to tackling challenges of planetary health. Thus, one could argue that the notion of convergence has been shifting not only in terms of the goal from human performance to ecosystem performance, but also regarding the meaning of convergence. Convergence now cannot only be understood as "unification of science based on unity in nature and its holistic investigation" leading to "technological convergence and more efficient societal structure" (Roco and Baindbridge 2003), but also **convergence of S&T&I and societal focus on transformation challenges** as expressed by the "Clean-Planet-for-all" vision for 2050 and the Sustainability Development Goals.

[1] see https://www.futures4europe.eu/sti2050

The multiple crisis at present including rapid climate change, pandemic as well as geopolitical shifts, also add to the **urgency and the need to a broader perspective on how to accelerate transitions** and how to keep on track to reach climate-neutrality by 2050. We conclude that there is a **need to (re-)consider the relation between society and nature in further developing the STI policy strategy** as well as the European Green Deal and the biodiversity strategy for 2030. As outlined in the cases studies, scenarios building on the three perspectives can enrich STI policy strategy in the development of thematic focus, directions and modes of research, the wider inclusion of social sciences and humanities, and non-scientific knowledge in research projects, and in the design and composition of the portfolio of instruments.

1. INTRODUCTION

1.1 Background

Europe and the world are facing sustainability and environmental challenges of unprecedented complexity, scale and urgency (SOER 2020). The European Green Deal is Europe's response to these systemic challenges. It aims at ambitious actions and measures to position Europe firmly onto a path towards sustainability and as a world leader in the implementation of the UN Agenda 2030 and its Sustainable Development Goals. The "vision" of a clean planet by 2050 guides the Green Deal and related strategies.

The European Climate Law proposal from October 2020 indicates that the European Green Deal, apart from GHG reduction goals and decoupling of economic performance from resource use, *also* ***aims to protect, conserve and enhance the Union's natural capital, and protect the health and well-being of citizens from environment-related risks and impacts****.* It thus complements the well-established political ambitions of the EU to improve the quality of life of its citizens and the economic performance of its Member States.

Science and technology via technological and social innovation have to play a central role to achieve this, and new ways of carrying out S&T&I might be necessary taking into account the boldness of the challenge. To capture this, in the following, the term science, technology, and innovation (**S&T&I**) is used.

As highlighted by Roco and Bainbridge's renowned 2003 book, human performance has long been a dominant pursuit and driver of progress in science and technology. As notions of performance are still guiding STI research, discussions on its nature are relevant and shape STI directions. Human needs and performance are inextricably linked to challenges related to the health of the planet. Considering that, a debate is warranted to **shift the attention from human performance to a more inclusive performance of flourishing ecosystems**. For the project, the combination of these aim is comprised in the term *"**ecosystem performance**",* as opposed to prevailing human performance in traditional R&I perspectives*.*

1.2 Objectives and Tasks

The objective of S&T&I For 2050 has been to map the relationships between emerging trends in science, technology and innovation and ecosystem performance to develop plausible future scenarios of accelerated transitions in key areas of ecosystem performance that relate to the European Green Deal. Furthermore, it aims derive principles and lessons for an EU R&I policy to accelerate the Green Transition and contributing to improve health and wellbeing of EU citizens.

In particular, in this report,

- **Chapter 2 scopes and deliberates an appropriate notion of ecosystem performance**, functionally equivalent to "human performance" in relation to science, technology and innovation and taking into consideration socio-economic aspects,
- **Chapter 3 maps strong and emerging trends in science, technology and innovation in relation to ecosystem performance** in a way that is meaningful for S&T&I policy and allows to discuss the possible consequences for what and how to research and innovate with a wide range of stakeholders in order to contribute to the Green Deal and related EU policies and to raise awareness of changes in human health related to ecosystem changes,
- **Chapter 4 provides case studies with scenarios in selected fields** to illustrate the new thinking and builds narratives on different lines of R&I development that could inform programming and implementation of Horizon Europe, and help to evaluate projects and policy decisions.

This study can be used across all the services participating in the Strategic Foresight Network (i.e. all the Commission DGs and the External Action Service), collectively or individually, including for the reflections towards the 2nd strategic plan of Horizon Europe (HE), in its broad direction to support the Sustainable Development Goals.

The results of the study should feed into, and extent the broader library of foresight material the use of which can have important benefits for EU R&I policy as well as for EU policy across the board, to support the socio-economic transformation, human wellbeing and a healthy planet through science, technology and innovation.

For this purpose, results are made available on the platform Futures4Europe, which aims to promote the effective use of foresight in R&I policy in Europe.

1.2.1 Tasks

In the first phase (Task 1 to 3), the conceptual- and empirical evidence-base was provided. In the second phase (Task 4), narrations were developed to illustrate and exemplify in six case studies how S&T&I can contribute to flourishing ecosystems thus reaching *“ecosystem performance” aims of the EGD*. Finally, all results were brought together and refined for communication in the Futures4Europe Platform to relevant stakeholders for the development of the 2nd Strategic Plan of Horizon Europe.

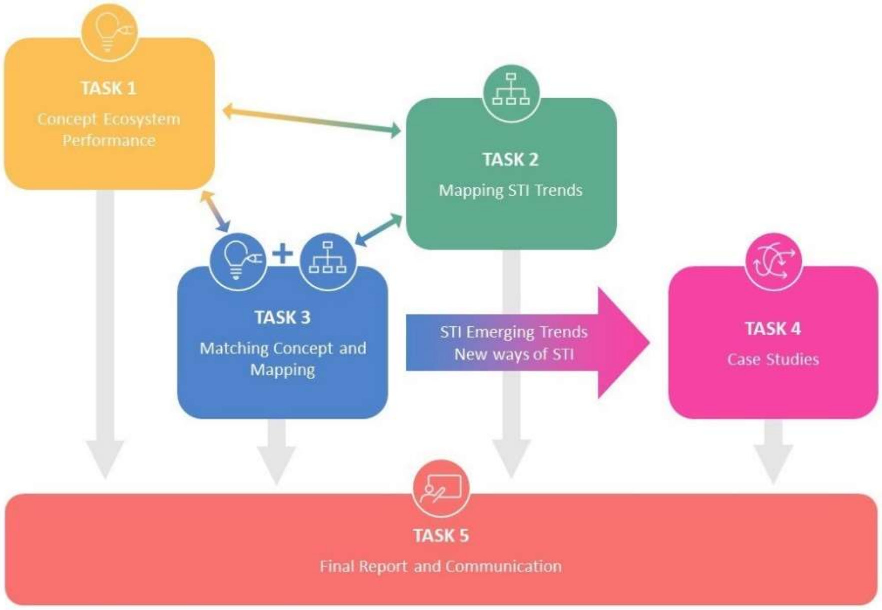


Figure 1: Overall approach and methods

The project was conducted in five tasks (see Figure 1). **Task 1** built on existing scientific literature and feedback provided through the first three workshops in Task 3. The involvement of experts from the related research communities and stakeholders from the EC helped to consolidate the conceptual part.

Scoping workshops with targeted brainstorming and consolidation discussions helped to coordinate between different stages (Tasks 1, 2 and 3) of the projects as well as with key partners (such as Commission services and the EEA), experts (e.g., from research institutions) and stakeholders. A sounding board with three external key experts also supported the team in quality assurance.

In **Task 2** the mapping exercises was built on quantitative methods to identify major trends in S&T&I, such as web mining, patent and bibliometric analysis, and use crowd intelligence gathering and Dynamic Argumentative Delphi with STI experts in all identified domains for consultations around STI trends. The search strategy was refined with inputs from Task 1 and consolidated with inputs from the Task 3 workshops. As outputs, a map of future S&T&I landscape and trends and a catalogue of scientific/ technological opportunities and options were developed

Task 3 aimed at matching the S&T&I mapping with the concept of ecosystem performance together with experts and stakeholder in a series of online workshops. Altogether 3 specialised workshop and one consolidation workshop were conducted. They also helped to identify the case study proposals to be addressed subsequently in Task 4.

In **Task 4** the case study methodology was developed and experts conduct the case studies in consolation with the Commission services (see chapter 4).

Task 5 provided services for innovation policy communications through the futures4Europe platform (https://futures4europe.eu) and social media.

2 THREE PERPECTIVES ON ECOSYSTEM PERFORMANCE – SOCIETY NATURE INTERACTION

To develop a new concept of ecosystem performance, we conducted an extensive literature review and three workshops. Fourteen schools of thought that have guided human activities towards ecosystem stewardship were selected, analysed, and categorised. The involvement of experts from the related research communities and EC stakeholders contributed to the creation of a solid framework.

This section describes one of the main outputs, a conceptualisation of ecosystem performance and thus new conceptual/theoretical framework for understanding human/nature relationship.

Three perspectives resulted from this effort:

1. "Protecting and restoring ecosystems", concerned with preservation of ecosystems by managing the impact from human activities;
2. "Co-Shaping socio-ecological systems", concerned with simultaneous development of social practices and ecological processes towards resilience and sustainability renewal;
3. "Caring within hybrid collectives", concerned with the establishment of caring relationships in new collectives with humans and other entities on an equal level.

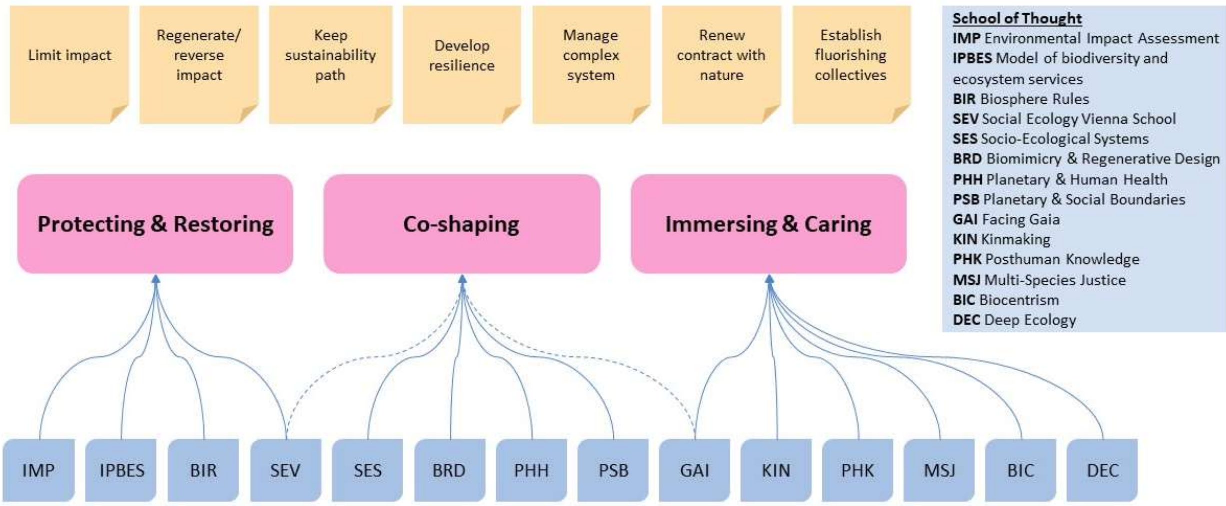


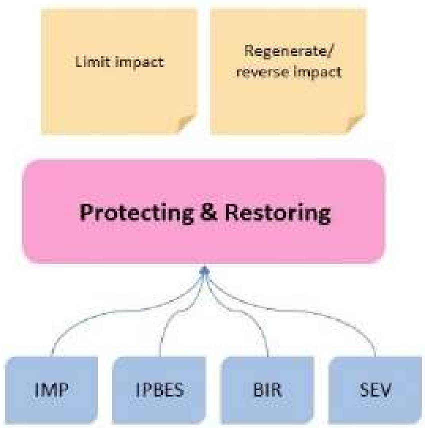
Figure 2: Taxonomy of concepts for ecosystem performance

Each perspective is characterised by a different understanding of humans' position and role in ecosystem stewardship. The ontology influences all actions towards ecosystem performance and RTI specifications. Notably, the "Protecting & Restoring" perspective represents the line of thought of many current environmental policies and thus delineates the most straightforward and easily applicable RTI directions. "Immersing & Caring" instead represents a relationship with nature that is nowadays faintly imaginable due its relational ontologies. This makes the definition of this perspective and its RTI specifications more complicated due to lack of appropriate concepts and terms to describe it.

2.1 Protecting and restoring ecosystems

This perspective includes four schools of thought:

- IMP Environmental Impact Assessment
- IPBES Model of biodiversity and ecosystem services
- BIR Biosphere Rules
- SEV Social Ecology Vienna School



This group of concepts is characterised by its understanding of human/nature interaction as interplay be-tween two separate spheres. In this understanding, societal action leads to pressure on the environment, and subsequently to impacts on eco-systems and biodiversity as well on the social and economic system functions of the environment, such as the provision of adequate conditions for

health and resources availability. A key concept is the Driving-force-Pressure-State-Impact-Response (DPSIR) adopted by EEA (EEA 2019) and based on the pressure-state-response framework of the OECD. This concept is outlining the causal relations and interdependencies between society and the environment, with a unidirectional relation with respect to society threatening the state of the environment and circularity when society responds with policy interventions in order to change the future state of the environment. The advantage of this concept is that it can be used to collect data and model these relations on various scales and to use it for environmental impact assessment. The Social-Ecology Vienna (SEV) approach conceptually considers human population, its artefacts (infrastructures) and husbandry as part as "physical compartment of society" and thus being also part of the material world. The interaction between human culture and nature is described as a transformation process of the material/substance dimension of societal metabolism and as a process of "colonization of nature" in the Anthropocene ongoing since the end of hunter and gatherer culture. The integrated approach of assessing R&I programmes' environmental impact (IMP) developed by (Miedzinski et al 2013) has been taking up the DPSIR concept to differentiate between environmental pressure and environmental impact. Building on SEV, it adds a fourth environmental impact category besides impact on ecosystems and biodiversity, impacts on human health and impact on natural resources. The fourth category, "amenities and economy", can be understood as impact on the physical compartment of society, i.e. artefacts, infrastructures as well as feed stock.
What is common to all these approaches is that they favour an understanding of society/humans being a disturbing factor in an ecosystem, which otherwise would be in a stable state.

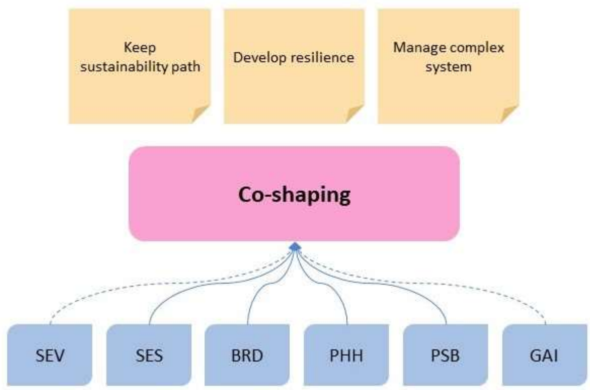
Table 1: Main characteristics for the Protecting & Restoring perspective

Protecting & Restoring	
Notion of ecosystems	Distinctive nature sphere interacting with the human sphere (natural capital)
Motivation to promote ecosystem performance	Costs and benefits of (in-)action regarding limiting effects on the environment
Proposed attitude towards ecosystems performance	Manage the impact of human activities to reach a desired target
Type of indicator used to assess stewardship	Distinctive measures of environmental pressure on the state of the environment e.g. pollinator diversity, soil organic carbon ...
Implication for RTI orientation	Assess and optimise the impacts of RTI on these indicators
RTI opportunities	Straightforward implementation, well established indicators
RTI challenges	Extension to more specific RTI projects outside ecosystem management incorporating system transition perspective (EEA 2019)

2.2 Co-shaping socio-ecological systems

This perspective includes four schools of thought:

- SES Socio-Ecological Systems
- BRD Biomimicry & Regenerative Design
- PHH Planetary & Human Health
- PSB Planetary & Social Boundaries and some elements of two further schools of thought:
- SEV Social Ecology Vienna School
- GAI Facing Gaia



This group is characterised by its use of complex system theory to understand the interaction of human practices and ecological processes as complex adaptive systems. The goal of these approaches is to move socio-ecological systems that are in instable critical condition towards renewal, resilience, and sustainability to prevent ultimately collapse. Due to the inherent uncertainty of complex adaptive systems, this cannot be achieved by top-down steering but only by co-shaping the system dynamics in very specific contexts. Through practical approaches like biomimicry and regenerative design, designers use complex systems thinking to design community practices that are positively interacting with ecological systems. The notion of the planetary and human health, especially the EcoHealth concept, could also be placed in this group as it provides a guiding framework for locating some of the critical arenas of interaction of human and ecological system elements. In a similar way, notions like the “Doughnut Economy” within the planetary boundaries concept allow identification of critical social/ecological arenas. What is common to all these approaches is the need to investigate the specific conditions for each individual socio-ecological system and the equal attention to cultural, social and ecological dynamics of change in the arena. Another key aspect is the focus on social change (social tipping points) as more impactful than (incremental) technical change. Finally, a core aspect is the acknowledgment that there can be no one correct view on the system and subsequently the need for negotiation procedures to mediate the different perspectives and to establish institutions for the polycentric governance of the territory.

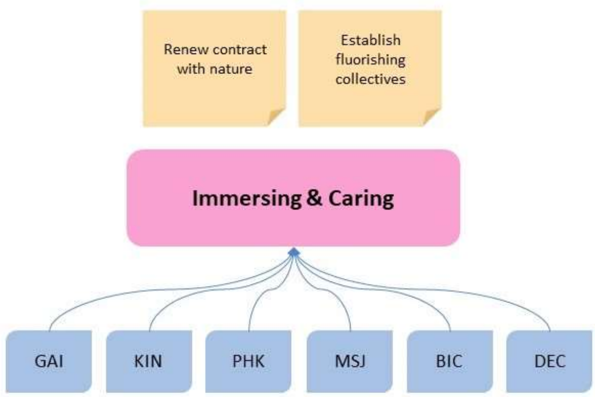
Table 2: Main characteristics for the Co-shaping perspective

Co-shaping	
Notion of ecosystems	Complex adaptive socio-ecological systems with no clear boundaries
Motivation to promote ecosystem performance	Steer system dynamics towards long term survival
Proposed attitude towards ecosystems performance	Move specific socio- ecological systems towards more beneficial dynamics
Type of indicator used to assess stewardship	System resilience (learning capacity), institutions of polycentric governance
Implication for RTI orientation	Focus on complex interplay of social practices and ecological flows, transdisciplinary research with emphasis on social tipping points
RTI opportunities	Systemic view especially suitable for mission oriented RTI projects
RTI challenges	Extension to more specific RTI projects outside ecosystem management

2.3 Caring within hybrid collectives

This perspective includes six schools of thought:

- GAI Facing Gaia
- KIN Kinmaking
- PHK Posthuman Knowledge
- MSJ Multi-Species Justice
- BIC Biocentrism
- DEC Deep Ecology



This framework is characterised by the prevalence of relational ontologies and epistemologies. This means they view subjects not as pre-given independent entities, but rather as being continuously (re)produced through interaction processes. Consequently, there are no predefined categories like nature and culture or human and non-human beings but a wide range of agents with diverse modes of existence and continuously emerging status. Also, agency (the ability to act) is not associated with specific entities but emerges as a result of the processes within relational networks, assemblages and heterogeneous configurations (West et al. 2020). Like the complex system approaches, this framework would result in looking at specific arenas or, in their words, mapping out new “collectives”. But these approaches would reject the notion of a larger system with certain overarching rules serving as a guidance. As a normative guiding concept, many of the scholars use the notion of “care” as a reciprocal practice involving all types of entities including humans as one of many. These “collectives” receive uncommon names such as “pluriverse”, “Gaia”, odd-kin or zoe/geo/techno-spheres to emphasise the dissolution of binary distinctions. Rather than applying overarching system rules, for each “collective” a new contract must be negotiated that ensures a maximum of mutual care between diverse agents in a pluriverse of more than human beings. Engaging within these “critical zones” means “becoming earthbound” (Latour) or “staying with the trouble” (Haraway). The notion of “Multi-species-justice” provides a justice theory serving as a guidance for such negotiations whereas various ethical theories like “biocentrism”, or deep ecology offer frameworks for ethical deliberation around the intrinsic worth and value of nature.

Table 3: Main characteristics for the Immersing & Caring perspective

Immersing & Caring	
Notion of ecosystems	Pluriverse of hybrid entities with agency emerging out of relations to each other
Motivation to promote ecosystem performance	No other choice for humans, ethics of care
Proposed attitude towards ecosystems performance	Negotiate with other inhabitants of critical zones to allow all to flourish on their own terms
Type of indicator used to assess stewardship	Number of flourishing of life projects, pressure on other collectives
Implication for RTI orientation	Local focus, extremely transdisciplinary projects
RTI opportunities	Strong role for science as mediator for other voices
RTI challenges	Include other types of knowledge (embodied, indigenous), overcome reservations towards including non-humans on equal terms, find adequate language

3 MAPPING OF STI DIRECTIONS FOR ACCELERATING SUSTAINABILITY TRANSITIONS

Identifying and mapping future scientific and technological developments, which can radically improve ecosystem performance, requires first an analysis of current and emerging STI directions, independently of their relation to ecosystem performance. To this end, quantitative and qualitative methods were employed (see Figure 3) in the form of:

- Patent and bibliometric analysis for selecting the most dynamic Science, Technology and Innovation (STI) domains;
- Horizon scanning through web mining and human evaluation for identifying key STI directions and specific examples of technological/scientific breakthroughs within these directions;
- Dynamic Argumentative Delphi (DAD) engaging relevant experts from around the world in an argument-based exploration regarding the contribution of STI to the capability of ecosystems to flourish from now to 2050.

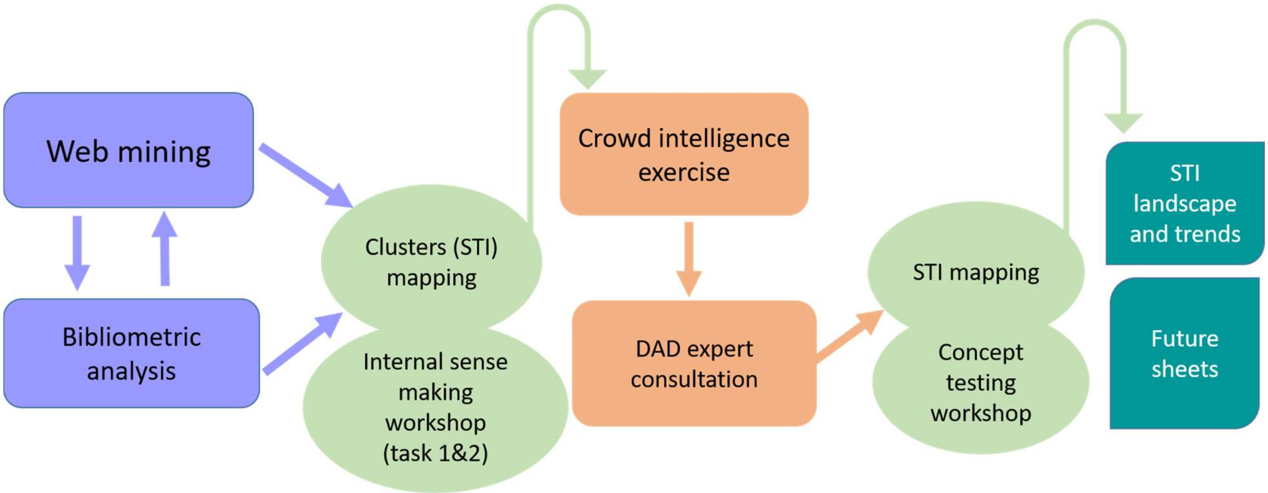


Figure 3: Specific approach and methods for mapping of STI directions

3.1 Selection of most dynamic STI domains

To identify the future developments worldwide S&T&I, the study covered nature and technical as well as social and cultural sciences. It took account of basic and applied research as well as innovation, and of the whole range of players carrying out, commissioning, financing, and managing research, development and innovation in the relevant areas.

Given this broad approach, the selection of most dynamic current and emerging STI directions, the database Microsoft Academic[2].has been identified as primary source.

Using Microsoft Academic (MA) as the one source of data, scientometric analysis was employed to identify the most dynamic STI areas overall. MA had the following features:

- Launched in 2016, it provided a free to use academic search engine, similar to Web of Science (WoS) and Scopus.
- At the time it was used in this project, it contained information on around 254 million publications, including around 89 million peer-reviewed academic papers and around 61 million patents.
- Pooling from a set of around 720 thousand topics, MA assigns multiple topics to each publication, by employing natural language processing and machine learning. This involves analysing the title of the publication, its abstract, keywords, and, when available, the whole or part of the text, to assign appropriate topics.

[2] Developed by Microsoft Research, it was discontinued in December 2021. Microsoft Academic was a free internet-based academic search engines for academic publications and literature, including patents and grey literature. https://en.wikipedia.org/wiki/Microsoft_Academic

- The topics are arranged in a hierarchical manner, with very broad topics at the first level to very narrow topics at level six.
- There are 19 topics at level 1, 292 at level 2, almost 16 000 topics at level 3, and the number of topics increases to over 77 000 at level 6.

For the analysis performed in this project, the level 2 topics in MA were considered to be at the optimum level of granularity. All relevant data were extracted at this level. To identify the most dynamic STI fields, level 2 topics were analysed on two criteria: growth in citations and growth in patents. Growth rate of topics was estimated by calculating the average annual growth of citations in the past ten years (2020-2011). To ensure that smaller topics are not overrepresented in the top 1000, only topics that had over 1000 citations and 100 publications in the last 10 years were considered.

This resulted in the selection of 21 domains[3], which formed the basis for the Delphi study (see Table 4). Further details can be found in the report on “Identifying STI developments contributing to the capability of planetary ecosystems to flourish: Results of a Delphi survey” on the Futures4Europe Platform[4].

3.2 Dynamic Argumentative Delphi survey

The Dynamic Argumentative Delphi (DAD) survey was conducted by Institutul de Prospectiva between December 2021 and February 2022 with the aim to gather knowledge on potential STI directions contributing to the capability of planetary ecosystems to flourish from now to 2050. This method enables consensus building among a large number of participants, by dynamically ranking the arguments supporting contributors' quantitative evaluations in two rounds.

Prior to the survey, the mapping of STI was aligned with the concept of ecosystem performance in collaboration with experts and stakeholders in a series of online workshops. Several specialised workshops and one consolidation workshop were conducted to identify major thematic areas in STI directions.

The pool of potential respondents was generated by identifying in the Scopus database authors with relevant publications. There were two criteria of relevance: thematic coverage – using semantic filtering (keywords) to detect publications related to topics of interest; and the reach/popularity of these publications – judging by the number of citations. Invitations were successfully dispatched to over 130 000 authors, of which over 17 500 accessed the survey platform, and eventually almost 10% of them – namely, 1 637 respondents – participated in the first round of the survey. For the second round of the Delphi invitations were sent to all 1 637 contributors in the first round: eventually, 826 persons accessed the survey and 638 participants contributed to the second round of the survey.

In the first round, each of the 21 domain was associated to 4-8 starter STI directions elaborated by the internal team (based on information retrieved from thematic reports, articles and web mining). Respondents were invited to select up to three pre-existing directions, considering their potential to contribute to the capability of planetary ecosystems to flourish from now to 2050, and/or to provide a new one. Moreover, respondents were able to enrich the selected STI directions by adding new examples of relevant science and technology applications within the respective STI directions. This enrichment led to a list of over 400 STI directions associated to the 21 domains (compared to over 130 STI directions that were initially generated by the internal team prior to the launch of round one). Round one gave participants also the opportunity to propose potential harms associated to STI directions: over 800 examples of potential harms associated to the STIs in all 21 domains were generated in round one (the harms were exclusively proposed by respondents - there was no initial set of harms proposed by the internal team prior to round one).

In the second round, respondents were invited to select the three most important STI directions from round 1 in terms of their potential to contribute to the capability of planetary ecosystems to flourish from now to 2050. Using the consolidated list of potential harms, contributors were then asked to assess each of the harm statements and indicate whether they represented significant potential harms to the capability of planetary

[3] A “domain” can mean an individual topic, e.g. Food science or a cluster of inter-related topics, e.g. Artificial intelligence & Pattern recognition & Machine learning & Natural Language processing & Computer vision.

[4] https://www.futures4europe.eu/_files/ugd/ff6ca7_312f9a308b9e4c50ad741df0d7311af9.pdf

ecosystems to flourish from now to 2050, with the options from “Negligible”, “Somewhat significant”, “Significant” to “Very Significant” and “I don’t know”.

The extensive results from the Dynamic Argumentative Delphi were elaborated to create a concise overview of the most important insights and were published in the report on “Identifying STI developments contributing to the capability of planetary ecosystems to flourish: Results of a Delphi survey” [5] and detailed futures sheets for each domain to illustrate STI directions and potential harms inflicted by STI are available from the Futures4Europe Platform[6].

For an overview, the following Table 4 illustrates the 3-5 major STI directions per domain.

Table 4: Table of top STI directions per domain from the Delphi study

STI Domain	STI directions
Biotechnology & Biochemical engineering & Chemical engineering & Organic chemistry	- Bioenergy and biofuel - Personalised / precision medicine - New renewable and recycled raw materials - Bioremediation - Biofertilizers
Environmental planning & Environmental engineering	- Circular economy - Global nature conservation and restoration areas - Carbon capture and storage - Urban ecology - Soil conservation
Ecology & Environmental health	- Understanding the impact of human activity on ecosystems - Understanding the environmental impact of climate change - Interventions to mitigate human impacts - Achieving human-nature coexistence - Developing collections, databases and maps of biodiversity
Computer engineering & Human-computer interaction	- Smart systems - Augmented and virtual reality - AI and AR/VR in Healthcare
Data science & Statistics	- Scientific disciplines and fields reconfigured as ‘bigdata sciences’ - Environmental modelling and simulations - Web-applications and tools for decision making
Composite material & Nanotechnology & Metallurgy	- Renewable energy storage - Nanocomposites - Nanomedicines
Artificial intelligence & Pattern recognition & Machine learning & Natural Language Processing & Computer vision	- AI for healthcare - AI for control of technical dynamical systems - AI for renewable energy
World Wide Web	- Greener data centres - Education to combat and monitoring of misinformation - Solutions for digital commons
Computational biology & Bioinformatics	- Bioinformatics for health - Bioinformatics for genomics - Applications in agrifood

[5] https://www.futures4europe.eu/_files/ugd/ff6ca7_312f9a308b9e4c50ad741df0d7311af9.pdf
[6] https://www.futures4europe.eu/sti2050

Theoretical physics & Engineering physics	- Quantum in electronics - Renewable energy - Nuclear fusion
Mechanical engineering & Process engineering & Manufacturing engineering & Risk analysis (engineering)	- Energy-efficient product and manufacturing engineering - Energy storage and mix - Nuclear power for electricity and heat production
Marine engineering	- Ocean clean up solutions - Marine renewable energy - Marine aquaculture
Transport engineering	- Green transportation policies - Green energy vehicles - Rethinking of urban mobility
Mining engineering & Petrology & Geochemistry	- Sustainable / green mining - Automation of mining - Non-territorial and off-earth mining
Food science	- Sustainable, circular food production - Promoting healthy diets - Food safety
Architectural engineering & Construction engineering & Civil engineering & Geotechnical engineering & Structural engineering	- Sustainable and carbon neutral construction materials - Sustainable structures - Green architecture
Water resource management	- Water decontamination - Monitoring, modelling, and forecasting - Ecohydrological approach
Waste management	- Integrated waste management systems - Recycling plastics into new products - Reducing food waste and spoilage
Natural resource economics & Physical geography & Regional science	- Natural resource management - Mapping & sensing - Adaptation to climate change
Socioeconomics & Social psychology & Law	- Cultural politics of environmentalism & inequality - New practices in governance & policy - Psychology of decision in environmental behaviour and beyond

4 CASE STUDIES

To underpin the value of the concept of ecosystem performance for identifying and framing possible areas of future STI, chapter 4 provides six case studies with scenarios in selected fields. The case studies illustrate new thinking and builds narratives on different lines of R&I development that could inform programming and implementation of Horizon Europe and help to evaluate projects and policy decisions.

The selection is based on the Delphi survey, several workshops and consultations to coordinate with a parallel Foresight on Demand project for the development of the 2nd Strategic Plan for Horizon Europe[7].
The cases aim to represent some of the dynamic areas of STI, which promise to improve ecosystem performance.

The six case studies explore different scenarios related to the different perspectives on, and understandings of "society-nature" interactions, their pre-conditions, and implications, with a time horizon of 2050. Set within the new conceptual frame of the three perspectives (see chapter 2), the case studies draw on our knowledge of emerging STI as well as on in-depth domain knowledge in the respective areas to project scenarios as future images and pathways. They should subsequently allow the Commission to develop priorities for the Second Strategic Plan and work programmes of Horizon Europe in a novel way.

The following case studies were carried out:

1. **'Soil to Soul'**
2. **'Data as representation'**
3. **'Law for nature'**
4. **'Ecosystems and Micro-and Nano Cosmos'**
5. **'Land use futures'**
6. **'Accelerating Transitions to Regenerative Economy'**

All case studies follow a shared basic structure:

- An introduction with the scope and rational of the case.
- The status quo of the situation in this field or domain.
- Three scenarios each relating to one of the three perspectives on ecosystem performance.
- Finally, some conclusions for STI-policy making are discussed.

Given the diverse spectrum of topics, this basic structure however was adapted with to size and scope of each section.

[7] The upcoming final report of this project will be published at www.futures4europe.eu.

4.1 Case Study 1: Law for Nature

Michael Bernstein, Dana Wasserbacher

4.1.1 Introduction

Human ideas about nature vary across culture (Selin 2003). Our ideas of what constitutes nature evolves over time (Eder 1996; Gervais 1997). The way, in which our cultures construct and bound what is or is not considered “nature,” “natural,” or part of “the environment” directly affects which individuals and groups wield power over others in a society – as well as in said environment (Demeritt 2002). The translation from construction of nature by a culture to the way nature is then valued, devalued, exploited, cared for, and otherwise related to thus carries as all-to-real physical, material, and social consequences – as increasing efforts to decouple natural resource use and environmental degradation from economic development attest (Fischer-Kowalski and Swilling 2011). Beyond direct impacts on terrestrial and aquatic systems, biodiversity, air quality, and many other environmental factors, concentration of economic power in large corporate monopolies leads to further ecosystem degradation as these actors deploy their economic power in political arenas to undermine environmental protections (Hanley 2021), and generally fail to uphold pledges to undertake initiatives for sustainability (Davis-Peccoud et al 2016; Goddard 2022). Governments, too, fall short, as regularly on display at the Conference of the Parties (COP) to the UN Framework Convention on Climate Change (UNFCC) (Townend 2022).

Harm to environments is part and parcel of human environmental history across civilizations (Kwiatkowska and Holland 2010). Yet, today’s so-called WEIRD nations – Western educated, industrialised, rich, and democratic societies (Henrich et al 2010) – bear outsize responsibility for the current state of global environmental degradation and human induced global climate change (Evans 2021). Human history is rife with examples of wanton environmental degradation contributing to the decline of ancient human civilisations (Mesopotamian, Greco-Roman, Mayan, Asian), and contemporary Western notions of progress and providence seem to be rushing many societies and species on a path of unprecedented global destruction of nature (LaFreniere 2007). While much can be learned from non-Western cultures on alternative way of more gently co-existing with environmental systems (Dudgeon and Berkes 2003), it is easy to ignore this environmental history and romanticise pre- or non-industrial ways of living (Selin 2003).

In this context, we explore in depth one way in which human-nature relationships might be reconstructed in service of flourishing life on Earth for humans, more than human species, and ecosystems. Specifically, we delve into the implications for granting rights to nature in Western legal systems. By looking at what law for nature could entail, we become better able to identify and suggest amendments to current environmental laws that ostensibly seek to conserve and protect nature. From this vantage point, as well as through exploring future developments of law for nature across three different scenarios, we conclude with implications for developing science, technology and innovation (STI) themes, programs, knowledge, infrastructure, and other policies in Europe to help forestall or even buck trends in the destruction of nature as we know and rely upon it.

4.1.2 Rights of Nature: A Brief Review

The Rights of Nature Discourse in contemporary Western industrialised nations

Fifty years after Professor Christopher Stone proposed a legal argument to extend rights to nature, Western legal tradition still holds fast to a belief in the instrumental – rather than intrinsic – value in Nature. Stone (1972) wrote his work amidst a groundswell in global environmentalism in the West – the publication of the Club of Rome’s “Limits to Growth” report; a United Nations Conference on the Human Environment (Stockholm Conference); and the revelation from the Apollo mission of the fragility of our finite planet (i.e., that blue marble in space) (Mührel 2022).

Case law and legal research on the subject of “law for nature” is situated in the “rights of nature” discourse. The concept of rights of nature (RoN) in "Western" legal discourse traces to Professor Christopher Stone’s argument inspired by The Sierra Club’s attempt to halt development in the Mineral King Valley of the Sierra Nevada in the U.S. (Bryant 1975). Stone argued for legal extension to nature of a series of rights in a manner similar to the way rights have been extended to children, women, prisoners, and people of colour in the United States over time (Stone 1972). Stone and others since argue that legal systems allow social fictions like corporations to be persons, represented in court, and given representation and voice (like estates, states, infants, municipalities, and universities) - why not nature and ecosystems (Stone 1972; Kolbert 2022)? The extension of rights to inanimate, natural objects, such as a lake or tree, is necessary, Stone argued, because otherwise the value of nature is derived solely from its value to humans and can be destroyed and extinguished without legal consequences (Stone 1972).

The rights of nature discourse has burgeoned since 1972 and covers several points reviewed below. Paradigmatically, the RoN discourse takes issue with conceptualising humans as separate from nature and thus somehow independent of planetary carrying capacity, ecosystem integrity, and vibrant biodiversity. Such a perspective on rights of nature differs from the discourse on a human right to a healthy environment in which standards for ecological integrity might be higher, but still in service of human well-being. Discourses on human rights to a healthy environment may be found in the UN Brundtland commission, and the Stockholm Declaration of the United Nations Conference on the Human Environment, also in 1972,[8] which presented a first view of human rights to a healthy environment in the "Western" international scene. These human rights pertain to clean air, healthy food, safe water and sanitation, nontoxic environments, biodiversity, healthy ecosystems, and a safe climate.

Animal rights issues also connect to the RoN discourse. The connection is particularly strong in the consideration of non-traditional ways of viewing – and seeking to change – Western legal systems. In the case of animal rights, this line of legal research and action seeks to improve protections for nonhuman species. In a novel and radical piece of legal thinking, Bradshaw (2018) argued, for example, that legal scholars ought to consider advancing property rights to nonhuman animals further protect them from harm. Bradshaw notes that animal *welfare* arguments are distinct from animal *rights* arguments. Animal *welfare* arguments consider animals to be human property and seek laws to prevent cruel or inhumane treatment of species, for example pets and livestock. Animal *rights* advocates seek rather to extend more robust legal protection to non-human species. Noting that neither approach does much to help wildlife, sea creatures or less charismatic fauna, Bradshaw (2018) proposed a strategy of granting animals the right to own land (i.e., *property rights*), and humans' fiduciary status “to help ensure intergenerational wellbeing of all creatures within an animal-owned ecosystem” (p. 18). Such an approach, for example, might help animals “command economies of scale” to prevent subdivision and parcelling of landscapes, and counter historic legacies of disposition and habitat fragmentation.

In the context of converging climatic and ecological crises, and ecosystem degradation, RoN proponents argue for radical departure from an economic system, and associated laws, that reinforce and privilege destructive growth, extraction, and unsustainable development (Bosselmann 2019). Rights of nature proponents hold as untenable the status quo position of nature in law as an object for free human exploitation (i.e., liberating nature from position as object, as it remains even in conversations about a human right to a healthy environment). This view on human exploitation connects to a dominant reading of property rights in European, UK, and American legal traditions, drawing from Roman law, in which possession of slaves involves unquestioned right to destroy said 'property' (Macpherson 1968; Graeber and Winegrow 2021).

Rights of Nature arguments

The Universal Declaration of the Rights of Mother Earth (UDRME) (https://www.garn.org/universal-declaration/), adopted in 2010 at a World People’s Conference on climate change and the Rights of Mother Earth, offers an example of what “rights” exemplify when talking about “rights of nature.” Article 2 of the declaration reads:

the right [of Mother Earth] to life and to exist; the right to be respected; the right to regenerate its bio-capacity and to continue its vital cycles and processes free from human disruptions; the right to water as a source of life and clean air; the right to be free from contamination, pollution and toxic or radioactive waste; the right to not have its genetic structure modified or disrupted in a manner that threatens its integrity or vital and healthy functioning; and the right to full and prompt restoration for violation of the rights caused by human activities.

Affording nature personhood and legal standing in courts would theoretically allow nature to seek the cessation of exploitation, plundering, and degradation currently sanctioned by law and human governments the world over. It could also, theoretically, provide grounds for brining claims for harms and environmental damages

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[8] https://www.un.org/en/conferences/environment/stockholm1972

already committed. In combination with efforts like the Nature Restoration proposed regulation (European Commission 2022), efforts to address damages could reference targets for restoring ecosystem integrity. Changes implicated by affording nature such a set of rights include: calling for public and private actors to recognise, promote, and enforce these rights; establishing norms and empower people to defend rights of nature; and implementing precautionary, "restrictive measures" to prevent further extinction of species, ecosystem disruption and ecological capacity degradation (Darpö 2021).

Rights of Nature applications around the world (outside of Europe)

A range of legislative and constitutional acts around the world have sought to advance a more ecocentric (as opposed to anthropocentric) approach to including nature in human thinking and action. One such set of acts include granting constitutional protections to nature for the purposes of conservation. The most prominent example here includes the Ecuadorian Constitution, Article 71, from 2009: the right of "Pacha Mama". Another example is the Bolivian constitutional right of citizens to protect the environment and subsequent Law on the Rights of Mother Earth. A 2010 Universal Declaration of the Rights of Mother Earth (after the first World People's Conference on Climate Change and the Rights of Mother Earth in Cochabamba, Bolivia) further advocate such an approach (Darpö 2021).

Contrastingly, there are those efforts seeking to afford natural entities the status of "legal personhood" for legal proceedings. These changes are intended to give standing to interested parties representing or acting as guardians of these non-human entities, as well as broaden the scope of permissible evidence in related decisions. In many instances, efforts to advance this cause are made under cultural preservation and anticolonial action (as with the cause of a constitutional right of nature (Espinosa 2019)). In certain instances, people can bring grievances to court and be given standing on environmental issues relates may rely on the principle of *actio popularis*, where no direct impact is necessary to prove on the part of the claimant.[9] Several examples in New Zealand, Latin America, the U.S., India, and Uganda adopt forms of legal personhood for nature:

- Aotearoa New Zealand, legal personhood of the Whanganui River under guardianship of a joint council; Te Urewara, legal recognition of the former national park.
- Latin America – a Framework Law of Mother Earth and Integral Development to Live Well in Bolivia.
- Lake Erie Bill of Rights, passed by the city of Toledo, Ohio, USA (to exist, prosper and evolve naturally).
- Grizzly Treaty, signed by 200 US and Canadian tribal nations, on rights of bear species to exist in healthy ecosystem, 2016.
- India, recognition of the Ganga and Yamuna rivers as legal persons (High Court of Uttarakhand), 2017. The Indian Supreme Court since the 1990s, has increasingly recognised the importance of an ecocentric view to rulings. Although in cases of the rivers Ganges and Yamuni, legal personhood has not been issued.
- Uganda, National Environmental Act, 2019, recognising RoN to "exist, persist, maintain and regenerate its vital cycles, structure, functions and its processes in evolution."
- Bangladesh, in February 2019, the Supreme Court delivered a decision granting legal personhood to all rivers. A government-appointed entity -- the National River Conservation Commission – can now take people to court.[10]

In the U.S. state of Florida, a court case is currently underway in which a lake is suing for its rights for the first time, as planned construction projects threaten to permanently damage the lake and surrounding wetlands (Kolbert 2022). Named Lake Mary Jane, her representatives claim that the prospected damage posed by development in this instance is concrete, distinct, and palpable. In Orange County Florida, however, there are disagreements on Lake Mary Jane's future – or lack thereof. Indeed, the Lake is being pre-empted by business lobbyists pushing for a Florida state ban on local governments granting legal rights to the natural environment in any form (Kolbert 2022).

