EPFL

Guidance to distinct actors

Ensuring the environmental sustainability of emerging technologies - 3

International Risk Governance Center

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Introduction

To support economic development, governments and industries in major countries are committing to massive new technological investments before, or perhaps without, undertaking a comprehensive assessment of their environmental impacts. Existing policy frameworks concerning some emerging technology applications do not provide sufficient clarity for how these technologies will be regulated, especially if the risk of environmental harm is not proven and impacts are indirect or manifest in the longer term. For example, this is the case of the transition to a digital economy that requires building massive data centres; innovation in advanced materials such as semiconductors or smart materials[1] expected to offer major improvements in a wide variety of domains; or the transition to all-electric vehicles. Do we know the full extent of consequences on the environment?

So far, the transition to sustainability has not been accompanied by the development of suitable political, governance, and management guidance concerning technologies. It is very difficult for policymakers tasked with promoting innovation to design appropriate constraining and incentivising governance mechanisms to ensure that an emerging technology can be qualified as 'sustainable' over its life cycle, i.e., that it will contribute to meeting the needs of the present without compromising the ability of future generations to meet their own needs, and balancing economic, environmental and social priorities.

These concerns are already on the radar of most governments, and this guidance document is intended to support efforts to better identify, anticipate and early-manage potential risks to environmental sustainability. For example, the European Chemicals Strategy for Sustainability[2] requires the development of innovative approaches for substituting toxic chemicals with more sustainable chemicals, ensuring 'safety and sustainability-by-design' (SSbD), and implementing circularity.

In 2021, IRGC started project work on "ensuring the environmental sustainability of emerging technologies" (ESET), with a brief description here and a first report published in March 2022 (ESET report 1). Our priority is not on emerging technologies with environmental sustainability as a goal (technology *for* sustainability) but primarily on others that may have indirect adverse environmental consequences. Examples include advanced materials, gene editing, digital technologies, and space technologies, discussed in the ESET report 1. In addition, some technologies, such as carbon dioxide removal (CDR), purposely developed for the urgent need to mitigate climate change, may overlook potential threats to environmental sustainability.

The second phase of the project produced twelve case studies on a selection of emerging technologies and instruments to identify, assess

[1] Smart materials are materials that respond in a controllable and reversible way, modifying some of their properties as a result of external stimuli such as certain mechanical stress or a certain temperature, among others. Because they are reactive and adaptive, their behaviour in an open natural environment is difficult to predict.

[2] See "The EU's chemicals strategy for sustainability towards a toxic-free environment", published by the EC in October 2020.

and manage threats to environmental sustainability in specific cases. The twelve papers and an introduction are available as an edited volume published in February 2023 (ESET report 2).

This report (ESET report 3) concludes the third and final phase. It provides some generic guidance targeted to lawmakers and regulators, technology developers, research funding organisations, technology investors, industry and standard-setting organisations[3]. Our purpose is not to judge whether a particular emerging technology is good or bad, but to help steer its development in a way that its deployment will not cause damage to the environment in the long term, while enabling other priorities such as innovation.

The process of identifying, analysing and managing possible threats to environmental or climate sustainability might become similar to the process of ensuring compliance with ethical prescriptions and social norms. This is because of the ongoing building of social norms around environmental and climate sustainability, and liability risks that could increase if courts are perceived as legitimate actors to substitute or complement regulation in this domain[4]. For example, many climate change litigation cases around the world[5] have recently provided indications that industries or governments may be held liable by national courts and required to compensate for damage if they do not take sufficient action to mitigate climate change.

This report assumes that there is a normative objective to preserve the environment and the climate. Environmental sustainability is not a matter of choice. However, the ways to get there are not prescribed. For example, if any regulation is needed, it is preferable that it is performance-based, i.e., it is technology-neutral and does not mandate specific approaches or tools.

This guidance document presents matters in a concise manner. Readers are advised to consult the supporting material comprising the 2022 report (ESET report 1) and the 2023 report (ESET report 2). Together they include information about various ESET approaches. Links to additional sources of information are provided in the footnotes. However, this document is neither a manual nor a checklist. It can be adapted to specific needs or audiences.

Disclaimer
The IRGC ESET project deliberately focuses on environmental aspects only, acknowledging though that ethical, social, political and economic dimensions must also be considered, which would nuance the conclusions. For an emerging technology outcome to be acceptable, it should be sustainable on all three dimensions: environment, society and economy.

3 Guidance to **scientific research** is not explicitly targeted in this report. For example, the guidance would not be helpful to address needs to establish solar radiation modification (SRM), or solar geoengineering research governance, i.e., how to conduct research on SRM. This would be outside of IRGC's project scope. Similarly this document does not provide guidance to **users of technology**, whether governments, businesses, or consumers, because it is placed earlier in the technology development chain: before there are actual products or applications that can be used or placed on the market. However, a major driver of technology implementation in new products or services is the demand from business and end-customers, including when demand is created by marketing and the media. Those raise appetite for and even 'fascination' in new technology, before tools exist and mechanisms are in place to do comprehensive early-assessment of their possible threats to environmental sustainability, and in the absence of appropriate regulatory framework, requirements or guidance.
4 See some analysis in IRGC's ESET report 1, pages 30–31, and the ESET paper by Lucas Bergkamp on "Liability's role in managing potential risks of environmental impacts of emerging technologies".
5 See for example the "Climate Change Litigation Databases" developed at Columbia University.

Box 1 | Guiding questions

Throughout this project, the many contributors who provided their expertise and insights (see the Acknowledgements section) were asked the following questions regarding specific emerging technologies.

1. What are the expected opportunities or benefits?

2. Are there potential 'hidden' (ignored or neglected) risks to environmental sustainability?
   - Is there a reason to worry today?

2. What is currently done to address the potential risks?
   - What is the approach taken today by those who develop, implement, fund, encourage or regulate the technology to discuss (or not) the question of long-term sustainability?
   - What is being done to identify and assess sustainability risks at the design phase of the technology, i.e., early in the technology development process?

3. What could be done?
   - Is the technology suitable for 'safety and sustainability-by-design' (SSbD)?
   - How could tradeoffs between short-term expected benefits and potential long-term risks be resolved?
   - What new instruments, approaches or guidelines could be adopted to account for long-term impacts? For example, could standards, certifications and labels be helpful?

4. In general, how can decision-makers include the consideration of long-term adverse environmental impacts in their decisions regarding emerging technologies?

5. And finally, is the goal of ensuring ESET realistic?

Box 2 | Systemic impacts and collaboration between actors

Decision-makers are familiar with **feedback effects between technology, environment and policy**. First, technological choices can have environmental impacts. When a new technology development is anticipated to impact the environment, existing policies must be reviewed to check whether they are appropriate. Thus, the emergence of new technology requires policymakers to consider whether new policies or regulations, or adaptation of existing ones are needed. The actual environmental impacts of a technology development depend on response strategies implemented by policy, regulatory, and industry decisions. Second, when a public policy encourages or discourages the development of a specific emerging technology, it must consider the ancillary impacts, the risks involved, the tradeoffs between risks and between risks and benefits, countervailing risks, as well as co-benefits[6] that the policy decision may create. There is a feedback effect from policy into technology development, and policy decisions themselves can trigger environmental impacts.

[6] See Jonathan B. Wiener, "Learning to manage the multi-risk world" (November 2020). See also John D. Graham, Jonathan B. Wiener and Lisa A. Robinson, "Co-benefits, countervailing risks, and cost-benefit analysis", in *Human and ecological risk assessment: Theory and practice* (2021).

Thus, the possibility that risk materialises depends on resolving **tradeoffs**[7] at various levels. The different threats to environmental sustainability have interactions and tradeoffs, which, in theory, could be captured in life cycle assessment (LCA) and technology impact assessment, and addressed in circular economy action plans. Still, many obstacles come into play, including private interests and lock-in effects. Business and ethical aspects also often intersect with sustainability.

> The case of techniques and policies for carbon dioxide removal (CDR) illustrates the tradeoffs. For example, implementing technologies for CDR could deter from implementing those for CO_2 emission reductions. It also illustrates that methods currently used to assess secondary impacts and countervailing risks from deploying CDR are insufficient, and data are lacking. This is a chicken and egg question, because much larger scale experimentation and deployment will be needed before we can have a good enough qualification of the promises, challenges and uncertainties to support policy recommendations. We need policy and investment decisions on CDR to be taken urgently to address the climate challenge[8], and those decisions will have an impact on the environment and the climate as CDR is being implemented.

This can be generalised to feedback or systemic effects between all actors developing or affected by emerging technologies, or involved in ensuring that their outcome is sustainable, which calls for **collaboration and the building of sustainability as a shared value** (see figure 2 in Section 3).

Collaboration among actors to ensure ESET is needed to **improve conventional risk assessment methods** to analyse and make sense of the vast quantity of data that can be collected from environmental monitoring, increasingly using AI-based systems and advanced modelling. Risk assessment must also become much better at integrating social issues involving inequities and imbalanced exposure to emerging and growing environmental threats. As long as risk managers have not evolved their portfolio of risk management measures to integrate new knowledge from this type of advanced and holistic risk assessment and produce research- and risk-based recommendations relevant to policy, policy decisions may not be based on the best possible evidence[9].

This report is informed by IRGC
→ ESET report 1 (workshop report, 2022)
→ ESET report 2 (edited volume, 2023)

[7] Once the boundaries of the system affected by an emerging technology have been defined sufficiently large to include systemic impacts and consequences, it may appear that most decision options include benefits and risks. Tradeoffs result from different actors pursuing different goals that cannot be reconciled.
[8] As emphasized in IPCC "AR6 synthesis report", released in March 2023. The Carnegie Climate Governance Initiative notes that the development of evidence from both natural and social sciences must be accompanied with a debate in policy.
[9] See US NAS report on "Transforming EPA science to meet today's and tomorrow's challenges" (2023) that calls for a substantially broader and better integrated approach to risk assessment and environmental protection, for example by improving the incorporation of emerging science and systems thinking.

1.

Priorities for ensuring that emerging technology outcomes are environmentally sustainable

The first two IRGC reports on ensuring the environmental sustainability of emerging technology (ESET report 1, published in 2022, and ESET report 2, published in 2023) have emphasised certain aspects that must be acknowledged by those concerned that things might go wrong with specific applications of new technology. This section provides a brief reminder of some priorities. In summary, every actor should enable or consider the need to:

- frame risk management in an appropriate way,
- make sense of uncertainty and ambiguity,
- develop and implement methods to assess potential future impacts,
- work to address systemic impacts,
- create and assign responsibility.

1.1 Frame risk management in an appropriate way

- When there is a threat to environmental or human health, safety and security are the first steps, before sustainability.
  Example: the two-tiered framework approach adopted by the European Commission in December 2022 for 'safe and sustainable-by-design'[10] chemicals in Europe recommends assessing safety first, using tools and methods for hazard and risk assessment, and then sustainability, using life-cycle instruments.

- Concerning environmental sustainability, risks caused by emerging technology applications occur either because the application itself is not sustainable (could cause environmental damage) or because the context in which the application is deployed does not enable the technology to produce sustainable outcomes.
  Example: growing biomass for bioenergy with carbon capture and sequestration (BECCS)[11] can be sustainable in some countries or settings, but less so in others where using land for that purpose is not appropriate.