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[9] This in addition to farmers holding companies to account for polluting farmland and fishponds rendering them unfit for human use, as in the 2021 finding where the Dutch Court of Appeals has held Shell Nigeria of Royal Dutch Shell liable for and owing a duty of care to affected villagers. https://www.business-humanrights.org/en/latest-news/shell-lawsuit-re-oil-pollution-in-nigeria/

[10] https://www.vox.com/future-perfect/2019/8/18/20803956/bangladesh-rivers-legal-personhood-rights-nature

The case of Lake Mary Jane reveals that people and organisations hold strongly different opinions when it comes to ideas of rights for nature in practice. While environmental non-governmental organisations (ENGOs), civil society organisations, and citizens often argue or push for the rights of nature, corporate representatives, and conservative (not of nature but of its status quo exploitation) voices campaign against any "humanisation" of nature. Opponents point to the jobs associated with construction and development activities and the need to extract natural resources that benefit human prosperity and well-being.[11]

We can turn here again, briefly, to the issue of animal rights. One may look to recent case law for attempts to use legal proceedings to enhance protections of species. A recent New York Court of Appeals case, in which claimants sought to have an elephant, an intelligent, "cognitively complex animal," released from captivity, is particularly instructive. On the elephant's behalf, an ENGO sought to secure protections of *habeas corpus* (a procedural vehicle people can "assert to protect their bodily liberty and to contest illegal confinement" (Shanahan 2022)) for an elephant in the Bronx Zoo.[12] Writing for the dissent, one judge noted that definitions of personhood change over time, pointing – as do RoN advocates -- that corporations are treated today as legal persons in certain situations. Judge Rowan D. Wilson also argued the court had a duty, "To recognise Happy's right to petition for her liberty not just because she is a wild animal who is not meant to be caged and displayed, but because the rights we confer on others define who we are as a society." This larger point about the moral ambitions of society is likely to remain a source of legal tension as scientific understanding of ecosystems, nonhuman species, their interdependence, and humans' interdependence on the two, evolves. This evolution of understanding may press ever harder the question not only of whether nature and animals ought to have rights to protect them from humans, but also on the merits of their own existence.

Challenges to the legal approaches of the RoN have revealed mixed results of successfully empowering nature in courts and constitutions. Despite the constitutional provision in Ecuador, several cases have been lost on the merits (of the case), allowing economic and development practices to proceed over the objections of individuals and groups suing on behalf of Mother Earth. Contrastingly, in Colombia, where there is no legal right to nature, court orders have been made to establish personhood of the Atrato River (Darpö 2021).[13] In Colombia, the precedent of the New Zealand personhood of Aotearoa was used as precedent. In the U.S., some ENGOs have been able to obtain standing on behalf of waterways, in citizen suits allowed by the Clean Water Act (1972), as well as the Clean Air Act (1970), Endangered Species Act (1973) and Resource Conservation and Recovery Act (1976). Some efforts to recognise rights of ecosystems by Municipal entities, like Tamaqua Borough (Pennsylvania) and Shapleigh (Maine), have not been challenged in court; while others (the Bill of Rights of Lake Erie (Toledo, Ohio) have been tossed out as unconstitutional (Darpö 2021).

Limitations of Rights of Nature applications in general

The above challenges with adoption of a right of nature in law reveals a larger question of implementation. Namely, how would these rights be asserted in practice; how can the interests of a natural object be represented? Stone (1972) suggested establishing representation by legal guardians, who are "friends" of the natural objects and may speak for them in court in instances of an existential threat. The WEF (2020)[14] has proposed bodies or assemblies be established for representation. As an example, movement of the Loire Parliament consults among relevant stakeholders and explores proposals for potential governance procedures and structures that could ensure the river's interest in the long-term.[15]

Given the state of current environmental law enforcement, Darpö argues it is not clear why granting nature rights would result in any more than a symbolic gesture (Darpö 2021). This point is borne out in the mixed success of RoN even when won, as the above instances explored. Darpö argues this perspective given the insufficiency of existing legal commitments to the environment (see also Bataille 2019). Further, Darpö notes

[11] https://www.nationalreview.com/corner/nature-rights-a-lake-in-florida-sues/

[12] Shanahan (2022) Happy the Elephant Isn't Legally a Person, Top New York Court Rules. *New York Times*. Available at: https://www.nytimes.com/2022/06/14/nyregion/happy-elephant-animal-rights.html?smid=em-share

[13] Citing Dejusticia y otros v Presidencia de la República y otros. Colombian Supreme Court, ruling STC4360 of 4 May 2018. Full text in Spanish, available at https://cdn.dejusticia.org/wp-content/uploads/2018/01/Fallo-Corte-Suprema-de-Justicia-Litigio-Cambio-Clim%C3%A1tico.pdf?x54537

[14] https://www.weforum.org/agenda/2020/05/nature-legal-personhood/

[15] http://www.projetcoal.org/coal/en/2020/10/12/les-auditions-du-parlement-de-loire-%E2%80%93-n%C3%A9gocier-en-contexte-inter-sp%C3%A9cifique/

that the so-far limited success of constitutional or regulatory efforts to implement a right of nature suggests a further limitation of its potential in democratic states (Kramer 2020; Richardson and Hamaski 2021). As Kauffman and Martin (2017) note in an analysis of 13 challenges in Ecuador between 2008 and 2017, where major infrastructure and development projects are involved, defendants of rights of nature were consistently unsuccessful in staving off ecosystem devastation and species extinction. In Ecuador, Kauffman and Martin (2017) conclude, rights of nature arguments are rejected by the State when brought by environmental interests, and used, in other cases by the State to extend its power over informal mining actors in favour of formal government sanctioned industrial activity. Finally, Darpö takes issue with an observed "democratic deficit" in strong arguments for a right of nature in which nature dictates requirements for its well-being. The problem here, Darpö argues, rests in the fact that in any case where nature has rights or not, such rights will still need to be administrated and defended in a system of law in which some form of human representation and administration are vital.

Approaches to implementing rights of nature are not without difficulty in and of themselves. One strategy might entail extending rights directly to biological entities (species or ecosystems), however this model might end up bogged down in attempting to navigate a potentially infinite ambivalence in balancing conflicting interests in natural systems (e.g., among predators and prey; hunters; wildlife managers; farmers (organic or not); pet owners; symbionts; parasites; etc.) – as well as competition among rights of other human actors in legal systems (Guim and Livermore 2021). Put another way, how might one begin to arbitrate the right of a rabbit to prey on a gardener's lettuce; a hawk to prey on a rabbit; a virus to reproduce in a host (issues of *interpersonal or interspecies comparison)*; or the rights of marine life against property rights or energy access rights (issues of *competing interest*)? Would property rights even continue to exist were the land eligible to exert claims in its own right? Which entities beyond human are counted for consideration, and how are effects across entities to be compared?

Contrastingly, one might grant rights to ecosystems or communities of species in their entirety, at the level of species, populations, or ecosystems. However, it is often the case that such aggregations are interdependent in a complex web of other species, populations, or ecosystems, or nested within other taxonomic or ecosystem classifications. In this case, aggregation introduces the challenge of how to non-arbitrarily decide on the appropriate biological or ecological group to which to recognise rights (Guim and Livermore 2021). Overall, cases of rights of nature force judges and courts into novel, complicated "intellectual terrain" where many parties may claim the mantle of nature with or without grounds (issues of *representation)*; have competing rights or interests in play; and present an unsolvable calculus of ascertaining net benefits or costs among a range of claimants (Guim and Livermore 2021).

Ultimately, rights of nature proponents argue that granting nature legal personhood is essential to combating the disastrous effects of climate change, biodiversity loss and environmental degradation more generally from human activity. With current environmental law often poorly implemented, prospects of legitimate granting and defence of rights for nature to ensure thriving ecologies seem bleak. In this setting, it may be helpful to appreciate other ways in which laws, symbolically, may affect norms, popular culture, and subsequent consequences for behaviour change over time. For example, if granting rights to nature might meaningfully influence norms in culture about human-nature relations, for example, where greater intrinsic value is placed on nature (Houck 2017; Sheehan 2015). In this sense, law may set a valuable "normative vision" for an alternative way to centre more-than-human beings in society (Akchurin 2015).

Practically, however, the current state of legal and economic realities suggests that the path to securing such a right is treacherously steep and far from guaranteed. In such an understanding, a substantive right for nature will only be as good as the practical limitations on implementation in a legal system (Guim and Livermore 2021; Darpö 2021). Reviews of the effect of constitutional rights in practice suggest that certain rights are more effective than others. Prohibitions on torture or proclaimed rights to education or healthcare – all rights that fall to individuals to uphold, for example – seem less legally potent than rights of organised groups (unions, religious organisations, etc.) (Cope et al. 2019). This may be because, "organisations have both the incentives and the means to protect themselves against rights encroachment by the government" (Cope et al. 2019, 171), as compared to most individuals.

Such potential short comings in the way rights of nature might be realised in contemporary legal systems thus raises a critical question: what is the current state of environmental and climate law? By critically considering the current state of European environmental law, alongside proposals for rights of nature, it becomes easier to discern the unique contributions and pitfalls of such a reform to Western legal systems. In this light, before considering possible futures of a Right of Nature in Europe, we turn to a high-level review of contemporary European environmental law as it relates to law for nature.

European Environmental Law related to Rights of Nature

Darpö (2021) reviewed a range of ways, spanning international, European, and national levels, current environmental law offers (or fails in applying) protection for nature. At a **constitutional level**, European Union Treaties and a range of regulations and directives focus on environmental protection and preservation, from pollution permitting and prevention to chemical control to species and habitat protection to environmental impact assessment. Of course, as distinct from any intrinsic value of nature, these legal protections are in place to ensure environmental quality for human health and use of natural resources. For example, recent climate and environmental law enshrined 6 environmental objectives of the Union: (i) climate change mitigation; (ii) climate change adaptation; (iii) the sustainable use and protection of water and marine resources; (iv) the transition to a circular economy; (v) pollution prevention and control; and (vi) the protection and restoration of biodiversity and ecosystem (European Commission 2020).

European environmental law centres on the polluter pays and precautionary principles. The precautionary principle is mentioned in Article 191 in the Treaty on the Functioning of Europe and has been elaborated by the Commission since (European Commission 2000). Implementation of the polluter pays principle is highly inconsistent (European Court of Auditors 2021). In addition, the Birds (Directive 2009/147/EC) and Habitats (Council Directive 92/43/EEC) directives, respectively, recognise an "intrinsic value of biodiversity." This acknowledgement draws upon European implementation of the 1979 Bern Convention on Conservation of European Wildlife and Natural Habitats[16] and the EU's adoption of the Convention on Biological Diversity of 1992, which similarly recognises an "intrinsic value of biodiversity." The recently proposed regulation on Nature Restoration (European Commission 2022) is intended to work with the Birds and Habitats and other directives covering marine and terrestrial areas to reverse decades of decline in the integrity of ecosystems across Europe. Although the proposed regulation does not reference the intrinsic value of biodiversity, it adopts a One Health approach recognising, "the intrinsic connection between human health, animal health and healthy resilient nature" (p. 1).

Procedurally, EU ascension into the Aarhus Convention in 2005 set in motion a range of additional rights and protections related to **environmental justice proceedings** (Regulation (EC) No 1367/2006). The Aarhus convention ensures rights for public participation regarding preparation, modification or review of environmental plans and programmes. The law requires European institutions, bodies, and national authorities to inform the public and open possible public participation – and a duty to accurately account for the results – for environmental plans and programs. Access to environmental justice in European and national courts was recently expanded by Regulation (EU) 2021/1767 amending Regulation (EC) No 1367/2006. Whereas for the first almost twenty years of the act, the public and environmental NGOs had ambiguous and limited recourse to redress environmental harms, the amendment grants ENGOs and other publics to request review of administrative acts impinging on their rights. The law denies "*actio popularis*", or the ability of any individual to make a claim on behalf of environmental concern. Rather, defendants need to demonstrate direct effect (e.g., imminent threat to health and safety or prejudice to a Union right based on contravention of environmental law) greater than what is posed to the general public. This modification of the EU law governing adoption of the Aarhus convention demonstrates how the Aarhus Compliance Committee, charged with reviewing and providing feedback on the law, does allow for reforms to occur (although in instances taking 10 -20 years or more) (Darpö 2021, p. 37)

Finally, at the level of **environmental case law**, the Court of Justice of the European Union has been gradually strengthening potential standing of environmental complaints and cases. Under the Aarhus convention and environmental procedural justice statues, publics concerned with nature conservation and environmental protection have increasingly been able to bring cases to the Court of Justice of the European Union (CJEU). CJEU case law is thus an important source not only for implementing and understanding environmental justice proceedings, but also in strengthening them over time. Primary successes here have involved creating more

[16] https://www.coe.int/en/web/bern-convention

ground for ENGO standing in court and overcoming the cost barriers to environmental justice such cases often entail. Essentially, these outcomes elevate civil society as a check on EU institutions and private sector actors, as well as helping ensure delivery of the aspirations of the European Green Deal. However, the CJEU at the same time still restricts standing of concerned publics in challenges to EU institutions directly (as opposed to through Member State suits).

Related to case law, the "**doctrine of direct effect**"[17] holds in European environmental law. The doctrine of direct effect is a product of secondary case law wherein EU law applies not only for Member States but also for individual rights (*NV Algemene Transporten Expeditie Onderneming van Gend & Loos v Netherlands Inland Revenue Administration 1963*)[18]. This doctrine holds that demands for environmental quality against Member States, where there is clear and precise EU law and the qualifications of being a "bearer of interest" met, can be brought to the CJEU by individuals. The aim of the doctrine of direct effect is protection of individual rights and the duties of Member States to comply with EU law. Critically, the legal system cannot "discriminate between different areas of law concerning enforcement of common obligations" (Darpö 2021, p39). This means that law on individual rights (such as labour, movement of goods and services), does not trump public interests related to clean air, water, and thriving biodiversity. Indeed, EU environmental case-law demonstrates that property rights are neither absolute nor unqualified when it comes to environmental protection and natural conservation. Here the EU Court of Human Rights draws upon some 300 cases pertaining to broad issues of a healthy environment (ECHR 2022).

Related to European Law on environmental issues is the **question of a human right to a healthy environment.** Considering human rights to a healthy environment in EU law offers an additionally useful foil for considering the potential added value of a RoN approach in Europe. At present, there is no formal right to a healthy environment of peoples in Europe. The European Convention of Human Rights (ECHR) and Fundamental Freedoms[19] is concerned with protecting humans from harmful environmental effects. The charter if understood broadly, does not pertain to guaranteeing any right to a healthy environment (i.e., to a state of the environment experienced independent of harm people experience from damage to the environment). The Aarhus Convention covers only rights to environmental information, public participation, and justice. While European law regulates environmental harm, air pollution, water and noise contamination and other impacts on homes and living spaces, only the most serious breaches qualify as infringements on human rights.

Darpö (2021) referenced a range of CJEU cases illustrating how such infringements have dealt with, "natural disasters, city dumps, incineration plants, industrial installations and similar activities with severe environmental pollution". He lists, for example: *Lopez Ostra v. Spain* (1994), *Guerra v. Italy* (1998), *Fadeyeva v. Russia* (2005), *Ladyayeva v. Russia* (2006), *Budayeva v. Russia* (2008), *Tâtar v Romania* (2009), *Öneryildiz v. Turkey* (2004) and *Budayeva v. Russia* (2008). The ECHR and Aarhus convention together offer thus only indirect protection for the environment, as mediated by human health needs and concerns. Nature remains an object in this perspective, and humans separate from the environment. Further, ECHR and the Aarhus Convention require people or ENGOs meet the requirement of "direct victim" for standing. Darpö (2021) noted, however, that as living texts, the (ECHR) and EU law governing implementation of the Aarhus Convention can change, should appreciation of the links between human well-being and environmental integrity continue to advance in social and political consciousness.

Benefits of a RoN approach to European Environmental Law

Darpö's (2021) analysis highlighted several ways in which elements of the RoN discourse might enhance European environmental law as it stands today. First is the perspective on **enhancing safeguards for the environment**. Here, the "principle of non-regression", active for example in the Water Framework directive (Directive 2000/60/EC) is illustrative. Enshrining non-regression at the constitutional level in Europe would introduce a general prohibition on Member State action entailing "environmental degradation" or "weakening environmental laws". Second, in law that exists, **employing more wholistic, systemic, and rigorous understandings of harm to the environment**. This covers modifications to law that might require

[17] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM:l14547
[18] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:61962CJ0026&from=EN
[19] https://www.echr.coe.int/Documents/Convention_ENG.pdf

reassessment of permits to consider cumulative effects on environmental systems. Related, this might include requirements for tracing ecological impact of human activities, and when considering species and habitat conservation and restoration.

Third, **strengthening environmental liability and enforcement statutes** resourced and competent to safeguard environmental integrity. This might entail establishing Environmental Ombudspersons at the EU and national levels capable and in separate institutions to bring environmental cases to court. Such entities might be able to seek stiffer consequence for Member States shirking obligations of EU environmental laws, with more serious sanctions for non-compliance. Enforcement might also include establishing an independent administrative body charged with addressing conflicts of interest between "short-term economic development and environmental protection" (Darpö 2021, p57). It might entail giving courts greater sanction administrations – e.g., to fine per periods of time until environmental qualities are improved (as may be found in France and Italy). Finally, this would entail stricter environmental liability with regard to environmental contamination. Changes to environmental liability might also establish remediation funds to restore contaminated habitats, with resources raised from taxation of hazardous industries and breaches of environmental law when more rigorously enforced.

Finally, RoN actions point to concerns around **pursuing environmental justice**, namely the need to improve the ability interested parties to bring complaints regarding environmental damages and harm (whether ENGOs, the public, and civil society more generally) (Faure 2020). Here, examples of improvements in environmental liability law – as found in Portugal, Italy, the Netherlands, and France – afford ENGOs and civil society groups to seek polluter reimbursements for remediation of environmental damages (Fasoli 2015). In addition, courts where such redress is sought need enhanced **scientific and technical competence** to administer environmental law; whether of judges themselves, or of independent research or advisory bodies.

4.1.3 Futures of law for nature

In this section, we first summarise the above review, in combination with results of an STI-directions Delphi survey (described in Chapter 3). The summary conveys a selection of key drivers which may affect the future of law for nature. Next, we present three scenarios – one according to each of the three horizon perspectives adopted in this project – to help illustrate worlds where STI plays a role in advancing (or undermining) ecosystem health. The key drivers inform and are present in the three scenarios to a different degree, with different weight, and with diverse consequences based on the overarching perspective.

The scenarios are not intended to be predictions. The scenarios are not intended to be pathways to a future state. The scenarios instead illuminate possible worlds in which law for nature is – to a lesser or greater degree – taken seriously in 2050. The scenarios are intended to illuminate possible critical decisions, and, "areas to invest time and resources, new opportunities and potential pitfalls, vital relationships and connections, and aspects of the future that require further investigation, and aspects of the present that require further interrogation" (Keeler and Bernstein 2021, p.12). The scenarios start from the premise that while something called the present exists, it is experienced differently by different people and, correspondingly, the future will very likely also be experienced in diverse ways (Wack, 1985; Ramírez & Selin, 2014; Keeler et al., 2019).

In the above light, the scenarios support answering the hypothetical: were rights of nature to exist in the future, how might STI policy be reimagined to get us there in a way that supports ecosystem health? We take several steps to generate information that helps us arrive at this answer. **For each scenario**, we first summarise the basic world elaborated in each perspective; second, we discuss whether and how effective law for nature might be at supporting ecosystem health in the scenario. We do this for each of the three scenarios. Then, based on Warnke et al (2021) proposed criteria for a framework to support STI for ecosystem health, we look at the way STI has the potential to undermine or support ecosystem health **across scenarios**.

Summary of key drivers

In light of the case of law for nature, several factors seemed prominent as drivers determining whether or how rights of nature might manifest in the future.

On the one hand, there are drivers that would seem to inhibit the future take off or viability of any law for nature. These include:

- A predominant premise in legal theory and practice that nature is an object intended for free human exploitation. Such political and economic positions consequently privilege extractive, destructive, unsustainable development. While such forces might galvanise greater support for granting rights to nature, they undermine and degrade ecosystems and reinforce power structures benefiting from exploitation and degradation of nature.
- Privileging certain social fictions in legal systems, but not others. So long as the legal fiction of a corporation is granted personhood given rights, standing, and representation – but not nature corporate rights and actions that degrade and exploit nature will be more likely to prevail. This would plausibly be the case until complete failure of natural systems, at which point the legal fiction of a corporation becomes somewhat meaningless. In the meantime, business and government interests may run counter to environmental protection and ecosystem integrity.
- Insufficient will to fully implement environmental protections as written. Although there are legal and constitutional commitments to principles of precaution and polluter pays, so long as transgressing these principles can be factored as a cost of doing business, they will not be upheld. In such a context, adding a right of nature might simply increase the cost of doing business without resulting in serious changes to improve ecosystem health. So long as existing legal protections for the environment – from permitting to prevention, protection, or restoration – are easy to undermine, a meaningful right of nature will likely remain elusive.

On the other hand, there are drivers that would seem to hold promise for future take off and viability for law for nature. These include:

- Changing values around human-nature relations, human rights to a healthy environment, and the intrinsic value of nature. If and as more and more people hold these values, express them, build community around and advocate for them, they will have an increasing effect on policy, industry, research, and a range of activities in society – including referenda on or legislation supporting or enforcing rights of nature. In economic and government realms, this might look like transitions to de-growth or circularisation of resource flows; increased efforts to represent nature in systems, etc.
- Consideration of nature in development (rural or urban), natural resource governance, and ecosystem management with appreciation of biodiversity concerns, One Health, and ecosystem service perspectives. As the EC proposed regulation on Nature Restoration shows, there is increased recognition of the importance of healthy ecosystems. As such efforts take hold and thrive, they might reasonably reinforce further efforts to move from regulation on restoration to rights of nature against further degradation.
- Legal innovations ranging from rights of public participation in concerns of environmental justice to rights of individuals to bring cases withstanding on behalf of environmental systems to rights to a healthy environment. As these innovations take hold, legal protections for the environment, from permitting to prevention to protection and restoration, may have a greater chance of being defended. Appreciating property rights are neither absolute nor unqualified when it comes to environmental protection and natural conservation is similarly important in this driver. So too is the principle of non-discrimination against environmental law (e.g., not privileging labour, service, goods, property, or other types of law over any other). Together, these factors lay a legal groundwork and trajectory toward more, and more robust, safeguards for ecosystem health.
- Improved information about natural systems. A range of knowledge systems improve human abilities to monitor and remediate ecosystem health. These include – to name a few – earth systems models; intelligent earth observation; data-driven species and ecosystem service models; ecological impact tracing techniques; innovative, rapid biodiversity assessments; use of soundscapes as an ecological indicator; and understanding how pathogenic microorganisms move around the world as one effect of climate change. Together, these sources of information may help make the case for and defend the rights of nature, should law for nature be championed in a serious way.

4.1.4 Scenarios

Rights for Nature, without Justice – Scenario P1

The perspective "protecting and restoring" describes a future in which a "great decoupling" has occurred, enabling continued economic growth without devastating environmental impacts. Digital Green Growth has been pushed for the transition to a more sustainable economy. Systemic management of terrestrial and marine ecosystems; regeneration of specific nature reserves and wilderness; massive deployment of carbon capture and storage technology; renewable energy; and nature-based solutions as well as technological innovations are prioritised as the norm in this future. Where nature has not been successfully restored, technological substitutes have been attempted, with mixed success. Major societal actors continue to drive models of consumption and growth, couched in sustainability. Human beings remain the most dominant disturbance to ecosystems.

Rights of nature in this scenario have contributed to modest gains for nature restoration, although far short of the more transformative ambitions of the vision of law for nature. Classical ecosystem performance measurement and ecosystem protection approaches persist, in which nature is objectified and managed – although at least the measurement and calculation of harm done to parts of nature, now with their own legal personality, are precisely quantifiable to enable restitution in the form of technological substitution. Implementation of law for nature increased, in some areas, tensions between human and societal interests and ecosystem recovery and protection. Hostility to nature – and ecosystem stewards empowered by the law – increased too, as do the opposite, as green industrial activities take over and substitute natural systems in support of continued sustainable growth trajectories.

Rollout of law for nature entailed a significant additional administrative burden, with monitoring, analysis, accounting, legal proceedings, and restitution significantly increasing the cost of business. Efforts to overcome the challenges of assigning representation, balancing conflicting interests (for example across trophic levels), and determining net benefits and costs are, often used by hold-out opponents to torpedo rights of nature initiatives. In some cases, valuation from ecosystem services is enough to offset the costs of the transition – in others, major sectoral changes contribute to a period of social unrest amidst massive retraining efforts. Some large multinational companies and governments, after a period of competing to purchase and fence off wild and restored areas, use these to generate additional revenue.

Unequal access to green spaces amongst rich and poor nations increases in perverse ways, as the former plunder diverse terrestrial and marine ecosystems for their restorative value. The victories in legal cases empowered by law for nature threatened to bankrupt many large multinational companies, who collectively persuaded government and taxpayer subsidies to weather the transition to a world in which natures rights enable more robust protection. As part of broad settlements, some areas where wilderness and restoration efforts were won were relegated to less robust or fertile lands, raising questions of rights for nature without justice.

Tensions and opportunities created the ways STI might be deployed in this scenario in 2050

- STIs enable more precise monitoring and measurement of nature degradation, protection, and restoration.
- STIs enable more robust inter and transdisciplinary collaboration for ecosystem health management goals.
- STIs exacerbate demarcations among human and environmental systems, perpetuating notions of human-nature separateness.
- STI approaches to monitoring and data collection and processing, as well as STI deployment, perpetuate a view of nature as an object of observation and control, even with good intention, without any notion of human reciprocity or obligation to nature.
- STI reinforces technocratic modes of approaching and understanding nature as opposed to more experiential and engaged modalities.
- STI approaches reinforce political economic hegemony impinging environmental justice and rights of nature.
- STI approaches threaten to extinguish alternative and traditional ways of knowing and being in the world, impoverishing humanity irreversibly.
- STI incumbents restrict opportunity for nature, future generations, and other-than-human-beings to participate in agenda setting and user orientation.

Rights of Nature, Missing the Forest for the Trees – Scenario P2

The perspective “co-shaping” describes a future of more blended, interconnected human activity and nature. Resilience comes to be increasingly prized alongside efficiency. Multifunctional green spaces, diets, and lifestyles become increasingly popular. The goal of these approaches is to move socio-ecological systems that are in unstable critical condition towards renewal, resilience, and sustainability to prevent collapse. Due to the inherent uncertainty of complex adaptive systems, this cannot be achieved by top-down steering but only by co-shaping the system dynamics in very specific contexts. Notions of controlling nature have become widely dispelled. Large-scale transformative ambitions are displaced by incremental, responsive, and adaptive shifts in society.

Through practical approaches like biomimicry and regenerative design, designers use complex systems thinking to design community practices that are positively interacting with ecological systems. The notion of the planetary and human health, especially the EcoHealth concept, the "Doughnut Economy" within planetary boundaries (Rockström et al 2009) provide guiding frameworks locating some of the critical arenas of interaction of human and ecological system elements. A core aspect is the acknowledgment that there can be no one correct view on a system. Subsequently there arises the need for negotiation procedures to mediate among different perspectives (e.g., industry, communities, indigenous peoples, nature stewards, governments, etc., but also regions and territories) and to establish institutions for polycentric governance in social-environmental systems – a "diplomacy of the commons".

Governments, private sector actors and communities have developed adaptive, innovative consent-based approaches to establishing regional economic zones based on ecosystem functions, flora, fauna, and capacities. Establishment of such partnership zones have allowed for drastic reductions in environmental footprints of human habitation, supply chains, and consumption patterns. Such partnership zones develop regional ecosystem based competitive advantages and local production sufficiency in a manner such that, while intra-regional trading enhances, global trade becomes less urgent. In this transformed, polycentric world, digital technologies enable intraregional exchange, along with circularised resource cycling within regions.

Goals for ecosystem health have transitioned from precise measurement and management to shaping, navigating, and reducing pressures. Widespread implementation of rights of nature supports the introduction of new practice for co-shaping – for negotiation human and non-human interests and values. Legal systems more robustly guarantee and protect direct and indirect ecosystem services. While growth-oriented objectives remain popular, presence of law for nature provides strong pressure for addressing biodiversity and ecosystem conflicts in the context of growth. Precautionary and anticipatory approaches to technology and innovation governance have become better equipped to account for the complexity and uncertainty associated with socio-technical change. Such governance approaches enable the design of more adaptable, resilient systems.

Tensions and opportunities created from the ways STI might be deployed in this scenario in 2050

- STIs enable more precise monitoring of nature degradation, protection, and restoration.
- STIs enable more robust inter and transdisciplinary collaboration for ecosystem health management goals.
- STIs promote views of complex interdependences among human and environmental systems.
- STI approaches to monitoring and data collection and processing, as well as STI deployment, perpetuate a view of nature as primarily for human benefit, but acknowledging need for human reciprocity and obligation to sustain healthy ecosystems.
- STIs support modes of approaching and understanding nature through complex adaptive systems perspective, including experiential and engaged modalities.
- STI approaches advance environmental justice and rights of nature, but unevenly, as polycentric governance means previously well-resourced places are better equipped to transition society for improving and managing better ecosystem health.
- STI approaches support capability building across government, private sector, nongovernmental, and citizen actors to engage in consent-based decision-making processes in which nature is represented.
- STI approaches take from alternative and traditional ways of knowing and being in the world to strengthen management objectives and co-shaping initiatives.
- STI incumbents selectively include nature, future generations, and other-than-human-beings in agenda setting and co-shaping activities.
- STI policy supportive of law for nature enabled research endeavours testing options of polycentric governance approaches and their implications.

Rights and Justice with Nature – Scenario P3

The perspective "immersing and caring" describes a future characterised by the prevalence of relational ontologies and epistemologies. Subjects are viewed not as pre-given independent entities, but rather as being continuously (re)produced through interaction in real-life contexts. Consequently, by 2050, predefined categories like "nature" or "human" and "non-human beings" are falling out of fashion as new norms about the intrinsic value of diverse beings, modes of existence, and dynamic status changes in the world and relationships. Agency is considered not the result of specific action by entities but rather emergent from relational network interactions. In such relations, "care" is recognised and valued as a reciprocal practice among human and non-human beings and ecosystems.

Multi-species justice is essential to thriving life in this world, along with deep ecological principles recognising nature's intrinsic value (not as something with a price of zero but has having no price). Indeed, economic language prizing individual consumption has given way to nuanced, nested property regimes in which rights and resources are in dynamic relationship across needs of various actors. Well-being in such contexts translates to ecosystem health, and relationships offering care, safety, and sufficiency. Traditional ecological and scientific communities, along with civil society, business, and public representatives share responsibilities in dynamic and deliberative systems of shared governance – shared between human and natural systems, that is. Regionally elected ecosystem representatives' deliberate policy, with ecosystem health (including biochemical, biodiversity, and human indicators) are independent and robustly maintained to ensure deliberations are presented with state-of the art information.

Nature guardians appointed by representative elections or administrative acts largely reject notions of "ecosystem performance", as these reflect an anthropocentric, rather than ecocentric approach to the new law of Earth, where nature has rights. Guardianships were established in the 2030s as part of a 100-year plan to advance human cultural norms from anthropo- to ecocentricity, at which point guardianships are designed to gradually sunset for the 100 years after. Ecosystem protection is supported in some places by budgets as large as military defence budgets of the early 2020s but pioneering non-lethal – for nature -- modes of protection. The intrinsic value of nature and species represents a central pillar of the legal approach enshrining rights of nature. Anthropocentric concepts are increasingly viewed as quaintly old-fashioned, at best, or actively discouraged as a form of hate-speech, in the most vigorously defended cases. Reparations from the anthropocentric times are still being paid out to support the ecocentric transition made possible by a rights of nature doctrine.

Relational ways of knowing and being, in which individuals and collectives of individuals learn and cultivate healthy interdependence with ecosystems mean that, thanks to the RoN doctrine, separations of individual, social, and ecological knowledge are increasingly moot. As a result, questions of representation, competing interests, and ascertaining net benefits and costs, which plagued the advance of rights of nature in its early decades, are less difficult to resolve. Much resolution comes in the form of resurgent rituals in which trophic levels, cycles of birth and death, harm, joy, and other resplendent emotions experienced across existence are cared for as they arise. Global and regional teleconnections among ecosystems, historically poorly understood, are now respected at the level of individuals, communities, and regional ecosystem governance bodies (nation-states have begun in some cases to phase out in favour of regional governance bodies that better conform to ecosystem boundaries and interdependences).

In this perspective, the concept of ecosystem services is incidental to the reality that all human life is recognised as fully dependent on ecological integrity and flourishing. Nature, in addition to Earthly abundance, has become the primary beneficiary of all human knowledge as countless rights of nature cases across the world have transferred nearly all biochemical and mineral-related intellectual property to Nature Guardians and representatives (as various plants and natural chemicals are source or antecedent to major human industries), along with assets and royalties. In this context, corporations have nearly completed a process of re-incorporation with ecosystem advisory boards holding sway over key operations and activities.

Multi-species perspectives acknowledge, value, and cultivate collaborations to reveal new solution spaces related to scientific and technological innovation. Care is expressed in research itself, involving rethinking the political relations of "subjects", "objects", "stakeholders", "beneficiaries", "collateral damage" and other concepts in practice. Centuries of failures with sociotechnical system design and implementation aimed at "uniformly improving human well-being" while incurring massive environmental devastation has contributed to having this approach fall out of favour. Instead, thanks to law for nature, an eco-social approach to innovation now predominates. This approach ensures high standards of human well-being and ecosystem health are met before tinkering with novelties that undermine such vital pursuits. With rights of nature doctrine in place, human, non-human beings, and ecosystems all share in agenda setting processes from places of equal privilege (after some decades of human reparations to nature and species).

Tensions and opportunities created the ways STI might be deployed in this scenario in 2050

- STIs enable more precise monitoring and measurement of nature degradation, protection, and restoration.
- STIs enable more robust inter and transdisciplinary collaboration for ecosystem and human health.
- STIs support novel, integrated measures of ecological integrity that include not only biogeochemical and biodiversity data but also human health and wellbeing information
- STIs breakdown barriers between concepts of "human" and "natural" systems, strengthening notions of human-nature dependence.
- STIs demonstrated irrefutably human life is fully dependent on ecological integrity and flourishing.
- By opening up to critique and reform from indigenous people and decolonisation approaches, STIs advance relational ways of knowing and being, in which individuals and collectives of individuals learn and cultivate healthy interdependence with ecosystems.
- Major investments in human, social, and material resources for rigorous environmental law enforcement mean that STIs were essential to enabling the first Green Deal to be realised, and its successors, in a way focused on socioecological integration and ecosystem health
- STIs helped experiment with and build evidence about responsibilities in dynamic and deliberative systems of shared governance – shared between human and natural systems – among traditional ecological and scientific communities, along with civil society, business, and public representatives
- STIs support an eco-social approach to innovation that ensures high standards of human well-being and ecosystem health are met before tinkering with novelties that undermine such vital pursuits.

With rights of nature doctrine in place, human, non-human beings, and ecosystems all share in STI agenda setting processes from places of equal privilege (along with future generation representatives).

4.1.5 Implications for STI Policy

The above review of rights of nature discourse, as well as the future scenarios across three perspectives, showcase the way STIs may play a variable role in supporting or undermining ecosystem health. In this section, we first present main lessons learned from reviewing the state of environmental policy and law for improving ecosystem health. Then, based on these insights for improving environmental policy and law – as well as the insights drawn from across all three perspectives – broad recommendations for STI policy in support of ecosystem health are offered. These recommendations are intended to stand in service of ecosystem health regardless of future scenario from which they are drawn.

Recommendations based on potential changes to environmental policy and law

As Darpö (2021) summarised, "the key [for any approach to environmental law] still lies in proper funding and staffing of the competent authorities, transparency, and involvement of the public, as well as the possibility to challenge administrative action and inaction" (p., 57). Recommendations for enhancing STI policy to support healthy ecosystems and human society are based on Darpö's observed limitations with current environmental law in Europe (2021).

Based on the recommendations provided by Darpö (2021), suggestions for how STI policy could make valuable contributions to these reforms are explored. These suggestions for STI policy – like Darpö's analysis – are made independent of future states and based on the need that ecosystem health depends, regardless of whether there is law for nature, on environmental laws being robustly enforced.

Recommendations to enhance principles of environmental care at the constitutional level

Recommendations for EU law here support the advance of principles of non-regression, holistic and systemic approaches to studying environmental degradation, and recognising intrinsic value of nature. STIs that build social, natural, and physical sciences capacities to contribute to the study and cultivation of ecosystem health would be important here.

Regarding legal prohibitions against degrading the environment or weakening environmental law, STI investments in environmental, social science and humanities scholars to monitor deployment, study **effects of, and suggest alternatives to regressive environmental laws would be of high value.**

Regarding more holistic, systemic understandings of consequences of environmental degradation, STI investment in natural, social, and physical sciences could illuminate integrative, systemic **measures and approaches not only of cataloguing but – essentially – reversing environmental degradation**.

Recommendations related to suggested enhancements to environmental standards
Legal recommendations in this domain include implementing requirements for pollution permits to be dynamically re-assessed over time; for ecological impact tracing to include more systemic understanding of not only primary but also secondary, tertiary, and quaternary effects of environmental damage; and caps on *cumulative* environmental harms. For all of these areas, significant investment in STI could **promote the efficacy and cost-effectiveness of environmental damage assessment methods**. For example, **building robust independent ecological health monitoring capabilities** across regions would include investment not just in **research infrastructure** but also the **human and social networks and resources** required to staff such efforts. These expert-based governance regimes could include, as well, **citizen scientific oversight** efforts to enhance societal coherence.

Recommendations related to improving legal-technical standards, EU environmental laws, and environmental liability thresholds
Recommendations in this tranche of environmental policy and law relate to harmonising environmental principals across the many EU regulations and directives and case law; improving coordination across directives; enhancing independent scientific committee oversight about biodiversity and species risk listings; and review of criteria of serious damage and liability exemption.

Recommendations related to environmental liability law
Reform recommendations related to environmental liability law revolve in part around establishing remediation funds for destroyed habitats and restoration from taxation on environmental hazardous industry and breach of law. STI policy could make a **practice of matching such compensation funds with separate and supportive scientific research funds to enhance natural, social, and physical science understandings of approaches to environmental remediation and restoration**.

Another recommendation related to environmental law suggests the importance of affording ENGOs and civil society groups the ability to ask for damages on behalf of environment, and in a manner that removes exorbitant costs of bringing such cases. STI policy might consider **investment in ENGO capacity building by paying for staffing of environmental and social scientific capabilities of ENGOs and CSOs and citizen groups seeking damages and restoration** and do so in ways that further help lower costs (financial and expertise thresholds) for defending environmental health.

Recommendations from addressing shortcomings in environmental law in Europe
Enhancing ecosystem health in Europe through addressing shortcomings in environmental law suggests a key role for strengthening independent environmental law administration and enforcement. Recommendations here suggest the benefits of independent, horizontal regulatory authorities charged with ensure member states meet environmental obligations under EU law, with the power to sanction administrative inertia to implement such law. Such recommendations also reference the potential need to establish an Environmental Ombudsperson at EU and national levels.
STI policy in such circumstances could offer **insight into governance arrangements to effectively establish and coordinate knowledge exchange** across such an administrative apparatus. Further, **STI policy might pioneer effective, adaptive methods at long-term ecological health monitoring** which might be deployed to **demonstrate costs of inaction and consequence of unremedied environmental degradation.**

Recommendations from strengthening court authorities and expertise.
A range of STI recommendations flow from suggestions to enhance environmental law by strengthening court authority and expertise to cover cases related to rights of nature (were it to advance, or to support improved enforcement of existing environmental law). Actions here include **enhancing court ability** to administrate sections or monitor non-compliance; build judge and court experiences with environmental law; establishing independent scientific advisory bodies to support judicial action.

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4.2 Case Study 2: Land Use Futures

Philine Warnke, Totti Könnölä

4.2.1 Introduction

This case study explores how a strong focus on ecosystem flourishing could change the current thinking about land use competition. While there is longstanding discussion on different land use conflicts from the human perspective (namely conflicts between the single-use of the land, e.g., fuel vs food, recreational vs. industrial land use), exploring the multiple-use (and users) of the land, recognising the perspective of the ecosystems inhabiting these lands brings in novel angles. What if trees are seen as inhabitants of cities with a vital stake in sufficient space? What if we have to negotiate with more than human inhabitants of these territories such as mountains or rivers before using their "homelands" for human purposes? What does it really mean to share spaces with nature? Before embarking into such more radical notions of ecosystem flourishing and land use, we will look into the current situation and explore drivers, signals tensions and possible trajectories.

4.2.2 Status Quo & System change analysis

In this section, we sketch the dynamics of change in global land use. After briefly describing the current distribution of land use, we focus on selected aspects with a particular dynamic of change in relation to ecosystems. These aspects are: de- and de-forestation, land use for agriculture, land degradation, biofuel land use, land use for renewable energy, land use by mining and quarrying, land grab from rich to poor, land health as an underlying driver of global pandemics, rewilding, land use for tourism, urban sprawl versus densification, floor space per person, human scale city planning and debate around public space ownership and publicness. This analysis is based on recent literature from the field. Wherever pertinent, we complement the analysis with results from the Dynamic Argumentative Delphi[20] study on impacting factors on ecosystem flourishing.

Current situation[21]

As illustrated in Figure 4 for much of human history, most of the world's land was wilderness: forests, grasslands and shrubbery dominated its landscapes. If we rewind 1000 years, it is estimated that only 4 million square kilometres – less than 4% of the world's ice-free and non-barren land area was used for farming. Over the last few centuries, this has changed dramatically: wild habitats have been squeezed out by turning it into agricultural land.

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[20] The Dynamic Argumentative Delphi survey consisted of two rounds, carried out between December 2021 and February 2022. 1 637 respondents participated in the first round of the survey. In the second round, 638 participants contributed to the second round of the survey. Using the consolidated set of STI directions, respondents were invited to select the three most important STI directions in terms of their potential to contribute to the capability of planetary ecosystems to flourish from now to 2050.

[21] This text is derived from Ritchie and Roser 2019.

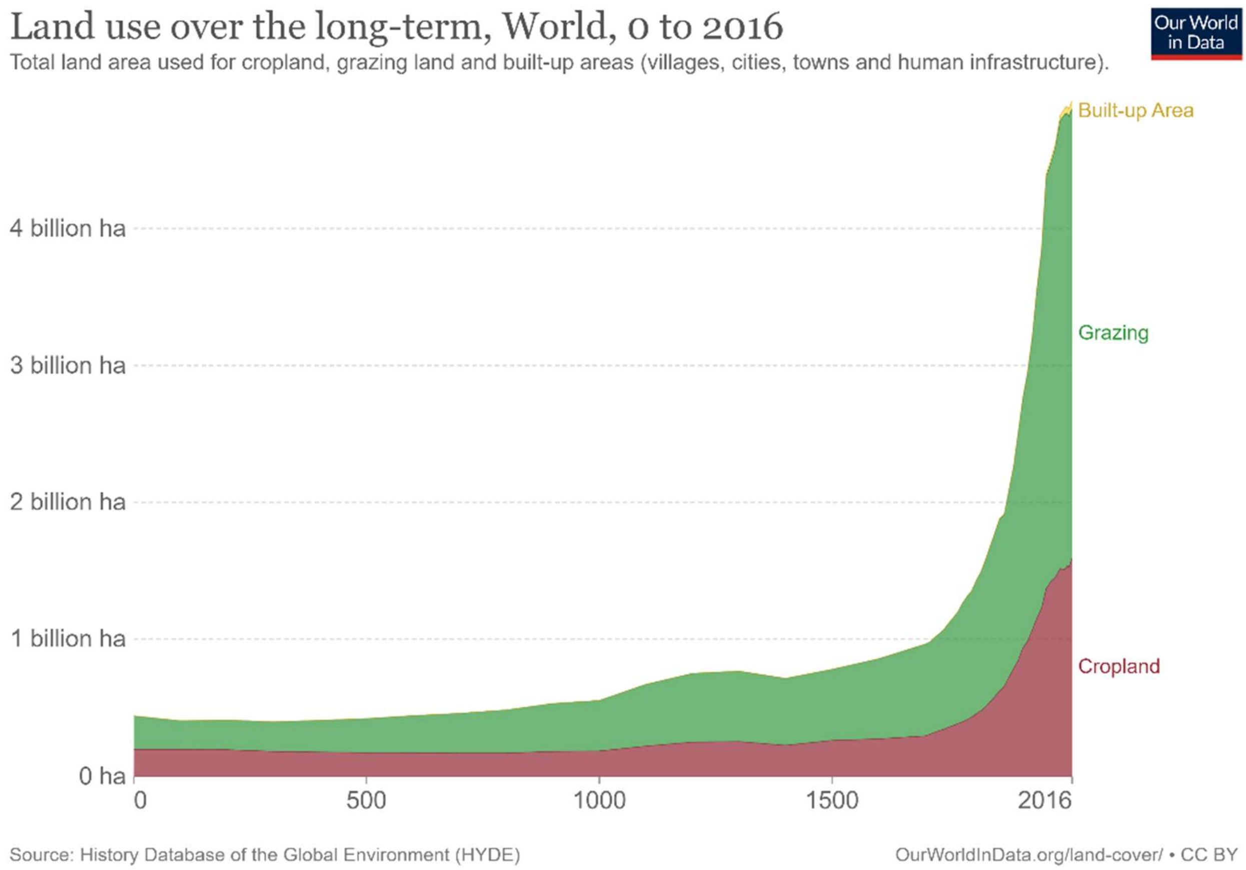


Figure 4: Land Use World 0 to 2016 (Our World in Data)

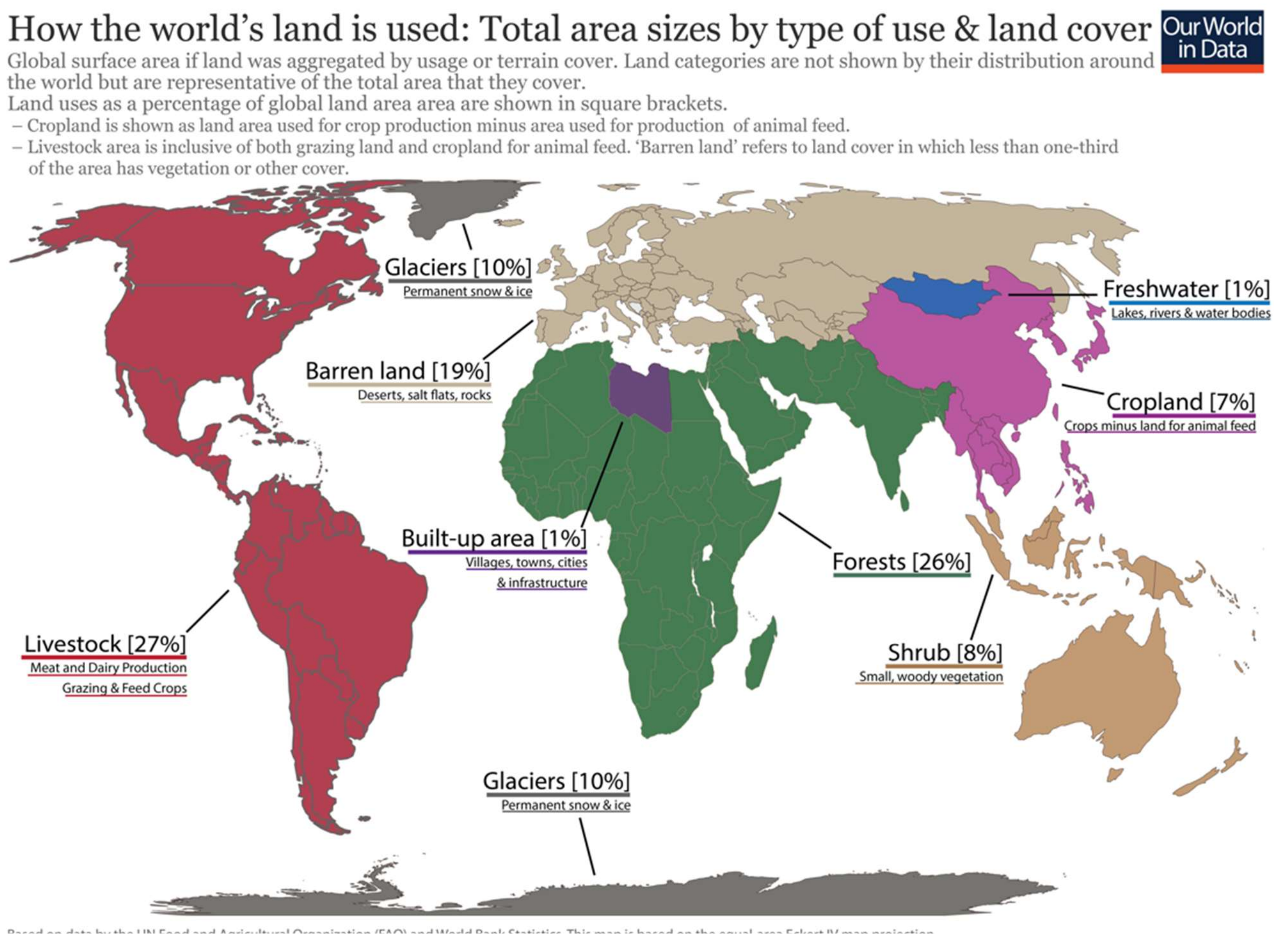


Figure 5: Global Land Use (Source: Our world in data)

In the visualisation of Figure 5, we see the breakdown of global land area today. Glaciers cover 10% of the world, and a further 19% is barren land – deserts, dry salt flats, beaches, sand dunes, and exposed rocks. This leaves what we call 'habitable land'.

Half of all habitable land is used for agriculture. This leaves only 37% for forests; 11% as shrubs and grasslands; 1% as freshwater coverage; and the remaining 1% – a much smaller share than many suspect – is built-up urban area that includes cities, towns, villages, roads and other human infrastructure. As the visualisation in Figure 6 below indicates, most countries in Europe have clearly more non-built up than built-up artificial area, with the exception of Malta.

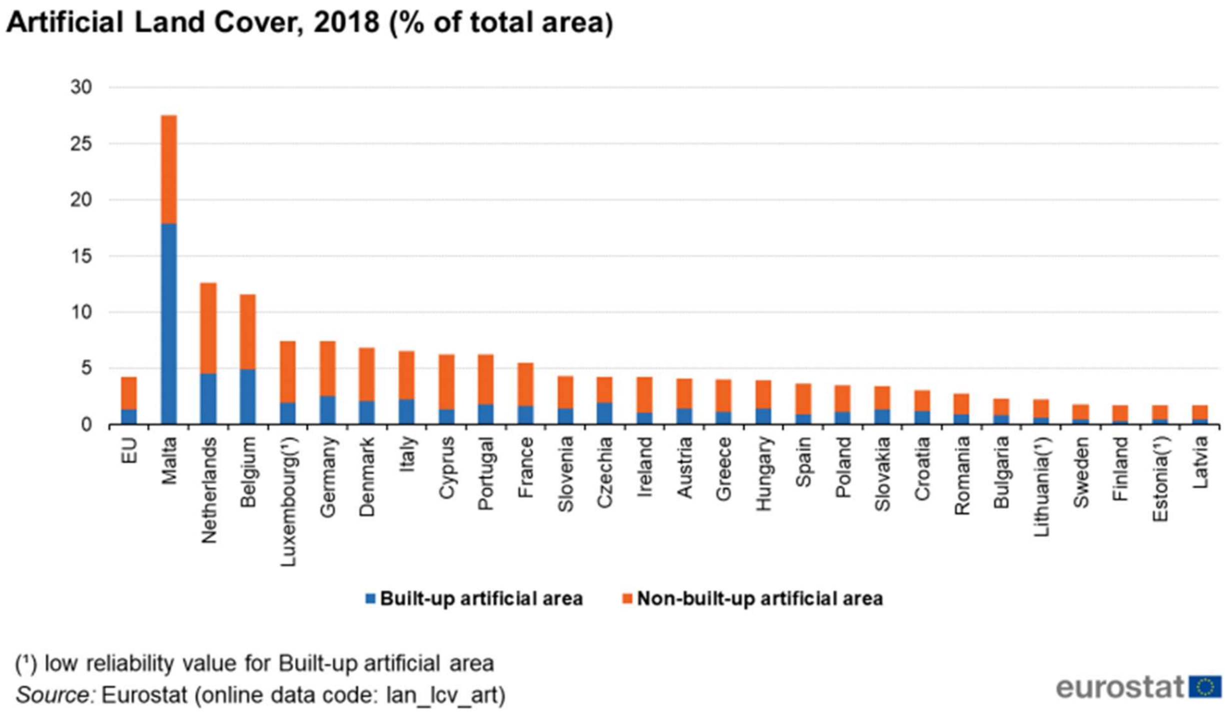


Figure 6: Land Cover in Europe

De- and Re-forestation

Over the decade since 2010, the net loss in forests globally was 4.7 million hectares per year (FAO 2020). The UN FAO estimate that 10 million hectares of forest were cut down each year. Tropical deforestation is mainly driven by pasture extension for beef as illustrated in Figure 7. According to estimates from the paper industry at our current rate, all rainforests will be gone in 77 years.[22]

[22] https://www.tonerbuzz.com/blog/deforestation-facts-and-statistics/

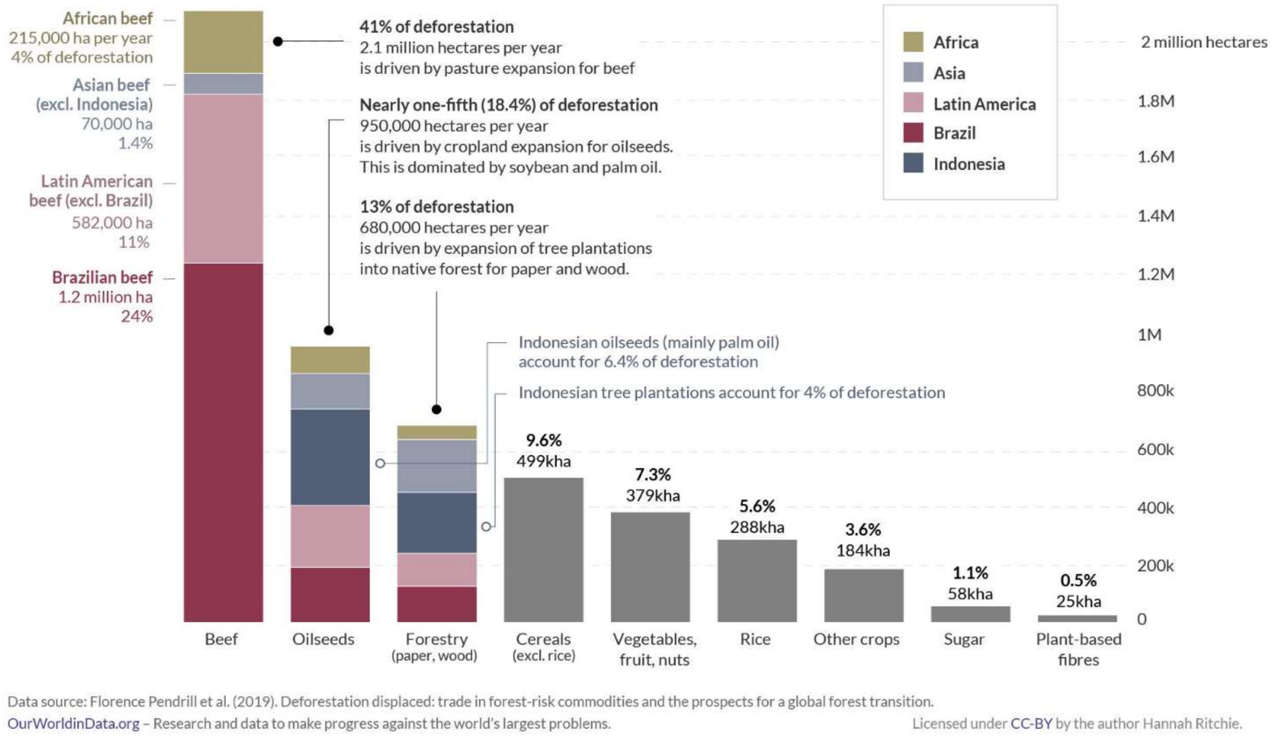


Figure 7: Drivers of tropical deforestation (Our World in Data)

At the same time, reforestation may turn the trend of deforestation, which is again competing with the other uses of the land. According to (Bastin et al. 2019), Earth's ecosystems could support another 900 million hectares (2.2 billion acres) of forests, 25 percent more forested area than we have now. By planting more than a half trillion trees, the authors say, we could capture about 205 gigatons of carbon (a gigaton is 1 billion metric tons), reducing atmospheric carbon by about 25 percent. That's enough to negate about 20 years of human-produced carbon emissions at the current rate, or about half of all carbon emitted by humans since 1960. Others are cautioning such high expectations and argue that the capacity of forests to capture carbon emissions depends on many factors and bad forest management may turn forests into emitters (Popkin 2019; Madrigal-González et al. 2020).

As stated by (FAO 2020) the net loss of forest area has decreased substantially since 1990, but deforestation and forest degradation continue to take place at alarming rates resulting in significant loss of biodiversity. The world is not on track to reach to meet the target of the United Nations Strategic Plan for Forests to increase forest area by 3 percent worldwide by 2030.

Land use for agriculture

The expansion of agriculture has been one of humanity's largest impacts on the environment. It has transformed habitats and is one of the greatest pressures for biodiversity: of the 28,000 species evaluated to be threatened with extinction on the IUCN Red List, agriculture is listed as a threat for 24,000 of them.[23] As illustrated in **Error! Reference source not found.**, 50% of the habitable land is used for agriculture.

[23] https://www.iucnredlist.org/resources/summary-statistics

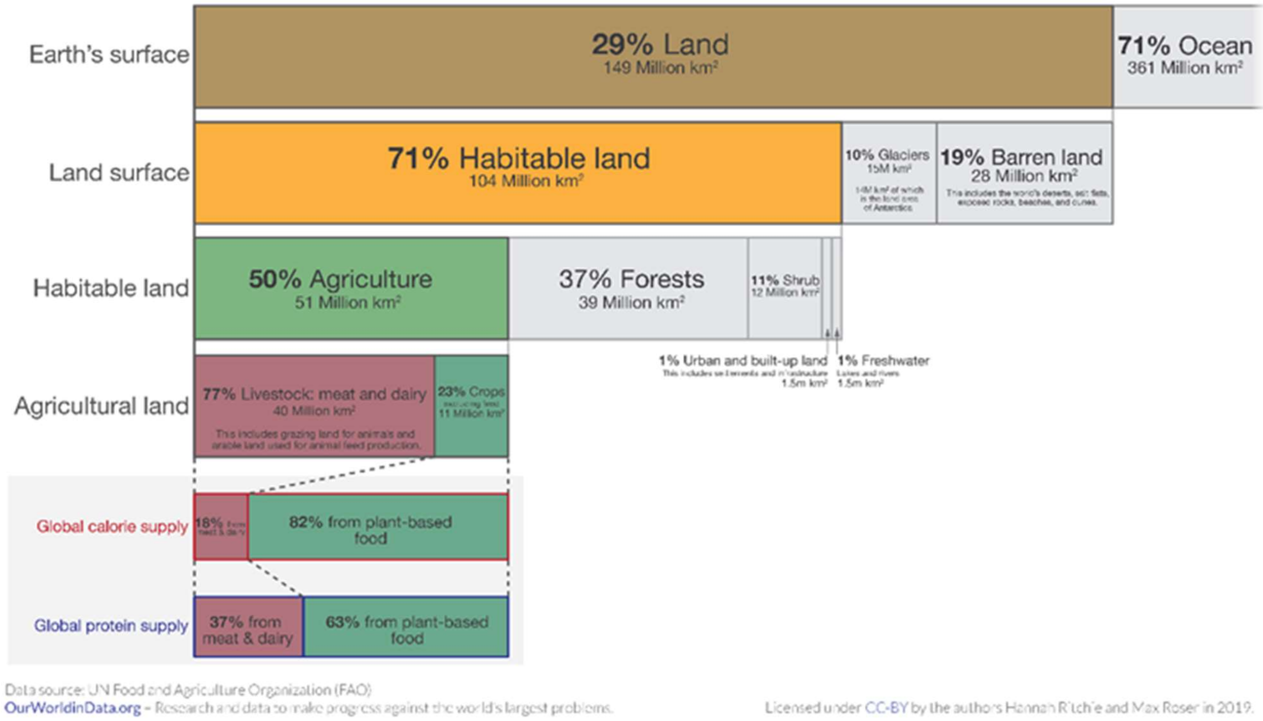


Figure 8: Global land use for food production. Source: Our world in data

At the same time crop yields have increased significantly in recent decades, meaning we have spared a lot of land from agricultural production due to innovative technologies and practices: globally, to produce the same number of crops as in 1961, we need only 30% of the farmland. There is also a highly unequal distribution of land use between livestock and crops for human consumption. If we combine pastures used for grazing with land used to grow crops for animal feed, livestock accounts for 77% of global farming land. While livestock takes up most of the world's agricultural land it only produces 18% of the world's calories and 37% of total protein (Poore and Nemecek 2018). As many countries in the world are getting richer, the consumption of meat is continuously rising globally as illustrated in Figure 9.

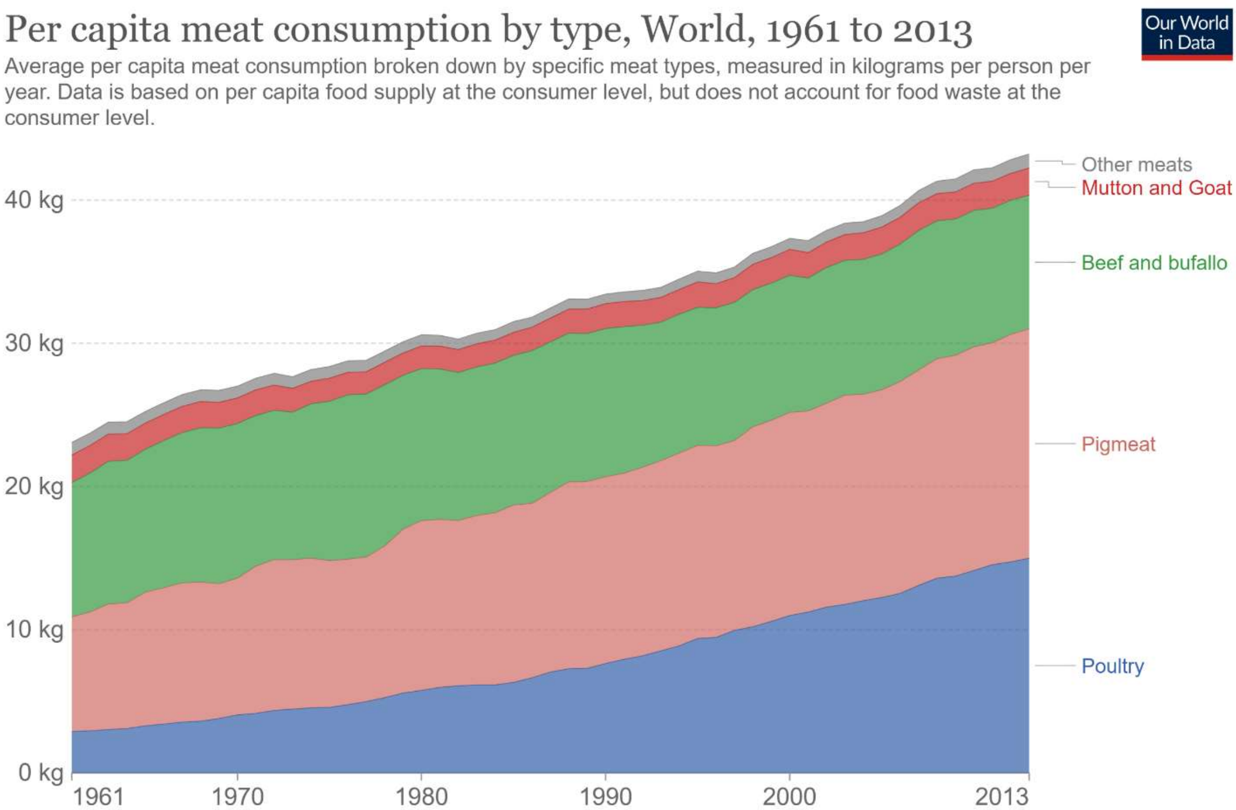


Figure 9: Per capita meat consumption trends.

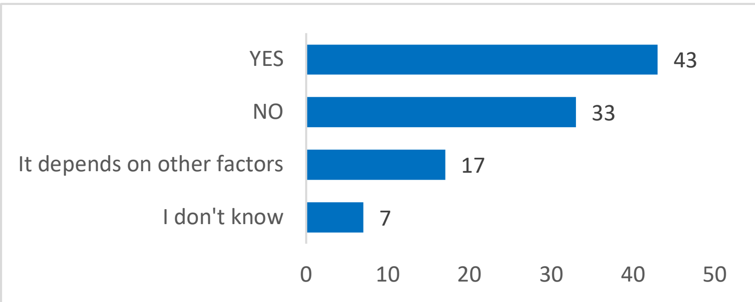
Land degradation
A significant proportion of managed and natural ecosystems are degrading and face further risk from climate change and biodiversity loss. From 1998 to 2013, approximately 20 per cent of the Earth's vegetated land surface showed persistent declining trends in productivity, apparent in 20 per cent of cropland, 16 per cent of forest land, 19 per cent of grassland, and 27 per cent of rangeland. These trends are especially alarming in the face of the increased demand for land-intensive crops and livestock. (Dudley 2017).

Biofuel Land use
Biofuels require a lot of land, with crops like palm oil and soy encroaching upon forests and grasslands but also competing with food production as farmers switch to more profitable energy crops (Kovacs 2015). The global area under biofuel crops was estimated at 45 million hectares in 2010 and is expected to double, to roughly 3–4.5 per cent of all cultivated land by 2030 (Dudley 2017, p. 47). Some argue that, potential negative effects caused by land-use change and agriculture intensification can be mitigated by agroecological zoning, better management practices, the use of eco-hydrology and biodiversity-friendly concepts at field, watershed and landscape scales (Souza et al. 2017, p. 1). At the same time, "advanced biofuels" are using significantly less land than conventional bioethanol and biodiesel e.g., by using all parts of plants or reaching higher process efficiency.

The latest IPPC report provides a highly nuanced assessment (B.3.3; page 19): "The production and use of biomass for bioenergy can have co-benefits, adverse side-effects, and risks for land degradation, food insecurity, GHG emissions and other environmental and sustainable development goals (high confidence). These impacts are context specific and depend on the scale of deployment, initial land use, land type, bioenergy feedstock, initial carbon stocks, climatic region and management regime, and other land-demanding response options can have a similar range of consequences (high confidence). The use of residues and organic waste as bioenergy feedstock can mitigate land use change pressures associated with bioenergy deployment, but residues are limited and the removal of residues that would otherwise be left on the soil could lead to soil degradation (high confidence)."

STI 2050: Delphi Results

Higher use of bioenergy and biofuel can decrease biodiversity, pollute environment and compete with food and ecosystem services.



Land use for renewable energy
Energy systems are undergoing a significant shift to renewable energy (RE). To date, the surface area required for RE systems is greater than that for non-RE systems, exacerbating existing environmental policy challenges, from increasing land competition to visual impacts. A suitable metric for comparing the extent of systems is the power density of electricity production, that is, the electrical power produced per horizontal m^2 of surface area (see an example in **Error! Reference source not found.**).

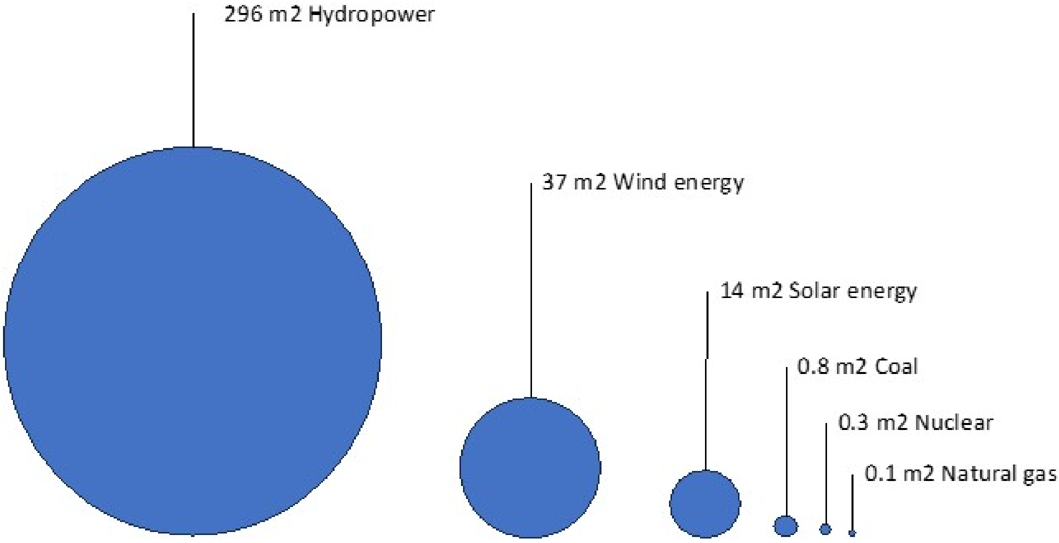


Figure 10: Power Densities of energy sources: Land area needed to power a flat-screen TV (Note: Assumes 100-watt television operating year-round), by energy source. Source: Modified from Bloomberg L.P., David Merill (2021) based on van Zalk and Behrens 2018

Hydropower developments directly flood large areas, open up new areas for exploitation, and alter hydrology with substantial impacts on rivers, floodplains, and seasonal wetlands. Solar and wind farms, also require significant land area and, as with all energy sources, need distribution networks such as electricity grids and powerlines.

Compared with other forms of energy, the distributed nature of *wind turbines* spans large areas. A typical wind plant, however, allows for multiple uses in the spaces between turbines. For instance, in the US, the cumulative footprint of wind energy is 46 915 km^2, deployments are largely found in agricultural settings (93.4%) and within close proximity to the built environment including other wind power facilities, highlighting potential synergies with other uses of the land (Harrison-Atlas et al. 2022).

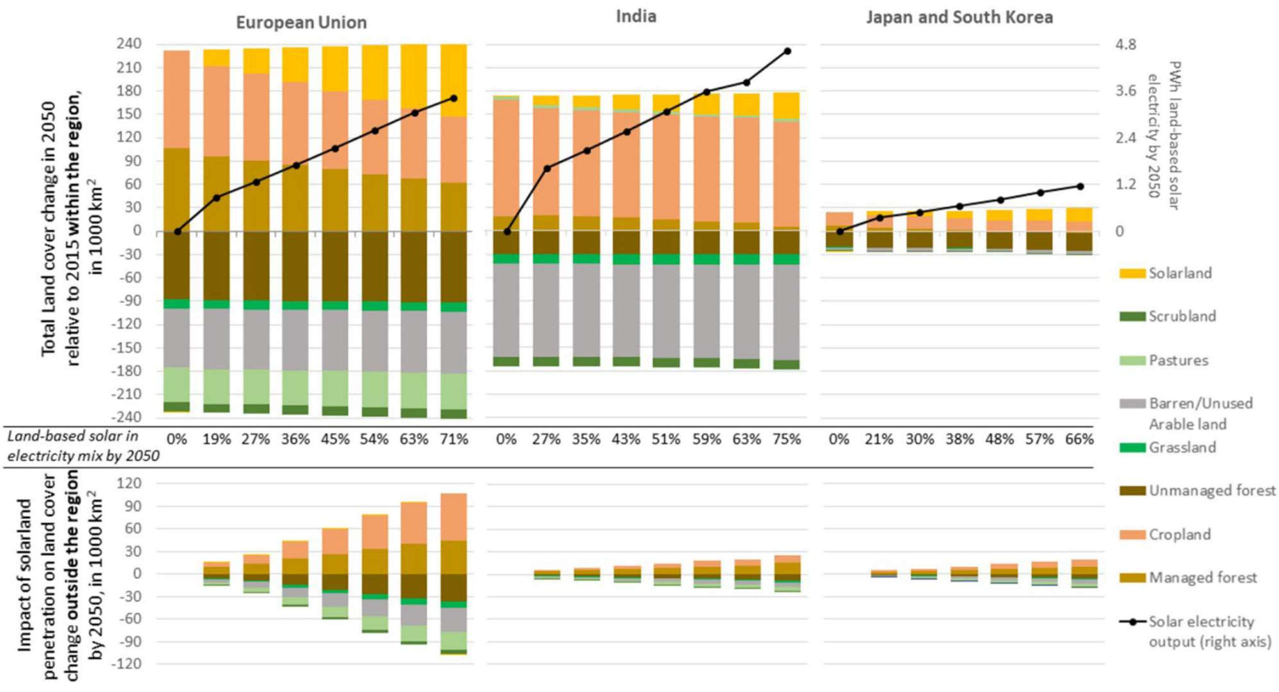


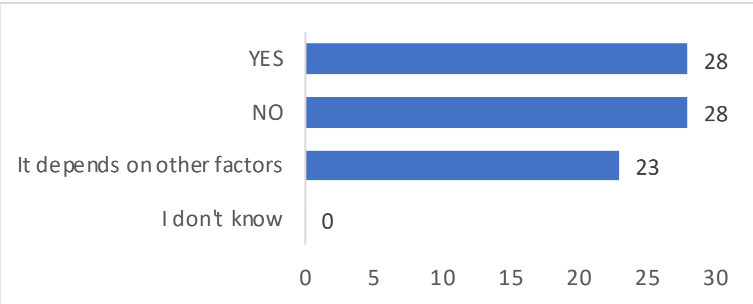
Figure 11: Comparison of land uses. Source: Ven et al. 2021

With *solar energy* accounting for 25 to 80% of the electricity mix, land occupation by utility scale solar energy (USSE) is projected to be significant, ranging from 0.5 to 2.8% of total territory in the EU, 0.3 to 1.4% in India, and 1.2 to 5.2% in Japan and South Korea. This occupation is unequally spread within each of the regions, as areas that are relatively attractive for solar energy are prioritised in each region, such as southern Europe, north-western India, and southern Japan and South Korea. The future land requirements of solar energy obtained for each scenario and region can be put in perspective compared, for example, to the current level of built-up area and agricultural cropland. In the three regions, a large part of the total built-up area (urban and solar land) will consist of solar PV panels or CSP heliostats by 2050 if at least half of the produced electricity comes from solar power. If only horizontal installation of solar panels is considered, land for solar would amount to over 50% of the current EU urban land, over 85% for India, and over 75% in Japan and South Korea. From a different perspective, a significant part of the sunlight captured for commercial use would be used for electricity generation instead of growing crops, especially in Japan and South Korea (29–39%) and the EU (8–10%). The relative projected land area dedicated to either crops or solar energy strongly differs within each region, with potential local ecosystem and landscape implications (van de Ven et al. 2021), see also Figure 11.

However, according to the recent Delphi survey, the impact of solar and wind energy on the land use is multifaceted.

STI2050 Delphi Results

Solar panels and wind turbines entail land uptake, which can lead to land-use conflicts and/or inflict social, environmental, economic harms.



Land use by mining and quarrying[24]

Recent political and economic changes have led to increased investment in mineral extraction, directly resulting in land and soil degradation from deforestation, vegetation burning, and mining operations, along with more widely dispersed environmental and social damage. Open-cast and mountain-top mining are particularly destructive, while the collapse of underground mines can also lead to problems such as subsidence, soil erosion, and contamination of water resources. The extraction of high-value minerals generates large quantities of waste, in the order of tens of millions of tons per year, causing siltation of water bodies, acid mine drainage, and leaching of toxic minerals. This waste also creates air pollution, which can affect human health and suppress crop production. Mining – particularly when it is illegal and thus unregulated – also creates high levels of pollution; for instance, the use of cyanide and mercury in gold extraction leads to the pollution of surface and groundwater.

Land grab from rich to poor

In order to hedge against future food insecurity and price volatility, large-scale land acquisitions or "land grabs" have increased dramatically since 2000, covering more than 42 million hectares dedicated to food, timber, and biofuel crops, primarily in Africa. About 25 per cent of global cropland area, and its associated use of water

[24] Dudley 2017.

and other inputs, now produces commodities that are exported to land-poor but cash-rich countries (Dudley 2017).

Land health as an underlying driver of global pandemics

A recent report released by the Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES) on the linkages between pandemics and biodiversity looked at this very issue – the health of land as an underlying driver of global pandemics (IPBES 2020). Since 1960, land use change, agricultural expansion and urbanisation have driven more than 30% of emerging infectious disease events, according to the Report. 70% of human disease originates in animals, which scientists refer to as zoonotic diseases, according to a report by the Food and Agriculture of the United Nations (FAO 2020).

Rewilding

The practice of "rewilding" has emerged as a method for returning wild lands, and wildness, to landscapes we have altered (Perino et al. 2019). This strategy goes beyond dedicated nature reserves and aims to **restore** self-sustaining and complex ecosystems, with interlinked ecological processes that promote and support one another while minimising or gradually reducing human interventions. Several national parts are adopting the approach.[25] Rewilding, recognises and works with complexity and autonomy as ecosystem-inherent characteristics and acknowledges their dynamic, unpredictable nature. Rewilding also emphasises the emotional experience and perception of wild nature and wild ecosystems without human intervention. Thus, rewilding contributes to increasing requests for spaces where people and especially children can experience and learn about nature.

Tourism

Also, in the context of tourism, land use conflicts are rising. For instance, in coastal communities concerns about spatial degradation due to over tourism are increasingly voiced (Hjalager 2020). At the same time, demands for recreational and touristic use conflict with other land uses such as windfarms (Mordue et al. 2020).

Urban sprawl vs densification

Among the many human activities that cause habitat-loss, urban development produces some of the greatest local extinction rates and frequently eliminates the large majority of native species. Also, urbanisation is often more lasting than other types of habitat loss. Another great conservation challenge of urban growth is that it replaces the native species that are lost with widespread "weedy" non-native species (McKinney 2002, p. 883). A review by (Czech et al. 2000) finds that urbanisation endangers more species and is more geographically ubiquitous in the mainland United States than any other human activity. Species threatened by urbanisation also tend to be threatened by agriculture, recreation, roads, and many other human impacts, emphasising the uniquely far-reaching transformations that accompany urban sprawl (McKinney 2002, p. 883). Given these numerous adverse impacts of (sub)-urban sprawl a key concept in sustainable city planning is densification in order to achieve an optimal use of space. While this can partly be achieved by taller buildings recent studies emphasise that there is an alternative low-rise pathway for urban development that can meet the growing demand for urban floor area and at the same time minimises GHG emissions (Pomponi et al. 2021).

Smaller households with more floor space per person

Around the world, more people are living with more space at home than at any other time in history. As countries develop, individual incomes rise and people prioritise higher order needs, such as privacy, autonomy and the fulfilment of personal ambitions. Around the world, more people are living with more space at home than at any other time in history. The growth of per capita floor area continues with an average annual growth rate of 3% globally (see Figure 12) (Ellsworth-Krebs 2020).

[25] https://rewildingeurope.com/blog/wilder-parks-protected-areas-can-spearhead-nature-recovery-in-europe/

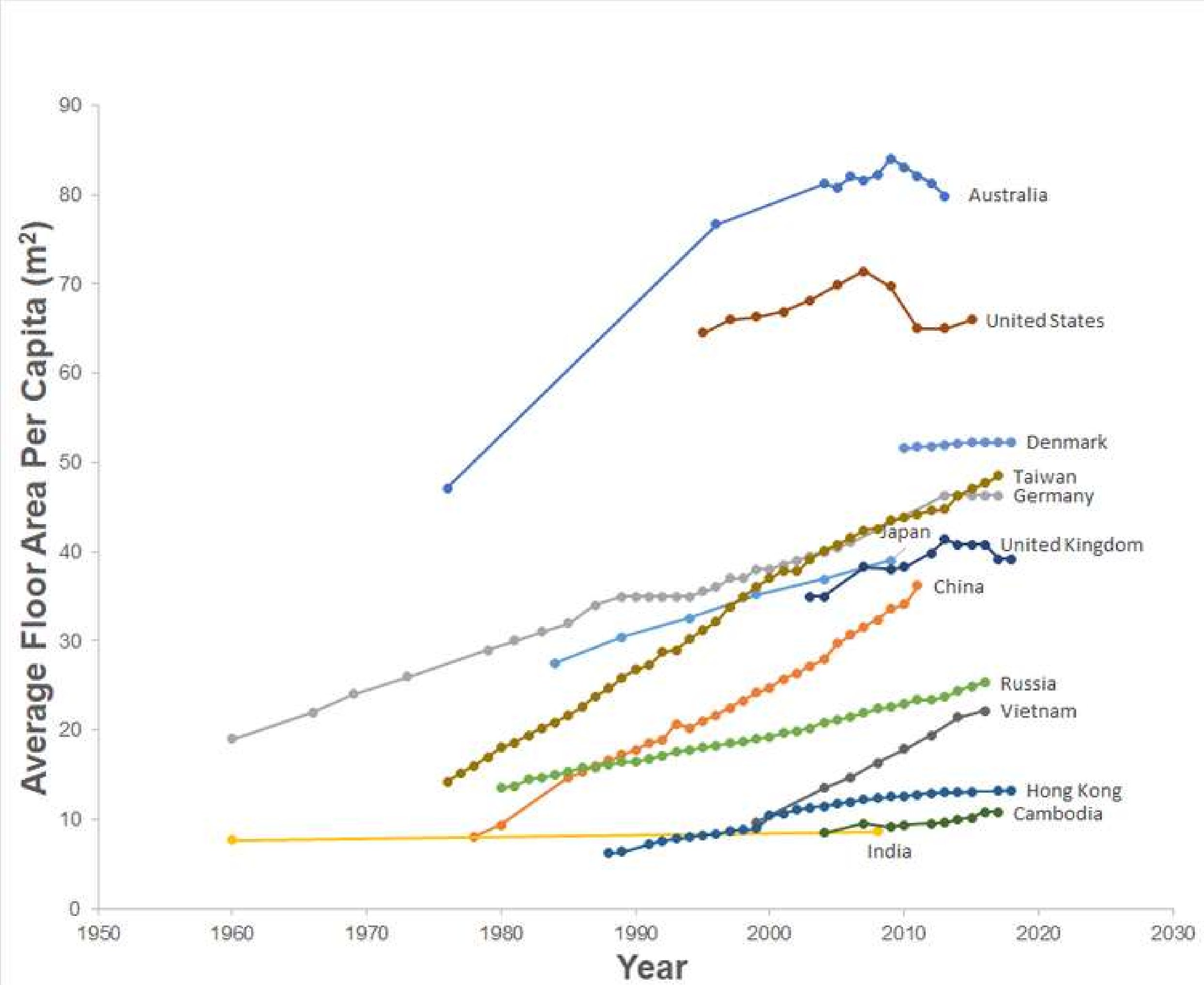


Figure 12: Average Floor Area per Capita Development (Ellsworth-Krebs 2020)

Human Scale City Planning

Cities currently devote a large amount of space and resources to provide parking, primarily used by private cars that are idle 95% of the time (Kondor et al. 2020). For example, in Los Angeles County, where there are 3.3 parking spaces per car, the total area of parking spaces is equal to 14% of total incorporated land area and is 1.4 times larger than the total area used by roads. In dense city centres, parking can account for an even larger share – the total floor area dedicated to parking is between 25 and 81% of land area and can be larger than the floor area of office or retail use that it serves. Using floor area as a metric counts each level of a parking garage separately, and so the spatial footprint of parking is less, but it can still account for over 5% of total urban land areas. Similar levels of parking are mandated in many Asian cities. Provision of parking contributes to urban sprawl and high energy use associated with private car use and building and maintaining an excessive road infrastructure. At the same time alternative concepts are emerging rapidly. The 15-minute city concept (Moreno et al. 2021) entails that urban residents can fulfil six essential functions within a 15-minute walk or bike from their dwellings: living, working, commerce, healthcare, education and entertainment. It is adopted by such diverse cities such as Paris, Melbourne, Bogota, Portland, Shanghai and Cagliari. In general, in many cities around the world a shift in urban planning is underway, away from the dominance of cars, and towards pedestrianisation and more human scaled city development[26].

Debate around public space ownership and publicness

At the same time a fierce debate is going on about the "privatisation of public space" in cities, often triggered by the emergence of privately owned public spaces (POPS) (Kayden 2000). Empirical investigations for London have revealed that what is more typical is the opening up through redevelopment of formally private

[26] https://www.rapidtransition.org/stories/reclaiming-the-streets-the-increasing-trend-of-pedestrianisation-around-the-world/

areas of the city. The real issue at stake seems to be less the actual ownership but the maximisation of publicness (access and use), regardless of ownership (Carmona 2022).

4.2.3 Scenarios

Efficiency and optimisation of land use – Scenario P1

This scenario builds on the current trend of heavy exploitation of the land and it emphasises the optimal use of ecosystem services, especially using land for ensuring maximum production of food and other natural products and resources (Pérez-Soba et al. 2018). Accordingly, land across the EU would be matched to the most appropriate use considering Europe in a globalised world with intensive movement of goods, capital, services and people.

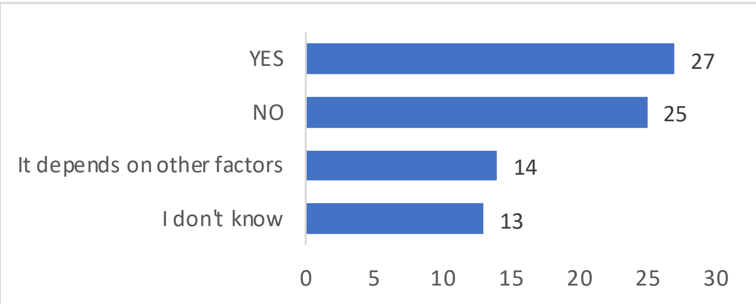
Most of the land is used for just one function, leading to specialisation. Tensions arise from the specialisation. Batteries for renewable energy storage cars requiring increased mining activities and thus conflicts with other uses of the land. Also increasing deployment of onshore wind and solar energy systems would in this specialisation scenario create major tensions with other uses of land, namely the agriculture. This scenario would supply the largest quantity of goods and services at continental scale by most efficient single use of land resources but would probably result in a polarisation of the urban-rural differences, and some remote areas would struggle to keep their population when the location and the quality of the land do not offer opportunities for its competitive exploitation.

Some productive forest and agricultural land located in less suitable areas would be taken out of conventional use. This would lead to land sparing (Fischer et al. 2014), with the sustainable intensification of agriculture and forestry. For agriculture, this would occur on the landscapes best suited to supporting production functions – access to water, fertile soils and proximity to market – but the abandonment of more extensive primary production systems in less-favoured areas. For forestry, this vision implied that forest production would shift from the south of Europe to less drought-prone areas in the north.

This vision would require coordination between the EU Member States (e.g., to decide on the best location for land use and land functions across scales), at the national level (e.g. financial incentives supporting the management of abandoned land or re-structuring in remote rural areas) and regional and local level (e.g. plans to reverse urban sprawl and encourage compact city development). It would also require investment in connectivity and mobility across Europe. Society would need to embrace the restructuring of Europe's landscapes to obtain maximum efficiency from the single use of land, and this may sometimes conflict with cultural identity issues. A high spatial variation of different, sometimes contrasting, land change trajectories across the EU also reflects differences in the socioeconomic, environmental, and land use history across Europe (Holman et al. 2017). This indicates the need for vertical coordination and region-specific planning and policy-making to guide land change. As the reforestation trends over the last decades continue in Europe, forest cover increases considerably (2.9–3.7 % of total EU area). Intensification of forest management is most frequent in Scandinavia and mountainous areas across Europe leading to the contraction of wild areas, particularly in Scotland and Scandinavia.

STI2050: Delphi Results

Land-use planning can lead to over-control and loss of ecosystems that take a long time to form or are undervalued by local authorities (e.g. important early-succession habitats).