- So, at least in theory, risk management can target either the source (the technology) or the impact of the risk (the sector of application, the affected environment). Risk management activities can thus consist of minimising risk in the existing environment or changing the environment.
  Example: the risk of collision with space debris[12] can be mitigated by avoiding damage — avoiding collision and improving impact tolerance — and by limiting the number of debris to create a more sustainable environment.

1.2 Make sense of uncertainty and ambiguity

- Emerging technologies are accompanied by pervasive uncertainty about the future. In addition to helping deal with uncertainty, guidance should help cope with pervasive ambiguity associated with sustainability. While the concept of sustainability is clear, its application is fluid and subject to various interpretations.

- Decision-makers would be advised to adopt mechanisms for robust decision-making, i.e., decisions that will be good enough in a range of possible situations[13].

- Adaptive governance and regulation may be considered, unless there is a risk of irreversible catastrophic damage from which adaptive learning would be precluded (in that case, precautionary approaches[14] and resilience building[15] are generally more appropriate). Adaptive governance is a concept that embeds learning into policymaking and regulation (as in planned adaptive regulation - PAR) as well as in industry strategy. Because we face uncertainty, strategies need to be flexible. The essence of risk and uncertainties related to new technologies is that learning occurs over time. So we need to have adaptive approaches that sequentially or iteratively update with monitoring of the broad scope of impacts, and then revision of strategies to deal with them[16].

- Policy initiatives to improve 'anticipatory technology governance'[17] could address this goal. They aim to develop governance arrangements for deciding how to deploy an

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[10] See the framework published in the JRC technical report, "Safe and sustainable by design chemicals and materials. Review of safety and sustainability dimensions, aspects, methods, indicators, and tools" (March 2022). See also the ESET paper by Steffen Hansen and Xenia Trier, "Smart materials and safe and sustainable-by-design – a feasibility and policy analysis".
[11] Bioenergy with carbon capture and sequestration (BECCS) is one of the techniques to reduce CO_2 atmospheric concentration. See also the ESET paper by Benjamin Sovacool and Chad Baum, "Ensuring the environmental sustainability of emerging technologies for carbon dioxide removal".
[12] See the ESET paper by Romain Buchs, "Ensuring the environmental sustainability of emerging space technologies".
[13] About robust decision-making, see "IRGC guidelines for emerging risk governance", page 37, and the Appendix to the guidelines, Section 2.5, page 22.
[14] See "Consider precautionary approaches" in Section 3.1.
[15] For information about resilience, see the resilience page on the IRGC website.
[16] Planned adaptive regulation (PAR) is an approach in which a regulation is designed from its initiation to learn from experience and update over time. In the face of uncertain evidence used to underpin a rule, regulators plan both for scheduled adaptation of the rule and for producing decision-relevant knowledge that further characterises or reduces the uncertainties pertaining to the risk regulated. PAR can only be developed with strong collaboration among actors that engage in monitoring and data sharing, and are willing to work with some kind of regulatory uncertainty. For a summary information about PAR, see an IRGC presentation (2018).

emerging technology when significant benefits are anticipated and there is only a suspicion of environmental harm. They also aim to resolve the tradeoffs between conflicting objectives.

- Procedural validity and deliberative methods may provide legitimacy to decisions when scientific evidence is insufficient[18].

1.3 Develop and implement methods to assess potential future impacts

- There is generally a lack of appropriate tools and data to understand the possible impacts and consequences of potential risks and, therefore, to develop appropriate response strategies. Identification and characterisation of many emerging technology-related risks to environmental sustainability are at a preliminary stage.

- Life cycle assessment (LCA) and environmental impact assessment (EIA) are instruments of choice, yet incompletely developed for technologies whose outcomes are not yet final. Methods for forward-looking (*ex-ante*, anticipatory, prospective) LCA of technological products that do not exist beyond experimentation should enable assessing the uncertain impacts of emerging technologies, which requires tools that characterise uncertainty and adopt a long-term perspective[19]. However, those methods are not available in standard form. Their development requires close collaboration between LCA experts, technology developers, industry, standard-setting organisations and regulators, who will consider whether new types of LCA can be mandated for regulatory assessment. Section 3 of this document discusses LCA in various actor-specific guidance, indicating what specific roles actors can play.

- Early-stage or anticipatory technology assessment (TA) could be given a more prominent role, especially when used by policymakers (who adopt strategies or public policies in favour or against certain technology developments) and regulators (for regulatory risk assessment and management)[20]. A question, though, is to what extent it is possible to systematise early-stage TA at the regulatory level, which implies making the tools available to technology developers and others in the technology development chain.

1.4 Work to address systemic impacts

- The impacts of many emerging technologies will be systemic, i.e., they will have cascading effects on the economy, society and environment, often with shocks and crises. Actions that focus on sectors and risks in isolation and on short-term gains often lead to maladaptation over the long term, creating lock-ins of exposure, vulnerability and risk that are difficult to change[21].

- There exist generic recommendations about how to identify, assess and prepare for systemic risks[22]. Those usually include adopting a systems thinking approach, organising foresight activities, engaging stakeholders and collaborating with others, developing resilience, and adapting policy frameworks to address systemic risk issues. However, those are challenging to implement in practice.