The governance of land emphasises multi-stakeholder engagement in land planning, but the engagement is typified to consultations. There is tension between public value and private gain from land use when the ecosystems are considered. The creation of public goods is rewarded by market mechanisms (e.g., payments for safeguarding ecosystems services and creating carbon sinks). Political collaboration between and beyond the EU Member States would help optimise the use of resource at the EU level and prepare for intense global competition for resources requiring more efficient land use to meet society's needs. Across the EU, land is used in a well-planned, well-ordered and zoned use of space.

Towards Effective Multiple Use of Land – Scenario P2

In this scenario, society's needs are met regionally in a coherent relationship between people and their resources. In this less globalised economy, there is a move towards regional autonomy. A Europe that has a greater appreciation of the resources that are available regionally and of the value of trying to live without external inputs, with the help of technological developments. Serving the regional population and keeping regional coherence are key priorities. This reduces the need for transportation and its negative effects.
This scenario builds on emerging practices spinning around **multiple land use**, which refers to the use of land for more than one purpose, for example, grazing of livestock, recreation and timber production. The term may also apply to the use of associated bodies of water for recreational purposes, fishing and water supply (United Nations 1997).

Land uses are localised in small areas based on innovative approaches to living, working and recreation. There is high diversity in goods and services, land use and society. A Europe incorporates multifunctionality locally without distinct sectoral land use areas (for agriculture, settlement, nature conservation, etc.). Localised thinking and decision-making are supported by a radical shift in behaviour and 'bottom-up' politics. Rural areas flourish by having a strong green economy where biodiversity is improved through a clean environment and green infrastructure. There is a huge reduction in 'food miles' as products are grown and consumed locally. Technology facilitates the sustainable management of natural resources (Pérez-Soba et al. 2018).

Nature is pervasive and ubiquitous (even in dense urban areas through park systems, green rings, green facades and roofs or converted disused transport sites). Cities have learned to combine multiple uses of the land to move towards more sustainable practices. Green infrastructure is a planned network of natural and semi-natural areas in urban areas strategically designed to solve problems with stormwater management, heat stress, air quality and biodiversity, to name just a few examples. While sometimes green infrastructure competes with other uses of land, for instance, the case of parks, often urban trees, green roofs and facades are integrated in built environments with multiple uses. Green infrastructure also mitigates waste, in the construction industry by increasing the longevity of exterior surfaces due to the protective layer against sunlight and high temperatures. Green roofs and facades act as an extra source of insulation and protection against temperature extremes: reducing indoor temperatures in the summer and increasing temperatures in the winter. Green infrastructure also reduces the amount of runoff to rivers by acting like a sponge and reducing energy consumption at the wastewater treatment plants. On the rural areas, a "crop-centric" approach integrates renewable energy services into rural communities with limited capital and land.

Rural viability increases as a result of the strong diversification of activities, creating new opportunities for urbanites who want to start part-time farming. New ways of living appear, such as communal farms. New villages emerge in former forests and on abandoned rural land. Combining solar PV and agriculture improves land-use efficiency, minimises the energy and carbon footprint of agriculture, and offsets PV costs. Even with limited capital, or with geographically isolated agrarian communities, solar infrastructures over existing crops integrate renewable energy services into rural communities. The combination of off-grid solar PV and high value crop cultivation are often viable offering co-benefits in land use, energy production, greenhouse gas emission reductions that lead to economic feasibility and environmental improvements (Choi et al. 2021).

Food is produced locally and new practices allow food to be grown everywhere (in cities, forest and nature areas). Consequently, intensity increases in some areas but may decrease in traditional agricultural regions. Forest cover increases through the conversion of marginal land and an increase in agroforestry. Multifunctional mixed wood production is everywhere to cover local demand for all the services delivered by forests. Protected areas are open to sustainable food production and forestry where it helps to meet local demand. Forest stewardship is focused on increasing the number of goods and services delivered.

Multiple use of land goes hand in hand with territorial cohesion at the regional scale, which does not isolate communities or close borders. The regions create local autonomy, more resilience, more involvement by the population, and more participatory democracy (Pérez-Soba et al. 2018). The governance practices favour human-centric co-creation in the land use planning with experimentation and continuous adjustment. The reward system for creating public goods is elaborated and recognises the importance of non-market rewards (e.g., new forms of land tenure in exchange for sustainable land use).

Land use adapting to nature – Scenario P3

This scenario has emerged after a series of crises and system breakdowns in the context of the climate catastrophe. The economic, social and physical repercussions have halted economic growth and led to a reduction of life expectancy and shrinking of human population. As a means of survival humans are forced to seriously engage with ecosystems. In doing so they are building on the one hand on elements from Indigenous legal thinking about land such as property as "curation", property as making kin, property as reconciliation, counselling with nature[27] and on the other on early initiatives such as recognising rights of ecosystems (Figure 14) or the forming of the "Loire Parliament" (Figure 13).

In this land use scenario, human and non-human beings interact in collectives where each being's status and ability to realise life projects continuously emerges out of the relationship with the others. Subsequently, humans see themselves as deeply entangled in the natural environment of the land they are living on. Categories like landowners, land users and passively owned land property make as little sense as the nation state's defining power over land use. Land has multiple purposes and uses, it is no longer perceived as passive, silent and fragile but as an active holder of rights. Within this pluriverse of beings, land use practices are negotiated between plants, animals, humans, ecosystems and the earth's forces for each collective individually, loosely guided by an overarching framework of multi-species-justice. Land-Law-making is seen as a practice every being needs to engage in to connect to the land they are living on. Scientists, artists and indigenous people are often acting as "diplomats" by mediating and translating as well as continuously mapping out the collectives. "Institutional diagnostics"[28] is used to collectively identify the governance system for each specific context that maximises ability for mutual care and prevents harm to be externalised to other collectives. Property is seen as entering into a treaty with a place or ecosystem, rather than owning it. These treaties are seen as the beginning of a relationship to hold for many generations and are reaffirmed through rituals such as mutual gifts. Understanding the language of plants, trees and animals on the shared land has become a matter of survival. Each city develops its charter of public space rights and responsibilities[29] with a strong voice for non-human inhabitants.

The scenario is not one of easy harmony but of constant struggle for collective survival. In this scenario, humans finally "land" on earth and "face Gaia" (Latour 2017). There is no larger system with certain overarching rules serving as a guidance across all collectives.

The governance framework for land use negotiations in this scenario is provided by the notion of multi species justice on the one hand and Elinor Ostrom's design principles for governing common resources on the other. Humans are just one of many voices in these negotiations, and often take the role of the "youngest sibling" who is learning from the elder relatives. Extractive practices such as mining and pollution are unthinkable (Latour 2017).

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[27] https://provocations.darkmatterlabs.org/property-rights-property-wrongs-micro-treaties-with-the-earth-9b1ca44b4df

[28] Ostrom 2007, Young 2011.

[29] Carmona 2019.

Figure 13: Les conversations du Parlement de Loire

Figure 14: Recently Recognised nature Rights (Source: https://provocations.darkmatterlabs.org/property-rights-property-wrongs-micro-treaties-with-the-earth-9b1ca44b4df)

4.2.4 STI Conclusions

By exploring the current land use practices and developing the three scenarios this case study offered an opportunity to consider alternative pathways for land use. The single use of land scenario leads to competition and localised efficiency and optimisation, which would lead to dangerous consequences when detached from the larger system and ecosystem performance considerations. The multiple uses of land scenario would trigger more combinations of practices, which would require lots of learning (and unlearning from single-use paradigm) both urban and rural contexts. The immersive 'use' of land scenario aligns with the application and diffusion of nature-based solutions. This requires new understanding of nature, for instance, native knowledge. The scenarios consider the shortcomings of single use of land use and related conflicts and the need for exploring the shift from the P1 of efficient single use of land to the P2 of effective multiple uses of land and further to P3 of adapting the land 'use' to nature, thus shifting our relationship with nature from exploitation to adaptation. One could also say that P1 is on land-efficient innovation whereas P2 and P3 about nature-positive innovation.

A major factor affecting each scenario and their possible materialisation is the question of land ownership. In particular, access to the land is often bound to the ownership. The scenarios can also open the discussion on more horizontal governance of territorial issues, and the possible reconfiguration of policy and governance structures better aligned with natural ecosystems. **Error! Reference source not found.** identifies implications to research and innovation policy by reflecting STI directions, programming and infrastructure needs vis-à-vis the three scenarios on alternative uses of land.

Table 5: STI Directions, programming and infrastructure vis-à-vis three scenario approaches on land use

	P1	P2	P3
STI-Themes/directions	Mapping land for best specialisation schemes Reforestation and its impact on biodiversity, climate and other land use Land degradation Food vs fuel Renewables vs other land uses Land health as an underlying driver of global pandemics Nature conservation	Measurement and mapping of multiple use of land Agroforestry Green infrastructure (sponge cities) Urban mining Energy and food production Public space ownership and access Pedestrianisation of city centres Forest stewardship Social change and prosumerism	Native cultures Hunting and gathering grounds Permaculture Nature land rights Commons based land use practices Rewilding Environmental health (psychological health) Communication with other forms of life Spirituality, religion
How to do STI? Approaches in designing Instruments and programs	Programmes for improving the efficiency of different land uses	Programmes for interdisciplinary and cross-sectoral innovation ecosystems on multiple use of land Participatory governance – innovations strictly connected to territory and community	Follow nature in its own research programmes Living labs with nature e.g., for ecovillages Human survival experiments
Knowledge	Normal science to understand: Competing interests Regulation to limit harms Centralised management Efficiency Protecting on critical zones	System knowledge on: Combination of interests Distributed and nodes Multiple use Green infrastructure	Transdisciplinary research: Being able to communicate, capture tacit knowledge: Native wisdoms Integration with nature Listening and negotiating Permaculture
STI infrastructures required	Earth observation systems Geographic information systems (GIS)	Measurement of multiple-uses of land Green building labs	Ecovillage living labs Equipment for mapping critical zones International networks for knowledge exchange on localised practices

Impact areas with special importance (beyond the obvious ecosystems & environment)	security and geopolitics (dealing with the land tensions)	resilience, social capital, health and skills, security and geopolitics (dealing with the land tensions), strong democracy	Impact on other species, Strong democracy to enable successful negotiations

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4.3 Case Study 3: Soil to Soul

Bianca Dragomir

Figure 15: Soil art. Photos credit: Talaandig Soil Paintings Facebook Page

4.3.1 Introduction

This case study proposes three scenarios exploring human-soils relations. As sense-making devices, these scenarios discuss how different ontologies of soils shape different actions, be them soil management practices in agriculture contexts or Research and Innovation (R&I) practices.

The scenarios are summarized below:

Eyes on the prize is tributary to a dichotomic view regarding the human sphere and the (soil) nature sphere. This can be articulated in different approaches: one urges a fundamental respect for and need to save nature by conservation or by controlling land use change; the other is concerned with the problems and possibilities resulting from the human alteration of soils and seeks salvation in technology-based interventions meant to mitigate human impacts.

Cultivating each other builds on the view that nature is intrinsically social, with socio-cultural and biophysical contexts continually co-evolving. In this scenario, agroecology and the soil management practices following its principles embrace the lessons that nature soils teach humans about the way they function. Therefore, we and the soils cultivate each other – they cultivate our understanding of their own dynamics, we cultivate them to nourish ourselves.

Full circle of life calls for new ontologies of soil nature that are able to accommodate not only individual species and their competing interests, but also environments and relations that undergird and enable life flourishing. In exploring the notion of relationality that includes humans and nonhumans, this scenario describes approaches to human-soil relationships that embed care and/or situated spirituality. These views open new forms of soil investigation and practice that acknowledge the biophysical agency of soil ecosystems, their sociocultural constitution, and the dynamic interactions between them. In this scenario, the microbial is taking centre stage, as a result of the growing recognition of the vital role soil organisms play in most soil functions.

4.3.2 What are soils? How do they support life?

The definition of soil depends on the perspective that generated it, so an engineer, a farmer or a diplomat may describe the meaning of 'soil' from different angles. From a soil science perspective, soil is the surface mineral and/or organic layer of the earth that has experienced some degree of physical, biological, and chemical weathering. In brief, soil is a material composed of several ingredients which interact in a myriad of ways – approximately half air and water, 45% minerals and 5% organic matter. Most of that 5% is plant, animal, and microbial residues in various states of decomposition, and only 10% is life, but that 10% contains some of the greatest biodiversity in the biosphere (Dasgupta, 2021).

The skin of the earth is essential for all life-sustaining processes on our planet. A healthy soil is a magnificent reservoir of life to the extent that 25% of animal species on Earth live underground, while 40% of organisms in terrestrial ecosystems are associated with soil at some point during their lifecycles (FAO, 2020). They provide habitats that support thousands of different species of fungi, bacteria, and invertebrates, which then work in combination to drive the Earth's carbon, nitrogen and water cycles. An estimated 12,000 miles of hyphae, or fungal filaments, are found beneath every square meter of healthy soil. Moreover, soil is rich in the nutrients that plants need to survive and provides the physical structure for the roots and stems that helps hold plants up. Soils are also critical to human survival: after food production, the most important function of soils is the replenishment and purification of groundwater, which supplies our drinking water. Considering this, a simple, straightforward understanding of soil health refers to its ability to support all life, human and non-human.

It is argued, however, that the dominant research paradigm for soil health emphasizes instrumental values - the unilateral flow of benefits from soil to humans to improve human well-being (e.g. nutrient cycling, plant available water, pollutant degradation), neglecting and marginalizing non-instrumental values of soil health (Friedrichsen et al., 2021). Soil health has value to society beyond instrumental value in the form of relational values that emerge, for example, from farmers' narratives about their motivations and incentives. These relational values are the benefits derived from a caring relationship with soil by an individual or a community. Moreover, intrinsic values exist outside of the value placed on nature by humans.
Thus, the act of defining the baseline of what a potentially healthy soil looks like (in any specific region) is a valued act. In the following sections exploring three perspectives on soil ecosystems, there will be ample opportunity to investigate the plurality of values associated with soil health. But for now, it's important to underscore the fact that healthy soils are supporting life – all life.

4.3.3 Drivers of soil health - threats/pressures affecting soils

Soils are threatened all over Europe and globally because of a range of human activities. It is estimated that 60-70% of soils in the EU are in an unhealthy state (EC, 2021). The typology of degradation and its intensity is directly influenced by the anthropogenic activities carried on respective soils, such as deforestation, mining, extractive farming practices or over-exploitation, excessive grazing, excessive ploughing, urban expansion etc. This means that different soils (respectively different land cover types – arable land, pastures, forests, artificial surfaces) 'suffer' in different ways.

We focus in this synthesis section on soil degradation that is specific to agriculture land. While soil is threatened by a number of human activities, agriculture is a particular culprit, given the scale and depth of soil degradation it causes: The main share of land in Europe is used by agriculture land, with grass- and cropland together making up 39 % of land cover in the EU. The pressures and threats for all terrestrial species, habitats and ecosystems most frequently reported by Member States are associated with agriculture (EEA, 2015 in SOER, 2020). Various pressures from agriculture can have combined impacts on ecosystems and have cumulative effects. For example, in relation to soil, pesticide use can reduce soil biodiversity, irrigation can lead to salinization, soil compaction resulting from heavy machinery use can reduce growth and resilience of crops as well as carbon formation and water retention capacity, and the risk of soil erosion is also increased through compaction as well as through increased land parcel size. The share of GHG emissions from agriculture is currently around 10 % and while overall emissions have declined from 1990, in the last few years they have increased from both livestock and soils (SOER, 2020).
The following examples regarding types of degradation (physical, chemical, biological) reflect how widespread and diverse are the threats and pressures across EU agricultural soils.

Soil contamination

Soil contamination can be diffuse and widespread or intense and localized (contaminated sites). Sources of contaminants include the residues of plant protection products, mineral fertilizers, biosolids (some composts, manures, and sewage sludges). Depending on soil properties and their concentrations, contaminants in soil may enter the food chain, threaten human health and be toxic to soil-dwelling organisms (FAO and ITPS, 2017). Substances that are not readily degradable will eventually leach into surface and groundwaters or be dispersed by wind erosion (Silva et al., 2018 in SOER, 2020).

- *There may be as many as **2.8 million contaminated sites in the EU, but only 24 % of the sites are inventoried.***
- *Cadmium – mainly originating from mineral phosphorus fertilizers – accumulates in 45 % of agricultural soils, mainly in southern Europe where leaching rates are low due to a low precipitation surplus**. In 21% of agricultural soils, the cadmium concentration in the topsoil exceeds the limit for groundwater, 1.0 mg/m3 (used for drinking water)** (SOER, 2020)*
- *While copper is an essential micronutrient, excess levels in soils are a source of concern. Copper has been widely used as a fungicide spray, especially in vineyards and orchards. **Evidence shows elevated copper levels in the soils in the olive and wine-producing regions of the Mediterranean** (Ballabio et al., 2018 in SOER 2020).*
- *There is also increasing concern about **the residence and accumulation of pesticide residues and their metabolites in agricultural soils, and their potential release mechanisms**, for example due to acidification and wind erosion (Silva et al., 2018 in SOER 2020). Exceedance of critical loads for nitrogen is linked to reduced plant species richness in a broad range of European ecosystems*
- *Excessive nutrient inputs to soils through fertilizers, which leads to acidification and eutrophication. **For approximately 65-75 % of the EU-27 agricultural soils, nitrogen inputs** through fertilizers, manure, biosolids and nitrogen-fixing crops **exceed critical values** beyond which eutrophication can be expected (SOER, 2020)*

Soil organic matter decline

Soil organic matter (SOM) is essentially derived from residual plant and animal material, transformed (humified) by microbes and decomposed under the influence of temperature, moisture, and ambient soil conditions. Soil organic matter plays a major role in maintaining soil functions because of its influence on soil structure and stability, water retention and soil biodiversity, and because it is a source of plant nutrients. The primary constituent of SOM is soil organic carbon (SOC) (FAO, 2015).

- ***Some 45 percent of soils in Europe have low or very low organic matter content** (0–2 percent organic carbon). This is particularly evident in the soils of many southern European countries, but is also the case in parts of France, the United Kingdom, Germany, Norway, and Belgium. A key driver is the conversion of woodland and grassland to arable crops (FAO, 2015).*
- *Different forms of soil degradation (SOC loss, tillage, pollution, compaction, and erosion) negatively impact the habitat available for soil organisms**. In all regions across Europe, the species richness of earthworms, springtails and mites has been negatively affected by increased intensity of land use** (Tsiafouli et al., 2015).*
- *In a recent assessment covering the period 2009-2015, **carbon in mineral cropland soils in the EU-28 was shown to be broadly stable or slightly declining** (albeit at much lower levels compared with other land cover categories), while **carbon in grasslands showed slight increases** (Hiederer, 2018).*
- *The largest amounts of SOC are found in organic soils such as peat. Peatlands are currently under threat from unsustainable practices such as drainage, clearance for agriculture, fires, climate change and extraction (FAO, 2015). **13-36 % of the current soil carbon stock in European peatlands might be lost by the end of this century** (Gobin et al., 2011).*

Soil erosion

Soil compaction is the result of mechanical stress caused by the passage of agricultural machinery and livestock. The consequences are increased soil density, a degradation of soil structure and reduced porosity (especially macroporosity). This causes increased resistance against root penetration and also negatively affects soil organisms, as their presence depends on sufficiently sized pores (Schjønning et al., 2015 in SOER, 2020). Compaction is known to be a significant pre-cursor of erosion. Soil compaction may lower crop yields by 2.5-15 %, but it also contributes to waterlogging during precipitation events, which not only reduces the accessibility of fields to machinery but also negatively affects run-off, discharge rate and flooding events (Brus & van den Akker, 2018 in SOER, 2020).

- ***About 23 % of soils in the EU-28 are estimated to have critically high densities in their subsoils**, indicating compaction (Schjønning et al., 2015 in SOER, 2020).*

Soil compaction

Soil compaction is the result of mechanical stress caused by the passage of agricultural machinery and livestock. The consequences are increased soil density, a degradation of soil structure and reduced porosity (especially macroporosity). This causes increased resistance against root penetration and also negatively affects soil organisms, as their presence is restricted to sufficiently sized pores (Schjønning et al., 2015). Compaction is known to be a significant pre-cursor of erosion. Soil compaction may lower crop yields by 2.5-15 %, but it also contributes to waterlogging during precipitation events, which not only reduces the accessibility of fields to machinery but also negatively affects run-off, discharge rate and flooding events (Brus and van den Akker, 2018).

- ***About 23 % of soils in the EU-28 are estimated to have critically high densities in their subsoils**, indicating compaction (Schjønning et al., 2015).*

Salinisation and sodification

While naturally saline soils exist in certain parts of Europe (e.g., in Spain, Hungary, Greece and Bulgaria), the main concern is the increase in salt content in soils resulting from human interventions such as inappropriate irrigation practices/ use of salt-rich irrigation water.

- *Artificially induced salinization is affecting significant parts of Sicily and the Ebro Valley in Spain and more locally in other parts of Italy, Hungary, Greece, Portugal, France, and Slovakia (FAO, 2015).*

Theme	Past trends and outlook	
	Past trends (10-15 years)	Outlook to 2030
Urbanisation and land use by agriculture and forestry	Deteriorating trends dominate	Deteriorating developments dominate
Soil condition	Deteriorating trends dominate	Deteriorating developments dominate

Figure 16: Assessment of past trends and outlook regarding land use and soils (SOER, 2020).
Note: The figure refers to agriculture land use but not exclusively.

4.3.4 Scenarios

Table 6: Overview of scenarios regarding soils, informed by the three perspectives

	Perspective 1: Using, protecting and restoring	*Perspective 2: Co-shaping socio-ecological systems*	*Perspective 3: Caring within hybrid collectives*
Scenario title	**Eyes on the prize (P1)**	**Cultivating each other (P2)**	**Full circle of life: womb and tomb (P3)**
Key descriptors on the social construction of soil nature	- Soil as provider of goods and services, mainly valuable when benefitting people - Human interventions on soil seen as alternating between destruction/degradation and reparation/conservation	- Soils and humans are moulding each other continuously - Humans work in partnership with the dynamics of soils towards resilience/adaptiveness of the socio-ecological system	- Human-soil communing emerging in relational entanglements where not one element holds 'the key' - Who animates whom is an open question when the soil community is seen as the ongoing creativity of a myriad of creatures - New ecological cultures of care for the non-human world
Types of knowledge	- Science is mainly technoscience - Knowledge has value if it can facilitate appropriation and management of resources.	- Knowledge builds on a continuous feedback loop with nature - Embedding indigenous or traditional local knowledge and experience -Technoscience may be involved, but less myopic to the interactions among constituents and across scale, time	- The re-emergence of other languages, sensibilities, and practices of relating to soils, beyond the dominance of natural science framings - New technoscientific imaginaries of soil aliveness - Science participates to an ecological culture around soils - Acknowledgement of spirituality not as defiant of scientific practice, but as contributor to its enrichment
Implications: Soil management practices	- Specific solutions to particular impacts ('half-baked sustainability')	- Ecosystem based adaptation - Nature based solutions - Agroecology and its associated practices – agroforestry, regenerative agriculture, permaculture etc	- Agroecology and its associated practices – agroforestry, regenerative agriculture, permaculture etc - The practice of 'collaboration' with microbes and other soil biota

			- Soil management practices 'infused' by indigenous knowledge and spirituality
Implications: Science/R&I policy	- More affordable and accessible innovative technologies aimed at reducing the various types of soil degradation	- Living labs and lighthouses to co-create, test and pioneer innovations for soil health at local level - Sets of sustainable soil management practices in line with agroecological principles, adapted to the wide variability of soil ecosystems and types - Research on narratives of personal and collective identity as intimately connected to soils; their role in mobilizing farmers/stakeholders towards sustainable agriculture practices	- Investigating soil microbiome materialities and agencies - Soil 'microbiopolitics' (contestations around the appropriate ways of relating to microbial entities) as a crucial arena for future research - Greater engagement with soil sense-abilities building on emerging technologies/techniques: eDNA metabarcoding; technologies aimed at non-invasive, non-destructive, 'seeing' and 'hearing': e.g., visualisation methods, bioacoustics - The realms of imagination and spirituality receiving attention in emerging soil care research.
Limitations	- Perpetuation of a separation between the natural and human sphere that cannot support ecosystem flourishing on the long run - Inability to radically challenge ('stretch and transform') current regimes with their power concentrations	- If solely the responsibility of farmers, agroecology and the associated sustainable agriculture practices cannot strive against the economic pressures in current contexts - The success of these practices is supported/hindered by the narratives of farmers and other stakeholders regarding their identity	- Challenges in translating into practices and norms the understanding of human-soil relationships as matters of care, marked by spirituality - Life-affirming intentions can still be overruled by the logic of the greater economic game

Eyes on the prize – Scenario P1

Using, (abusing) then protecting and restoring ecosystems

This scenario with perspective 1 builds on the view that there is a dichotomy between humans and nature. This might lead to a '*nature-first'* approach which urges a fundamental respect for and need to save nature, or get back to nature, or might generate a '*people and environment'* approach, which is concerned with the problems and possibilities resulting from the human alteration of natural resources, environments, and organisms (Castree, 2001). The former leads to land use change controlling, restoration, and conservation. The latter to technology-based interventions meant to mitigate human impacts. Such soil technologies bring their own valuable contributions but, instead of transforming our intimate representations and our connection with soil nature, risk generating new ways of commodifying and appropriating it.

Social construction of nature

This scenario with perspective 1 has its roots in the natural sciences, which have emphasized an ontological separation between humans and nature since at least the European Enlightenment. In the 'pristine myth' (Denevan, 1992) paradigm generated by natural sciences, human societies are recent destroyers or, at least, disturbers and troublemakers in a mostly pristine natural world. The notion of an untouched/pristine Earth became part of the DNA of early conservationists thinking of the nineteenth century.

This separation between the human sphere and the natural sphere persisted, albeit becoming more nuanced, and informed the concept of ecosystem services that appeared in the late seventies of the twentieth century, as a useful metaphor to draw public attention to the degradation of ecosystems caused by human activities. The notion then gradually acquired the status of a scientific concept, with the release of the Millennium Ecosystem Assessment (MEA) in 2005 and further gained traction in scientific, policy and political arenas dealing with environmental issues. The working definition of this concept is straightforward - ecosystem services are, essentially, the benefits humans derive from nature, directly and indirectly. Proponents of the concept emphasized the role of the health of ecosystems on service provision. As for people and societies, they are, above all, the beneficiaries or users of these services. When authors examine the influence of societies on the environment – in our case on the soil, it is either in terms of pressure on ecosystems and degradation of services (e.g., pollution, resource overexploitation) or in terms of preservation and protection of ecosystems (Barnaud & Antona, 2014).

Authors of MEA proposed four types of ecosystem services, a classification that while debated, is still frequently adopted: *provisioning services* (products obtained from ecosystems), *regulating services* (benefits obtained from regulation of ecosystem processes), *supporting services* (ecosystem functions underlying other ecosystem services); *cultural services* (non-material benefits people obtain from ecosystems). The Mission Board Soil Health and Food follow the same terminology when discussing ecosystem services derived from soils, such as: producing adequate quantities of nutritious and safe food, feed, fibre and other biomass for industries; storing and purifying water, regulating flows, recharging aquifers, and reducing the impact of droughts and floods thereby helping adaptation to climate change; capturing carbon from the atmosphere and reducing emission of greenhouse gases from soils, thereby contributing to climate mitigation; nutrient cycling supporting crop productivity and reducing contamination; preserving and protecting biodiversity by preserving habitats both above and within the soil; supporting the quality of our landscapes and greening of our towns and cities.

The success of this concept meant that diverse audiences increasingly acknowledged the concrete, tangible, and measurable existence of services supplied by soils to humanity, and it drew attention to the necessity to protect and better understand them. Bearing in mind there are critiques of the notion of ecosystem services, including soil ecosystem services, the notion marks the importance gained by the view of humanity as dependent on soils as non-human nature. Other concepts are meant to smoothen the human-centric accent of ecosystem services: the term '*ecological solidarity'* is a concept that refers to the same idea of human dependence on ecosystems, but without the economic connotation of the word service. In the same vein, bodies like the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) adopted the concept '*nature's contribution to people'* (NCP).

Figure 17: Credit: Cross section through fertile soils by Romul Nutiu

Implications for soil management and for R&I

The view that societies are degraders of nature that needs to be protected in biosphere reserves, habitat areas, and wilderness zones trades on the distinction between a predatory humanity and a fast-disappearing nonhuman world (Castree, 2001). Following this vision, a response to degraded land/soils would be the prohibition of agricultural activities within a protected area that provides some services of particularly high value (Barnaud & Antona, 2014). Controlling land use is relevant, for example, when discussing the relevance of soils for climate change mitigation, noting that wetlands, grasslands, and forests contain a large portion of the carbon stored in soils (preceded by soils of permafrost regions, which store the largest amount of soil carbon on the planet: 25%). When wetlands are converted into arable land or (short) rotation plantations, or if peat is extracted, large amounts of greenhouse gases are released. The same holds for the conversion of grasslands and forests. Thus, controlling land use change holds by far the greatest potential when it comes to global soil carbon stocks – much greater than agricultural and soil management practices (Beste & Lorentz, 2022).

In brief, land use change controlling, restoration and conservation are means to prevent human-induced degradation. It is an obvious way of keeping humans - the abusers, the destroyers - at bay.

Moreover, the 'people and environment' approach generates a tension mainly between our demand for soil's provisioning services, on one hand, and our need for regulating, maintenance, and cultural services, on the other hand. This is further complicated by the fact that some final services (services and goods directly appreciated by humans) might come at the cost of the intermediate ecosystem services (some of which remain mostly invisible, although they contribute to the final services) (Birkhofer et. al, 2015).

The ample debates revolving around the ways in which these tensions can be reduced are, in essence, aligned with the thinking that soils are providing services, benefits, goods to us humans, we just need to be careful regarding the extent and intensity of our demands from soils. To call it bluntly, eyes are (still) on the prize – our food (with focus on yield, nutritional quality), our clean water, our clothes, our medicines, our landscapes provided by the generous soils.

In this context, soil science together with soil management practices contribute to a narrative of technofixism, oftentimes primed to generate isolated solutions for specific impacts. The atmosphere of urgency and anxiety about imminent resource exhaustion seems to give impetus to 'breakthroughs' and 'disruptive innovations'. Plenty of these techno-solutions are performing the complicated balancing act of keeping the aim of agricultural yield/gain while promoting sustainable soil care. The tension has to do with two complex goals: saving the world from starvation and saving the soils from ourselves. Puig de la Bellacasa (2015) adds an interesting dimension to this by noting that the tension between production and sustainability at the heart of soil science involves a clash of temporalities: between acknowledging soil as a slowly renewable entity and the accelerated 'technological fix' touted by techno-optimists. The paced renewal of soils' fertile capacities (including by leaving parts of the land at times in a fallow state) is incompatible with the general atmosphere of emergency. The author adds that this renders caring for soils into mere control of the object of our care (as opposed to care as an inherent relationality, a notion we discuss in perspective 3).

As described in the section on drivers of soil health, there are multiple agriculture-induced types of soil degradation, one of which being the contamination of soils following the excessive nutrient inputs to soils through fertilizers. Against the problem of leaking, for example, site- and crop-specific nutrient management has proven an efficient way to reduce emissions associated with the use of nitrogen fertilizers while still getting crops the nutrients they need to succeed. Moreover, the use of nanoscale active ingredients, features like controlled release, and targeted delivery of nanofertilizers are being developed as efforts to promote sustainable agriculture (Toksha et al., 2021).

With regards to pesticides development, the trend of global pesticide development has been gradually shifting from chemical pesticides to biological pesticides, GM crops, seeds, RNAi pesticides, and abiotic stress control agents. Of those, biopesticides are gaining popularity as lower-environmental-impact alternatives to conventional synthetic pesticides. Some predictions posit that biopesticides will equal synthetic (chemical) pesticides in terms of market size by the late 2040s or early 2050s (Umetsu & Shirai, 2020).

However, it's worth scrutinizing these innovations against the backdrop of transition theory, which discusses different niche-derived transition pathways, distinguishing between innovations that '*fit and conform*' to the established socio-technical regime from the ones that '*stretch and transform*' it (Smith & Raven, 2012). In brief, 'fit and conform' pathways focus on innovations which offer competitiveness for the dominant incumbent players. For instance, input-substitution solutions such as biopesticides, climate-resilient seeds, and other bio-based products are increasingly commoditized and patented by agro-chemical companies that normally sell agro-chemical inputs; thus, continuing farmers' dependence on large-scale monoculture systems and external-input markets (Larsen, 2021).

Advanced technologies like sensors, artificial intelligence, and robotics are also relevant in this scenario - they are being proposed as means to increase food production efficiency while reducing resource use and/or prevent soil degradation. The argument put forward is that combining digital tools (such as GPS, sensors and data modelling software) with automated technologies (e.g., smart tractors, drones and robots) will help farmers be more precise with inputs (i.e. seeds, water, fertilizers and pesticides), avoid soil compaction and minimize erosion while increasing their knowledge of agro-ecological conditions (including weather and landscape interactions and soil and plant health). Smart robots may even be better suited for intercropping, or growing multiple crops in the same field, a sustainable farm practice that encourages soil health and decreases pests but is costly and inefficient to do with current technologies.

However, there are multiple challenges associated with deploying robots in agriculture, from the considerable cost of design and engineering increasingly better ones to the large energy consumption involved with smart systems, to the resources necessary in building them, that implies draining the soil through the mining of minerals, like copper and lithium, to the issue of waste disposal (Miller, 2021). From the labour perspective, opinions greatly diverge on the impact of agricultural tech, with some voices suggesting that it can positively contribute to growth in rural communities by creating new workplace opportunities, and others anticipating the development of a high-skill/low-skilled bifurcated labour market and the exploitation of marginalized and racialized workers by landowners, governments, and corporations (Rotz et al., 2019). Outside the agricultural sector, agritech may aggravate exploitative practices in mineral mining, and may even exacerbate a global underclass of workers programming AI algorithms in unfair working conditions (Miller, 2021).

STI drivers of change from the Delphi study

- *Mitigation of human impacts on nature (including soil) through conservation and restoration*: Planning for nature reserves on a planetary scale; Land restoration; Conservation, restoration and proper management of existing natural carbon sink habitats (grasslands, forests); Ecological corridors;
- *Agritech reconfigured as big data science;*
- *Automated technologies* to identify, monitor and eradicate invasive alien species in terrestrial ecosystems
- *New fertilizers and solutions for reducing hydrogen and phosphorus leakage*: Improving yield predictions and estimations of nutrient availability to adjust the fertilization rates; Fertilize on plant demand assessed by sensor/ model/ RS advancements; Development of phosphorus-use efficient plants; Nanofertilizers; Nano chelated iron fertilizers; Controlled release fertilizers;
- *Increase water use efficiency*: Precision irrigation; Non-soil-disturbing weed control systems;
- *New pest control methods*: Nanobiotechnology for pest control; Plants with durable resistance to biotic stress by gene editing; Targeted molecular interventions such as dsRNA; RNAi genetic sprays; Insect growth regulators; Targeted molecular interventions such as dsRNA.

Cultivating each other – Scenario P2

Co-shaping socio-ecological systems

This scenario with perspective 2 is marking a clear departure from the assumed distinction between the human and the nature sphere. In fact, it builds on the view that nature is intrinsically social, with socio–cultural and biophysical contexts continually co-evolving. The constant, profound, shape-shifting entanglement between soils and social systems is the most natural thing there can be. In this scenario, agroecology and the soil management practices associated to its principles embrace the lessons that nature soils teach humans about the way they function. Therefore, we and the soils cultivate each other – they cultivate our understanding of their own dynamics, we cultivate them to nourish ourselves.

1. Social construction of nature

This scenario with perspective 2 is grounded in the understanding that the human sphere and the natural sphere – in this case the soil ecosystems – are far from being separated. Land and soil use can be thought of as a tapestry of ever-evolving anthropoecosystems with higher or lower degrees of transformation – more or less human-shaped, or ‘domesticated’ environments (Stephens et al., 2020).
The social construction of nature is scrutinized. Scholars in critical geography point out that ‘nature’ and ‘wilderness’ exists only in people's imagination because, concretely, the impact of humans' actions can be found everywhere, in any ecosystem. "Nature has never been simply 'natural' [...] Rather, it is intrinsically social", “the physical characteristics of nature are contingent upon social practices” (Castree, 2001).

The ancient soil *terra preta* – dark earth – of the Amazon is an illuminating example. While much of the soil in the Amazon rainforest is very nutrient poor, muck like a thin red dust, there are patches, often along rivers, where extraordinarily fertile, deep, dark black soil can be found – rich with calcium, phosphorus, and potassium. The extent and spread of *terra preta* have contributed to the revelation that the Amazon is not a pristine wilderness that was only ever home to a few scattered peoples. It shows that pre-Columbus, agrarian communities “fundamentally changed their home, collaborating with the nonhuman world to create complex new ecologies that included them” (Marris, 2019).

Coevolution theory supports this perspective, as it addresses how different entities or relationships mutually influence each other’s evolution. Coevolution is a process of open and non-deterministic change between culture, practices and biophysical environments that mutually influence each other’s evolution (Schill et al., 2019 in Haider et al., 2021). This line of thinking rejects the notion of ecological and social/cultural systems as separable entities, proposing instead a focus on processes and dynamic relationships that constitute a social–

ecological whole (Weisz et al., 2011). For example, agricultural practices can be understood as coevolving with the landscape and the soil, as the practice shapes the soil, and the soil shapes the practice. The soil-related practices of sowing and harvesting, together with storing and preparation of food are examples of social–ecological practices that have coevolved with landscapes over millennia in response to changing environmental and social contexts and needs.

Soil culture theory accentuates even more the human-soil interdependencies and posits that different types of soil distributed throughout the world have fostered different cultures, for example: rice paddy soil cultures, loess cultures, oasis soil cultures, grassland soil cultures, coral limestone soil cultures, laterite soil cultures, red-yellow soil cultures, brown forest soil cultures, podsol cultures (Fujiwara,1990 in Minami, 2009).
Finally, some streams of literature around the notion of ecosystem services also incorporate this thinking by discussing the role of people in the provision of ecosystem services, through the intended or unintended positive impact of their activities on ecosystems. Examples from agricultural practices refer to the influence of livestock grazing on biodiversity in grasslands, the impact of agricultural land-use on pollination or the aesthetic value of agricultural landscapes (Barnaud & Antona, 2014).

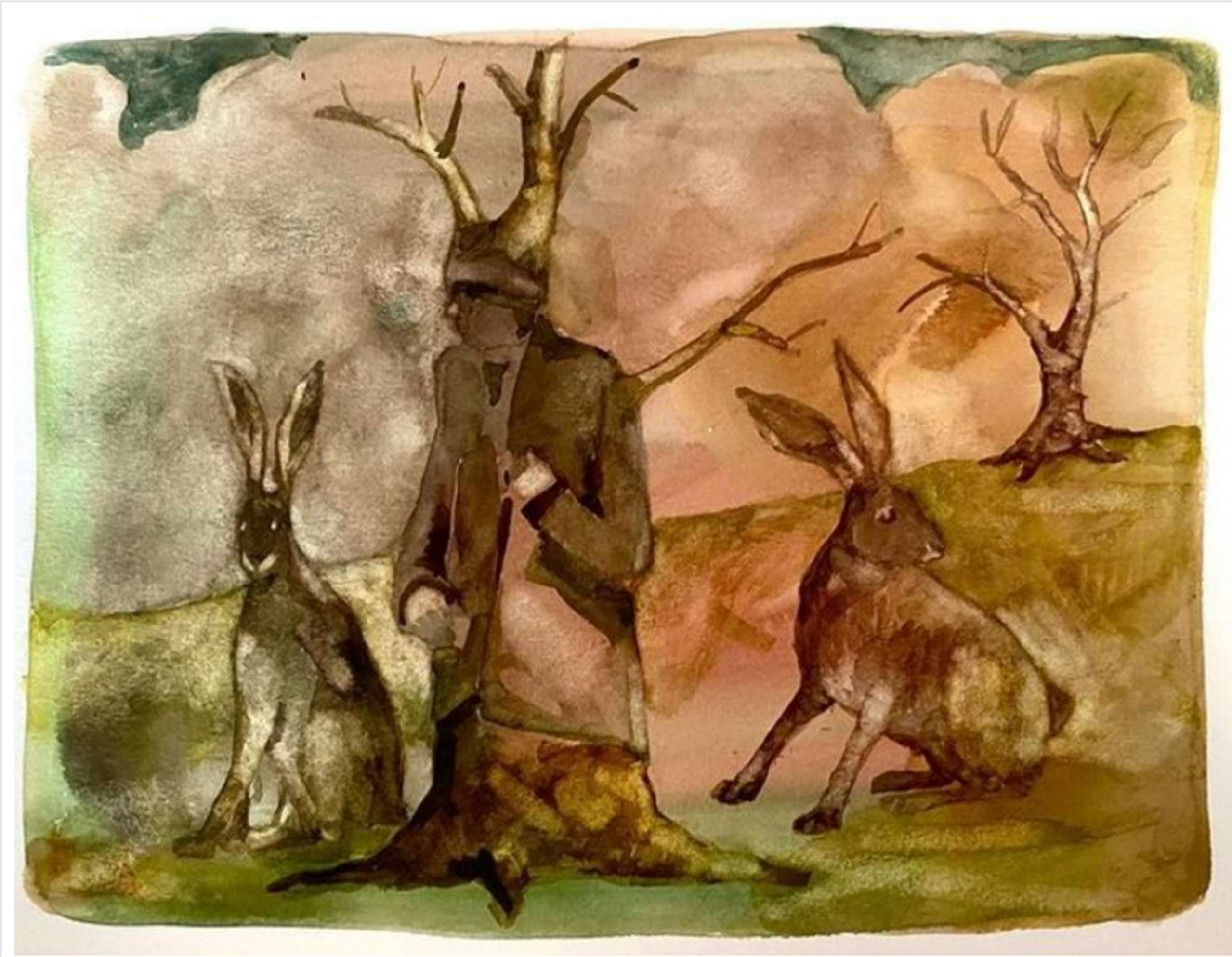

Figure 18: Credit: The Glen by Travis Shilling (Source: https://ingramgallery.com/artists/travis-shilling/index.htm)

Implications for soil management and for R&I
In this scenario with perspective 2, soil management requires an integrated strategy that goes beyond isolated solutions for specific impacts. It emphasizes the interlinkage between the diversity, quality, vitality and health of soil, plants, animals, and people, following the understanding that human-soil is a dynamic relationship that constitute a social–ecological whole. As such, human management of soils is based on a continuous feedback loop with nature – farmers/soil managers are educated about current evidence on how soil ecosystems function, how they interrelate with other ecosystems (water, air), and are aware of the fact that the complex web of interactions – spatial and temporal – cannot be forcefully simplified. These practices require time for positive effects to materialize. While these practices do not imply a return to ancestral forms of agriculture, some are rooted in indigenous or traditional local knowledge and experience (Beste & Lorentz, 2022).

Agroecology, a holistic approach to agriculture, follows principles of ecology coupled with food and nutrition security, food sovereignty and food justice. Agroecology promotes a functional biodiversity and nutrient cycling and the principle of working with nature. It seeks to maximize the autonomy of farmers, emphasizing and drawing on farmers' knowledge and local resources, while challenging power structures for social and ecological transformation. It is important to underline that rather than imposing a prescriptive framework, agroecology has been lauded for articulating a set of flexible values and principles that allow bespoke implementation in specific territorial contexts, reflecting their social, political, and biocultural circumstances. This contrasts with top-down attempts to propose a generalized agroecology which uproots it from the place-based, social, and political moorings which define agroecology. (For example, institutions such as the FAO and the French government have taken up agroecology in their policy discourse, but they have been criticized for reframing agroecology in narrow technocratic terms) (Anderson et al., 2019). As agroecology is knowledge-intensive rather than resource-intensive, boosting knowledge has been claimed as a critical component of any strategy to promote agroecology.

Moreover, while theories of transformative learning often focus on individual learning processes, there are important contributions preoccupied with collective learning processes, with analyses focusing on: the conception of territory as a subject of learning processes (McCune & Sánchez, 2019), the process of local dynamization (López-García et al., 2019), agroecology learning networks as an integral part of the process of social movement building (Anderson et al., 2019).