See also: (1) Lawrence E. McCray, Kenneth A. Oye and Arthur C. Petersen, "Planned adaptation in risk regulation: An initial survey of US environmental, health, and safety regulation", in *Technological Forecasting & Social Change*, July 2010; (2) Lori S. Bennear and Jonathan B. Wiener, "Built to learn: From static to adaptive environmental policy", A better planet: Forty big ideas for a sustainable future (2019); (3) Lori S. Bennear and Jonathan B. Wiener, "Adaptive regulation: Instrument choice for policy learning over time", draft working paper (12 February 2019).
Note that PAR can follow from dynamic risk assessment. See for example "KPMG's Dynamic risk assessment".
17 See the OECD Global Forum on Technology, launched in March 2023.
18 See more information about procedural validity in the ESET report 2: "Introduction" by Marie-Valentine Florin, and paper by Jennifer Kuzma, "Gene drives: Environmental impacts, sustainability, and governance".
19 See the ESET papers by Stefano Cucurachi and Carlos Felipe Blanca, "Practical solutions for ex-ante LCA illustrated by emerging PV technologies" and by Thomas P. Seager, "Anticipatory life cycle assessment for environmental innovation".
20 See initiatives of the European Parliamentary Technology Assessment Network (EPTA).
21 As reminded in IPCC "AR6 synthesis report – Climate change 2023: summary for policymakers", B.4.3.
22 See "IRGC's guidelines for the governance of systemic risks" and the ESET paper by Rainer Sachs, "Ensuring environmental sustainability of emerging technologies – the case for applying the IRGC emerging and systemic risk governance guidelines".

1.5 Create and assign responsibility

↦ A question for legislators and industry is whether the law could begin to create and assign responsibility even when neither the sustainability nor the un-sustainability of a technology application can be proven i.e. when possible environmental damage can neither be excluded nor demonstrated, measured and attributed at the time when it is caused, before some development at scale. This is because the absence of proof of harm at the time of introduction does not guarantee the absence of harm in the longer term. Establishing responsibility would create a legal basis for liability regimes to act as an *ex-ante* incentive to technology developers and industry[23]. Currently, courts and plaintiffs, especially in the EU, seem to use soft law to make judgments or sue companies in so-called 'climate cases'[24].

Actors in many (but not all) technology and innovation domains tend to have a retroactive approach toward sustainability risks: a reaction is often triggered by a move from adversely affected stakeholders or by environmental NGOs who are vocal about a particular concern. Initiatives for proactive approaches exist, are often encouraged by public policy and in lawmaking (for example, in parliamentary technology assessment), but are rarely consensual in their implementation. There would be some benefit in establishing a place and process where technology developers, funders and investors convene stakeholders to take into account broader considerations and expectations as they plan their work, allocate budgets and fund technologies.

Economic, industry and security interests are the primary drivers of innovation policies, outweighing concerns regarding the environmental impacts of industrial activities. For now, sustainability is too often an afterthought and is not prioritised by private actors. However, with the growing evidence of harm and concerns around climate change and loss of biodiversity and ecosystem services, greater environmental consciousness can help move the sustainability of technology higher on the political agenda.

[23] See the ESET paper by Lucas Bergkamp, "Liability's role in managing potential risks of environmental impacts of emerging technologies".
[24] In the "Milieudefensie et al. v. Royal Dutch Shell plc." 2019 case, the Dutch Court verdict was that the Shell company owed a duty of care towards the Dutch citizens to care about climate change and reduce its carbon emissions by net 45% by 2030. This is an approach to not wait until an environmental/social harm is materialized, and to force an entity to act proactively to prevent the risk by a case law. In this case, the Dutch court, used two soft-law instruments: the UN Guiding Principles on Business and Human Rights and the OECD Guidelines for Multinational Enterprises.

2.

A sustainability compass

In analogy with a GPS and Google map, a compass that indicates the direction of sustainability to those who encourage, develop, fund and engage in business resulting from emerging technologies could orientate towards making business sense and ensuring environmental sustainability.

First, an initial assessment of an emerging technology outcome (through early-stage innovation and technology assessment) would indicate in which quadrant of figure 1 below the anticipated outcome is expected to be found.

Then, recommendations will depend on the initial assessment and the sustainability goal:

- **In case of low business potential and low expected sustainability:** Recommendation to stop or fundamentally review the technical design and development of the technology.
- **In case of low business potential and high expected sustainability:** Recommendation to work on making business sense of the environmentally promising outcome.
- **In case of high business potential and low expected sustainability:** Recommendation to work to find ways to make it sustainable, for example, by changing the technical design when it is still doable.
- **In case of high business potential and high expected sustainability:** Recommendation to strongly encourage the technology, including with regulatory incentives and standards.

Recommendations concerning how various stakeholders can ensure sustainability are provided in the following section, in the form of guidance to lawmakers and regulators (Section 3.1), technology developers (Section 3.2), research funding organisations (Section 3.3), technology investors (Section 3.4), industry (Section 3.5) and standard-setting organisations (Section 3.6), to move or steer the final technology outcomes into the top right quadrant (green)[25].

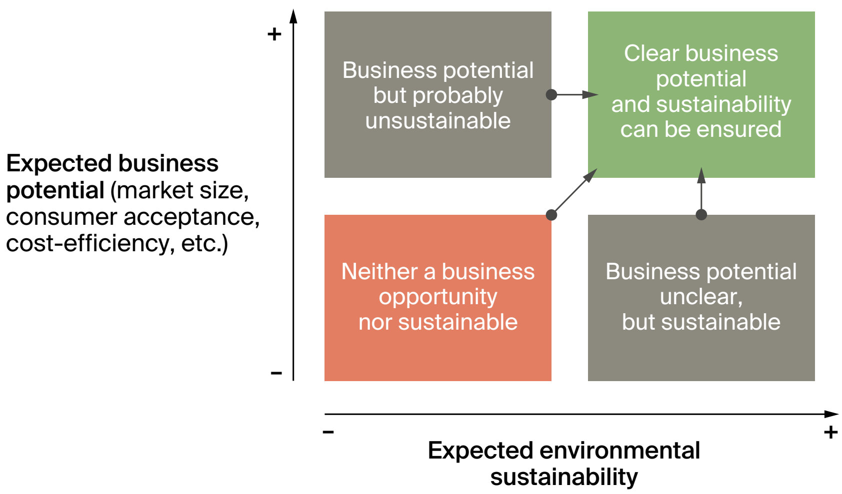

Figure 1 | Moving toward ensuring the sustainable outcome of an emerging technology

[26] See note 3 above.

3.

Guidance

Systemic effects and reinforcement mechanisms occur between all actors developing or affected by emerging technologies, or involved in ensuring that their outcome is sustainable. This calls for collaboration and the building of sustainability as a shared value.

In figure 2 below, the arrows indicate the direction and strength of influence between actors.

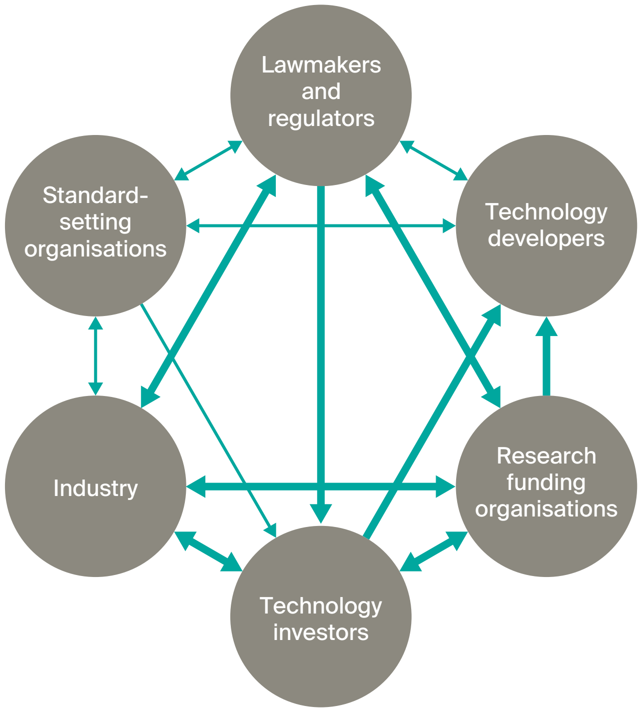

Figure 2 | Systemic influence between actors

3.1 Guidance to lawmakers and regulators

The deficiencies in regulatory frameworks to address specific risks or uncertainties of new technologies are explainable by the very nature of innovation, and it is a real challenge to remedy them. For example, methods for hazard or risk assessment of advanced materials that are adaptive by nature and whose assessment may vary depending on the deployment context are insufficient[26]. Policymakers are advised to consider systemic impacts, benefits and risks, integrate the assessment of social aspects into the evaluation of risks related to emerging technologies, work to address tradeoffs (including when factors of competitiveness with other countries influence policy decisions), and advance new policy frameworks that are systemic and adaptive.

Guidance to regulators includes that they must and can intervene to ensure ESET in several manners:

1. **Work with governments and industry to embed principles and values into regulation and establish the necessary legal basis for sustainability**, in a way that can be detailed in specific rules. For example, the law could recognise more clearly that technology very often generates impacts on ecosystems, and that many ecosystems are limited shared resources with the characteristics of 'common-pool resources'. This would be a stepping stone to managing ESET effectively nationally and globally. Application by the judiciary in liability frameworks would follow[27]. For example, the European Commission is actively moving with mandatory environmental, social justice and governance (ESG) issues disclosure frameworks, which will contribute to strengthening the legal basis for sustainability[28]. At a global level, the Financial Stability Board created the Task Force on Climate-related Financial Disclosures (TCFD) to improve and increase compulsory reporting of climate-related financial information[29].

2. **Consider precautionary approaches**. When laws and uncertainty meet, an ideological trap may arise with discussions around the precautionary principle, especially in Europe. Precaution can be desirable as a strategy to anticipate and prevent catastrophic future harms, but we also need to consider the unintended impacts of precautionary measures, such as potential risk-risk tradeoffs (see box 2) and potential impediments to innovation[30]. To narrow it down, the applicability of the precautionary principle could be linked to the transgression of 'planetary boundaries'[31] or to the 'overshoot' concept[32]. The two concepts refer to the need to avoid potential catastrophic harm.

3. **Mandate the use of certain instruments**, such as anticipatory/*ex-ante* LCA or SSbD, in early-stage technology assessment, with the achievement of specific outcomes required in regulatory approval processes and decisions. This is the general goal pursued by the European Chemicals Strategy for Sustainability[33], which might lead to revising the REACH regulation[34]. Update regulatory risk assessment methods to integrate output from machine learning systems that analyse large datasets, can establish correlations and causalities, and model future behaviours in a much more accurate way than conventional methods. Reward the adoption of standards that encourage good practices.

4. **Implement principles of planned adaptive regulation** (PAR), which can be a form of proactive governance of emerging risk (see Section 1.2)[35].

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[26] See the ESET paper by Steffen Hansen and Xenia Trier, "Smart materials and safe and sustainable-by-design".

[27] See note 4 above. In the World Business Council for Sustainable Development (WBCSD)'s report "Uncovering trends: what is behind the increase in ESG-related litigations", WBCSD notes that the lawsuits against companies concerning ESG issues increasingly involve supply chains, refer to the duty to maintain a standard of care, and are based on soft law sources.