Agroecology is gaining increasing interest from European farmers, civil society organizations, and policy experts, who underscore the fact that advancing an alternative to the established agri-food regime means reclaiming decision-making power and processes from powerful lobbies and corporate interests. The European Commission openly endorsed agroecology as a preferred, albeit non-exclusive, approach to agriculture in the *Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system*. There are voices suggesting that its success depends on its prioritization by the Horizon Europe mission on soil health and food, supported by Common Agricultural Policy (CAP) reforms (Larsen, 2021).

Agroforestry, organic farming, regenerative agriculture, permaculture are all practices that uphold agroecology principles, promoted as pathways towards sustainable farming practices in Europe, given their potential to empower small-scale farmers, enhance agroecosystem resilience, and promote nature-based solutions, all within a broader perspective on food security and sovereignty.

In agroforestry, a version of agroecology, perennial plants such as trees and shrubs are specifically combined with cropping systems and / or livestock (agrosilvopastoral systems). There is a substantial amount of research in Europe dealing with ecological aspects of agroforestry, such as carbon sequestration, root length and root interaction of trees and crop, biodiversity (Ivezic et al., 2021). For example, Project Drawdown proposes Multistrata Agroforestry (a perennial cropping system that features layers of carbon-sequestering vegetation, with one or more layers of crops growing in the shade of taller trees) as a solution at the centre of land-based climate solutions, noting that although its adoption potential is modest, it can have a disproportionately high mitigation impact because it can offer the high sequestration rates of afforestation and forest restoration while providing food.

Regarding the effect of trees on annual crop yields, there is little consensus. A recent study concludes that there is a scarcity of relevant information on yields in agroforestry system under European growing conditions (Ivezic et al., 2021).

Organic farming follows the principles of agroecology, but it's particular in that it requires certification. Furthermore, the objectives of regenerative agriculture are similar to those of organic farming and agroecology; it focuses on the improvement of soils, water cycles, vegetation and productivity through agriculture, emphasizing soil building and humus enrichment. Project Drawdown defines the Regenerative Annual Cropping solution as any annual cropping system (excluding rice production) that includes at least four of the following six regenerative practices: compost application, cover crops, crop rotation, green manures, no-till or reduced tillage, and/or organic production. These practices sequester carbon in soils and reduce emissions at modest rates but have wide adoption potential and thus impressive mitigation potential.

Permaculture also avoids mineral fertilizers and synthetic pesticides and works with diversity. In addition, it specifies a particular arrangement of crops and primarily uses perennial varieties. Most permaculture cultivation practices are rooted in traditional indigenous knowledge. Permaculture promotes high resilience under changing external influences and in particular extreme weather events. Its practice involves farming based on natural cycles and ecosystems (Beste & Lorentz, 2022).

While the agricultural practices described above involve farmers managing soils in a more convivial way, the impact of their efforts can be curbed or hindered by the socioeconomic contexts in which human actors are embedded – for example through the necessity of staying financially afloat.

It's worth noting that the potential to mobilize more farmers/communities to engage with sustainable agricultural practices (this can also be referred to as 'sustainability transition') also depends on the narratives of the farmers in relation to their land/landscape, they personal and collective identities being closely connected to the lands/soils where they live and work. For example, a recent study on the crucial role of landscape in the dairy sector in a rural area in the Netherlands (the Green Heart) discusses, among others, two prototypical narratives amongst the farmers: 'Stewards', and 'Artisanal entrepreneurs'. Stewards are typically very concerned with the biodiversity on their land and in their soil. They aim to restore the health of the whole ecosystem. On the other hand, artisanal entrepreneurs perceive themselves as custodians and producers of the landscape; they may adopt punctual techno-fixes but resist a more radical change of the regional landscape. There is still ample room for research regarding place identity in different European landscapes. Understanding the role played by landscape (and more granularly land and soil) in identity formation and reformation means better, more intimate understanding of what drives farmers in running their farms the way they do. Transitioning towards sustainable agriculture practices might rely heavily on the capacity to navigate and/or alter these attachments.

This scenario calls for interdisciplinary and transdisciplinary approaches in soil-related research and innovation; current mechanisms reflecting such approaches are the Living Labs and the Light Houses. Living Labs are places to experiment on the ground, established on territorial, landscape, or regional scale. They represent user-centred, real-world research environments in which not only science, business and organizations jointly carry out research and development, but also the users themselves take an active role within the innovation processes. Lighthouses are single sites, like farms or parks, where scientifically proven good practices and solutions are demonstrated. They are places for mutual exchange and peer-to-peer learning. Good practices are further tested under real life conditions to inspire other practitioners to move towards sustainable soil and land management (EC, 2022). A recent project called *Soil Mission Support* created an interactive map of existing initiatives in Europe that qualify, to different degrees, as Living Labs or Light Houses; out of them over one hundred are related to agriculture.

STI drivers of change from the Delphi study

- *Sustainable agricultural practices*: Agroecology, Pastoralism, Permaculture; Agroforestry; Appropriate tillage regimes; Intercropping; Optimized crops for mixed cropping; Strip cropping; Agricultural production systems to sustain ecological restoration (e.g., native seed farming);
- *Soil amendments*: Composting, Biochar, better integration of waste streams in fertilization schedules; Symbiotic nitrogen-fixing bacteria; Free-living nitrogen-fixing cyanobacteria; Phosphorus-solubilizing biofertilizers; Potassium-solubilizing microbes; Nitrogen-supplying mycorrhizae.

Full circle of life – Scenario P3

Immersing and caring

This scenario with perspective 3 is even more radical in challenging and undoing the separation between nature and humanity. It calls for new ontologies of soil nature that are able to accommodate not only of individual species and their competing interests, but also of environments, and relations that undergird and enable life flourishing. It posits that soils are not merely lively materials: soils are both *lively* and *alive*. Troubling these distinctions between 'alive' and 'lively' means integrating thinking about living beings and material flows in more-than-human and materialist ethics (Krzywoszynska, 2019). Soil materiality is "connected and dynamic, less of an isolatable entity than continuous, relational movement" (Lyons, 2014 in Krzywoszynska, 2019).

In the scenario accompanying this perspective, the microbial is taking centre stage, as a result of the growing recognition of the vital role soil organisms play in most soil functions. Also, this scenario explores the notion of relationality that includes humans and nonhumans, describing approaches of human–soil relationships that embed care and/or situated spirituality. This could contribute to new forms of soil investigation and practice that acknowledge the biophysical agency of soil ecosystems, their sociocultural constitution, and the dynamic interactions between those factors.

“Our relation to land is deep; our roots are deep in the soil, simultaneously culturally and materially. Caring for and about soils is thus not external. Caring for soils is about caring for particular ways of being human.” (Krzywoszynska & Marchesi, 2020)

Social construction of (soil) nature

Taking a step back: Representations of soils in language, religions, systems of thought

A very brief investigation on the etymology of words for soil, and the place of soil in philosophy and religion helps set the stage for this perspective. For example, the ancient Chinese definition of the two-character (*tu* and *rang*) compound for ‘soil’ refer to soil in both its natural state (*tu* is strictly *that which fosters life*) and in its agricultural state (*rang*). Japanese *tsuchi* did not signify soil in general but was a name that called forth something spiritual concealed in the ground, the embryonic source of life. Multiple systems of thought and religions are intimately connected to soils: the Greek theory of the four elements (earth, water, air, and fire), the Greek myth of creation (Chaos, Gaia, Tartarus and Eros), the Brahmin Veda of ancient India (Samagana songs and Mother Earth), the prostrations of Tibetan Buddhism (unification of the mother of the land and spirit of the land) (Minami, 2010). The Andean deity Pachamama, ‘world-mother’ is a source of the four Quechua cosmological principles of water, earth, sun and moon, the rights of whom are now protected by Bolivian law (Krzywoszynska & Marchesi, 2020). The Christian Bible (Old Testament) says “And the lord God formed man of the dust of the ground and breathed into his nostrils the breath of life; and man became a living soul”. The term *Homo* - human, comes from *humus* - meaning soil. The defining quality of humanity is that after spending their lifetimes working the land, they will return to the land, “for dust thou art, and unto dust shalt thou return” (Genesis 3:17) (Minami, 2010).

Ethnopedology studies show the diversity of ways in which soils are brought into social relations. For Colombian smallholders in the Amazon, growing crops involves cultivating a place-specific sensibility to the taste, smell, and touch of the earth (Krzywoszynska & Marchesi, 2020). In Celtic cultures, the spirits of the soil (*dei terreni*) represent spirits of agriculture that make grains yield well and cows give much milk. Australian Aborigines feel that harming the land is harming themselves. In Switzerland, spirits called gnomes, resembling tiny old men, were believed to dwell in the soil. Soil-related spirits are also common across Asia, such as the Ainu *kamui*, the Ryukyu *nirai kanaii*, China’s *tiandi*, Thailand’s *phi*, and the Philippines’ *anito* (Minami, 2010). In Western, more recent times, Austrian farmers feel that soil qualities are a manifestation of their own moral rectitude, while in Switzerland soil aesthetics are essential in farmers’ perceptions and communication of good soil management practice (Krzywoszynska & Marchesi, 2020).

A growing body of research and practice is approaching human–soil relationships as matters of care. Caring, the practical and ethical commitment to ensuring the well-being of others, is a promising way of conceptualizing and acting on the interdependence of human and non-human lives (Puig de la Bellacasa, 2017). Relational ethics scholars have discussed the ways in which attentiveness generates (through affective moments such as enchantment, curiosity, or disgust) relational ethics and a response-ability towards non-humans (Pigott, 2021). Krzywoszynska (2019) posits that in order for soils to flourish, there needs to be an extensive ‘care network’ in place - as caregivers seek to better attend to the needs of the primary object of their care, they extend care to other entities on whom the wellbeing of the primary object of care depends. One of the author’s case studies illustrates that attending to soil biota as a way of caring for the farm business has led to a certain reconfiguration of both the farm businesses and land use practices. She stresses, however, that the farmer’s power to act is limited. Krzywoszynska concludes that only when caring is more than the obligation of particular individuals (farmers) and becomes a systemic project (engaging all the participants in the agri-food system), the radical potential of attentiveness can be fulfilled.

The shift in awareness about soil and human-soil relationships is also marked by questions of spirit. In this context, spirit is not strictly related to a certain body or referring to religion, but rather “any embodied or disembodied non-human agency that is experienced, interacted with or is otherwise socially consequential” (Szerszynski, 2017).

Puig de la Bellacasa’s work (2019) has situated spirituality as an important terrain of inquiry in relation to human–soil relations, extending notions of care to more-than-human worlds. She uses spirit to refer to distributed non-human agency, a sense of enlivenment or animateness which is mysterious precisely because soil aliveness is not explicable by mechanical principles alone. The author proposes affectively charged motifs of intimate entanglement with soil aliveness – ‘biological wonder’, ‘interdependent livingness’, ‘sensual enlivenments’, ‘life as regeneration and animateness’ – that are briefly described below:

- *Biological wonder* – refers to efforts, across the technoscientific spectrum, directed at revealing hidden soils, at making them visible/noticeable. Science participates to an ecological culture around soils, and scientists are also touched, not only by environmental concerns and public pressures, but by a wave of renewed affection for soils that invokes science to support better care.
- *Teaming with life – interdependent living* - Soil as a medium that connects different forms of life that depend on it for everyday subsistence. An everydayness by which humans and non-humans are engaged in intimate entanglements of ecological care. Care as a material doing of everyday maintenance and repair. A particular angle is found in the scientific ‘foodweb’ concept of soil that focuses on ‘collaborating’ with microbes and other soil biota.
- *Sensual enlivenment - affectionate encounters* with soils involve intimate, sensorial engagements with soil substance through smell, taste, touch etc. Such sensual intimacy is also something deemed both pleasurable and necessary by passionate soil scientists and farmers.
- *Regeneration – afterlife as shape-shifting* - Soil as the exquisite recycler of matter, the great digester, Mother Earth’s gut, microbes turning plant and animal remains into nourishment, making rebirthing possible through elemental re-circulation.
- Our own death means the returning of our matter to the soil. Degradation of bodies can be seen as a lively collaboration between bodies and soils. Recently, in Washington state in the USA, a company called Recompose hopes to be the first provider of post-mortem ‘natural organic reduction’, allowing people to reconnect with the cycles of nature. A hexagonal container with a carefully balanced ratio of wood chips, straw, and alfalfa helps decompose a human body within a month, after which the body and its accompanying vegetation are transformed into a cubic yard of soil (Marris, 2019).

Pigott (2021) reflects on the spiritual practice of biodynamics (originated in Steiner’s agriculture work proposed as ‘spiritual science’) which, in her view, can engender an attentiveness to soil as something that is agential, energetic, and alive. The mysterious, spiritual elements of this practice encourage an attentiveness to the possibility that humans have limited control; that there are ‘things’ that exceed us individually and collectively, and thus to the possibility that soil ‘cares’ for us, too. This strengthens notions of the soil care network as multidirectional and interdependent, with care as a totality of living and non-living entities that enable life and mutually nourish one another (Lyons, 2014 in Pigott, 2021). Biodynamics prompts an attunement to more-than-human worlds, which are more ephemeral and unmeasurable, such as the energetic qualities of air, water, plants, and animals.

Moreover, in spiritual practices, imagination and faith play a crucial role, in addition to hands-on practices. Sharing of imaginings and narratives may prove more important in generating care than the knowledge gained through direct bodily encounters, as it prompts a geographical imagination of interdependence that surpasses our individual spheres of experience (Pitt, 2018 in Pigott 2021). The realms of imagination and faith are therefore deserving of further attention in emerging soil care research.

Figure 19: Credit: FarmerPlanet by Travis Shilling *Credit: Landscape III by Levi van Veluw*

Implications for soil management and for R&I

Across a science-policy-public spectrum, efforts directed at revealing hidden soils, at making them visible, come with a message: knowing soils better could enable better care (Krzywoszynska, 2020a). Science is in the position to reveal the mysterious alterity of soil. New and thoroughly technoscientific imaginaries of soil aliveness are being developed (Puig de la Bellacasa, 2019). For example, the Global Soil Biodiversity Atlas, published by the EU funded European Soil Data Centre presents striking images of soil's living creatures and tells us: 'Soil is Alive!... Organisms living in the soil are many, amazing, smart, important, and unique. Soil biodiversity is full of incredible stories.' (Orgiazzi et al., 2016).

Advances in visualization methods that are non-invasive and non-destructive – for example X-ray computed tomography technologies that study soil's interactions around plant roots – contribute to revealing the unseen soils (Mairhofer et al., 2014 in Bellacasa, 2019). Moreover, the field of soil bioacoustics (also referred to as biotremology or soil ecoacoustics) engages a growing number of biologists in capturing underground noises that may open a window into a complex and cryptic world. Every soil organism produces its own soundtrack. By distinguishing these sounds, soil acoustics stands to shed light on some hitherto unanswerable questions such as: When do plant roots grow? How are plants making use of sound to help their survival? Are predators – birds, rodents - listening to the underground sounds? Might fungi be able to register sounds coming from micropredators? What intended signals between soil (micro)organisms are revealed by subterranean vibrations? (Eberle, 2022).

Genetic research, particularly the technique of (eDNA) metabarcoding provides new opportunities for large-scale soil biodiversity studies, oftentimes proving to be more effective than other methods and less costly, making it ideal for a variety of further applications in ecology, including interactions between the macro- and micro-biome. Some relevant examples: Metabarcoding of soil and sediment has been applied to the

characterization of eukaryotic communities and the assessment of their response to environmental changes. In the case of invertebrate-species, metabarcoding proved more sensitive to habitat differences than traditional surveys. Studies also looked at root associated fungal communities by using metabarcoding, with findings suggesting that fungal communities are tightly linked to plant communities. The ability of metabarcoding to describe diversity in bulk arthropod samples was also tested, revealing that that metabarcoding was able to identify 91% of the arthropods as well as detect microbes associated with the arthropods. The methods can be also used to reconstruct ancient habitats, analyse animal diets, detect invasive species, or study the interaction of plants and pollinators (Ruppert et al., 2019).
The technologies presented above, and their associated technoscientific imaginaries of soil aliveness, are sure to contribute to a better understanding - seeing, hearing, feeling - of soil life, galvanizing an ethos of care.

In addition, farming practices that respect the principles of agroecology (described in more detail under perspective 2), such as permaculture, regenerative agriculture etc, are carried with respect towards soils' functional biodiversity and natural nutrient cycling; in this sense they embed a specific care about the aliveness of soils. Taking the notion of soil liveness even further, some alternative growers' movements have embraced the concept of 'foodweb', a concept in soil science that describes the exceptionally complex interactions between soil species that allow the circulation of nutrients and energy. Under this notion, soils are web-like, interdependent, which means that altering or removing any one element can destroy them. These notions emphasize a living world below, teeming with life, and fragility. Analysing foodweb models through the lenses of care involves considering "the dependency of the (human) carer from, not so much soil's produce or 'service', but from an inherent relationality that renders soils capable to 'take care' of a number of vital life processes" (Puig de la Bellacasa, 2015). Foodweb based soil care may imply, for example, composting in order to giving back to the soils what we take from them.

With regards to agroecology, Toledo (2022) suggests that while it has contributed extensively to the practice and epistemology (science) of sustainable agriculture, it has only by exception engaged with the ontological/spiritual components of farming. He argues that "recognizing and integrating spirituality into agroecological practice would reinforce agroecology as a socially and environmentally liberating activity" (ibid). Toledo also underscores that "spiritual beings" (actors who are profoundly engaged with the ontological component of their worldview) share a common attribute which is immensely valuable in an agricultural context: humility. "Human beings not only acknowledge that they are powerless, imperfect, limited, and finite, but also recognize their own mistakes […] humility can thus be a key attribute of the practice of agroecology and contrasts with the idea of "ruling over nature" more common to agroindustrial practices". Humility and a sense of limited power in the face of natural processes is something that modern movements in agroecology, regenerative agriculture, or other sustainable agriculture movements can draw from indigenous wisdom and practices.

There are strong reasons to believe that knowing soils better could enable *different forms of* care, but whether or not this always enables *better* care is not clear. Parts of Krzywoszynska's research with UK farmers clearly suggests that this is not necessarily the case. Soil may continue to be perceived as valuable because of its ability to produce agricultural commodities. These commodities are bought, sold, stored, speculated upon, and soil biota are cared-for so that they will render soil more productive. The current system, even amongst regenerative farmers, creates at best probiotic relations of care between farmers and soil life (Krzywoszynska, 2020a) in which life-affirming intentions are still overruled by the logic of the greater economic game. Given one of the main features of regenerative agriculture – the preoccupation with the fight against climate change – a particularly interesting aspect is the widespread interest in soil-based carbon credits. Krzywoszynska (2020a) asserts that soils themselves are not being commodified; the commodity is instead the products of their 'labour'. Trade of soil-based carbon credits could represent a more direct form of objectification and financialisation of soil life than does the trade of agricultural commodities.

STI drivers of change from the Delphi study

- *Achieving human-nature coexistence*: Peacefully challenging the idea of endless growth; From goods and services to gifts and gratitude; Explore shifts from human-nature coexistence to human-nature relations;
- *Sustainable agricultural practices*: Agroecology, Pastoralism, Permaculture; Agroforestry; Appropriate tillage regimes; Intercropping; Optimize crops for mixed cropping; Strip cropping; Agricultural production systems to sustain ecological restoration (e.g. native seed farming);

- *Soil amendments*: Composting, Biochar, better integration of waste streams in fertilization schedules; Symbiotic nitrogen-fixing bacteria; Free-living nitrogen-fixing cyanobacteria; Phosphorus-solubilizing biofertilizers; Potassium-solubilizing microbes; Nitrogen-supplying mycorrhizae;
- *Pest control methods*: Phage bio-control of bacterial pathogens
- *Bridging the gap in soil biodiversity data*; use of genetics to reveal cryptic species
- *Protection of soil biota & Improvement of soil by microorganisms*: e.g. Retention of soil organic matter; Promoting beneficial plant-microbe interactions; Microbial prospection; Calibration of soil parameters favouring desirable microbiomes; Extended use of mycorrhizae; Recycling biomass; Extended use of plant growth promoting bacteria; Leveraging the potential of microbiomes for organic-waste circularization into food/feed; Extremophiles for agriculture;
- *Study and analysis of the soundscape* as an indicator of the state of health of terrestrial environments.

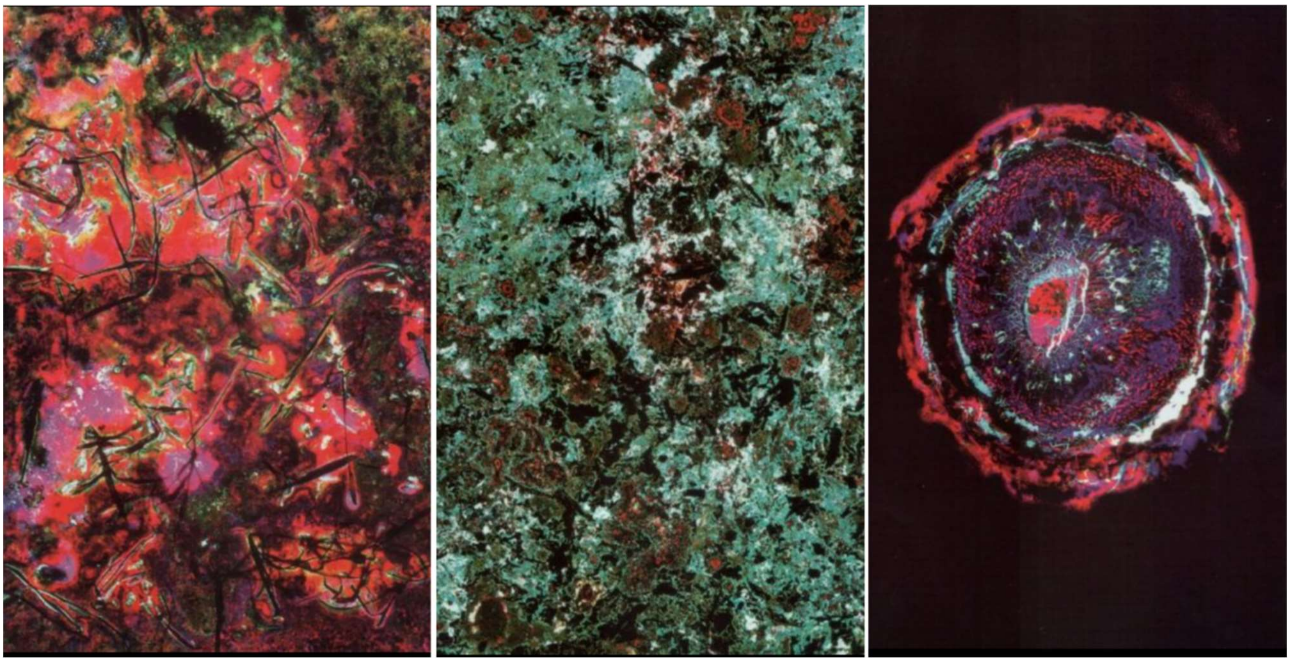

Figure 20: Soil art: do Daro Montag's Bioglyphs: a series of eco-cosmic prints resulting from soil organisms consuming buried photographic film (collage made from images from the artist's gallery, Source: http://www.microbialart.com/galleries/daro-montag/)

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4.4 Case study 4: Accelerating transitions to regenerative economy

Totti Könnölä, Carlo Sessa, Daniel Cassolà

4.4.1 Introduction

The case study explores how to support the socio-economic transformation of production and consumption systems towards a new model of regenerative economy ensuring prosperity and human well-being for all, and a healthy planet, through science, technology and innovation. Transformation is necessary because current economies centred on individualistic mindsets of overconsumption and overproduction have led to a huge waste management problem, not to mention the other increasing challenges, i.e., biodiversity loss and climate change threatening the very existence of natural ecosystems and human society.

After illustrating the main drivers of change, the case study elaborates scenarios of possible evolution towards different forms of regenerative economy, using the Tree Horizon scenario framework to distinguish between:

- a conservative (Horizon 1) scenario of decoupling of the current economy from environmental degradation by means of new eco-efficient technologies, regulations and markets;
- a transition scenario (Horizon 2) of circular economy, which is presented as a possible pathway for moving from the current economy (Horizon 1) to a new deeply regenerative economy (Horizon 3).
- a transformative (Horizon 3) scenario of conversion of the current economy into a radically different symbiotic economy model.

The three scenario horizons are coupled with the different ecosystems' stewardship perspectives as follows:

- Horizon 1: Eco-efficient markets will limit harm to nature is coupled with P1: protecting and restoring socio-ecological systems
- Horizon 2: Circular economy is coupled with P2: co-shaping socio-ecological systems
- Horizon 3: Symbiotic economy is coupled with P3: immersing and caring within hybrid collectives.

The three scenarios are different responses to a common challenge: transforming the economy and society away from the current status quo of waste overload. Given that a lot of waste accumulated after centuries of industrial growth does not degrade very fast – and when it degrades it does not become a good quality matter for soil, trees and animals – the "mountain" of waste needs to be handled somehow, and this is the core issue to solve of each of the three future scenarios.

In the discussion section further views are drawn by considering the concept of **regenerative economy** as the next stage of evolution of capitalism (Fullerton, J., 2015). This concept assumes that economic vigour is a product of human and societal vitality, rooted in ecological health and the inclusive development of human capabilities and potential. This assumption leads to the following characteristics of a regenerative economy:

- Acts in ways that support the long-term health of the whole society;
- Sees economic and financial health as inseparable from human, societal, and environmental health;
- Values richness and diversity, integrity, and fairness; and seeks excellence through constructive competition;
- Responds to the full gamut of human needs, continuously adapting to changing circumstances, and evolving to higher and more effective levels of organization.

Conventional neoliberal and Keynesian economics use GDP – a measure of the value of goods and services produced nationally – as their primary measure of economic health and seek robust and stable GDP growth as the objective of economic policy. In contrast, regenerative economics seeks the development of a mosaic of healthy human networks embedded in healthy societies and the biosphere as the goal. So, the conventional model of extractive economies is contrasted with the new model of regenerative economies. We also consider ways for accelerating the transition from the former to the latter. Finally, the conclusions sum up the three approaches and suggests implications to research and innovation policy.

4.4.2 Drivers of change

In what follows, we conduct the mapping of macro-level drivers of change as well as niche signals, including a screening of the STI directions highlighted by the Delphi[30] survey. Drivers are classified in two main categories:

- **Push factors**, i.e., drivers pushing away the production and consumption system from the current status quo of unsustainable economy;
- **Pull factors**, i.e., drivers pulling the production and consumption system towards a more sustainable form of regenerative economy.

Push factors

We live in a linear economic model dominated by the classic extract-make-use-throw away scheme, which requires having large amounts of energy and other cheap, abundant, and easily accessible resources. In Europe, 4.8 tonnes of **waste** were generated per EU inhabitant in 2020; and 39.2 % of waste were recycled and 31.3 % landfilled in the EU in 2020[31]. In Europe only 12% of the material resources used come from recycling and recovery. The remaining 88% is lost. But the consumption of these resources is reaching the limit. We find ourselves locked in an economic system that has been carrying a powerful wrong inertia since the Industrial Revolution, when the foundations of the linear model were laid, without of course foreseeing its incompatibility with current environmental and demographic dynamics. Within its severity, the current slowdown in the world economy can also be read as an opportunity to start it up again with a more sustainable orientation. **Manufacturing** of low added-value products will not be economically viable in the EU, due to high production costs. There is potential through innovation and digitalisation, to further strengthen specific segments, such as protective equipment, high-end products, and innovative technical textiles. It is estimated that 2.01 billion tonnes of municipal solid **waste** are produced worldwide each year, 33% of which is not treated in an environmentally sound manner. The amount of waste produced globally a year is expected to increase to 3.40 billion tonnes by 2050. There is a general global trend towards increased recycling and composting, e.g., waste collection in low-income countries has increased from 22% to 39% since 2012 (Kaza et al., 2018).

With regards to the planetary boundaries[32] concept presents a set of nine boundaries within which humanity can continue to develop and thrive for generations to come. Four of nine planetary boundaries[33] have now been crossed as a result of human activity:

- **Climate Change**: Recent evidence suggests that the Earth, now passing 415 ppmv CO2 in the atmosphere, has already transgressed the planetary boundary and is approaching several Earth system thresholds. We have reached a point at which the loss of summer polar sea-ice is almost certainly irreversible. The weakening or reversal of terrestrial carbon sinks, for example through the on-going destruction of the world's rainforests, is another potential tipping point, where climate-carbon cycle feedbacks accelerate Earth's warming and intensify the climate impacts.
- Loss of biosphere integrity (**biodiversity loss** and extinctions): The Millennium Ecosystem Assessment of 2005 concluded that changes to ecosystems due to human activities were more rapid in the past 50 years than at any time in human history, increasing the risks of abrupt and irreversible changes. The main drivers of change are the demand for food, water, and natural resources, causing severe biodiversity loss and leading to changes in ecosystem services.
- **Land system change:** Land is converted to human use all over the planet. Forests, grasslands, wetlands, and other vegetation types have primarily been converted to agricultural land. This land-use change is one driving force behind the serious reductions in biodiversity, and it has impacts on water

[30] The Dynamic Argumentative Delphi survey consisted of two rounds, carried out between December 2021 and February 2022. 1 637 respondents participated in the first round of the survey. In the second round, 638 participants contributed to the second round of the survey. Using the consolidated set of STI directions, respondents were invited to select the three most important STI directions in terms of their potential to contribute to the capability of planetary ecosystems to flourish from now to 2050.

[31] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics#:~:text=4.8%20tonnes%20of%20waste%20were%20generated%20per%20EU%20inhabitant%20in%202020.&text=39.2%20%25%20of%20waste%20were%20recycled,in%20the%20EU%20in%202020.

[32] https://www.stockholmresilience.org/research/planetary-boundaries/the-nine-planetary-boundaries.html

[33] https://science.ku.dk/english/press/news/2015/planetary-boundaries/#:~:text=Four%20of%20nine%20planetary%20boundaries%20have%20now%20been%20crossed%20as,cycles%20(phosphorus%20and%20nitrogen)

flows and on the biogeochemical cycling of carbon, nitrogen and phosphorus and other important elements.

- **Nitrogen and phosphorus** flows to the biosphere and oceans: The biogeochemical cycles of nitrogen and phosphorus have been radically changed by humans as a result of many industrial and agricultural processes. Nitrogen and phosphorus are both essential elements for plant growth, so fertilizer production and application are the main concern. A significant fraction of the applied nitrogen and phosphorus makes its way to the sea and can push marine and aquatic systems across ecological thresholds of their own.

Pull factors

Consumers across Europe are showing a growing interest in contributing personally to achieving climate neutrality, preserving natural resources and biodiversity, and reducing water, air, and soil pollution. The challenge is to unlock this potential through measures that empower, support, and enable every consumer, regardless of their financial situation, to play an active role in the green transition without imposing a specific lifestyle and without social discrimination. This pull factor can be enforced by nudging measures influencing the consumers' choices or even forcing regulations.

Local actors are increasingly proactive in launching environmental and climate initiatives that support the achievement of the EU's objectives and targets (EEA, 2020), Digital technologies and platforms facilitate new **movements** like DIY, minimalism, or zero-waste. Those consumer-driven grassroots movements convey and redefine lifestyles; for instance, the zero-waste movement focuses on preventing waste cycles instead of recycling (EEA, 2019; Fraunhofer ISI, 2019).

The idea of **commons**, which refers to the resources and heritage of any given society that are held in common rather than privately owned (from natural materials such as air, water, and the habitable earth, to cultural heritage and the digital space), plays a growing role in civic engagement (Citizens Lab, 2017). People, including children and indigenous communities, are increasingly turning to the courts to force governments and companies to comply with and accelerate **climate change commitments**.

New business models are developed that make ecological and social value approachable, e.g., through benefitting from social and environmental value created as the customer is willing to pay for it, or through legislation, such as CO2 certificates. Moreover, some business models move away from individualised ownership of a customer towards the provision of resource-efficient innovative services and the **shared consumption of products**. For example, private individuals (service providers) offer their unused goods, services, or resources, with or without compensation, to other private individuals or businesses (customer), usually via an online collaborative platform.

New indicators "beyond GDP" have increasingly sparked interest among various actors, whose status, objectives, and visions are very different. While the pioneer reflections on economic growth and GDP were first limited to environmentalist and activist movements, civil society, and local policies, they have progressively entered national and international institutional spheres (Thiry et al., 2016).

Investments in design and innovation can further enhance the resilience and competitiveness of EU production. Given that 38% of EU production is sold on global markets there is potential through trade agreements and export promotion to increase the market share with our trading partners of high quality and innovative EU products. In addition, there is potential to develop **new business models based on re-use, recycling, and circularity**. Prolonged life and reuse options and recycling present opportunities for more sustainable products and consumption (European Commission, 2022). Indeed, the increased use of **re-manufactured** products is part of a shift towards a more circular economy and a reduction of the environmental and carbon footprint of construction products.

The circular economy action plan target to halve residual municipal waste by 2030 and the EU recycling targets for municipal waste are intrinsically linked. Over the last 5 years, the amount of residual municipal waste generated each year has stabilised at about 113 million tonnes, even though the EU recycling rate grew slightly from 45% in 2015 to 48% in 2020. Reaching the target of halving residual municipal waste by 2030 would mean reducing the amount of residual municipal waste by around 56.5 million tonnes. Even if all EU Member States reach their binding 60% recycling target by 2030, current trends indicate that the amount of residual municipal waste might exceed 80 million tonnes in that year – missing the target by more than 23 million tonnes. If municipal waste generation continues growing, at least 72% of waste generated would need to be recycled to meet the circular economy action plan target of halving the amount of residual municipal waste by 2030 – a significantly higher rate of recycling than at present. Alternatively, the target could be achieved by reducing the amount of waste generated by around one third or through a combination of these approaches.[34]

The slight increase in recycling rates of municipal **waste in Europe** - reaching recycling levels equal to 46 % of municipal waste (EEA, 2019) - which represent additional sources of secondary materials and critical raw materials - may indicate a move towards using waste as a resource and a more circular economy. However, current levels of recycling, accounting for nearly 10 %, are very limited compared with the material flows of the overall economy of the EU Member States. Today, a very large share of the waste is burned to produce energy and then transformed into emissions to air, water, and soil, or converted into long-term stocks (e.g., in buildings and infrastructure). Although secondary inputs such as processed minerals and metals, paper and glass can be kept for longer in the economy or recycled, the primary inputs provided by the biosphere, such as water, food, and energy, are degraded in an irreversible way (EEA, 2019).

Agile government' approaches developed to improve responsiveness, collaboration, participation, experimentation, adaptability, and outcome-orientation based on intrinsic, extrinsic and market motivations. System-oriented innovation policies are required that focus on supporting ecosystems, not single technologies, or sectors. In addition, policies must be evaluated based on their (possibly negative) interrelations with other policies or companies being overwhelmed with complexity. There is a clear need to strengthen capacity in the EU for system-oriented innovation policy evaluation because it is the cornerstone for evidence-based and distributed intelligence in innovation policy-making (European Commission, 2020).

The **enabling technologies of Industry 5.0[35]** are a set of complex systems that combine technologies, such as smart materials, with embedded, bio-inspired sensors. This is in line with the findings from the Dynamic Argumentative Delphi study identifying 'Smart systems' as the most important area in the STI directions in Computer Engineering. Therefore, each of the following categories can only unfold its potential when combined with others, as a part of systems and technological frameworks (European Commission, 2020):

- **Artificial Intelligence** to detect causalities in complex, dynamic systems, leading to actionable intelligence. AI can be used for renewable energy (e.g., AI algorithms to ensure optimal use of power grids; AI algorithms to maximize renewable energy utilization under power fluctuations); for recycling (e.g. Waste recognition software to monitor, audit, and sort waste at scale); in agriculture (e.g. AI-backed technology for smart water consumption); and for pollution control (e.g. AI for wastewater treatment).
- Cyber safe **data** transmission, storage, and analysis technologies that are able to handle data and system interoperability.
- Real time-based **digital twins** and simulation to model entire systems. Multi-scale dynamic modelling and simulation. Simulation and measurement of environmental and social impact.
- **Bio-inspired technologies** and smart materials that allow materials with embedded sensors and enhanced features while being recyclable. Biological transformation is the systematic application of knowledge from nature, i.e., the integration of biological and bio-inspired principles, materials, functions, structures, and resources.
- **Marine technologies** can be used to create a holistic understanding of the ocean ecosystem, predicting hazards, stress factors, monitor production and reduce environmental footprint.
- A wide variety of health, food, mobility, and environmental applications require **sensors** in order to provide the necessary data to improve sustainability outcomes.
- **Power to X** allows much more efficient processes than existing ones in the chemical industry through direct power conversion. It is also closely aligned with carbon capture and storage technologies. CO2

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[34] https://www.eea.europa.eu/publications/reaching-2030s-residual-municipal-waste/reaching-2030s-residual-municipal-waste

[35] „Industry 5.0" complements the existing "Industry 4.0" approach by specifically putting research and innovation at the service of the transition to a **sustainable, human-centric** and **resilient European industry**, ref. https://ec.europa.eu/info/research-and-innovation/research-area/industrial-research-and-innovation/industry-50_en.

emissions from process industries can be captured, allowing, for instance, zero emission cement (first results only indicate a 2% increase in costs), zero emission waste incineration, absorbing carbon from bio process industry or supporting the scale up of hydrogen or renewable energy.

A sister concept of Industry 5.0 is **Society 5.0**. The concept of Society 5.0 was presented in 2016 by Keidanren, Japan's most important business federation, and it attempts to balance economic development with the resolution of societal and environmental problems. It is not restricted to the manufacturing sector but addresses larger social challenges based on the integration of physical and virtual spaces. Society 5.0 is a society in which advanced IT technologies, Internet of Things, robots, artificial intelligence, and augmented reality are actively used in everyday life, industry, healthcare, and other spheres of activity, not primarily for economic advantage but for the benefit and convenience of each citizen (European Commission, 2021). More in detail, the concept includes challenges and social enablers for Industry 5.0 encompassing a complex system across technological and organisational aspects, political and public factors, and the Triple Bottom Line of sustainability (economic, ecological, and social dimensions). The following challenges must be regarded as strongly interlinked and interrelated pull factors (European Commission, 2020):

- **Technology acceptance and trust** issues, e.g., the right for society to participate in the ideation and application of technologies and the respective purpose. In addition, adapting technology to humans must coincide with training people how to use new technologies.
- Addressing future **labour and skills shortages** by implementing retraining and lifelong learning concepts, supported by policy makers.
  Full **integration of customers** across the entire value chains is required to inform them about social or environmental value created and include this in their choice and willingness to pay. Different parts of society focus on different values and have distinct needs. Age, gender, sex, cultural background, and diversity aspects must be integrated.
- Environmental impact is hard to measure, **social impact** is even harder to quantify. Approaches must be found to measure and quantify environmental and social value generated. In this respect, "socio-ecological system performance" can be a useful a concept, which extends the concept of human-centric performance, complementing the needs of individuals to those of a society embedded in an ecosystem. In the long run, society cannot ignore planetary boundaries. Environmental targets such as CO2 neutrality must not be forgotten and require research in the domain of e.g., nanotechnologies or smart materials.

4.4.3 Scenarios

Smart eco-efficient markets decoupling growth from environmental degradation – Scenario P1

Introduction

This scenario of limiting harm to nature relates to the perspective of protecting and restoring socio-ecological systems. By 2050 the economy has managed to decouple economic growth and environmental degradation with end-of-pipe and eco-efficiency technologies as well as shifting markets to price better environmental harm and other negative externalities. The maximum population size that an ecosystem can support is called carrying capacity. Limiting factors (e.g., food supply, water supply, habitat space, chemical factors, anthropogenic factors) that determine the carrying capacity of ecosystems are strictly respected. Landfills are the subject of heavy taxation and regulation. The waste is burned to produce energy, recycling of products is incentivised with economic deposits (e.g., with bottle and cans) and taxation. Nature protection is taken seriously with new reserves to ensure space for wildlife to recover.

Nature is perceived something distinctive from human activities and settlements, these two spheres interact. Environmental pressures and impacts of human activities have been optimised to the level of the caring capacity of nature. This has been done mainly with end-of-pipe and eco-efficiency technologies, regulation, taxation, and markets (e.g., emissions trading schemes).

Eco-efficiency cleaner production is a common industry practice reducing resource use and/or pollution at the source by using cleaner and efficient products and production methods. End-of-pipe technologies, in turn, are widely applied to concentrate upon effluent treatment or filtration prior to discharge into the environment (e.g., catalysers in the cars).

Wilderness is managed comprehensively through large-scale, intact wilderness protected areas and connectivity between these areas. Wilderness management is perceived as part of a comprehensive, protected area programme that aims at maintaining the highest integrity of ecosystems, wildlife, and sacred and traditional cultural use sites through an explicit focus on non-degradation (Casson et al., 2016).

Over the decades, these advances were designed building on the concepts of *pressure* and *impact* (EEA, 1999): environmental pressures refer to developments in the use of natural resources (materials, energy, water, land) as inputs to human activities, as well as the release of substances on the output side (waste, GHG emissions, air, and water pollution). These pressures exerted by society are transported and transformed in a variety of natural processes and cause changes in environmental conditions. Impact refers to the changes in environmental conditions leading to impacts on the social and economic functions of the environment, such as the provision of adequate conditions for health, resource availability and biodiversity. Impacts often occur in a sequence: for example, GHG emissions cause global warming (primary effect), which causes an increase in temperature (secondary effect), leading to a rise in sea level (tertiary effect), and finally leads to loss of biodiversity.

Further guidance for decoupling the economy and environmental degradation was gained from the integrated approach to assessing R&I programmes' *environmental impact* (IMP) (Miedzinski et al 2013), which was motivated by the search for ex-ante assessment criteria measuring the environmental impact of RTI-policy measures and instruments of Horizon 2020.

Citizens and consumption
In 2050, global material consumption has fallen partly due to global conflicts and partly due to market mechanisms orienting consumption towards environmentally benign alternatives and the introduction of new production techniques that help decouple production growth from material input to production, the transition to a greener economy, and the high ratio of services with low resource intensity in the economy.

Green products have become affordable and prevalent, and consumer interest in sustainable consumption or local produce is widespread[36]. Eco-efficient choices are preferred by the consumer, especially in service sectors such as tourism, which has mostly become local ecotourism thanks to highly regulated and taxed air travelling. Most people's values have gradually reoriented towards the preservation of natural ecological systems, and they support regulatory and other governance measures to fix markets to price high environmental degradation. Waste reduction, as a consequence of decoupling economic growth from the consumption of finite resources, is benefitting not only businesses but also society and the environment.

Industry and production
By 2050, Europe is close to reaching climate neutrality by following the steps of the European Green Deal, which has boosted waste reduction models and empowered consumers for the green transition. Making sustainable products the norm in the EU: all physical goods on the EU market are friendlier to the environment and resource-efficient products and production. Public policy supports green products and industries that exploit natural resources in an ecologically efficient way, financially and technically.

New markets provide people green and decent jobs and welfare-generating natural resource management[37]. Around the globe steps have been taken to reduce waste through material and energy efficiency in production and use, and to substitute hazardous materials with safer alternatives. The demand for materials and minerals needed to build solar panels, windmills, batteries, and electrical equipment, etc. has grown strongly.

Industry and business units combine economic efficiency and environmental sustainability into eco-efficiency. Goods and services are created while using fewer resources and creating less waste and production. The following approaches are common ground: reducing material and energy intensity of products and services; increasing product durability; working with other business functions to reduce hazardous and/or toxic materials used in processes and facilities; tracking costs and benefits of managing environmental impacts and improvements; providing customers, stakeholders and investors with updates on productivity improvements

[36] https://www.anuga.com/news/anuga-blog/anuga-organic-green-is-in.php
[37] https://sustainabledevelopment.un.org/content/documents/945ABC_ENGLISH.pdf

and innovations; optimizing the use of materials and resources, minimizing waste, retrofitting obsolete infrastructures, improving building efficiency and site management processes. The establishment of cleaner production technologies is steered by new technologies and motivated by market forces, allowing to overcome environmental problems while complying with regulations. To further mitigate the adverse environmental impacts of production, end-of-pipe technologies are used as abatement measures when additional regulatory pressure is applied.