[28] See a guide to sustainability reporting regulations in 2023, published by Sustainable Future News. In Europe, the Sustainable Finance Disclosure Regulation (SFDR) that affects investors and other financial market participants has become effective on 1 January 2023.

[29] See the "Task Force on Climate-related Financial Disclosures".

[30] See "Guidance for future application of the precautionary principle" produced by the Horizon 2020 RECIPES project (2022), where "the precautionary principle can serve as an important tool to make innovation governance more anticipatory, more reflexive, more inclusive and deliberative".

[31] In 2009, the Stockholm Resilience Center defined the concept of "planetary boundaries" to illustrate the existence of thresholds beyond which irreversible changes may occur, with adverse consequences through ecosystemic cascading impacts.

3.2 Guidance to technology developers

Those who develop technology are often primarily motivated by specific goals, such as improving an industrial process, starting a business or seeking profit, or a vision, such as supporting the development of a better world. Technology developers are at the origin of solutions, as well as potential threats, to environmental sustainability. Assuming that innovation is their prime motivation, we want to address the problem that technology developers rarely consider safety, risk and sustainability beyond regulatory compliance requirements. Therefore, most of the guidance to them will involve steering their thinking towards considering the environmental sustainability of what they do, which also implies speaking with stakeholders concerned by the technology they develop.

1. Any ESET guidance to those who develop new technology must encourage a **positive attitude towards sustainability and emphasise the benefits of considering potential long-term environmental threats that applications of the technology would cause**. Technology developers must be triggered to think in terms of scenarios, scenario planning and strategic foresight in a way that makes it exciting and attractive, and demonstrates that it pays off to envisage the downside of innovation (adverse side effects, tradeoffs, etc.).
   They can be encouraged and rewarded to collect and share data on the potential impact on sustainability, generate information about incidents or deviations from expectations, which could be exploited as early-warning signals of something that might evolve as risk, and monitor impacts of early deployment.

2. Guidance should **build upon personal thinking and individual convictions** about the value of sustainability and responsibility, e.g., the desire to 'do good' as in 'technology for good', and have a positive impact on people's and environmental welfare. It is primarily a question of mindset and shared values expressed in laws (see Section 3.1), codes of conduct and personal ethics.
   Encouraging technology developers to express publicly their commitment to sustainability can have a positive impact on their reputation, with positive feedback in support from technology funders and the industry.

3. It may be that guidelines developed for **responsible research and innovation** (RRI)[36] could be used as examples for sustainability guidelines. RRI is an approach that anticipates and assesses the potential implications of research and innovation on the environment and society, to make it inclusive and sustainable. In a nutshell, technology developers should be able to answer the following questions, similar to those posed in an RRI process:
   (a) What is the problem that you want to address with the expected emerging technology outcome?
   (b) What are the opportunities and benefits that you think it can bring to the environment?
   (c) What are the risks? To what (ecosystems, natural resources, biodiversity, climate)? How to avoid, prevent, mitigate risks, or adapt to them?
   (d) Who are the final (ultimate) beneficiaries, i.e., specific parts of the natural environment and people? How are they involved in the design of the technology?
   (e) Is there a risk of misuse of the technology?

4. The concept of **sustainability-by-design** looks promising: innovation should design conditions of sustainability at an early stage, and innovators should work with regulators (see Section 3.1) and others to implement it. The concept applies in defining requirements for re-using materials in circular economies and safe and easy recycling at the end of life.

[32] The IPCC uses the concept of climate overshoot to describe a temporary exceedance of a specified level of global warming. See "IPCC special report on global warming of 1.5°C" (2018) and "What is climate overshoot?" defined by the Climate Overshoot Commission.
[33] See note 2 above.
[34] See the European regulation concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH, 2006).
[35] See note 16 above.
[36] Development of RRI and recent interest for linking with anticipatory governance can be found on Rene von Schomberg. The concept of RRI was formalised by the EC in "Options for strengthening responsible research and innovation" (2013).

3.3 Guidance to research funding organisations

By prioritising certain research topics, research funding organisations can be powerful actors in orienting future technology development and building shared values around sustainability. In doing so, they must balance freedom of academic research with more scrutiny on the environmental impact of future technology outcomes.

1. Public research funders (e.g., national science foundations) need a **legal basis** before deciding to establish sustainability as a requirement in grant applications. However, even without a specific legal basis, environmental sustainability can be included in research ethics[37] or integrity[38]. For example, the Code of Conduct for Scientific Integrity of the Swiss Academies (a soft law instrument) requests researchers to "design, undertake, analyse, document and publish their research with care and with an awareness of their responsibility to society, the environment and nature"[39].

2. Funding organisations could establish (more) **criteria to evaluate the attention of the researchers to environmental sustainability**. In particular, criteria or benchmarks are needed for identifying in project descriptions those specific aspects of the technology that could threaten environmental sustainability. Questions here include: What could go wrong? How? For whom? As a result of what? In case technology developers do not seem to pay attention to the environment, for example by over-prioritising short-term economic interests, it could be helpful to draw their attention to (a) the adverse consequences that the deployment of the technology could have in the future, and (b) that their project will simply not succeed because it will not be authorised by regulators or accepted by society and customers. Vice-versa, criteria for identifying in emerging technology project proposals those aspects of the technology that enhance environmental sustainability could be helpful to reward those applications.

3. Funding organisations are well placed to **guide researchers' thinking** about the purpose, goal, risks and benefits of the future technology outcome. Given the multidisciplinary nature of environmental sustainability, this involves necessarily encouraging and funding interdisciplinary research and collaboration mixing natural and social sciences for the adoption of technical applications.

4. Funding organisations could **fund applied research on tools to identify, assess and manage risk to sustainability** and then mandate the use of (for example):
   - forward-looking LCA,
   - safety and sustainability-by-design in various sectoral domains,
   - so-called 3R principles (reduce, re-use, recycle) to establish circular economies.

[37] While established principles for research ethics primarily focus on humans (cf. 'golden rules' of ethics: respect of persons, beneficence and justice) and do not include environmental sustainability, it is worth noting that principles of business ethics sometimes include environmental concerns. See 'environmental concern' in "Business ethics: Definition, principles, why they're important" (17 March 2023).
[38] See the "European code of conduct for research integrity" of the ALLEA (All European Academies) (2017) that serves the European research community as a framework for self-regulation, and the "Code of Conduct for Scientific Integrity" (pp. 16, 20, 22) of the Swiss Academies (2023).
[39] See note 37 above.

3.4 Guidance to technology investors

Organisations that invest in and buy access to technology may be interested in some guidance that will help them meet expectations on sustainable investment. The technology industry is increasingly targeted by the trend to sustainable/green finance, which aims to ensure that a healthy and sustainable environment is prioritised in investment decisions, and that the risk of environmental damage is identified and minimised. Philanthropic organisations that fund new technology, venture capitalists and financial institutions are thus advised to consider the extent to which the technologies they invest in contain any potential environmental threat. This could be achieved by:

1. **Requesting the fulfillment of certain conditions** by applicants, who would be mandated to provide:
   - Outcome of forward-looking LCA conducted on the prospective application of the emerging technology considered;
   - Application of sustainability-by-design principles, which requires concrete plans for circularity, including reducing the use of natural resources, re-using materials, and recycling at the end of life. Innovation will increasingly be required to include these sustainability factors, and technology investors are influential and enabling actors in this respect.

2. **Accelerating the design and deployment of environmental, social, and governance (ESG) investing and, particularly, double materiality**[40]. Regarding the environmental aspects of standard ESG, companies mainly report on significant environmental threats (material risks) that could affect their balance sheet. Sustainability professionals working in investment firms, private equity or venture capitalists are requested to identify and rank ESG risks. ESG rating provides information about how vulnerable a company's earnings may be to ESG risks (this is: 'outside-in'). Indirectly, this rewards the use of environmentally sustainable technologies by companies. Example: renewable energy for data centres. However, standard ESG ratings rarely tell how a company's practices affect the external environment (that is: 'inside-out'), so ESG investing is of limited interest in pursuing the goal of environmental sustainability. What is needed is so-called 'double materiality'. Here, companies and investors also identify environmental material risks that a company could create: how its operations affect the environment.

3. **Acknowledging and supporting the trend towards environmental accountability or responsibility**, which might increasingly assign legal responsibility (liability) to those actors that contribute to an unsustainable environment or climate[41]. Responsibility is often grounded in principles such as human rights. Technology investments are at risk of a financial loss if they do not comply with hard and soft laws to ensure sustainability.

4. **Reducing greenwashing** and overcoming critics of ESG[42] ratings and investing. One needs to understand the financial materiality of ESG factors better, particularly those 'inside-out', and separate the cheap talk from real insight[43].

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[40] About double materiality, see "What new ESG approach 'double materiality' means'– and why JPMorgan is a fan", published by Bloomberg on 21 September 2022.
[41] See notes 4, 5 and 27 on liability.
[42] About sustainable investing, see Terry Yosie's article on "Loosing ourselves in the Tower of (Risk) Babel" (6 February 2023). See also The Economist's article on "The fundamental contradiction of ESG is being laid bare" (29 September 2022) and special report on "ESG investing" (23 July 2022).
[43] See the Wharton School's "ESG initiative" and the "Opinion: How to confront the anti-ESG campaign" (5 September 2022).

3.5 Guidance to industry

Industry is primarily motivated by the industrial application of new technology in a way that benefits their business and shareholder value. However, this increasingly includes matters of societal responsibility and environmental sustainability. Regarding ESET, guidance to the industry involves:

1. Selecting those emerging **technologies with dual benefits**: to business and to the environment. Companies are encouraged to focus explicitly on serving society and addressing social and environmental damages. The guidance could support the selection of technologies that improve the ability of a business to operate successfully so that it can also operate sustainably (see Section 2)[44].

2. Developing and implementing **business models that reward sustainability** and attention to the long term. In particular, such business models can help companies redefine value creation[45], act as leading actors that push environmental sustainability higher on the innovation agenda, fully embrace sustainability reporting and assessment of ESG double materiality[46], and adopt TCFD recommendations[47].

3. Working fully with the **value chain** that will be built around the future technology. This includes two aspects. First, do not transfer environmental sustainability risk to contractors, especially downstream, when technology development is outsourced and plans are to subcontract the production, and encourage those actors to conduct and share their assessment of expected environmental sustainability. Second, capitalise on the resources of a supply chain and leverage business relationships to join forces in larger and more optimistic environmental sustainability goals than individual actors would be able to pursue if they were alone.

4. **Sharing data with regulators** to develop better sustainability-informed regulation and to enable regulators to prescribe evidence-based requirements for risk assessment and management that are acceptable to the industry. With data sharing, environmental risk and sustainability can be externally evaluated. Given the many constraints associated with data sharing, most companies will be reluctant to do this, except if it can be associated with future business opportunities or reduction of liability risk[48].

Box 3 | Insurance

In general, environmental sustainability contributes to creating a lower-risk landscape for insurance than when environmental risks are high. Thus, it makes sense that insurance actively contributes to shaping the conditions for improving sustainability.