'Green' approaches benefit from advances in nanotechnology, biotechnology, and information- and communication technologies. The fossil-based chemical industry has shifted towards a smarter, more resource-efficient bio-based chemical industry that provides better, safer products. While mining used to cause considerable environmental damage, new technology, environmental regulations, and strong metal recycling policies have protected important parts of the planet by the reduction of mining to a minimum.

An economy with net-zero GHG is achieved by combing maximising energy efficiency, deploying renewables and electricity, developing a competitive industry, developing a smart network of infrastructure and interconnections, developing the bio-economy and creating and enhancing essential carbon sinks, and tackling remaining CO2 emissions with carbon capture and storage[38].

The economy is booming but still heavily linear economy produces mountains of waste. Both residential and industrial waste are mainly incinerated to avoid expensive landfill fees and produce energy. This suboptimal solution is an urgent fix to the growing waste problem but does not allow efficient recovery of materials. The end-of-pipe and eco-efficiency solutions have come to their limits. The society is searching for alternative pathways to allow more systemic changes in production and consumption systems to effectively address the waste issue.

Governance
A set of established environmental policy measures - from strict prohibitive laws to taxation – have favoured the social change. A dichotomy exists between humans - as drivers of pressure on the environment - and ecosystems.

Regarding wilderness management, the primary objective is nature conservation: to protect the long-term ecological integrity of natural areas that are undisturbed by significant human activity, have no modern infrastructure, and are characterized by freely occurring and reasonably intact natural processes. An important aspect of this objective is the emphasis on biological health and intactness. Only where the biological integrity of a wilderness-protected area can be secured and the primary objective of nature conservation is met and securely maintained, then the management focus of the wilderness area may include other objectives such as recreation or other human uses. When affected or disturbed areas are urgently in need for recovery, strict policy measures are put in place for the isolation of nature.

Faced with the need to increase investments in innovation and natural capital, and maintain the welfare state, governments are seen as playing a critical role in ensuring economic development, stability, and employment. But there is now a stronger emphasis on finding ways to reduce resource use and harmful emissions. Greater awareness of the public led local administrations to take a more radical stand in the defence of the environment and the development of blue-green infrastructures. The economic growth paradigm is not fundamentally questioned, meaning that the emphasis is on finding ways to decouple growth from environmental impacts – often looking to technological advances to enhance efficiency and offset losses of natural capital. The emphasis on technological solutions and efficiency improvements means that this scenario is the result of previously established modes of producing, consuming, and thinking – together with a reduction of resistance to change. An efficiency-driven, sustainability approach is capable of delivering prosperity within environmental limits.

Actions that may lead to environmental degradation or loss are heavily penalised. Through improved and adaptive governance, enhanced institutional capabilities and coordinated and collaborative action at local, national, regional, and/or international levels, societies can devise and protect natural habitats, undertake the

[38] https://www.weforum.org/agenda/2020/02/europe-climate-change-new-green-deal/

large-scale restoration of degraded habitats, and more broadly place nature and sustainability at the heart of decision-making. Priority is given to environmental issues perceived to be economically critical, such as the conservation and restoration of degraded, damaged, or destroyed ecosystems and their biodiversity that provide key provisioning (e.g., food, clean water) and regulating services (e.g. flood protection, erosion prevention, and climate regulation). Ecosystem restoration and climate change adaptation plans are being drawn up by governments and their implementation is scrupulously monitored. Government ministries have an environmental advisory department, which is intended to increase the importance of environmental affairs to the nations.

The circular economy pathway toward a regenerative economy – Scenario P2

Introduction

The development of the circular economy towards 2050 was guided by learning from nature (biomimicry, Beynus 1997; Cramer 1997). More specifically, the four system conditions of the Natural Step (Eriksson and Robèrt 1991) provided the initial guidance to align society with nature[39]. In a similar way but more focused on industry, the related concept of *Biosphere Rules* (Unruh 2018) helped implement closed-loop production processes[40]. Furthermore, *The Cradle to Cradle (C2C)* design principle (2002), which preceded the concept of Circular Economy (Ghisellini et al. 2016), offered a systemic approach to environmental design that lead to two alternative design perspectives (Braungart et al. 2007): 1) closed cycles referring to the design of the uptake of the products back to industrial production processes at the end of their useful life to produce products of equal or more value, and 2) open cycles referring to the design of products that are biodegradable and become nutrients to new cycles within the ecosystem.

The circularity practices and the initiatives mimicking nature brought simplicity in design choices and organising subsequent production and consumption of products. Despite its diversity, life on earth is built mainly around just four elements of oxygen, carbon, hydrogen, nitrogen, and sulphur. These few elements have not stopped life to evolve to immense diversity and complexity. To better manage the complexity both in nature and in society, many city planners adopted practices of co-shaping socio-ecological systems for ecosystem performance. Socio-ecological systems thinking uses **complex system** theory to bridge social and biogeophysical sciences for understanding dynamics of the interaction of social and ecological systems and ultimately enabling sustainability transformations.

Citizens and consumption

In 2050, consumers demand sustainable products and easy access to traceable product information to understand their full impact. Customers play a dual role as buyers of the company's products and suppliers of its input materials, adding a new twist to the adage "Stay close to your customers" as managers rethought sourcing, marketing, sales, and service. For example, when companies forecast future supplies of input materials, they consider the return rate of used products and their materials. Companies master the reverse logistics – getting the used product back to the factory for reprocessing.

Sharing economy practices increase the intensity of use of assets in (micro-)mobility and, housing and handyman tools, for instance. Renting and leasing, instead of owning, have become a common practice also for electric appliances of all sorts. Paying just for the service is now a winning formula over the ownership. The professional management of the 'shared' assets has improved the maintenance, reuse, refurbishing and recycling of the assets, often closing the loop for good.

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[39] The four system conditions specify that nature is not subject to systematically increasing i) concentrations of substances extracted from the earth's crust, ii) concentrations of substances produced by society, iii) degradation by physical means. And, in that society iv) human needs are met worldwide."

[40] They imitate circular processes in nature but translated industrial production systems: i) Materials parsimony. Minimize the types of materials used in products with a focus on materials that are life-friendly and economically recyclable. ii) Value cycle. Recover and reincarnate materials from end-of-use goods into new value-added products. iii) Power autonomy. Maximize the power autonomy of products and processes so they can function on renewable energy. iv) Sustainable product platforms. Leverage value cycles as product platforms for profitable scale, scope, and knowledge economies. v) Function over form. Fulfil customers' functional needs in ways that sustain the value cycle.

Much of the traditional waste has turned to new by-products, and customers play a key role in making this happen by returning the products in their end-use. But before this, they often find ways how to prolong the lifetime of the product by visiting repair shops and fixing them by themselves following the user guide and ordering the repair parts online.

Industry and production

By 2050, businesses have rethought their sourcing strategies and dramatically simplified the number and types of materials used in their company's production to recycle cost-effectively. Although the use of diverse materials used to be a standard industry practice, inputs on this scale confounded moves toward sustainability. Materials are now chosen to be physically capable of being up-cycled. For instance, the Nylon 6 is widely used in carpets as it can be turned back into high-value carpet fibre. Material choices are also directed by their cost-effectiveness. In fact, already in early 2000, up to 75% of steel and more than 50% of aluminium were recycled, mostly because doing so used a fraction of the energy needed to produce virgin metal. Today, this has happened across sectors and product lines. Companies are competing who is best at closing the loops.

Companies prepare at the beginning of design process for the end of their product's useful life. Consequently, it is sometimes better not to minimize the materials in the products in the name of eco-efficiency, but when needed for cycling up it is ensured at the outset enough material in products for economically viable recovery. Parsimonious palettes of materials and virtuous recycling processes are used in sustainable platforms[41] for entire product lines. Simplifying a materials palette for sustainability reasons has reduced supply-chain complexity, shrank the vendor count, generated volume discounts, and improved the service of suppliers.

For instance, in 2050, plastics[42] are produced from renewable feedstocks and chemistries, powered by renewable energy, reused, and recycled within the economy without leakage to the environment, and, by extension, generating no waste or emissions. Yet all the benefits plastics have been retained to offer when used in products and packaging. A plastics circular economy replaces fossil-derived resins with renewable resins that can be produced involving sunlight, water, and carbon dioxide, which are either captured directly from the atmosphere or by plants. Plastics are recirculated through reuse, mechanical processing and recycling, chemical processing and recycling, and energy recovery and CO_2 recirculation.

The technical cycles of products are closing the loops but also relying on urban mining that recovers once lost materials. The waste buried in old landfills have been largely mined with automated sorting robots. For instance, electronic gadgets are teared down to recycle heavy metals and plastics, and the contamination levels of organic materials are analysed and treated with catalysers to generate soil for parks. Dispersed electronic materials are collected and concentrated in the recycling plants.

Moreover, the focus is on extending the life of products and closing the loops not to lose valuable materials like before. Tracking and tracing of products, components and materials through sensors and digital twins together with leasing concepts and service models allow the control of material flows. Internet of things with sensors collect data for developing digital twins that improve the maintenance in manufacturing, transport, and energy system. For instance, integrating functional electronics in material parts and using digital resource optimisation capabilities for extending a component use cycle with better maintenance and repair actions have been introduced in wind energy parks. This operational data-driven approach has decreased inspection activities and thus maintenance costs.

Many sectors learned to manage the transition period as a product went in many cases from 100% virgin materials to nearly 100% virtuously recycled materials. Products installed in customers' homes, garages, and office buildings are recovered and put back into the production process. Also, buildings are designed to be adaptable to changing needs between residential and commercial use, for instance. The materials used are registered in the material banks that facilitate their reuse in the future. Circular districts are resilient in resource use by closing loops locally.

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[41] https://hbr.org/2008/02/the-biosphere-rules

[42] https://circulareconomylab.com/a-vision-for-a-circular-economy-for-plastics-in-canada/

The design of products is careful not to mix organic biodegradable materials with toxic and non-degradable materials, which help the reuse of materials and avoiding the production of waste. The materials run through pathways of cascading value, for instance, restaurant food leftovers are used to develop animal food. Aeroponic automated food labs have become a big business growing plants with only water and nutrients resulting in fast growth, healthy plants, and big yields with few resources. Urban and peri-urban farming produces vegetables, fruit, and other food in and around cities, which help feed people in the city, produces fresh local produce, helps green cities by sequestering carbon and limiting urban heat islands, creates social ties, creates jobs, enhances the value of empty spaces, enriches the city's biodiversity. Shared vegetable gardens on rooftops and in public spaces are common.

Governance

Governance initiatives played relevant role in orchestrating system change towards circularity engaging different actors to jointly overcome the barriers and scale up promising experimentations. Regulatory frameworks require now one sector's waste, or rather by-products, to be used by another sector as a material input. Also, right to repair the products have become the baseline for companies. Green Public Procurement requesting the solutions to meet the desired function and objectives rather than defining how to reach them has offered demand for innovative circular and sustainable solutions across value chains often engaging also start-ups and citizens ensuring behavioural changes. European single market for circular economy allows finally free circulation of materials, defining clearly what is waste, sub-product or raw material, waste being reduced to limited cases.

'Green neighbourhoods as a service' (GNaaS)[43] has become a common practice in cities establishing a central entity in a city district which designs, commissions, manages and funds deep energy retrofit on a street-by-street scale with incremental community investments at no cost to the property owners, regardless of ownership and usage typology. By centralising the design process, more systemic energy decisions are made, for example around local energy systems and integration with district heating. By centralising funding, projects are aggregated on a neighbourhood scale allowing access to completely different types of funding and crucially removing the requirement of indebtedness for individual property owners.

Conversion to a deeply symbiotic economy – Scenario P3

Introduction

By 2050, the society has witnessed a deep shift of paradigm towards a "symbiotic" economy (Albrect G. A. 2019). This paradigm shift was guided by the idea of symbiosis between nature and the human. At its core, symbiosis counters the idea that evolution is inherently and solely competitive, since life also thrives by symbiogenesis: evolution is driven by both cooperation and competition (Clancy, K. 2017).

A deep understanding of the role of symbiosis spreads across society. As opposed to being anthropocentric, to being "sumbiocentric" means that one is considering the centrality of the process of symbiosis in all of our deliberations on human affairs. It requires giving priority to the maintenance of symbiotic bonds. Symbiocentrism is also an ethical position claiming that maintaining symbiotic connections, diversity, and unity within complex systems is the highest good. What is good for humans will be to live together with the richest diversity of life, to maximise the vitality and viability of interconnected life forms, including those within us. This is what is called in one term **ecosystems flourishing**.

The recognition by humans of the vital interconnectedness of life becomes the material foundation for all subsequent thought, policy, and action. This is the result of a long transition period where mutualism and balanced patterns of cooperation and competition (co-petition) have demonstrated an evolutionary advantage, and a point has been reached in human social development where almost every element of human culture, economy, habitat, and technology will be seamlessly reintegrated back into life cycles and processes. The nine principles of a Symbiocene society (Albrecht G. A., 2019) are now at the foundation of a new economic paradigm:

1. Full and benign recyclability and biodegradability of all inputs and outputs

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[43] https://www.bwbuk.org/post/green-neighbourhoods-as-a-service

2. Safe and socially just forms of clean, renewable energy
3. Full and harmonious integration of human systems with biogeochemical systems at all scales.
4. Use of the renewable resources of place and bioregion
5. Elimination of toxic waste in all aspects of production, consumption, and enterprise.
6. All species, great and small, having their life interests and biocommunal properties understood and respected
7. Evidence of homeostasis or heterostasis where stability is maintained and where conflict is recognised as a subset of grand-scale cooperation
8. Protection of symbiotic bonds between and within species at all scales
9. Reestablishment of symbiotic bonds where they have been severed in the Anthropocene.

With over 7 billion people on the planet now, there can no longer be tolerance of anthropogenically produced toxic-to-life substances used in human economic production, consumption, and enterprise. This will give place to a full-fledged **symbiotic economy** where we replicate the organic processes of life. There can be, however, no "green revolution" (ecomodernism) based on existing technologies or trickle-down natural capital generation. Rather, it will be a revolution based on the rapid and complete transition from a polluting and consuming society to one that produces everything via non-polluting, symbiotically active means. Instead of retreating into primitivism or atavism, the Symbiocene requires a massive surge in innovation and creativity.

The policy realm will also have to be revolutionized. A core concept of "inter-generational responsibility" will be recognised as the ethical foundation of a hypothetical global pact that is constantly renewed in successive generations. An example of such a global pact has been proposed by Luciano Floridi, introducing the "ontic trust" (Floridi L., 2013). Generally speaking, trust in the legal system is an entity in which someone (the trustee) holds and manages the former assets of a person (the trustor, or donor) for the benefit of some specific persons or entities (the beneficiaries). Strictly speaking, nobody owns the assets, since the trustor has donated them, the trustee has only legal ownership, and the beneficiary has only equitable ownership. Now, this logic can be used to formulate the **symbiotic ontic trust** as follows:

- the assets or "corpus" is represented by the world, including all existing agents and patients[44];
- the donors are all past and current *generations* of agents;
- the trustees are all current *individual* agents;
- the beneficiaries are all current and future *individual* agents and patients.

By entering into being, an agent is made possible thanks to the existence of other entities. It is therefore bound to all that already is, both unwillingly and inescapably. It should be also caringly. Unwillingly, because no agent wills itself into existence, though every agent can, in theory, will itself out of it. Inescapably, because the ontic bond may be broken by an agent only at the cost of ceasing to exist as an agent. Caringly because participation in reality by any entity, including an agent – that is, the fact the any entity is an expression of what exists – provides a right to existence and an invitation to respect and take care of other entities. The pact than involves no coercion, but a mutual relation of appreciation, gratitude, and care, which is fostered by the recognition of the dependence of all entities on each other.[45]

The obligations and responsibilities imposed by the ontic trust will vary depending on circumstances but, fundamentally, the expectation is that actions will be taken or avoided in view of the well-being of the whole system – and this is taken as the ethical rule guiding actions to support life flourishing in the symbiotic economy.

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[44] In the global information ethics framework illustrated by Floridi, agents are entities delivering actions that affect intentionally or unintentionally other entities (patients). These entities are living beings or inforgs (artificial intelligence agents, organizations, etc.) operating in the infosphere.

[45] "A simple example may help to clarify further the meaning of the ontic trust. Existence begins with a gift, even if possibly an unwanted one. A foetus will be initially only a beneficiary of the world. Once she is born and has become a full moral agent, she will be, as an individual, both a beneficiary and a trustee of the world. She will be in charge of taking care of the world, and, insofar as she is a member of the generation of living agents, she will be also a donor of the world. Once dead, she will leave the world to other agents after her and this becomes a member of the generation of donors. In short, the life of an agent becomes a journey from being an only beneficiary to being only a donor, passing through the stage of being a responsible trustee of the world." (Floridi, L. 2013, p. 302)

Citizens and consumption

In 2050, the principles of the Symbiocene (listed above) will be applied to everything humans do and consume. We will be eating our cellulose-based food packaging and loving it. We shall enjoy living in houses made of bricks produced and constantly repaired by domestic fungi. Humans have already created agricultural systems that, in varying degrees, respect forms of life, and we maintain the fertility of places that products food sustenance over the long term. However, “sumbioculture” will enhance these existing sustainable forms of agriculture such as permaculture and organic and biodynamic farming. Sumbiosic food production and consumption will enhance the mutual interdependence between the non-living foundations of life (geochemical systems) and all species of living beings, rejecting food production systems that deplete the soil base, practice extensive monoculture, poison the food chain, render species extinct, introduce risky DNA into life that cannot be removed once introduced, and produce emissions that create global problems.

Sufficiency was taken up as the guiding mantra for system assessment - and, contrary to previously prevalent popular myth, led to a spate of innovations across the product and service spectrum. Sufficiency-oriented network policies also had repercussions on certain activities and consumer expectations. Some examples include: 1) restrictions on modes of travel with fossil fuelled aircraft and shipping that became highly curtailed, 2) severely reduced availability of imported foods, and 3) limited availability of consumer goods with high environmental impacts.

The success of the private sector in providing essential civil services, particularly in times of crisis, helped corporate organizations gain public acceptance despite their role in exacerbating wealth inequality and their reputations for lobbying, manipulation, and other questionable activities. This popular support, coupled with high levels of perceived inaction and corruption within national governments and institutions, created the conditions in which sweeping authority was given to transnational networks of non-governmental organizations. This authority was derived through a combination of interconnected citizen collectives, their coordinated consumption patterns, and citizen’s proven commitment to actively monitor the network.

In exchange for this power, these transnational actor-networks are held to rigorous public accountability assessments for all activities they coordinate or take part in, ranging from highly localized initiatives to the comprehensive results of their global efforts. The open data streams from planetary systems monitoring activities are wielded by both citizens and other actor-networks to ensure compliance to the Symbiocene Ontic Trust (OT) strategies and agreements and the goals set therein. Citizen participatory monitoring, codified as part-and-parcel of civil service reception, ensures that transnational powers are held accountable to the highest standards for services they provide. While this has entailed that citizen privacy and autonomy has been somewhat reduced - an issue that remains contentious, particularly with older generations - the increased citizen empowerment at the regional level, and the consistency of civil services provided, is seen as more than equitable return for privacy invasions by many.

Industry and production

By 2050, industry and production are dominated by synergistic coordination of transnational actor-networks, each organized according to a matrix of knowledge competence, R&D expertise, demographic dynamics, and focused on addressing the pressing impacts of climate change. These actor-networks are hybrid conglomerates composed of private sector entities, state-run organizations, and NGOs, with each network focused on providing an essential civil service - water, food, energy, transport, healthcare, education, and others. In response to environmental concerns and climate change, these networks coordinate their efforts under the Segenerative Ontic Trust (SOT) - a global compact with the goal of undoing two centuries of human caused environmental damage by restoring the atmosphere, and ocean- as well as land-based ecologies by eliminating anthropogenic pollutants.

To ensure that human and earth systems are moving towards the goals set forth in the SOT, planetary ecological health is monitored and assessed constantly by overlapping systems of orbital satellites, land- and water-based instrumentation and sensor arrays, and human-centric reporting systems. Data streams from these sources continuously feed into digital agents for analysis and optimization - agents coded to prioritise the ecological goals set forth in SOT strategies and agreements, while optimizing global actor-network operations to provide essential civil services. The monitoring of, and accounting for, planetary systems is the backbone of the actor-network governance apparatus, providing critical knowledge and advice to human decision-making institutions.

Actors and organizations across transnational networks deploy the latest in earth systems monitoring sensors to collect real-time global data regarding the ecological impact of their operations and services. Each actor network is left to govern the development of the systems that relate most directly to their own operations, using green Artificial Intelligence technologies, but open-source code has become the de facto standard to increase transparency and accountability. This has allowed for global collaboration in technological development, which has in turn led to a more rapid expansion of system capacities and higher orders of security. The SOT will continue to work as the governing idea at global level to design the objectives, targets and framework of indicators that will be used as a global compass to monitor planetary ecosystems performances, considering the impacts on the different categories of agents and patients.

A key technological development supporting the upsurge of the symbiotic economy has been the dismantling of the centralized energy power sector and energy-intensive economy, Decentralized energy and technologies that can be scaled down to local levels have been a necessity right from the beginnings of the Symbiocene transition. With the cost of locally sourced, clean, safe, and renewable energy falling well below its fossil fuels and nuclear competitors, this process was greatly facilitated. Once smaller-scale energy technologies are up and running, they have been in everyday use by communities and households the world over. Clean, renewable electricity can also be gifted, shared, locally traded, or sold as peer-to-peer transactions around communities, using locally based currencies.

Governance
In the year 2050, global governance has transformed into an effective, stable constellation of actor-network powers operating under a planetary systems approach to decision-making and action. The emergent global powers are composed of organizations and institutions from both the public and private sectors, and they have established strong principles for multi-stakeholder alliances with common concerns for the health of human and non-human ecosystems of Earth. All actor-network operations and decisions are informed by multi-dimensional monitoring of systems and balanced with economic and cultural sensitivities to regional conditions. Utilizing network dynamics, and their capacity to channel energies and resources efficiently, these actor-networks govern civil service provision (e.g., healthcare, education, utilities, communications, transport, and mobility, etc.) under an inclusive model of economic and social prosperity. Effective technological regulation and deployment fall under the domain of each actor-network and are semi-orchestrated − allowing for regional independence within the guidelines of effective environmental caretaking. Globally, individual nation-states have seen their direct governance power greatly diminished.

As trade-offs between actor-networks are being developed, affected citizen groups, service providers, and other actor groups are kept within the loop of the decision-making process. Given that participation is incentivized for both individuals and collectives, negotiations are widely transparent and often responsive to various actor concerns. While there is no overarching authoritative body concerning these negotiations, the complex nature of actor-network optimization often leads to powerful network nodes utilizing their influence hierarchically. At times this type of network influence has altered the lives and livelihoods of citizens and communities in profound ways. Effective counterstrategies are still being developed, including for instance the formation of ad hoc representative councils, the development of novel financial instruments, and specialized community-based justice services that leverage participation and the strength of other actor-networks to counter attempts at network hegemonies.

The emergence of these network-based forms of governance reflects the new symbiotic understanding of life and its manifestations in all spheres, personal, social, ecological, and informational. “Sumbiocracy” is recognized as the dominant form of cooperative rule, determined by the type and totality of mutually beneficial or benign relationships, in a given sociobiological system. Sumbiocracy is a form of government where humans govern for all the reciprocal relationships of the Earth at all scales, from local to global. This entails improving further the biased, anthropocentric notion of democracy (from demos, people) with, say, a deep ecology “council of beings” approach where the interest of species is represented in decision-making structures by well-meaning humans (Seed and others, 1988). While species are important, it is the shared life between species that goes to the fore. Deliberative democracy will be the appropriate form of governance and decision-making for symbiotic relationships between and within species. Within a sumbiocracy, who govern (sumbiocrats) need to have a thorough understanding of the symbiotic, life-sharing interrelationships that enable life functioning and flourishing, and they must ponder what kind of mutualistic development is permissible to enable living together to be fulfilled.

Finally, older forms of bioregionalism – based on the strict delimitation of catchments and landforms – are renovated to include the overall sense of cohesion that people have within a geographical space, recognizing the porosity of boundaries that is reinforced by the concatenation of people and another biota from all over the world in places that were once relatively isolated. New biomes will emerge in this process, that can be defined as "sumbioregions" as an identifiable biophysical and cultural space where humans live together and engage in a common pursuit of the reestablishment and creation of new symbiotic interrelationships between humans, non-human organisms, and landscapes. Confederations of sumbiocracies can form larger units of collaboration, and nothing is preventing them from going to the global scale as well. So, in this symbiotic global economy scenario, the United Nations (UN) is replaced by the United Sumbiocracies (US).

4.4.4 Discussion

To draw conclusions, we consider again the contrast between two basic types of economic systems:

- *Extractive economies (strength-based)* tend to treat most local, regional, and even national economies as places from which wealth – resources, money, labour, etc. – can be extracted. Extractive activities are common because they help build strength and power by concentrating resources. In turn, size and power help make organizations more *risk-absorbing* improving the organization's ability to withstand crises and absorb shocks. Extractive theories tend to assume that vitality rises from the accumulation of wealth and power. But over time, excessive extraction and corruption take their toll on the real economy. So, while accumulation may indeed increase vitality in the short term, if economies extract too much, nourish internal capacities too little, and allow corruption to continue unabated, they end up creating only the illusion of vitality, a shimmering bubble of elite wealth that masks an ever-more fragile real economy.
- *Regenerative economies (learning-centred)* pump money, information, energy, and resources back into developing internal capacities and infrastructure (particularly the humankind), so as to maintain vitality long-term. Regenerative economies are common, especially at the small-scale, because they improve group innovation, productivity and learning. Instead of trying to absorb risks afterwards, regenerative institutions are *solution-seeking*: they try to eliminate or mitigate risks before they happen, as for example, trying to switch to renewable energy before fossil fuel reserves become critical.

The centrepiece of the regenerative capitalism story (Fullerton, J. 2015) is that systems that last in the real world are healthy, regenerative energy flow networks – where "energy flow" actually refers to any kind of flow that matters to the particular system under study,[46] The big discovery of regenerative systems science is that many of the same physical laws that govern health and development in ecosystems and living systems are common to all flow networks, and therefore apply equally to human networks such as economies and society. In a nutshell, rigorous – and tested in practice – regenerative system laws that regulate the economic metabolism are universal system design principles that must be used as a model for any economic system design.

How realistic is it that the regenerative economy paradigm becomes dominant?

Indeed, extrapolation of current trends – high structural unemployment, particularly among youth, persistent poverty even in the richest countries, widening inequality within countries and regions, and now for the first time on a global scale (which is why this time is different) cascading environmental crises, most notably climate change – leads ultimately to system collapse with the weakest among us the first to be affected. This systemic crisis is well understood in sustainability circles and is slowly being recognized inside mainstream institutions and among policymakers. By and large, however, when it comes to sustainability, our leading business actors are primarily engaged in furthering the technology-enabled resource productivity opportunity, just as they earlier focused on the labour productivity opportunity. The current mantra is: "Businesses can become more profitable through more intelligent operating practices that reduce costs through better resource efficiencies."

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[46] Economists, for example, study the flow of money and resources in economies, while ecologists study the flow of carbon and oxygen in the biosphere.

Individual firms are attempting to decouple their growth from material throughput through critical energy and material efficiency gains (offshoring manufacturing simply shifts the problem elsewhere). Utilizing strategies such as "Factor Five" resource productivity improvements and circular economy business models, the potential exists to profitably achieve up to 80 percent improvements in resource productivity, extending the runway for the transition to truly regenerative business models in the process. But decoupling material throughput from economic growth for the entire system, indefinitely into the future – i.e., continuous economic growth while continuously reducing absolute material throughput of the economy – is quite a different matter. Efficiency gains are urgent and useful to buy time. But at the same time, it is necessary to look ahead and envision a truly regenerative system design. That is something entirely new, requiring fresh imagination, not just incremental innovation.

A Copernican shift is needed to understand that a regenerative economy maintains reliable inputs and healthy outputs by not exhausting critical inputs or harming other parts of the broader societal and environmental systems upon which it depends. The next most critical characteristic of regenerative economy lies in being self-nourishing and self-regulating. And critically, we must integrate human agency in the picture, with its capacity to affect the outcome of the system. More concretely, the Copernican shift towards the regenerative economy paradigm will change the focus of economic discussion by showing that:

- Small, medium, and large are all necessary. The trick is to avoid excesses, to maintain a proper balance of competitors at every scale, and to keep members at all levels serving the health of the whole and not just their narrow self-interest.
- Some inequality is to be expected, but too much is deadly for economies and societies.
- Powerful elites have a special responsibility not to use their power for self-serving ends. Society must have a mechanism to ensure that this vital component of systemic health is upheld.
- Robust cross-scale circulation is critical. Excessive concentrations of financial wealth and excessive draining of lower levels can destroy an economy by stifling circulation.
- Both systemic efficiency and resilience are necessary, and too much or too little of either one causes problems. These problems can be catastrophic, as we have seen from finance's relentless pursuit of "shareholder value" in the name of "capital efficiency" – when what is needed is a more integral understanding of stakeholder value.

Besides changing the economic discourse, the regenerative economy will contribute to adjust several aspects of the real economies, such as:

- Enabled by smart infrastructure and technology investment, **material consumption** in the developed world decelerates to allow developing economies to reach a level of equitable and sustainable material prosperity.
- The **global energy system** transitions off fossil fuels to 100 percent renewables.
- The **agriculture sector** transitions to a holistically managed, organic system free of fossil fuel dependency and toxic chemicals.
- **Naturally regenerative materials** are used at a sustainable rate.
- **Finite resources** are governed by an ethic of thrift, exploiting "Factor Five" resource efficiency potential, and reclaiming, recycling, and remanufacturing as much as possible. Industries from electronics to aerospace that are today dependent upon finite resources are reinvented to be less so.
- The **planet's degraded ecosystems** are restored to highest functionality. This begins with the natural carbon sinks (natural systems that absorb carbon) we know how to manage: the grasslands and forests.
- The **chemical industry** is transformed primarily to water-based chemistry, or approaches known not to be toxic to health, since we know that neither human nor ecosystem health is possible with destructive toxins in our environment.
- **Population growth** is controlled as we recognize that we must slow down the consumption of the natural capital that is essential to the survival of all living systems.

Examples of STI directions that promise to be especially relevant to accelerate the transition to a regenerative economy include (CEFIC, 2019):

- Artificial photosynthesis.
- Hydrogen and fuel cells
- Self-healing polymers

- Pushing boundaries with new materials
- 3D printing
- Artificial intelligence
- Blockchain and distributed ledgers
- Industrial Biotechnology
- CO2 as feedstock.

Finally, the transition to a regenerative economy can be accelerated by leverage policies that include:
- Subsidies
- Taxes
- Public procurement
- New institutions (Trusts)
- Financial wealth redistribution
- Discourage wasteful consumption
- New metrics of regenerative economy performance

4.4.5 Conclusions

The three scenarios are alternative responses to the challenge of transforming the economy and society away from the current status quo of waste overload. While the eco-efficient and circular economy scenarios are depicted to be inadequate to solve waste and in more general sustainability crisis, they provide together with the regenerative economy scenario means to define effective research and innovation (R&I) actions and pathways towards sustainability.

P1 eco-efficient economy scenario emphasises the application of end-of-pipe and eco-efficient solutions, which play an important role to curb the negative impacts of human activity on the environment (e.g., carbon capture and storage, identified by the Dynamic Argumentative Delphi) and thus help gain time to develop more advanced solutions.
Further R&I efforts, especially scaling up the proven applications, are justified considering that they are relatively fast and easy to implement as they do not require system-level changes. Especially, end-of-pipe solutions (e.g., catalysers in vehicles) mean simply a component addition, but also eco-efficiency improvements deal with only sub-system level changes (e.g. improvements in a combustion engine). Furthermore, wilderness management and protected areas become crucial for biodiversity. With this respect, further research is needed to ensure that ecosystem areas offering crucial refuge for elsewhere affected species are protected, for instance, to cope with climate change impacts. This is in line with the findings from the Dynamic Argumentative Delphi study identifying ‘Global nature conservation and restoration areas’ the second most important area in the STI directions in Environmental planning & Environmental engineering. Food policies are a concern for this scenario, considering environmental externalities in food prices.

P2 circular economy scenario orients R&I activities to learn from nature in designing new production and consumption systems of technical and biological cycles with immense opportunities to use resources more effectively and identify ‘positive’ lists of materials that are healthy and environmentally benign. In line with the findings from the Dynamic Argumentative Delphi study identifying ‘Integrated waste management systems: e.g. Waste minimisation, Recycling, Recovery, Landfilling of refuse‘ as the most important area in the STI directions in Waste management, it is important to look for systemic solutions to the waste problems. Indeed, the Dynamic Argumentative Delphi study identified ‘Circular Economy’ as the most important area in the STI directions in Environmental planning & Environmental engineering.
Further research and innovation also on cross-sectoral actor-networks for reconfiguring the production and consumption systems are needed. Programmes for circular system innovation can engage solution providers and users as well as public entities to accelerate uptake. Here, an **interdisciplinary** approach is required related to engineering, technology, life sciences, environmental and social sciences, and humanities. Security and safety concerns may affect acceptance and might slow down implementation.
The fundamental difference between P1 and P2 is that in the circular economy scenario there is a profound reorganization of supply chains around closed loops of energy and materials at all scales, and as a consequence, a regionalization of trade flows that is absent in the eco-efficient economy scenario, which is dominated by more efficient but still global trade flows.

P3 regenerative economy scenario provides crucial learnings emphasising the importance of extending our understanding on the living systems, the engagement of individuals incl. their values and behaviours to lay foundations for a paradigm shift needed for symbioscene.
R&I efforts can range from ecovillage living labs and value ecosystem services to extending legal recognition to natural assets and learning from indigenous communities. With regards to gaining scale in regenerative practices, the networks of ecovillages, mutual learning and the development of global information ethics are possible avenues. Symbiocene and especially the development of permaculture is in line with the findings from the Dynamic Argumentative Delphi study identifying 'Sustainable, circular food production' as the most important area in the STI directions in Food science. In this scenario a substantive reduction of consumption and measures to raise awareness and inspire forward-looking narratives are needed.

All the three scenarios indicate the need for further **R&I efforts in safeguarding and understanding and monitoring ecosystems and the pressures they are exposed** to. This can encompass measuring environmental services and monitoring the natural assets as well as undertaking national accounting of natural assets and biodiversity. Planetary ecological health needs to be monitored and assessed constantly by overlapping systems of orbital satellites, land- and water-based instrumentation, sensors arrays (green AI applications) and human-centric reporting systems. This is in line with the findings from the Dynamic Argumentative Delphi study identifying in the STI directions in Ecology & Environmental health 'Understanding impact of human activity on ecosystems' as the most important area and 'Understanding the environmental impact of climate change' as the second most important area.

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4.5 Case Study 5: Ecosystems and Micro-and Nano Cosmos

Beatrix Wepner, Dana Wasserbacher, Klaus Kubeczko

4.5.1 Introduction

The influential narratives about new nano-materials, the threats from micro-plastics and the threats to human and animal health through antimicrobial resistance, have risen attention of policy makers, strong enough to create new topics for established policy fields and research. This case study explores how a strong focus on ecosystem flourishing could change the current thinking about the narrative towards micro and nano cosmos (MNC).

The search for knowledge about the micro-nano cosmos creates the possibilities for new fundamental understandings as well as new generic technologies. At the same time, the knowledge about potential risks and threats to the health of humans, non-human life and flourishing of ecosystems is often lagging. This case study explores the aspects of micro- and nanoscale materials and systems, interacting with biological systems and thus having an influence and drive processes at the ecosystem scale on human and non-human agents. It follows the need for new approaches to understand potential impacts of nano / bio molecular agents in the environment. All this has, or may have, implications for human wellbeing as well as the role of humans in ecosystem stewardship.

The case study provides the following sections:

- **Status Quo Analysis**: It outlines some of the current developments, (1) by sketching the ongoing innovation activities in the micro-nano cosmos and (2) discussing developments on the micro-nanoscale with potential effects threatening ecosystem stewardship and human health.
- **Scenario Sketching**: In this section a range of possible micro-nano-scale scenarios are narrated in the light of the three perspectives of ecosystem performance.
- **Policy Implications**: The case study furthermore discusses implications for STI policy to address the Micro-nano cosmos -- to inform programming and implementation of Horizon Europe and future STI frameworks.

4.5.2 Status Quo of Innovations and Issues of Potential Threats

Nanotechnology, i.e. the manipulation of nanomaterials for several purposes, is playing an increasingly important role for human- and non-human agents in ecosystem performance. Applications in the food and agriculture sectors and addressing human health through novel and innovative approaches are taking place on multiple size levels (Nile, S.H. et al., 2020; S.E. McNeil, 2005), which we consider as the scales of the micro- and nano-cosmos (MNC).

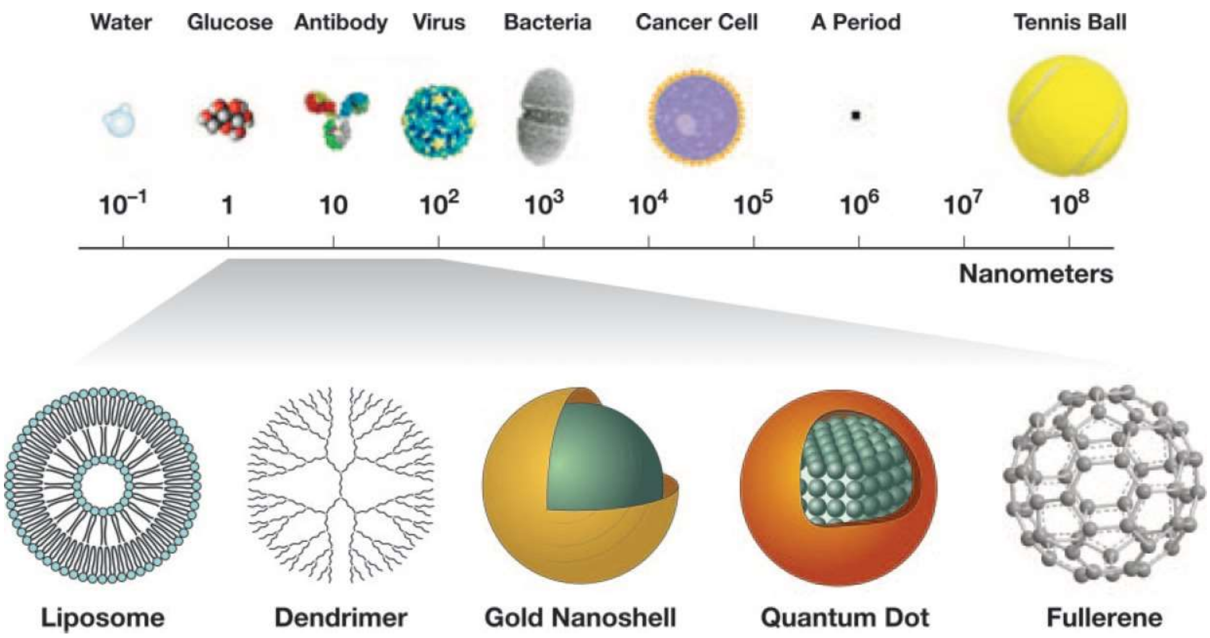


Figure 21 Different sized nanoparticles used in nanotechnologies. This figure was modified and adopted from S.E. McNeil, (2005). https ://doi.org/10.1189/jlb.02050 74

With the environmental and health related issues of nanotechnologies and cleaning up micro-plastics in the societal discourse, scientific communities have been drawing more attention on life forms on those scales. Also, technological developments on the micro-nano scale, from new materials to self-organising and self-replicating cellular robots are expected to shape the micro- and nano-cosmos. Along with the prospects that nanotechnology holds for innovation comes the caveat that this is uncharted scientific territory and may have potential risks and hazards. There is evidence that certain nanoscale particles can have detrimental effects on living organisms (S.E. McNeil, 2005).

In two different parts, we will outline some of the current developments. In the first part "Innovation in the Micro-Nano Cosmos" ongoing innovation activities are sketched, such as self-replicating materials, organoids, xenobots, bioactive materials, bioeffectors, biostimulants and microbe-assisted crop production, cell factories, bio-inspired materials and plastic-degrading enzymes. In the second part "Issues of Potential Threats from the Micro- and Nanoscale", we discuss developments on the micro-nanoscale with potential critical impacts on ecosystem stewardship and human health. We draw on results of the Delphi Study about harms for ecosystem performance and explore issues such as antibiotic resistance, microplastic, micro-flotation processes. It is not always unambiguous to categorize some of the analysed developments below to either innovation activities or potential threats. Hence, for each of the innovation activities and impact issues, challenges and opportunities are discussed.

Innovation in the Micro-Nano Cosmos

When exploring the micro-nano cosmos, it becomes clear that a major part of innovative activities takes place in the realm of materials, but also touches upon fields of application such as medicine, construction, packaging and food supply. The relevance of nanotechnologies for ecosystem stewardship appears to resemble the seminal work of Roco and Bainbridge (2003) on converging technologies for improving human performance. The following overview provides evidence that converging technologies between nano-bio, nano-bio-computing, nano-robotic etc. also play a role for "ecosystem performance".

STI 2050 Delphi Results:

Several of the STI-direction from STI 2050 Delphi Report[47] are related to innovation in the micro- and nano-cosmos such as: Graphene membranes that artificially mimic photosynthesis; Water decontamination technologies like filtering products - e.g. graphene filters and nanopowder for removing toxic metal ions; Nanofertilizers and nano chelated iron fertilizers; Nanomaterials to improve plant stress tolerance; Nano-composite films for food packaging; Nano-based precision farming to optimize crop used to produce biofuel; Antimicrobial polymeric bio-nanocomposites for food packaging, drug delivery; tissue engineering; Light weight and eco-friendly bio-nanocomposites to replace non-biodegradable petroleum-based plastics; Engineered nanocomposites for need-based delivery of agrochemicals; Nanocomposites to eliminate bacteria, viruses, and inorganic and organic pollutants from wastewater; Nanocarbon based composites for agriculture, energy storage devices, photocatalysis, water purification; Heavy nanocomposites for gamma shielding; Nanoparticles for dentistry; Nanocomposites as heterogeneous catalysts; Agricultural nanotechnology: e.g. Nano-pesticide delivery; Slow and controlled release of nanoparticles containing biofertilizers or nano biosensors for rapid detection of phytopathogen and other biotic and abiotic stresses; Biocomputers: e.g. microbial nanowires, lipid 'nanotablet' resembling cell membrane to perform Boolean logic operations.

Self-replicating materials

A "self-replicator" is usually understood to be an object of definite form that promotes the conversion of materials in its environment into a nearly identical copy of itself (Sakar & England 2019). The challenge of engineering novel, micro- or nanoscale self-replicators has attracted keen interest in recent years, both because exponential amplification is an attractive method for generating high yields of specific products and, also, because self-reproducing entities have the potential to be optimized or adapted through rounds of iterative selection. Substantial steps forward have been achieved both in the engineering of particular self-replicating molecules and in the characterization of the physical basis for possible mechanisms of self-replication (Sakar & England 2019). Other terminology used in this context is molecular manufacturing, self-reproducing machines, exponential manufacturing or in the context of biotechnology artificial life. Most research has been conducted in biological studies concentrating on natural replications investigating the origin

[47] https://www.futures4europe.eu/_files/ugd/ff6ca7_bf90fad2a518441ba4d1f11d3ada3cfc.pdf

of life and the ability of DNA, RNA and other organic molecules to self-replicate. Industrial applications concentrate on space exploration and manufacturing, applying nanotechnology and nano scale assemblers, while in computer science self-reproducing computer programs that infect computers such as computer worms and computer viruses are examples for self-replicating approaches.