Regarding emerging technologies, most underwriters have a natural aversion to the risk that may come with them because sharing the losses is difficult if there is little or no claims history to price the risk transfer. However, insurance can play an active role in selecting and encouraging emerging technology applications that would make sense to them in terms of business potential and loss profile. Thus, product innovation is a strong driver in insurance development.

When faced with uncertainties about future outcomes of emerging technology, insurance's attitude is, first, to reduce the probability of large losses that a small number of events would cause. This is because it is more comfortable with risks characterised by large numbers of small and randomised incidents. Risk measurement is more accurate in these cases, and costs can be distributed. This leads insurance to try to collect large quantities of data to inform risk assessment, but may also trigger, in specific instances, exclusion clauses for some technology applications.

The risk pricing indication is thus a contribution from insurers to inform about environmental risks and to formulate the risk appetite towards specific emerging technology, which also depends on the regulatory framework.

[44] See WBCSD's article "Innovations that could shape and transform 2020–2030" (26 August 2020).
[45] See WBCSD's "Redefining Value" project and BCG's article on "The strategic race to sustainability" (12 July 2022).
[46] About ESG and double materiality, see Section 3.4 and notes 40 and 42 above. See also how the European Financial Reporting Advisory Group (EFRAG) is developing draft EU Sustainability Reporting Standards.

3.6 Guidance to standard-setting organisations

Organisations such as the International Standard Organization (ISO), International Telecommunication Union (ITU)[49], or the US National Institute of Standards and Technology (NIST) have developed standards and norms that provide guidelines or frameworks for organisations that need to systematise and improve the environmental management effort and efficiency of mature supply chains, markets and processes[50]. Other standards, such as for conventional LCA (e.g., ISO 14040[51]) or eco-design, also contribute to environmental sustainability. In addition, at the product level, there are hundreds of private 'ecolabels' of various stringency and purposes.

However, there are at least three types of complications in providing guidance to standard-setting organisations such as ISO or ITU. First, standards are developed bottom-up. They rely on industry and others that, collaboratively, agree on what makes sense to them to achieve certain goals. Therefore, guidance should primarily target the lowest level, at national and industry levels[52]. Second, standards can support emerging technologies[53], but it may be an impossible task to develop standards for technology outcomes that do not exist yet. Nevertheless, ISO 31050 – 'guidance for managing emerging risks to enhance resilience'[54] addresses the pervasive uncertainty that characterises future products of emerging technologies. Third, interpreting the sustainability concept depends to some extent on regional, cultural and political variations. Norms that may exist at a regional level may not be transposable to the international level, and this could be particularly the case regarding the benefits and risks of emerging technologies.

To facilitate a global discussion about adapting established standards to long-term sustainability, efforts could begin with principles in line with the Sustainable Development Goals (SDGs) and very focused initiatives at national or industry levels to:

1. **Steer practices that prioritise the long term** beyond what markets may immediately reward, by systematising the anticipation of possible impacts and underlying uncertainty.

2. **Encourage the formal adoption of methods for decision-making under uncertainty** (in complement to evidence-based decision, as in ISO 9001 principles for decision-making, for example) by developing standards for robust decisions that are acceptable and legitimate even if the scientific knowledge that supports them is poor (focus on providing acceptable and legitimate procedural validity)[55].

3. **Intensify efforts to develop standards for forward-looking LCA**, whether *ex-ante*, anticipatory or prospective LCA[56]. In contrast to conventional LCA that applies to existing products, forward-looking LCA aims to model the life cycle impact of a future product in a future market.

4. **Develop principles or standards for emerging technologies**. ISO identified technological advances as having significant repercussions for standardisation, from the need for new standards to support the development and commercialisation of emerging technologies, to the potential for standards to support the good governance of these technologies[57].

[47] Recommendations about the types of information that companies should disclose to support investors, lenders, and insurance underwriters in appropriately assessing and pricing risks related to climate change. See note 32 above.
[48] About links between data generation and liability, see the ESET paper by Lucas Bergkamp mentioned above.
[49] See for example "ITU activities & Sustainable Development Goals".
[50] See for example the ISO project to look into environmental sustainability of AI systems "ISO/IEC AWI TR 20226 Information technology – Artificial intelligence – Environmental sustainability aspects of AI systems".
[51] See "ISO 14040:2006 – Environmental management – Life cycle assessment – Principles and framework", published in July 2006.
[52] For example, the WBCSD provides standard guidance to industry.
[53] See the British Standards Institution (BSI) on "How standards support emerging technologies".
[54] See "ISO 31050 – Guidance for managing emerging risks to enhance resilience".
[55] See note 18 above about procedural validity.
[56] See 'forward-looking LCA' in the following sections: Priorities (Section 1), Guidance to lawmakers and regulators (Section 3.1), research funding organisation (Section 3.3) and technology investors (Section 3.4).
[57] Following the publication of the "ISO Standardization Foresight Framework – Trend Report 2022", ISO is exploring the role that standards can play in technology governance in order to optimize societal benefits at the technological frontier. See also ISO Research Grant 2023 call for proposals: "Standards and emerging technologies: Risks, opportunities and governance challenges".

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About IRGC

The EPFL International Risk Governance Center (IRGC) is an interdisciplinary unit dedicated to extending knowledge about the increasingly complex, uncertain and ambiguous risks that impact human health and safety, the environment, the economy and society at large. IRGC's mission includes developing risk governance concepts and providing risk governance policy advice to decision-makers in the private and public sectors on key emerging or neglected issues. It emphasises the role of risk governance and the need for appropriate policy and regulatory environments for new technologies where risk issues may be important.

In this project, IRGC applies the guidelines for emerging and systemic risk to the challenge of emerging technologies concerning adverse impacts on environmental sustainability.

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