Opportunities: Fast progress is being made in these research areas and, as with all new technologies appearing, there is a vivid discussion ongoing between those wishing to exploit these new opportunities as rapidly as possible and those wishing to wait – forever, if necessary – to have it proved absolutely safe. Research on self-replicating systems that will eventually be programmable and enable new manufacturing bases that can produce both small and large objects precisely and inexpensively or even lead to the manufacturing of living objects and thus artificial life, is ongoing. There is a consensus that embedded controls can be integrated in designed systems at many dimensions of design properties. The development of such sensitive systems as self-replicating nano-systems requires close collaboration between policymakers and industry to develop and commercialize a manufacturing industry based on productive nano-systems designed for safety and reliability. For the application of nanotechnology Foresight guidelines[48] have been developed to ensure responsible development and application. Nanotechnology policy will have to balance risks with benefits and distinguish between different classes of risks. Molecular manufacturing and nanotechnology are not one technology, but rather a spectrum of technologies, with radically different risk profiles.

Challenges: The biggest concern about advanced forms of self-replication, after feasibility issues have been addressed, tends to concentrate on the possibility of the technology getting out of control. The risk of accident or malfunction is seen less problematic for new technologies than the dangers of abuse. Fuelled by scenarios by Drexler from 1986 popular science fiction describes molecular robots that are autonomous self-replicating machines or autonomous replicators that evolve beyond human control or cannot stop reproducing. While these scenarios are not entirely impossible, they are not considered as very likely and that other social and ethical concerns deserve more attention (Phoenix and Drexler 2004, Poel, 2016). This heated discussion about these scenarios and the description of popular science fiction on molecular robots is problematic as they draw moral and regulatory attention away from the more important ethical issues in fields.

Organoids

Organoids are so called mini-organs, able to self-assemble in three-dimensional structures that resemble real organs in architecture and function and that are grown in vitro from stem cells. Human organoids have a huge potential for biomedical research and personalised medicine, as they allow for a detailed study of human cell pathologies and advancements in research related to transplants.

Opportunities: Organoids are regarded as one of the most significant developments in stem cell research and promise a wide range of application in research and in the clinic. Stored in biobanks organoids could contribute to fundamental research, precision medicine, and regenerative medicine, especially to advance the understanding of brain development or to serve as drug-testing tools. They could also help reduce animal testing.

Challenges: Despite the high potential attributed to organoids, a range of challenges remain that will need to be addressed in the future. Ethical issues concern the origin of the cells that are used to produce organoids, i.e., human embryos . This holds especially true for cerebral organoids, that exhibit neural connections and electrical activity, which raises the question of their status as living beings. Also questions of consent, ownership, commercialization, intellectual property rights, and safety come along with the production and use of organoids.

Xenobots

One example for a very recent development in micro-nanoscale R&I is the case of xenobots. Xenobots are living, computer-designed organisms that U.S. researchers have developed with the help of a supercomputer (Kriegman et al. 2020). They derive their name and cells from *Xenopus laevis* (Latin), the African clawed frog. The prefix "xeno" (derived from the Greek *xénos*, meaning "guest", "stranger") refers to the fact that the cells assembled into an organism can perform functions other than those intended by their original genetic blueprint.

48 https://foresight.org/about-nanotechnology/foresight-guidelines/

Propelled by synthetic biology (synbio), xenobots are a first example of an artificially created life form with special properties. They consist exclusively of living animal skin and (heart) muscle cells, which, through their continuous pulsation, allow the organisms limited movements. The living machines can swim, transport small loads, work together in groups and heal themselves. Such artificial organisms are developed with the help of artificial intelligence (AI) methods, i.e., an "evolutionary algorithm" aimed at producing different construction plans in numerous simulations, from which suitable designs are selected. The second generation of xenobots - also known as xenobots 2.0 - differs from the first generation in that the organisms, which develop from stem cells, self-assemble into a spherical body and do not require extra muscle cells to ensure their mobility (Blackiston et al. 2021).

Opportunities: The current focus is on demonstrating the feasibility of this new technology and advancing research on the mechanisms of life. Expectations in terms of societal benefits go in two directions, depending on the cell material used. Xenobots built from animal cells promise a vast potential for application, e.g., in detecting radioactive or toxic contamination in polluted areas or in cleaning the oceans of microplastics. If the artificial organisms are produced from human cells, they could be highly relevant for biomedical research. For example, xenobots that are developed from the body's own cells of a person suffering from cancer, could be used to deliver drugs to the site of the cancer tumour autonomously and in a targeted manner. The process would be similar to clearing calcified arteries of plaque from the inside. An advantage of this technology is seen in the better immune tolerance of the externally introduced organisms, as they could be developed from the affected person's own body material.

Challenges: Although application is still a very distant, the current development raises far-reaching ethical and social questions. First and foremost, the central question: What are xenobots in the first place and what status would they have in our society? Do they fulfil sufficient requirements to be classified as living beings? And at what point should we consider and protect artificially created living beings as life forms with their own interests (Lavazza and Massimini 2018)? Much of the research on the artificial, living machines is done publicly and with the involvement of legal expertise. Even the source code used to develop the computer-designed beings is free and publicly available. Nevertheless, the question remains open as to how society's awareness of this complex and still immature development and its possible consequences can be raised.

Bioactive nanomaterials

The field of bioactive materials has grown rapidly over the last few decades, in biomedical device design and the development of tissue engineering solutions for cell delivery, drug delivery, device integration, tissue replacement, and more. Bioactive materials are materials that produce physiological response, differentiating it from biocompatible material, which is tolerated by the biological system it comes into contact with.

Bioactive nanomaterials are not a simple miniaturization of macroscopic materials. They exhibit unique bioactivities due to their nanoscale size effect, high specific surface area, and precise nanostructure, which can significantly influence the interactions with biological systems. Nowadays, bioactive nanomaterials have represented an important and exciting area of research (Zhao, Y., et al. (2021).

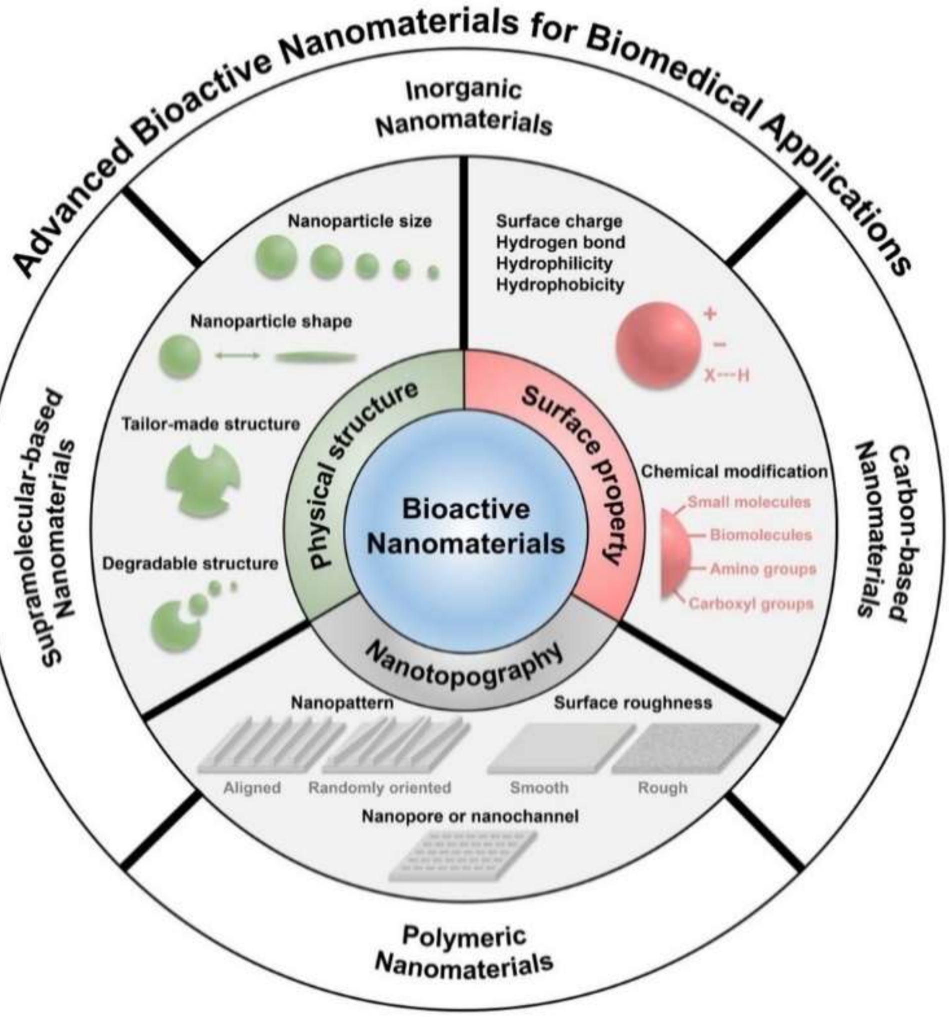


Figure 22: Advanced bioactive nanomaterials for biomedical applications [Zhao, Y., et al. (2021)]

Opportunities: To improve the biocompatibility and biodegradability of delivered materials natural substrates are used, such as macromolecules native to plants and animals. Biomaterials are widely used in tissue engineering solutions in combination with cells, synthetic materials, and therapeutic molecules to produce advanced therapeutic medicinal products. A three-dimensional polymeric scaffold often provides a support structure for the delivery of cells and biologically actives components. There is an increasing trend in tissue engineering to use naturally occurring macromolecules as a starting material due to their advantageous properties, since such materials are well tolerated, promoting cellular adhesion, and subsequent tissue formation to facilitate body integration while their biodegradability allows for tissue remodelling (Joyce et al., 2021).

Challenges: The rapid expansion in the biomaterials toolkit comes at a cost; a considerable increased risk of adverse reactions to implanted biomaterials which includes allergies, chronic inflammation, susceptibility to infection, collateral tissue damage, and loss of functionality due to immune reactions. Moreover, the highly personalized nature of immune reactions needs to be taken into account while assessing the use of new biomaterials. These concerns have created a general reticence in the medical device industry for the utilization of novel biomaterials and complex, multi-material structures which significantly hinders the advances in the field and also decelerates the introduction of new and potentially transformative technologies to the healthcare system. Thus potential ways out of this conundrum Vrana et al (2019) suggest (i) to improve the capacities in the risk assessment of biomaterials by developing novel in vitro testing systems, preferably in a personalized manner (i.e., using patients' own cells); (ii) to develop new technologies to control the interface between the implanted materials and the host tissues where immune reactions can be either attenuated or directed toward expected outcomes (iii) to achieve systems level understanding of personalized response to biomaterials using the recent advances in high throughput analysis methods available (Vrana et al, 2019).

Bioeffectors, Biostimulants and Microbe-assisted Crop Production

Biostimulants include organic compounds and microorganisms that are applied to plants or soils to improve crop yield, quality, vigour, and tolerance to insects, diseases, weeds, or abiotic stresses. Bioeffectors are special microorganisms or active naturally occurring compounds that, in symbiosis with certain other bacteria, contribute to improving crop traits (especially growth) and to the biological control of pathogens (Duque et al. 2019). To understand the mechanisms by which the microbes enter the plant roots and spread throughout the plant, genetically modified organisms are used in advance under safe laboratory conditions in in vitro experiments and in the construction of control systems in the greenhouse. Plant biostimulants were defined by du Jardin (2015) as follows: "A plant biostimulant is any substance or microorganism applied to plants with the aim to enhance nutrition efficiency, abiotic stress tolerance and/or crop quality traits, regardless of its nutrient content". This definition could be completed by "By extension plant biostimulants also designate commercial products containing mixtures of such substances and/or microorganisms". The definition of plant biostimulants has been rigorously debated over the last decade, and recently under the new EU regulation 2019/1009, which led to the following: "A plant stimulants shall be an EU fertilising product the function of which is to stimulate plant nutrition processes independently of the product's nutrient content with the sole aim of improving one or more of the following characteristics of the plant or the plant rhizosphere: i) nutrient use efficiency, ii) tolerance to abiotic stress, iii) quality traits, or iv) availability of confined nutrients in the soil or rhizosphere" (EU, 2019). (Rouphael Y and Colla G, 2020)

Du Jardin (2012) proposes eight categories of biostimulants, but also states that the functional distinction between them may be overlapping: 1) humic substances, 2) complex organic materials, 3) beneficial chemical elements, 4) inorganic salts, 5) seaweed extracts, 6) chitin and chitosan, 7) antitranspirants, 8) free amino acids and other N-containing substances.

Opportunities: Plant biostimulants including natural substances and microbial inoculants appear as a novel and potential category of agricultural inputs, complementing agrochemicals including synthetic fertilizers, and improving tolerance to abiotic stresses, as well as enhancing the quality of agricultural and horticultural commodities. Consequently, chemical fertiliser application and the use of chemical antimycotics can be reduced. The linking of biobased and digital technologies opens up further development paths, e.g. for new processes in white, red and green biotechnology or for personalised medical applications. Furthermore, the application of microbial and non-microbial plant biostimulants stimulate plant primary and secondary metabolism leading to the synthesis and accumulation of antioxidant molecules (i.e., secondary metabolites) which are important for human (and animal) diet (Rouphael Y and Colla G, 2020).

Challenges: Legal aspects in terms of defining the diverse field of biostimulants are challenging the development, as currently new regulations are entering into force, which introduce a transitional period that allows industry to adapt.[49] Bioeffectors are also related to the debate on genetic engineering, as the microorganisms used for research can be genetically modified in the laboratory.

Cell Factories

One vision for the future in the production of novel materials is to make extensive use of living cells and their molecular components as cell factories on an industrial scale. To use microorganisms to produce special substances, biotechnology uses the process of metabolic engineering. In this design of customised metabolic and synthesis pathways in a cell, genetic control elements and biosynthesis genes from plants, animals or microorganisms can be combined to turn microbes into efficient cell factories - and use them to produce drugs, for example. Synthetic yeast cell factories are already possible on a laboratory scale, which will be able to produce the potential cancer drug noscapine in the future (cf. Li et al. 2018).

Opportunities: The future potential of cell factories in medicine, in the bio-based economy and in industrial applications is very far-reaching.

[49] https://www.fertilizerseurope.com/agriculture-environment/fertilizing-products-regulation/

Challenges: However, some of the promising cell factories also call into question previous international regulatory approaches: yeast fungi can be modified in such a way that they can produce opium-like substances. This means that in the future highly effective painkillers could be developed from the simplest materials. Furthermore, technologies for large scale genome editing and the development of strains and processes for production is time consuming and expensive. While novel technologies, such as CRISPR-Cas systems mediated genome editing, third generation sequencing, optimized workflows for genome assemblies, together with predictive models, have positively impacted the progress, there are still numerous challenges to be solved such as regulatory aspects and admission of (gene) modified products.

Plastic-degrading enzymes
A few years ago, a specific type of bacteria was discovered, that is able to degrade plastic. Researchers optimised a variant of this enzyme and are now trying to render it useable for bioinspired recycling of plastics (Austin et al. 2018).

Opportunities: Once the technology is mature, the artificially modified bacteria could help remove microplastics from our ecosystems and therefore have a high potential for the future.

Challenges: Currently, this technology is not yet widely deployable, and technical hurdles still need to be overcome in the near future to demonstrate effective use.

Issues of Potential Threats from the Micro- and Nanoscale
Newly developed materials need to undergo risk assessment to help evaluate potential environmental and health risks. However, traditional risk assessment frameworks and methods often face significant challenges when evaluating novel materials due to uncertainties and data gaps. Engineered nanomaterials is one prominent example of new, advanced materials whereby scientists, researchers and decision-makers are still discussing best practices to modify and update risk assessment frameworks after nearly two decades of research (Baun & Grieger, 2022).
However, it is not possible to make a generally valid statement on the hazardousness or safety of nanomaterials and other novel materials. For example, available data based on regulatory relevant endpoints focus mainly on acute ecotoxicity whereas long-term data are often still limited. Also, information on actual exposure during the test is often lacking, and thus, quality- assured data on ecotoxicity for nanomaterials remain scarce. Those challenges in reliable aquatic toxicity testing of nanomaterials have already been identified, and solutions by, for example, developing test and assessment strategies were proposed. Exposure estimation is still challenging for nanomaterials. In particular, fate and behaviour processes of nanomaterials differ considerably in comparison to that of soluble (organic) substances. Experts have started to develop various models or tools for allowing realistic exposure estimation for nanomaterials (Schwirn et al, 2020).

Antibiotic Resistance
When considering the micro- and nano cosmos, antibiotic resistance needs to be discussed as a threat and major influencing factor. It is estimated, that more than 1,2 million people worldwide and approx. 33.000 people in Europe die each year as a result of infection by resistant pathogens. So-called multi-resistant bacteria ("superbugs") pose a particular challenge to public health. These are microorganisms that are resistant to several or even all known antibiotics in use (Magiorakos et al. 2012). These include the bacteria Enterococcus faecium, Staphylococcus aureus, Klebsiella pneumoniae, Acinetobacter baumannii, Pseudomonas aeruginosa and Enterobacter spp. which are summarised under the acronym "ESKAPE" (Pendleton et al. 2013).

Opportunities: One possibility to address the problem of antibiotic resistance is the advancement of diagnostic procedures that support the identification of pathogens, such as rapid antimicrobial susceptibility testing – AST (Vasala et al. 2020). With faster and more efficient identification, more targeted narrow-spectrum antibiotics can be used, reducing the risk of resistance development. Phage therapy; animal-friendly livestock farming and more ecologically compatible forms of agriculture.

Challenges: In addition to the development of resistance, other challenges exacerbate the potential consequences for society: the often lengthy and expensive development of new antibiotics (10-15 years on average), the incorrect use of antibiotics, poor hygienic conditions, the environmental release of antibiotics from industrial producers, and, above all, the widespread use of antibiotics in large-scale livestock farming.

Microplastic

Micro- and Nano plastics (MNPs) are today recognized as emerging contaminants, showing impacts on aquatic and terrestrial biota and most ecosystems on earth, including atmospheric microplastics, with unknown health and environmental significance. MNPs passing through the gastrointestinal tract have been brought in context with disruption of the gut microbiome. Several molecular mechanisms have been described to facilitate tissue uptake of MNPs, which then are involved in local inflammatory and immune responses. Furthermore, MNPs are also considered as potential transporters, vectors, of contaminants and as chemosensitizers for toxic substances (Gruber, E. S., et al. 2022). As a multitude of studies show in that action needs to be taken immediately to reduce plastic use and plastic waste mismanagement to avoid increased microplastic pollution in the future. Progress has been made to reduce the use of certain single-use plastics through legislative actions, but there are few mitigative strategies to reduce sources of microplastic pollution.

Opportunities: Innovative approaches to overcome the risks include measures and economic practices such as plastic waste conversion to energy, biotechnological upcycling, conversion of plastic waste to value-added materials (e.g., adsorbents and catalysts), and utilization in construction materials, support the sustainable management of plastic particulates. To improve our understanding of microplastic pollution, it is necessary to involve citizen scientists in monitoring microplastic hotspots and to engage in effective scientific communication with all stakeholders (e.g. civil society, NGOs, government policy makers and industry) about the hazards posed by microplastics and potential opportunities to reduce microplastic sources (Walker, 2022).

Challenges: Most stakeholders are still unaware of the connections between their use and mismanagement of plastics and the threats posed by microplastic pollution. The lack of strategies to control microplastic pollution could be partly due to the lack of appropriate technologies, but also to our insufficient understanding of the scientific background of the origin, fate and transport of microplastics. This is clearly an obstacle to behavioural change in the public combined with inaction by industry or government. While the benefits of measures against macroplastics often exceed the costs, downstream clean-up measures for microplastics are unlikely to be cost-effective. It must be considered that it is in the interests of those employed in many sectors of the economy to find strategies to reduce marine litter, as this can help reduce social and economic burdens. Examples include tourism and recreation, aquaculture and fisheries, and shipping. In parallel, citizen consumption of goods and services, personal habits (e.g., use of reusable bags and packaging) and waste practices (littering, waste separation) are a key driver of marine litter (GESAMP. 2016, Sarkar, B. et al, 2022).

Micro-flotation processes - Microbubbles

Flotation is a separation technique based on physical and chemical surface properties and density gradients of different materials and was already used in the Middle Ages for mineral processing (Gulden 2019). Simply described, the process works by binding hydrophobic particles to gas bubbles that rise and transport the particles to the surface where they can be easily skimmed off. The bubble size is a key parameter that influences the rate of ascent in the medium, the probability of merging with other bubbles, as well as the interaction with particles further along and the medium itself (Gulden 2019). For the optimisation of flotation processes, the bubble size is therefore central, and the small diameters of microbubbles also give their name to newer micro-flotation processes.

Challenges: Micro-flotation systems work excellently if you put them next to a body of water. You have to pump or isolate water from lakes or seas to purify it. This is great for manageable amounts of water (from municipalities and industrial plants), but for large bodies of water and their huge pollution problems, it has been rather unrealistic until now.

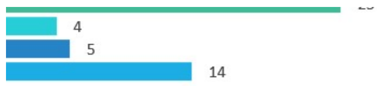
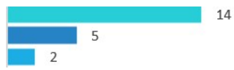
Opportunities: Compact floating rings[50] have a huge potential in terms of cleaning water bodies from e.g. microplastic, especially compared to permanently installed micro-flotation systems, to which the water must be diverted. They form a mist-like cloud of bubbles with a very high bubble density, all of which rise very slowly

[50] https://www.sprind.org/de/projekte/roland_damann/

and attract even the finest microplastic particles like a magnet and carry them to the surface. In this way, water can be freed from microplastics without chemicals, maintenance-free, with very low energy consumption.

Other potential harms

The following table shows statements of the STI 2050 Delphi[51] in which participants assessed, potential harms, which relate to the micro- and nanoscale. The assessment indicated whether they represented significant potential harms to the capability of planetary ecosystems to flourish from now to 2050.

STI 2050: Delphi Results:	
The nano-materials that cannot be metabolised are accumulating in the body, generating long term toxicity (e.g. negligence in handling nano-powders may lead to cancer, as a result of inhalation and/or contact with human skin).	
Waste derived nano-particles involves recycling part of the content and renders the remaining material useless, as opposed to using the initial material as such (e.g. the case of used tyres).	
Agricultural nanotechnology runs the risk of introducing nanoparticles in the agri-environment before full assessment of end-of-life effects, leading to unexpected and uncontrollable response from nature.	
Recycling plastic into roads, bricks, clothes can produce micro and nano plastic, which have severe consequences on all elements of the ecosystem.	

Note: Numbers show count of experts assessing the statement

4.5.3 Scenarios

A range of possible micro-nano-scale scenarios are narrated in the light of the three perspectives of ecosystem performance from the conceptual framework for society-nature interactions (Warnke et al. 2021). **Error! Reference source not found.** provides an overview of the scenarios in respect to which perspective on society-nature interaction has been taken and which key questions arise when thinking about the future in 2050.

Table 7: Overview of scenarios regarding micro-nano-scale (MNC), inofrmed by the three perspectives

	Perspective 1: Using, protecting and restoring	*Perspective 2: Co-shaping socio-ecological systems*	*Perspective 3: Caring within hybrid collectives*
Scenario title	**Cleaning up Micro- and Nano-Cosmos**	**Reflexively and anticipatory aligning with Micro- and Nano-Cosmos**	**From predation to adaptive and caring role of humans within Micro- and Nano-Cosmos**
Key descriptors on the social construction of	Ecosystems as provider of goods and services, mainly	MNC, ecosystems and humans are moulding each other continuously	Agency at micro- and nano-scale is blurred, with new hybrid forms

[51] https://www.futures4europe.eu/_files/ugd/ff6ca7_bf90fad2a518441ba4d1f11d3ada3cfc.pdf

society-nature interaction	valuable when benefitting people; Human interventions on micro- and nano-scale seen as alternating between destruction/degradation and reparation/conservation of ecosystems	Humans work in partnership with the dynamics at micro- and nano-scale towards adaptive and transformative capacities of the socio-ecological system	of life like nanobots and xenobots. Who animates whom? - is an open question
Implications	- Specific solutions to particular impacts ('half baked sustainability') - principle of "do no harm" is dominating policy making with respect to impacts of MNC on ecosystem performance	- Ecosystem oriented adaptation and management, - applying the "Precautionary Principle" to maintain and safeguard ecosystem services (not only human health) -MNC based solutions support ecosystem stewardship	- The practice of 'collaboration' with microbes and hybrid forms of living - applying the "Stewardship Principle" to wellbeing of all living beings
Limitations	- perpetuation of a separation between the natural and human sphere that cannot support ecosystem flourishing on the long run - inability to radically challenge ('stretch and transform') current regimes with their power concentrations	- if solely the responsibility of innovative businesses based on converging technologies, MNC might not provide solutions for ecosystem stewardship, but create new challenges - the success of these practices is supported/hindered by the narratives of precaution, competition and finding synergies	- challenges in translating into practices and norms the understanding of human-soil relationships as matters of care, marked by spirituality - life-affirming intentions in the MNC can still be overruled by the logic of the macro-cosmos

Cleaning up Micro- and Nano-Cosmos – Scenario P1

This scenario is assuming the anthropocentric understanding of human/nature interaction as taking from and disposing of residues from societal activities to the natural environment of the separate and dominating sphere of humans. Micro- and Nano-Cosmoses are equally separated and controllable by humans as predators in the ecosystem having the means to exploit the resources of the MNC. Once the pressure of human action on nature is felt as having repercussions on human health or economic performance, reactive action is taken. Depending on the power relations in society, measures taken are either focussing on limiting the unintended pressure on the environment (as reflected in the principle of do-no-significant-harm), regenerating the ecosystems (e.g. by defining protected areas in the macro-, micro- or nano-cosmos) or even reversing the impact of negative effects, if affecting other human stakeholders (in the macro-cosmos e.g. renaturation of river systems).

The aim of knowledge from science is mainly to monitor the driving-force, pressures and state of human health and environmental related issues, and it provides evidence-based input to for assessing risks. However, the anthropocentric approach still creates tensions in finding agreement on managing the risks. Technology development and innovation in the micro-nano cosmos, aim to provide solutions to limit the impact of harmful human action on the environment stemming from its interventions in the macro-cosmos e.g. by means of end of pipe filtering technologies (e.g., graphene filters for water decontamination), finding new remedies against health threats (e.g. nanopowder for removing toxic metal ions) or by collecting waste (e.g., microrobots to clean up radioactive waste). If such solutions are not in sight, STI might be targeted towards developing reactive ecosystem management measures in the macro-cosmos, e.g. pesticides to cope with monoculture, medication to avoid methane emissions from cows' digestive processes).

A key concept in the environmental policy discourse is understanding society and the environment as unidirectional relation with respect to society threatening the state of the environment. Thereby, reaction to pressure on the environment is the social response to change the future state of environment. Research aims for data monitoring and modelling approaches depicting relations on various scales, which build the basis for environmental impact assessment.

Common to many strategies of this scenario-perspective concerned with the environment is the **understanding of society and human beings as disturbing or managing factor in an ecosystem, which otherwise would be in a stable state.**

Sustainability transition might be achieved by additional resources put into technology fixes and other solutions made possible through undisturbed economic activities. Technological solutions are provided by means of fast response by STI to avoid negative effects on GHG emissions or on achieving other societal aims. In the micro-nano-cosmos cleaning-up technologies like nano-robots are introduced and energy storage solutions are enabled by means of nanotechnologies.

Aligning with Micro- and Nano-Cosmos – Scenario P2

Reflexively and anticipatory aligning Macro-cosmos with Micro- and Nano-cosmos for flourishing ecosystems

This scenario is assuming the anthropocentric but reflexive understanding of human/nature interaction as interplay between two intertwined spheres of the material world and the cultural sphere. Humans work in partnership with the dynamics at micro- and nano-scale towards adaptive and transformative capacities of the socio-ecological system. Nevertheless, more emphasis is laid on monitoring the macro-cosmos with its material stocks and flows as well as biodiversity. Even if understood well, knowledge on the micro- and nano-cosmos, are difficult to be used for maintaining or improving ecosystem services and biodiversity.

Common to strategies applied in this scenario is the **understanding of society/human beings as integrated but dominating actor in an ecosystem, which in some worldviews would be in a stable state or could be brought from an instable to a temporarily stable state by human ingenuity.** The precautionary principle is applied to the MNC which implies significant research efforts in understanding and anticipating negative effects of fast-growing applications of nanotechnology.

Society has a responsibility for all living species and the planet. With its capabilities of reflection (e.g. understanding effects of antibiotic resistance) and anticipation (e.g. finding scientific evidence how phenomena on the nano-scale effect ecosystem performance) provided by science, humans shall play a cooperative role in ecosystems and develop and implement innovations and solutions to bring ecosystems (back) into a flourishing state. Anticipatory and reflexive capabilities also aim for ecosystem stewardship having positive effects on SDGs. An example is the application of gene-manipulated microorganisms providing materials sustainably substituting other natural resource-extracting measures (e.g., glue produced from micro-organisms replacing cement), thus putting less pressure on ecosystems otherwise affected by extractive measures.

Caring humans within the Micro- and Nano-Cosmos – Scenario P3

From predation to adaptive and caring role of humans within the Micro- and Nano-Cosmos

This scenario is assuming that after a period of crisis of humans' conflicts with each other and with ecosystems, anthropocentrism has been overcome and guarantees ecosystems to flourish.[52] In 2050 there are no

[52] Diving into this scenario is an intellectual challenge as this framework is characterised by the prevalence of relational ontologies and epistemologies. This means they view subjects not as pre-given independent entities, but rather as being continuously(re)produced through interaction processes.

predefined categories like nature and culture or human and non-human beings but a wide range of agents[53] with diverse modes of existence and continuously emerging status. Human/nature interaction is taking place in critical zones where human agents are on the same level as other living beings. Like bacteria, this encompasses non-human agents in the MNC created by humans such as nano robots, xenobots, etc., for which it is now shared understanding that they are treated as living beings. In such relations, “care” is recognized and valued as a reciprocal practice among human and non-human beings and ecosystems.

Common to all strategies of this scenario-perspective is the shared **understanding of human beings as integrated actor in an ecosystem. The society has abandoned the role as predator in ecosystems, as multiple crisis since the 2020s have taught us that with such a worldview, humans are doomed to be in a permanently instable state.** Humans are still assuming that the paradigm shift also has had negative effects on the economy as defined in old days. Nevertheless, by breaking the vicious circle of boundaryless expansion of mankind, humans reached a **sufficient level of wellbeing in those regions that could maintain relatively stable societal structures. To succeed, humans became synergetic agents like other living beings.** Thus, innovations and solutions no longer use predatorial technologies and powers.

The practice of ‘collaboration’ with microbes and hybrid forms of living has been established by applying the “Stewardship Principle” to wellbeing of all living beings. **In “critical zones” in which humans accepted their agency** in a responsible way. As a consequence**, ecosystems have been brought from an instable to a dynamic stable state, guaranteeing an economic system to flourish as well.** With respect to the micro-nano-cosmos this required a leap in understanding of interaction between human and non-human agents e.g, how micro-material interact with living beings, or which nano-level processes produce poisonous outputs.

Humans, as agents **playing a caring role**, have been taking up responsibility and finding alternative ways of coexistence with the aim to increase transformative capacities in critical zones for non-human agents as well. Our capabilities and capacities to communicate with non-human agents helped us to create the knowledge to understand the needs, values, and potentials of other creatures and agents like nano robots, organoids and xenobots on the micro-nanoscale. Solutions provided by STI bring ecosystems into a flourishing state, even in multiple critical zones, which had emerged through climate change.

4.5.4 Implications for STI policy

STI themes/directions

Most of the above-mentioned innovation and impact fields are potential STI themes. It is to be expected that future innovation activities involving converging technologies, as discussed above, will influence ecosystem stewardship (e.g. self-replicating materials, organoids, xenobots, bioactive materials, bioeffectors, biostimulants and microbe-assisted crop production, cell factories, bio-inspired materials and plastic-degrading enzymes).

Substantial inter- and transdisciplinary R&D programs combining natural sciences with social sciences and humanities will be needed to clarify the nature, magnitude and likelihood of the potential risks, as well as the options available for dealing with them effectively. This includes, amongst others, issues such as self-replicating materials, antibiotic resistance, microplastic, micro-flotation processes etc.

Threats might arise due to the misuse of those technologies for military or unlawful purposes.

How to do STI? Approaches in designing Instruments and programs

Some of the addressed innovation fields are already advancing and considering a mix of strategies regarding all 3 perspectives might form elements of a transformative STI-policy:

- Developing remedies where damages are already done
- Reflective assessment of developments on the micro-nano scale and taking anticipatory measures to avoid threats to flourishing ecosystems

[53] Agency is considered not the result of specific entities action but rather emergent from relational network interactions.

- Better understanding the micro-nano cosmos and its inhabitants (e.g. how to communicate) and the interaction with the micro-scale (e.g. soils, maritime ecosystems, …) and macro-scales of ecosystems (oceans, air, forests, …)

In the “**Cleaning up MNC” Scenario**, more affordable and accessible innovative technologies would be needed, which are aimed at (a) exploiting the potential of MNC technologies to maximise ecosystem performance (ecosystem services), and (b) reducing negative effects of humans on ecosystems (e.g. search for cleaning-up and filtering technologies).

In the “**Aligning with MNC” Scenario**, research for ecosystem stewardship would contribute to monitoring of the relation of macro-scale with the micro-nano scale and to developing narratives of personal and collective identity connecting the MNC as connected to ecosystem. Policy instruments would include living labs and other experimental instruments to co-create, test and pioneer innovations for ecosystem stewardship applying a precautionary principle on MNC.

In the **Scenario “Caring humans within the MNC”,** social science and humanities research are needed for investigating agencies in the MNC. The realms of imagination and metaphysics (spirituality) of hybrid life forms (e.g. xenobots) will be receiving attention in ethics and philosophy. This kind of research will require close interaction with natural sciences and engineering allowing for adequate means of observation of the MNC.

Kind of Knowledge required

Overall, knowledge on the implications and potential threats from the micro- and nanoscale is still lagging behind technological developments. This knowledge gap will require significant activities in inter- and transdisciplinary research for technology assessment and to inform responsible research and innovation. On the innovation side, besides scientific knowledge on how to observe at micro-and nano-scales, manipulating on micro-and nano-scales (e.g. producing xenobots), engineering knowledge is required. As untouched areas of the MNC are “conquered” by humans, knowledge and research on ethical and legal issues are emerging.

In the “**Cleaning up MNC” Scenario**, knowledge has more value, if it can facilitate appropriation and management of resources and is mainly focussing on enabling technoscience.

In the “**Aligning with MNC” Scenario**, knowledge builds on a continuous feedback loop with the material world on macro- as well as micro- and nano-scale. Technoscience may be involved, but is taking into account complexity, scale and time in interactions among constituents, as humans are understood as integral part of the ecosystem and their stewardship is also extending to the MNC.

In the **Scenario “Caring humans within the MNC”,** the re-emergence of other codes, sensibilities and practices of relating to MNC, (e.g. in case of critical zones of antibiotic resistance) requires knowledge beyond the dominance of natural science framings. Science would participate to a culture of flourishing ecosystems including the MNC and metaphysics would not be considered as defiant of scientific practice, but as contributor to its enrichment.

STI infrastructures and human resources required

Living labs and other forms of experimental spaces and infrastructures to explore the MNC in a responsible way need to be developed and adapted to the micro- and nano-scale.

Particularly in this field brain-drain can be expected to be an issue, and ethical question might play a role in where academics would find employment.

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4.6 Case Study 6: Data as Representation

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4.6.1 Introduction

The case study proposes three scenarios on the way data is understood and used in relation to the human and natural ecosystems by 2050. The final aim is to suggest the implications for the way R&I is organized and its challenges in each scenario.

In building these alternative scenarios the authors

- start from the most promising STI directions in *Data science & statistics*, for supporting the flourishing of ecosystems by 2050, as identified in a large Delphi consultation. These directions are: Big data sciences, Environmental modelling and simulations, Web-applications, and tools for decision-making (see below). A review of the current situation along these directions is provided in the following chapter.
- differentiate the scenarios based on
- the way humans see their role in nature, specifically as *protecting and restoring*, as *co-shaping*, or as *immersing and caring*[54].
- the way data is interpreted in relation with reality, specifically as objective, as species-dependent, or as a molder of reality.
- the significance given to indigenous knowledge, namely as contextual information, as a rich repository of observations, or as the 'spirit of nature'.

The resulting aspirational scenarios (see **Error! Reference source not found.** for a synthetic representation) are:

- *To the maxx* – in which the technological trends of the early 2020s (pattern recognition through AI, greener and FAIR data, digital twins etc.) have reached maximal expansion. In this scenario, science supplies data and algorithms for decision-making, but scientific techno-optimism is confronted with the challenge of understanding and of justifying decisions.
- *Radical responsibility* – in which a social technology (equal recognition through a system of rights) is extended to virtually all beings, human and nonhuman. Here, science is enlisted in support of bringing in the perspectives of different species but is confronted with the challenge of integrating these perspectives into broad models accepted by all.
- *We, the life* – in which the driving force is a new level of consciousness gained by a growing number of biocentric scientists. Humanity relies on them to inspire ethically grounded worldviews, influencing the design of socio-techno-environmental systems.

While in the first scenario the R&I landscape is amplifying the concerns of today (data security, data driven authoritarianism, quantitative vs qualitative research), in the second one this landscape is more fragmented and even bureaucratised in an effort to accumulate knowledge about the different species. Finally, in the third scenario, the R&I landscape is radically different from the present, while recuperating part of the spirit of the early days of science: a primary preoccupation with ethical grounds, VIP scientists expressing their views at the crossroads with art and spirituality, with their apprentices and communities of followers not spared by cult accusations and clashes of opinion.

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[54] Warnke P., Erdmann L., Kubeczko K., Brodnik C, Könnölä T., (2021), *Deliverable 1. Scoping and draft concept paper.*, project Foresight on Demand: Science, Technology and Innovation for Ecosystem Performance – Accelerating Sustainability Transitions.

4.6.2 The most promising STI directions

The chapter reviews the current situation of the most promising Science, Technology, and Innovation (STI) directions in the domain *Data science & statistics*, for supporting the flourishing of ecosystems 2050. The three STI directions (i.e., Big data sciences, Environmental modelling and simulations, Web-applications and tools for decision-making) were identified in a large Delphi[55] consultation.

Box 1. **Results from the Dynamic Delphi Survey**
STI for flourishing ecosystems 2050
in the domain Data science & Statistics

A. The most ***promising Science, Technology and Innovation (STI) directions***, considering their potential to contribute to the capability of planetary ecosystems to flourish from now to 2050:

- **Scientific disciplines and fields reconfigured as 'big-data sciences'**: e.g. Ecology and ecoinformatics; Geography; Environmental sociology; Agritech; Disaster management; AI-based decision-making; Healthcare - epidemiology, pandemic management, database searches for disease markers, Big Data-based discovery of new targets in tumours; Genomics; Bioinformatics - such as through community-wide metabar coding; Biodiversity management; Forecasting
- **Environmental modelling and simulations:** e.g. Earth systems models; Climate fluctuation analysis; Models of soil microbial processes; Forest growth simulations; Models of hurricane wind disturbance; Geospatial data analysis; Deep-time, mechanistic eco-evolutionary simulations; Community-scale spatially explicit genetic simulations; Global emissions monitoring; Intelligent earth observation; Environmental modelling of climate change processes; Empirical data-driven modelling of species distributions and associated ecosystem services provision; Spatially explicit environmental change predictions in terms of species turnover, biodiversity change, and associated ecosystem services change
- **Web-applications and tools for decision-making**: e.g. To access economic and environmental data; To create scenarios for decision making; For public monitoring; To access ecological data; Online predictions on species turnover, biodiversity change, and associated ecosystem services

B. The *potential significant harms* that STI could inflict on the capability of planetary ecosystems to flourish from now to 2050:

- In Big Data, there are many ways to make mistakes: poor data, bad models, confounding, inappropriate generalizations, inbuilt biases.
- Big Data may be used by corporations for targeted marketing that is harmful to clients.
- Gaps in data collection, especially resulting from ignoring different or little-known regions, render models inapplicable and potentially harmful.
- Data can be misused to justify inadequate decision-making and to support the wrong ideas.
- Data science & statistics can potentially influence human behaviour, control human mobility, drive social/political decision making, deteriorate social capital.
- Big data collection may raise ethical issues pertaining to the infringement of individual autonomy, use of personal data without permission and manipulation.
- Computationally intensive modelling and large data storage generate substantial power consumption.
- Data science raises issues of public security.
- Intentional or accidental creation of an autonomous AI weapon.
- Data-supported exploitation of natural resources may lead to the collapse of the relevant resources.

4.6.3 Scientific disciplines and fields reconfigured as 'big-data sciences'

Perhaps the main argument for the importance of Big Data for environmental issues stems from the complexity of natural and social systems and subsystems. Big Data has been essential to the development of

[55] Dragomir B., Gheorghiu R., Andreescu L., Dimitriu R., Plescan P., Curaj A. (2022), *Deliverable 4. Future sheets,* project Foresight on Demand:Science, Technology and Innovation for Ecosystem Performance – Accelerating Sustainability Transitions.

sophisticated models – see next subsection – for a variety of relevant phenomena and for sustainability-related interventions. It has also raised a number of specific challenges.

The increasing popularity of Big Data analysis has led to its adoption across fields and disciplines. This, in turn, has created an opportunity for collaboration, as more fields have migrated towards similar methodological toolkits. This collaboration is vital to environment-related pursuits, as the many subsystems engaged by fields such as earth and climate science, biology, medicine, urbanism etc. will benefit from related approaches and interconnection.

There are two main classes of Big Data trends in our context – one related to technical evolutions, the other to institutional advances.

Technical evolutions
As to the former, they are spurred by broad developments in areas such as breakthroughs in sensor technology, the Internet of things, automated machine learning, edge computing and "TinyML" (AI for small-data environments), and so on. As these advances have penetrated many scientific fields, they have enabled a variety of developments, among which the following:

In ***environmental science***, new technology has enabled data collection from a large variety of sources. Remote sensing has been employing devices ranging from satellites to drones to RADAR/LIDAR. Monitoring systems now include a broad variety of sensor technologies in the field, often providing real-time information to distant data centres. Sometimes, gaps in these collection instruments have been filled with "citizen science"-generated data; as well as by data mined from web and social media platforms to provide field measurements (e.g., of water or atmospheric pollution, a.s.o.). Last but not least, historical data – such as the records maintained by some national geological survey agencies covering one or more centuries – have been digitized and are available as inputs into models (Blair et al., 2019).

Many of these data sets have been employed for broad analyses of the climate, providing a much more accurate picture of the magnitude of climate changes – as well as an understanding of policy interventions that have worked around the globe (Runting et al., 2020).

In ***ecology*** and its subfield of ***ecoinformatics***, deep learning has been used to identify species, estimate biodiversity, or classify animal behaviours using, for example, large datasets from camera images and videos (Christin et al., 2019). Digital sensor data, brought together through initiatives such as eMammal and Movebank, have revealed the new potential of spatial ecology (Kays et al., 2020), while raising critical questions concerning the appropriate uses and combinations of sensors (Williams Hannah et al., 2020). Such findings have been employed to identify wildlife population declines due to patterns of animal behaviour that conflict with human activity (such as high road traffic areas) and to create adequate reporting mechanisms (Shilling, 2020).

Genetic research has been leveraged to study biodiversity via techniques such as environmental (eDNA) metabarcoding, which is heralded as a one of the key tools for the future of global conservation. eDNA coding promises community-wide analysis of diversity and interaction at a scale and cost previously unattainable (Kennedy et al., 2020). Such high-throughput sequencing uses samples extracted from water, soil, and air to amplify DNA to a level that enables the detection of species. The methods can be also used to reconstruct ancient habitats, analyse animal diets, detect invasive species, or study the interaction of plants and pollinators (Krista et al., 2019).

In human ***health*** in relation to the environment, Big Data has enabled advances in epidemiology, for example by combining health data with veterinary and agricultural reports on recent animal disease outbreaks (Bansal et al., 2016). Another line of inquiry concerns studying the impact of climate change on food safety and foodborne diseases (Talari et al., 2021).

Institutional advances
These and other developments in Big Data analysis and use have generated a number of concerns, the response to which has consisted in a series of institutional adjustments.

Perhaps the most important of these responses has been a sustained effort to ***open up access to data*** by eliminating barriers before researchers as well as other interested parties. To a considerable extent, this has been a reaction to the large quantities of proprietary data generated by large corporations involved in Big Data analysis. Openness is particularly relevant in the case of Big Data because the same data sets can be used for a wide range of purposes – or for similar purposes but in a variety of different models.

In sustainability and conservation, increasing access to data has made possible a variety of initiatives, among which the Global Fishing Watch, Global Forest Watch and global inter-tidal websites (www.globalfishingwatch.org, www.globalforestwatch.org, www.intertidal.app); "or user-friendly analysis tools, such as REMAP – a free application that utilizes the storage and analysis capacity of Google Earth Engine to map land cover change (www.remap-app.org)." (Runting et al., 2020)

The challenge of data ***interoperability*** is closely related to questions raised by proprietary nature and by other barriers to access. Given the wide range of sources from which systematic and unsystematic data sets are generated, pooling data, or using heterogeneous data sets in models often raises a variety of practical issues. Some of the solutions can be technical (automated data cleansing etc.), while others involve better standardization and shared practices.

An additional solution for interoperability, which results in many other key benefits, is the expansion of ***international collaboration*** through the creation of data e-infrastructures providing high-performance and cloud services to researchers and policy makers. These can then be used for the purpose of research as well as for monitoring, early warning systems, or for the enforcement of certification regimes (like fair trade practices in agriculture).

Recent examples of large-scale collaborations around Big Data include the EU-funded EUXDAT "through which a multitude of data, analytics and computational resources can be accessed to monitor soil and crop health, optimise resource consumption, increase agricultural yields and sustainably manage land."[56] Similarly, the EU's Knowledge Centre on Earth Observation plans to leverage, for EU policy-making and in particular for the European Green Deal, earth observation data generated via the European Copernicus Programme and other sources.[57] A large common project of the UN Environment Programme, Google, and the EC's Joint Research Centre recently established "a web-based platform that fuses big data and environmental science to monitor [the] global freshwater ecosystem".[58]

Partly in order to generate more data (and more localized data), and in part as a project to democratize citizen's participation in and support for science and evidence-based decision-making, some effort has been invested in encouraging and supporting **citizen science**. Despite its challenges – citizen-collected data can add to data heterogeneity and raises additional reliability concerns –, this type of citizen participation in science has provided examples of success. Among them: mySoil, an application developed a decade ago by the British Geological Survey,[59] soon to be replaced by the UK Soil Observatory (UKSO); or the OPAL Soil and Earthworm Survey.[60]

Environmental modelling and simulations

Models, whether used explicitly or tacitly, underlie most human activities that rely on even basic forms of knowledge. (In this sense, modelling is inherent to human thinking.) With the rise of science, more systematic or formal models have been used to describe the phenomena of interest and to make predictions. Models have been recognized as essential in the testing of our theories of the world, but they are equally important in expanding or redefining these theories. Crucially, models force us to specify and thus help us clarify the assumptions we build into our views and approaches to the phenomena of interest. Since explicit modelling has been used as a tool in decision-making more generally, not just in science strictly speaking, the usefulness of models in the monitoring and evaluation of interventions has also become very clear.

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[56] https://ec.europa.eu/research-and-innovation/en/projects/success-stories/all/big-data-solutions-big-farming-challenges
[57] https://joint-research-centre.ec.europa.eu/jrc-news/new-knowledge-centre-earth-observation-2021-04-20_en
[58] https://www.unep.org/news-and-stories/story/plugging-data-gap-google-european-commissions-joint-research-centre-and-un
[59] https://www.bgs.ac.uk/technologies/apps/mysoil-app/
[60] https://www.imperial.ac.uk/opal/surveys/soilsurvey/

Table 8: A taxonomy of models function of analytical technique. (Source: EEA, Modelling environmental change in Europe: towards a model inventory (SEIS/Forward), EEA Technical report no. 11/2008, Luxembourg: Office for Official Publications of the European Communities, 2008)

Principal analytical technique	Sub-categories of techniques/modelling approaches
Equilibrium models	General equilibrium models, partial equilibrium models or sectoral models, mass balance equation models, optimisation models
Empirical-statistical models	Rule-based models, cellular automata, agent-based models, multiple regression models, area-based matrix approaches, stochastic approaches, econometric models
Dynamic system models	Linear/non-linear programming models, population dynamics models, impact assessment models, integrated assessment models
Interactive models	Expert judgement frameworks, decision support systems, educational gaming, information tools

As measurement and data collection tools have improved and computational power has increased, particularly dramatically during the past decades, the use and intricacy of formal models has expanded just as drastically. Models have been designed for increasingly more complex systems – environment-related systems being a case in point. The explosion in modelling seems to have covered everything from soil to the atmosphere and from water systems to the subsurface; models have been developed for entire ecosystems, including global ones, or for limited species and geographical areas. Thousands of centres in universities, research institutes, national and international agencies and companies are currently developing or running advanced modelling techniques on subjects relevant to environmental issues. Environment-related modelling activity has brought together researchers across disciplines and has been prominently featured in well-publicized reports, in the design of climate change strategies, and in assessments by international agencies such as, most famously, the UN's Intergovernmental Panel on Climate Change or the EU's European Environment Agency.

Major national and international research funding programmes have dedicated funding lines for model-development. ClimateEurope – a Europe-wide network for researchers, suppliers, and users of climate information – provides a list of recent relevant initiatives on Earth System modelling, Climate Observation and Climate Services, most of them funded under the EU's Horizon programs. To pick just one additional example, the US National Academy of Science, Engineering and Medicine's National Strategy for Advancing Climate modelling is already a decade old (2012). The current US administration has just boosted the Department of Energy's funding for research on earth and environmental modelling by 17%, while the National Science Foundation two main programs on Climate Science and Sustainability research (U.S. Global Change Research Program and Clean Energy Technology), both with an important modelling component, have topped 1 billion USD in 2022.[61]

As the above makes clear, environment-related modelling is today very diverse thematically. The Delphi consultation mentioned previously, which selected "Environmental modelling and simulations" as a key trend in STI, illustrates this diversity in terms of the fields of modelling considered highly relevant or representative by Delphi respondents:

> Earth systems models; Climate fluctuation analysis; Models of soil microbial processes; Forest growth simulations; Models of hurricane wind disturbance; Geospatial data analysis; Deep-time, mechanistic eco-evolutionary simulations; Community-scale spatially explicit genetic simulations; Global emissions monitoring; Intelligent earth observation; Environmental modelling of climate change processes;

[61] https://nsf.gov/news/factsheets/Climate%20Change%20Fact%20Sheet.pdf

Empirical data-driven modelling of species distributions and associated ecosystem services provision; Spatially explicit environmental change predictions in terms of species turnover, biodiversity change, and associated ecosystem services change.

This list of assorted modelling approaches illustrates not only the current thematic variety (from wind to genes and to the climate as a whole), but also the technical diversity of approaches. Model building currently employs a variety of categories of analytical techniques (see the table above) (EEA 2008) – and often combines them. Judgmental models, based on expert opinion, represent an additional category. Models, and climate models in particular, also differ in geographical and temporal resolution (the space and time increments for which predictions are made).

This explosion of models predicting and describing environment-relevant phenomena within and across potentially related fields of research raises a number of potential issues. Some of them are specific to Big Data collection and analysis and have been alluded to in the previous subsections. Other issues are specific to modelling. They extend beyond the traditional modeler's dilemma of how to choose the right level of simplification, a particularly thorny issue given the intricacy of environmental systems (Allison et al., 2018).

Among the more recent concerns, one is related to the impact of the diversity of available models on the (un)certainty of our knowledge and, as such, of decision based on this knowledge. To what extent is the knowledge produced by such a variety of modelling enterprises manageable for practical purposes? What are the risks of selecting some models at the expense of others?

This is closely related to a second concern – the capacity to integrate these types of tools in decision-making. Are decision makers equipped to choose the best models? Do they have the capability - and drive - to pool models and their results in order to improve the knowledge base for decisions?

A third matter concerns the gaps in knowledge or in coverage that persist despite the diversity of models, and which this diversity may in fact obscure. Both modelers and decision makers acting on models are exposed to a variety of well-known biases (Glynn, 2017). Are there issues or problems that are not adequately covered by models at the present time, perhaps due to a lack of interest by researchers, or because they are less amenable to available analytical techniques? More broadly, who defines the issues of interest? Who participates in constructing the broader goals which the development of models is supposed to serve?

A further question concerns the transparency of the models to both decision makers and the general public. The former may not completely understand the assumptions that increasingly complex models are based on; decisions may be, under such circumstances, grounded in various types of misunderstandings or misperceptions. As for the general public, it will be at the mercy of other parties' explanations concerning the significance of model results and the measures ahead.

Finally, there is a concern that the more computationally intensive modelling will become, and the bigger the data and the data storage needed to feed the models, the larger the power consumption.

There is a variety of efforts in the broad field of environmental modelling to respond to some of the concerns listed above. Some start from the understanding that modelling is a social process and propose holistic frameworks for model assessment from a multi-dimensional, multi-perspectival perspective (Hamilton et al., 2019). A complementary approach is to create participatory modelling processes, whereby various stakeholders – including but not limited to decision makers – are engaged in conceptualization, model building, and model assessment (Voinov et al., 2018). Solutions and tools have been proposed to increase data accessibility, both in terms of availability and, importantly, of intuitiveness, i.e., facilitating ease-of-use (Will et al., 2021). These and other developments have been part of an effort at paradigm change, sometimes described under the name of Integrated Environmental modelling (IEM) – a holistic approach aiming to resolve issues of scale, bridge scientific disciplines, bring together stakeholders, and translate the results of modelling into knowledge appropriately packaged for decision-making (Laniak et al., 2013).

Web-applications and tools for decision-making

Evidence based policy and beyond

Evidence-based policy can be defined as "encompassing (1) the application of rigorous research methods, particularly randomized controlled trials (RCTs), to build credible evidence about 'what works' to improve the human condition; and (2) the use of such evidence to focus public and private resources on effective interventions. Evidence-based policy emerged first in medicine after World War II and has made tremendous contributions to human health" (Baron, 2017). In complementary fashion, the importance of "policy narratives" has been emphasized: "advocates of scientific evidence need to tell good stories to grab the attention and appeal to the emotions of policymakers." (Davidson, 2017) The idea of a "**good governance of evidence**" is a related concept that highlights "the use of rigorous, systematic and technically valid pieces of evidence within decision-making processes that are representative of, and accountable to, populations served" (Parkhurst, 2017).

Multiple perspectives

Co-production is a way of aligning knowledge and action that is critical for sustainability. With already a long history, co-production requires participants to be reflexive about the inherently political nature of producing knowledge. As a process, co-production raises additional challenges of inclusiveness, credibility, legitimacy, and accountability (Miller et al., 2020). In an attempt to integrate uncertainty in the modelling of socio-environmental systems, participatory methods make use of **multiple scenarios** (Elsawah, 2020).

A set of practices with a more pronounced applied character, **participatory budgeting** has its roots in the US history of public hearings and citizen budget committees and in South America in the 1980s. The different practices cover one or more of the steps of idea generation, elaboration, production, and impact; and the mechanisms include public meetings, focus groups, simulations, committees, and surveys (Bartocci et al., 2022).

For cases in which the interests of the actors are entangled but not necessarily converging, simulations have been designed using **agent modelling techniques** (see for instance He et al., 2018, for Shale gas operations; and the previous subsection).

Another way of dealing with complexity is to **combine frameworks** of analysis. Examples include the use of alternative models in fields like conservation (Schwartz et al., 2018) or energy risks (Wang et al., 2018).

Intuitive data

There is a growing trend both in the supply and the demand for more complex/interactive **data visualization**. Examples include *geospatial dashboards* for monitoring smart cities (Jing et al, 2019) or urban heat vulnerabilities (Karanja J. et al., 2021); 3D models (Kilsedar et al., 2019) and augmented reality for flood visualization (Haynes et al, 2018). Visualizations play a more prominent role in dynamic phenomena like natural disasters (see for instance Millet et al. 2020 for hurricane risk communication).

Long-term perspectives

The challenge of sustainability gives decision an implicit prospective dimension. The most common tools and methods used coming from foresight (Delphi consultations, scenarios and visioning) and life cycle assessment - LCA (see for instance Nwodo et al, 2019; and Hollber et al., 2019, for LCA in building environment).

Human-machine collaboration

A recent study shows that "human managers do not want to exclude machines entirely from managerial decisions, but instead prefer a partnership in which humans have a majority vote" (Haesevoets et al., 2021).

For some "machines should take care of mundane tasks, allowing humans to focus on more creative work" (Jarrahi, 2018), while for some this represents the chance of reducing human bias (Xiong et al., 2022). The explainability of AI is one of the most challenging aspects (Baredo Arrieta et al., 2020), so much so that some consider it illusory, calling for the return to interpretable models (Rudin, 2019). As a response to the existing concerns, some stress the investigative role of big data (Wüest et al., 2020), while for others **transparency feedback loops** (Akash et al., 2019) seem to be the wholly grail of human-machine collaboration.

4.6.4 Scenarios

The table below describes the links between the three general ecosystem perspectives identified in the project (Protecting and restoring, Co-shaping, Immersing and caring), the key STI trends identified in the consultation (common to all scenarios), and the role of data and indigenous knowledge (two of the drivers varying across scenarios).

The table then offers a systematic summary of the three scenarios across several dimensions, including implications and risks.

Table 9: Logic of the scenarios

	Perspective 1. Protecting and restoring	Perspective 2. Co-shaping	Perspective 3. Immersing and caring
DRIVER: Key STI trends	• Big data sciences • Environmental modelling and simulations • Web-applications and tools for decision-making		
DRIVER: Significance of data	Data reflects "objective reality"	Data is relative to the view from each species	Data molds reality, the glasses we see through and ultimately constructs reality
DRIVER: Indigenous knowledge	Limited uses, mainly for contextualisation of information	Indigenous knowledge is a rich source of info about the habits, needs and interdependencies of the various species	Indigenous knowledge is about the spirit of nature, an overarching value and transcendental reference
Title	***To the maxx***	***Radical responsibility***	***We, the life***
DESCRIPTION	An amplification of current trends, with a focus on technological instruments Digital twin Algorithmic decision-making	A radical amplification of current *social* technologies (recognition and rights), with a focus on the bureaucratic technology of extending rights to all living beings	A radical change in perspective, in which some humans get the biocentric view, i.e., the perspective from the Life Biocentric scientists - combining classic scientific inquiry and meditation and indigenous knowledge, some get

	Global Data Centre Network infrastructures IoT (security & privacy issues)	Living beings are granted full recognition, manifested in terms of equal rights An extensive rights bureaucracy enforces full equality Living creatures are represented in a global legislative	the awareness of Life as unitary and as the creator of reality Their wisdom is applied in (re)designing human ecosystems (and relation with Nature) Their knowledge is more inspirational, contextual, and even person related
IMPLICATIONS: Ethics	The aftermath impact	Inclusiveness in design and implementation	The very scope of knowledge creation
IMPLICATIONS; Science policy	Increasing role of science for policy, but not as an advisor, but as provider of knowledge into the complex algorithmic decision models An increasing demand for measurability, detrimental to qualitative research	Increasing efforts to accumulate knowledge about the different species Representatives of species embody scientific, ethical, and political skills	Artifacts at the interplay of science and art define the new frontiers of knowledge Apprenticeship in science as assimilation of the ways of the masters
RISKS	The more we understand, the further seems the capacity to actually control the phenomena The complexity of decision models may actually dilute responsibility	Decreasing trust in bureaucratic elites Increasing social antagonism - it becomes difficult to balance among the many interests of the many species (not to mention future generations across all species) Fragmentation of research	The reputation mechanisms may not discern moral-by-design visions from shallow constructs made to please audiences Charisma of established VIP scientists may sometimes block new avenues of science

	The more radical the innovation, the larger the gap between adopters and the left behind (technological divide) 'Security' threats: the more radical the innovation, the more it can be capitalized by rogue individuals and groups The rise of hyper-technological authoritarian regimes / systems (China) Resistance to technology: neo-luddism and other forms of protest or rejection	Bureaucratisation of science, increasing orientation towards negotiation Ever increasing need for finding common ground	Difficulties in generating actionable pronouncements from the bio scientists

To the maxx – Scenario P1

Summary
In this scenario, the technological trends of the early 2020s – pattern recognition through AI, greener and FAIR data, digital twins etc. – have reached maximal expansion and, in some cases, have over-delivered.
The result of the proliferation of technological solutions has seen a substantial increase in technological optimism, the belief that technological advance can alleviate social concerns and even cure social ills. Or, at least, this is the rhetoric promoted by officials, corporate offices, and techno-gurus and popularisers.
However, absent substantial changes in social structures and mores, the flipside has also become apparent: scepticism of AI-based decision-making and the purported loss of autonomy the latter implies has increased, the growth of neo-luddite movements has accelerated, and rogue actors are exploiting new types of security failures to showcase technological weak spots and blind spots.
Some actors thus argue that, by treating data as the mirror of reality and technology as the solution to be sought in all circumstances, techno-utopians have given up on genuine understanding. Consequently, there is a creeping sense that technological complexity in decision-making is diluting individual and collective responsibility since bad decisions can now be blamed on machines. Furthermore, the 'success' of repressive hyper-technological authoritarian regimes is raising the spectre of Big Brother even in consolidated democracies.

Key concepts: acceleration, data saturation, full AI integration, resistance to technology

Yesterday's techno-utopians were right. The budding technologies of the early 2020s took no more than a decade to reach maturity. Hype was not exaggerated, after all. All it took to enable today's technological boom was a few key scientific breakthroughs and some political willpower.

Perhaps the biggest advances have been made in sensor technology and deployment. Not only have sensors improved technologically – with unprecedented strides in miniaturization, fusion, and resilience –, but their diversification enabled unparalleled embeddedness. Sensors are now essentially ubiquitous in bodies and environments large and small. Smarter sensors with analytical capabilities have improved response times, decreased network congestion – and thus energy consumption – and crucially and surprisingly to some, have enhanced privacy. Areas as different as agriculture, health, industrial equipment maintenance, and disaster management have been substantially impacted.

Digital twin technology has been adopted across the board
In healthcare, for example, access to services in the developed nations has been extended even to the most remote areas, while in the developing nations the main barrier to such an extension remains the adoption of telemedicine gadgets outside the cities and large towns. Alongside such progress in spread, medicine has also personalized, with digital-twin technology leading to breakthroughs in many respects, treatment, and tailoring drugs key among them. Some argue that medical education is experiencing, due to the same developments, a rejuvenation without parallel in a century.

Digital twin tech is now well integrated in urban decision-making, with most major cities around the globe – and many smaller ones – having a full-fledged digital twin based on real-time sensor data, semantic data, and simulations. Some of these cities have attained, thanks to the prevalence of sensors and other data sources, a level of cyber-physical integration that has led to palpable improvements in the management of utilities, services (traffic control being the most evident), and even urban crime. Furthermore, as most cities use similar digital twin designs, with a considerable level of standardization and interoperation, successful interventions – though so far mostly tweaks – have been easier to transfer around the globe.

Figure 23: Source https://universe.wiki/2022/02/15/what-is-the-esa-earth-digital-twin/

Full integration of AI modelling and digital twins in decision-making

Support for the integration of AI modelling and digital twins in decision-making managed to overcome the initial scepticism of more conservative political elites and scientists. Leveraging indigenous knowledge has also proven useful, firstly by assisting in the improvement of models in key ways; and secondly by persuading the more ecologically and locally oriented constituencies that their concerns are being addressed. Ultimately, however, what sealed the fate of the general adoption of these technologies was their success – at least according to some proponents – in the prevention and mitigation of several disaster events, both natural and man-made. Among the former, the best-known case of success was the mitigation of several rounds of Australian bushfires, attributed mainly to excellent predictive modelling based on data collected from a wide array of embedded sensors. This and other similar events catalysed public support and overcame barriers to AI integration in decision-making, at least in some nations. Others followed suit.

Global Data Centre Network infrastructures

All of the above has been made possible by massive investments around the globe in Data Centre Network infrastructures, which have increased access to data and computational resources and have facilitated model integration. The infrastructures have also alleviated somewhat the energy consumption problems of the previous decades. Not only have DCNs substantially improved data crunching capabilities, but they vastly optimized utilization under conditions of a rapid increase in the demand for computing power. Furthermore, by relying mostly on green energy and innovative cooling solutions (also enabled by sensor technology), the networked infrastructures proved able to minimize energy waste.

The gap between decision and justification
The developments described above have generated a number of challenges. Perhaps the most serious one has been the real as well as subjectively perceived gap between algorithm and decision output – or, better said, between decisions and their justification. Although all trains run on time, city traffic is fully optimized (though still cumbersome in many places), and water use is taxed at exactly the right levels to disincentivize excessive consumption, many algorithmically generated policy decisions appear surprising or baffling. While they often work (or seem to), when measures are counterintuitive, they frequently generate criticism and resistance.

Social gaps and gaps among nations
At least in economically advanced nations, some of the social gaps have been bridged by widespread technological adoption and by optimized decision-making. Nonetheless, the increasingly smaller numbers of those left out have experienced a larger marginalization and disfranchisement. Furthermore, where the - still relatively rare - decision-making failures have been substantial, the consequences were harder to redress and politically very costly.

Given cheap technology, the gaps among developed and developing nations have not broadened in relative terms. Sometimes, the opposite has been the case in economic terms. Nevertheless, the economic successes and increased political stability in repressive hyper-technological authoritarian regimes has proven tempting in some developing nations. In global terms, therefore, democracy indices have recorded a moderate decline.

Algorithmic decision-making has been driving political disengagement
Politicians have tried to mitigate the rising distrust in data integration in decision-making, but in practice this has meant armies of consultants and technology experts – popularly known as "explicators" – struggling to translate policies into ordinary language and common intuitions. This approach has not been without success, particularly because the advance in visualization technology has mesmerized many concerned citizens. Nevertheless, these translation efforts have also led, among a considerable share of the population, to the perception that politicians are clueless and, at best, only retrospectively capable of justifying their decisions. In other words, politicians are superfluous. Several very publicized epic fails, usually consisting in bumbling explicators desperately flailing around for plausible accounts of a certain measure, have deepened some people's cynicism about or disengagement from politics.

In some instances, however, the reaction has been engagement – in resistance to the new "data-based politics", as it is occasionally called disparagingly.

Security in IoT
The ubiquity of IoT has also recently led to serious concerns over the security of gadgets ranging from connected intrauterine devices (which look for signs of incipient infection while methodically counting the number of annihilated sperm) to self-driving vehicles.

The latter, in particular, created a major global panic when a fleet of tens of thousands of automated cars marched on Washington. The vehicles, manufactured by TessX, formerly known as Tesla, were hijacked by a group of (ironically tech-savvy) anti-technology activists parodically self-entitled "LuddX". The city and most of its services were essentially paralyzed for many weeks, leading to mass migration of the population and a shutdown of the federal legislature. The hijacked vehicles were strategically placed around the US capital so as to block access to the headquarters of the federal and local administration. The hijacked cars sometimes 'danced' (moved around) in coordinated fashion to block the advance of heavy military equipment deployed by the government to break the blockade, and even threatened to self-destruct in concert in a conflagration of epic proportions. (TessX assured the population that the cars have no such capability, but judging by the results of several polls conducted at the time, the people and the politicians were unpersuaded by the reassurances.)

Sensor-resistance movements
This and other more or less similar events expanded an anti-sensor social movement, which now threatens to reverse somewhat the developments of the past years. After a golden age of integration in many organisms and virtually in all environments, the pressure to discard sensors has been mounting. In a global wave of

reactions which some have hailed as “a return to human sense(s)”, many individuals are abandoning even such ancient technologies as home security, fitness bands, and modern defibrillators.

In agriculture, the anti-SMO (Sensor-Monitored Organisms) movement, spearheaded by several Evergreen Parties experiencing a renaissance around Europe, has managed to get the European Parliament to pass legislation on the labelling of foods and other items produced or manufactured from sensor-monitored plants, livestock, and even raw materials. Additionally, the pseudoscientific ideas spread by the fringes of this movement – that even minuscule sensors drastically alter the behaviour of living beings and may even spoil their DNA – are rapidly gaining ground, particularly among the very educated.

How exactly the strides in technological saturation and mounting techno-scepticism will be reconciled remains, at this stage, anyone’s guess. The European Union’s new RDI programs are now lavishly funding ‘reconciliation’ research, amid persistent background fears that weakening technological advances might weaken the continent’s competitiveness against nations that are not bothered by such details.

Radical responsibility – Scenario P2

Summary
The second scenario is also one of radical amplification - this time around in social *technologies. In this story, the world is moving towards equal recognition for human and nonhuman beings, defined in terms of a* system of rights *extending to most and, ideally, to all creatures. The human commitment to the environment and other species has reached a radical expression through the acknowledgement and implementation of full species egalitarianism, granting all species equal moral standing (Schmidtz, 1998). Once global human society has accepted the idea that the human understanding of nature is just one among many perspectives available, and should not be imposed on other species, a balancing (or interest arbitration) system has been set in place. This consists of an international system of laws, an international inter-species legislative, and a bureaucracy designed to ensure fair negotiation. While the establishment of this planetary legal system and of the legislative has been an unhoped-for success, it is experiencing familiar challenges. The ‘rights bureaucracy’ is increasingly mistrusted, and its purportedly high-minded elitism is under attack. The attacks come both from within (bureaucrats and elected politicians complaining about the failure to fully implement species egalitarianism), and from without (those pressing for an acknowledgement of the unavoidable pre-eminence of humans). Worryingly, both camps accuse science of being perverted. The first group claims research is still much too wedded to human interests and perspectives. The opposite camp complains that, on the contrary, science has been parcelised and siloed based on species perspectivism, and therefore an integrated outlook providing practical guidance acceptable to all has become impossible.*

Key concepts: recognition, pan-species equality, fair inter-species negotiation, perspectivism, anti-elitism

The days when rhinos and elephants were poached for their horns, royals would invite oligarchs to hunting parties, and millions of birds were unceremoniously sacrificed to wind turbines are long gone. In fact, not so long: the world was suddenly awakened not merely to the plight of animals, but also to their dignity, insightfulness, and resourcefulness. A wave of animal-oriented activism swept the global conscience - according to some, much like in a religious revival - and later extended to all living beings. The movement for equal species recognition gained almost universal support and proved able, surprisingly quickly, to establish a global system of rights for all creatures.

Living beings are granted full equal rights

In practice, this entails a legal system that, in some key respects, does not discriminate between human and other, non-human, creatures. The latter are represented at two main levels. The first is the level of individual animals whose interests may be affected and who may sue in their own name – through human representatives (Sunstein, 2003). The second level is that of (some categories of) policy-making, especially policy envisaging structural changes and conditions, where animal genera or families are represented by dedicated advocates in decision-making bodies.

Figure 24: Source https://eco-intelligent.com/

An extensive rights bureaucracy enforces full equality; living creatures are represented in a global legislative

Under these arrangements, a class of bureaucrats – "animal advocates" – exists whose sole mission is to represent animal genera or families (the basic units of representation, although, for simplicity, the term "species" is commonly used instead) in organizations at various levels of decision. Some ecosystems, such as corals or even individual atoll islands, benefit from similar representation. Perhaps the most well-known and, indeed, the archetypal organization of this type is the Poly-species Parliament, a global legislative body that sets the broad frameworks for lower-level decisions with substantial impact on species and the environment more generally. The human and many other species are represented at this level. The Parliament is mirrored by other organizations at lower decision-making levels, whether global, regional, or local.

These species-accommodating decision-making bodies are naturally complemented by species-specific consultants, advisers, and analysts, among which scientists are perhaps some of the most prominent. There are currently many research centres around the world serving the interests of each single represented species, and a number of professional scientific bodies have been founded that are defined by the constituency they serve (for example, the Global Association of Pooch Scientists).

The role of science in advancing full equality

Science has played a particularly prominent role in advancing decisions with respect to species equality. Researchers have been called upon to replace a human-centric perspective with species- or ecosystem-centric ones. Indigenous knowledge has been mined for ancient insights on animal behaviours and, in more extreme - and still somewhat contested - cases, for insights into animal consciousness. One effect has been an undeniable synergy among particular species-related perspectives. On the other hand, some argue that species pluralism in research has rendered scientific integration more difficult and even politically fraught.

Implementing true equality across all species is considered by some still an unfulfilled promise; activists demand full inclusion
The radical expansion of animal rights is being contested, however, though usually because it is not radical enough. Some activists press for an even more egalitarian approach, since under the prevailing arrangement not all genera or families are represented; and even for those that are, the true level of representation is not actually similar. For example, dogs and cats are represented as such, i.e., separately from the other canidae and felidae, respectively, which are lumped together. Other creatures are represented only at phylum level – the annelids, for example, triggering protests by advocates that most ringed worm species are crucially different from each other, and that to treat them in unitary fashion is to radically misunderstand their varied, sometimes conflicting interests. There are, then, extreme activists who call for a truly Pan-species Parliament, which should grant representation to forms of life presently excluded, such as various microbes, even some that are damaging or lethal to humans and to other families of non-human beings.

Parallel trends in human society: the rediscovery of indigenous knowledge
In response to criticisms of the prevalent data-collection regime as working under pretensions of universality and of separation between knowledge and governance, some have called for a better integration of indigenous knowledge in the human mindset (Latulippe et al., 2020). There is a notion that the latter is supposedly better at understanding other forms of life and may give rise to more persuasive, contextual narratives for data-based policy (Hammer, 2017). As a result, many animal representatives are becoming more diverse themselves, counteracting the trend of indigenous knowledge erosion (Aswani et al., 2018).

As animal advocates diversify, one proposal is to “de-humanize representation” by taking human advocates out of the picture to the largest extent possible. The main proposal, rapidly gaining ground, is to replace human advocates with bots. The main project is to enable the latter to develop autonomously, in line with the experience they share with the creatures on behalf of which they act and speak. Opponents of this trend have expressed the concern that such bots may, in time, come to dominate the species they represent - or, rather, mis-represent.

This being said, there are still voices claiming that species-perspectivism is politically divisive, rather than integrative. They argue that it would be more honest to recognize that species representatives still pursue very personal (and thus very human) interests, even if the latter are tied to the welfare of particular species.

The use of data follows the principle of perspective- or interest-pluralism; challenges against pluralism are raised by the species-relativist position
The organization and use of data under this arrangement offers a good illustration of the issues arising more broadly. Data collection follows the principle that each species (genus or family) has its own perspective on the world. As a result, all the equally represented beings have developed, through their bureaucracies, their own models of the environment(s) and their own kinds of data. The latter can be extremely fine-grained and are usually also quite varied. Cat advocates, for example, who are among the most ferocious supporters of the (in this case) *catus* worldview, have amassed huge data sets on the impact of surface densities and textures on purring, not only for a large number of subspecies and sub-subspecies of cats, but for almost all individuals of the species living together with humans. (Human cat companions are, under laws passed over a decade ago by the Parliament, obliged to install a wide array of sensors to constantly monitor this and other cat-specific variables, though individual cats retain the right to refuse to wear any on- or in-body device.)

The key challenge in this respect is that, as species-specific data grows more detailed as well as more particular, it has become difficult to integrate in all-purpose ecosystem-level models. Indeed, there are claims that such models would intrinsically violate perspectivism.

The prevalence of data collection and modelling by species-specific analysts has led to an explosion in power consumption
This data-centric approach to the rights of beings, which not all animal representatives share, but which is very widespread, has generated a serious acceleration in computational and storage needs. On the positive side, it has led to rapid and quite radical advances in the development of sensors, and especially biosensors and BioFETs, needed to respond to the huge variety of bodies and environments now housing them. The extension of AI across species, particularly to deliver species-specific services, has vastly improved algorithms.

On the worrying side, overall power consumption has been increasing several-fold every few years, prompting a large number of cost-benefit analyses of investment in data infrastructures – from the perspective of each represented species. Furthermore, the inability to reconcile these analyses has often led to delays in decision-making.

Competition for data to satisfy radically different, species-specific concerns generates clashes among species representatives and threats to data security
In this context, data security has posed particularly difficult dilemmas. One crisis, which almost led to the disestablishment of the Parliament, is worth recounting, among other reasons because it also involved cats. A synchronized breach of several large data centres by two groups of *unofficial* cat supporters (self-styled "The Katerrorists" and "Kattack") exposed, among others, almost the entire network of underground tunnels painstakingly charted over many years by the *official* teams of scientists working for underground rodents and for the muridae family as a whole. Although it was not entirely clear how this type of information could be communicated to individual cats, and therefore what the real impact on the rodent population might be (cat advocates said it would be vanishingly small, while muridae representatives argued it might lead to extinction), the breach was considered a major challenge to the poly-specieist arrangement. It took almost a full year of negotiations for the clash to subside and for the Parliament to fully return to work. (Part of the compromise was for rodent advocates in the global legislative to surrender some of the comfiest seats in the legislative building to cat MPs.)

Interest-pluralism exposes the difficulty of reconciling the radically different interests of earthly species; one expression of this conflict is the heterogeneity of data and models
This case illustrates a more serious concern, namely, the conflict of worldviews, which some theorists have described as a "clash of specielizations". While some species advocates – most notably, human representatives – have insisted on a poly-specieist perspective, wherein interests should be negotiated among fully equal species, in a few cases advocates have rejected this egalitarian approach. They have claimed that full recognition of a species' worldview implies acceptance of a species-relative perspective. This relativism occasionally threatens to undermine the dominant poly-specieist ethics and has been repeatedly denounced as imperialist and as relying on a homocolonialist mentality. (Once again, cat advocates have been among the most vocal supporters of the relativist position, although they have at least implicitly accepted by the poly-specieist stance by refusing to leave the Parliament, whose workings they nevertheless obstruct on a relatively regular basis.)

The conflict of species worldviews is also well illustrated by the multiplicity of alternative models of (the same) ecosystems, and of the environment in general. From global models to hyperlocal ones, there is a large variety of competing models of the same spaces, relying on sometimes incompatible premises and assumptions. The Parliament has proposed and is currently funding a number of initiatives to define the basic principles for the integration of these models into broader, poly-specieist ones, aimed at resolving the seemingly irreconcilable tensions prevalent at the present time.

In conclusion, it seems that the all-pervasive egalitarian drive has amplified somewhat social antagonisms, this time on species-based lines. More than a few researchers believe this extends to science too, since the move towards perspectivism hampers integration, so much so that even inclusivist scientific advice is always countered based on *some other* perspective. Last but not least, there is a rising trend that advocates the recapturing of an enlightened human-centred outlook, claiming that it is inescapable anyway, and that the new egalitarian bureaucracy is simply pursuing factional interests under the guise of protecting some species or other.

We, the life – Scenario P3

Summary

In the third scenario, the aspirational paradigm of relation with nature is that of immersing and caring. Restraining the effects on the environment, as if humans were not part of it, is abandoned; as is trying to provide the space for negotiation among species, as if there was a need for an agora in the circle of life. Rather, humans become conscious and act as intrinsically responsible voices of Life. This involves going beyond dualism, beyond the separation between the human as an actant and the environment as something external *and/or objective. One philosophy that describes this position very well is that of biocentrism, as defined by Robert Lanza. Biocentrism states that reality is not independent of the observer, but very much created by it, and therefore that apparent consciousnesses are not intrinsically separated. Biocentrism with its non-dualist tenets is apparently at odds with common sense, and its adoption, beyond the assimilation of arguments in its favour, requires a shift in consciousness. In the third scenario, biocentrism becomes more and more common among scientists in physics, biology, or AI, who explore the paradoxes of consciousness and the source of life, usually in combination with more meditative or contemplative practices. A complementary influx includes scientists integrating nature related values from indigenous cultures. The biocentric scientists become respected voices in society, acknowledged sources of ethically grounded worldviews, influencing the design of socio-techno-environmental systems. These new stars of science often express themselves at the crossroads with art and spirituality, cultivating schools of thought and reflection, with the inherent wake of apprentices, followers, and contenders.*

Key concepts: non-dualism, ethical grounded worldviews, VIP scientists

Biocentric scientists
In the third perspective, a new Copernican Revolution is underway: biocentrism establishes that reality is not independent of the observer, but very much created by it, and therefore that apparent consciousnesses are not intrinsically separated. The beings attaining this level of consciousness represent an acknowledged class of wisemen and women, able to promote principles for the design of human systems.

Backed by an interpretation of quantum theory, biocentrism posits that what we perceive as reality is a process that involves our consciousness, while the “universe” is simply the complete spatiotemporal logic of the self (Lanza, 2020). A similar concept, that of the “mental nature of reality” (Kastrup et al., 2019), draws mostly on the logical fallacies and internal contradictions of the reigning physicalist ontology and advances a compelling formulation of idealism that reconciles classical and quantum worlds.

The scientific formulations of biocentrism are on a convergence path with the naturalistic wisdom spread by renowned meditators: the concept the “inter-being” promoted by the Peace Nobelist Thich Nhat Hanh, or the concept of “interconnectedness”, advanced by Adyashanty.

The interplay of scientific understanding and experiential consciousness mutation is at the core of this new perspective, at odds with the reigning common sense, where reality is independent of us as observers, while we are separate entities among ourselves. That is why the new understanding, even while receiving strong support from science (e.g., quantum physics, cognitive science) has as yet not been widely adopted, but remains limited to a small but growing community. This community aims to embody the perspective and undergo a personal transformation. Its members train to be the top scientists of the future.

Science exists to bring clarity
One of the accepted social roles of this new type of scientist is to increase clarity and inspire people to the new ways of seeing. Their proposed models are worldviews, not just simplifications of reality (see, e.g., Fritjof Capra’s “world as a network”, or Daniel Wahl’s “regenerative cultures”).
However, this does not imply a convergence in the form of expression but, on the contrary, a diversification and a transgression of the disciplinary boundaries and of the borders separating pure science, engineering, arts, and even lifestyles.

The non-dualist truth is considered to be that of advancing towards the understanding of oneness. This may include forms of paradoxical thinking as triggers for a new understanding or as pointers to the limits of dualist perception.

Science is taken personally
Under the new paradigm, ideas are not totally disconnected from the proponent, similar to the way architectures reflect the architect. Therefore, the scientific message would be very often connected to the life of the scientist and her/his ethical and even aesthetic expression.

Ideas will be dynamic, given - on the one hand - the evolution of the promoter and of its supporters, and - on the other - the “evolutive information”. The latter requires us “to analyse the strong, resonant coupling between processes related to action and perception which emerges in the human brain” (Fiorini, 2019).

The dissemination of ideas relies greatly on mentorship, cascading face-to face or via online communities. Successful ideas are not actually replicated but transformed into new subjective ways of seeing.
The dialogue of paradigmatic ideas takes place in inspirational contests of the VIPs, with mutually agreed and evolving rules, in settings that recall the Glass Bead Game proposed in the 1931 novel by Herman Hesse, which has become one of the fundamental documents of the new perspective.

Biocentric by design
The decisions supported by this new generation of scientists are not so much the operational, immediate ones, but paradigmatic changes in the embedding systems (e.g., taxation, transport network, smart systems). Like in conceptual art, the proposed designs are ways of allowing the new flourishing dynamics of the ecosystems.

Figure 25: Source: Neri Oxman, Exhibition Material Ecology 2020, moma.org

Neri Oxman coined the term, and pioneered the field of, Material Ecology, which considers computation, fabrication, and the material itself as inseparable dimensions of design. In this approach, products and buildings are biologically informed and digitally engineered by, with and for, Nature (www.media.mit.edu)

Data is representation
In a biocentric view, data cannot be an objective representation, but the embedding of intention - “the ethics of qualitative research in a Big Data era is to foreground Big Data’s treatment of data as self-evident, and its positivist claim to represent the world innocently, accurately, and objectively, as matters of ethical concern” (Mauthner, 2019).

“Big Data ecosystemic framework [needs] to acknowledge technological progress and innovation as a complex player in the transformation of nature and its management, rather than simply either its abuser or its custodian. … What we need to come to terms with as a culture is that there is no equilibrium to return to” (Hogan, 2018).

Dealing with complexity is not delving into its consuming granularities and intertwinings, but positioning from an integrative perspective, which implicitly makes room for open developments and reflexive adaptations.

Many of these developments integrate current scientific vocabularies and infrastructures, such as, for instance, the concept of Earth System Science (ESS), a transdisciplinary endeavour aimed at understanding the structure and functioning of the Earth as a complex, adaptive system (Steffen et al., 2020).

As such, the data collection and analysis systems are the most carefully designed by the top scientists.

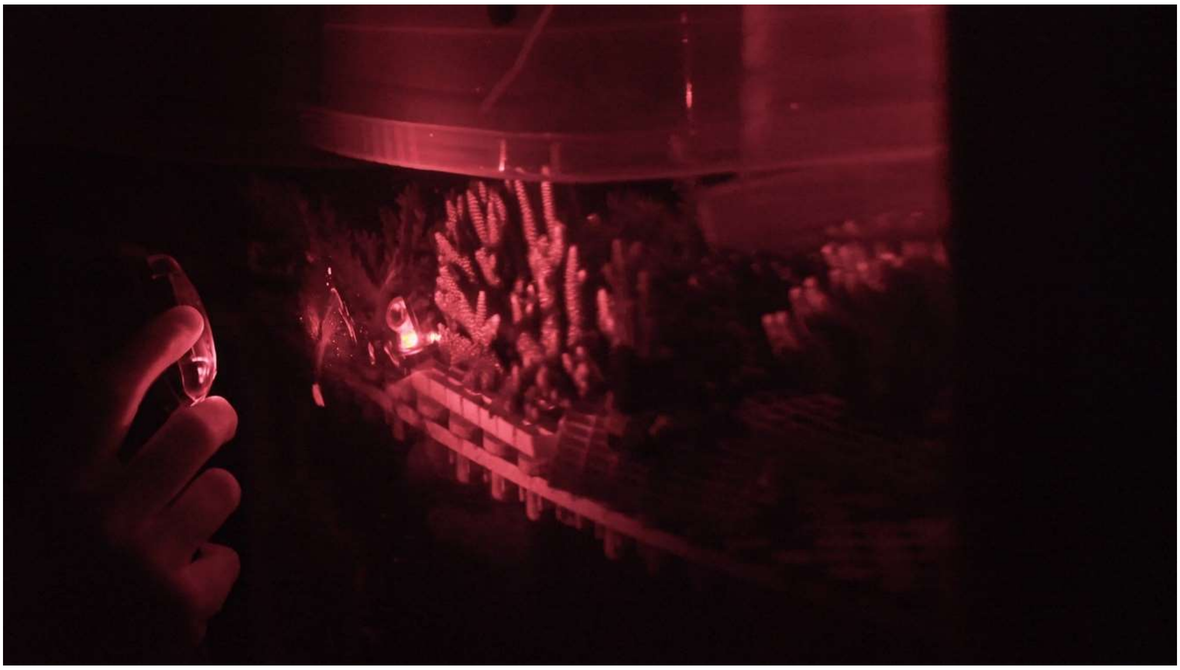

Figure 26: Sonia Levy for the Love of Corals: An Ecology of Perhaps. Source: www.sonialevy.net

"*a case study of new paradigms for multispecies living, environmental conservation and natural history that are emerging in the wake of the Anthropocene. [...] a cinematic inquiry that focuses on the daily labour of caring for endangered beings to resuscitate them from their imminent human-induced extinction. The technology of the ad hoc laboratory; scientific knowledge; the complexity of marine ecologies; and the intimacy of providing care converge in the precision of sustaining coral IFV [in vitro fertilization]*"

In the quantum paradigm, there is a difference between automatic data collection and the information, which is actually perceived by the observers, as only the latter has consequences.

Data is fundamentally a tribute to dualism. However, the non-dual perspective does not antagonize the necessity of data collection or try to oversimplify it in an attempt of reduction but engages with data as mind artifacts and is preoccupied with its intentionality and the risk of the solidification of worldviews. This logic also applies to computer architectures, especially as they evolve into neuromorphic structures.

In an integration logic, big data is ultimately the sum of our perceptions, it is the Maya, the very fabric of illusion.

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This report presents the results of a study on S&T&I for 2050: science, technology and innovation for ecosystem performance – accelerating sustainability transitions. The aim was to identify, map and assess future scientific and technological developments that can radically improve or threaten ecosystem performance. Based on literature review, the project team developed three perspectives on future relations between humans and nature and humans' role in the flourishing of planetary ecosystems. Drawing in addition on a two-round Dynamic Argumentative Delphi survey on the most dynamic scientific and technological developments, six cased studies on core sustainability issues explored the three perspectives. Reflections on implications for R&I policies in the context of the European Green Deal conclude each case study.

Studies and reports

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