IEEE SA STANDARDS ASSOCIATION

IEEE planet positive 2030

Strong Sustainability by Design

PRIORITIZING ECOSYSTEM AND HUMAN FLOURISHING WITH TECHNOLOGY-BASED SOLUTIONS

GUIDING PRINCIPLES

An initiative supported by the IEEE Standards Association

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IEEE

Strong Sustainability by Design

This Compendium has been created by committees of the IEEE Planet Positive 2030 Initiative supported by the IEEE Standards Association (IEEE SA). The IEEE Planet Positive 2030 Initiative community is composed of several hundred participants from six continents, who are thought leaders from academia, industry, civil society, policy and government in the related technical and humanistic disciplines. At least one hundred seventy members of this community from about thirty countries have contributed directly to this Compendium and have worked to identify and find consensus on timely issues.

The Compendium's purpose is to identify specific issues and recommendations regarding sustainability and climate change challenges to achieve "Planet Positivity" by 2030, defined as the process of transforming society and infrastructure by 2030 to:

- Reduce Greenhouse Gas (GHG) emissions to 50% of 2005 GHG emissions by 2030.
- Significantly increase regeneration and resilience of the Earth's ecosystems.
- Be well on the path to achieving net zero GHG emissions by 2050 and negative GHG emissions beyond 2050.
- Continue to widely deploy appropriate technology as well as design and implement new technological solutions in support of achieving technological solutions designed and deployed to achieve "Planet Positivity."

In identifying specific issues and pragmatic recommendations, the Compendium:

- Provides a scenario-based challenge (how to achieve "Planet Positivity by 2030") as a tool to inspire readers to get engaged.
- Advances a public discussion about how to build from a "Net Zero" mentality to a "Net or Planet Positive" ("do more good," that is, doing "more" than "don't harm") societal mandate for all technology and policy.
- Continues to build a diverse and inclusive community for the IEEE Planet Positive 2030 Initiative, prioritizing the voices of indigenous and marginalized members whose insights are acutely needed to help make technology and other solutions more valuable for all. Of keen interest is how to encourage more in-depth participatory design in these processes.
- Inspires the creation of technical solutions that can be developed into technical recommendations (for example IEEE SA recommended practice for addressing sustainability, environmental stewardship and climate change challenges in professional practice, IEEE P7800™) and associated certification programs.
- Facilitates the emergence of policies and recommendations that could potentially be intraoperative between different jurisdictions (e.g., countries).

By inviting the general public to read and utilize *Strong Sustainability by Design*, the IEEE Planet Positive 2030 community provides the opportunity to bring multiple voices from the related scientific and engineering communities together with the general public to identify and find broad consensus on technology to address pressing environmental and social issues and proposed recommendations regarding development, implementations and deployment of these technologies. You are invited to Join related IEEE activities, such as standards development and initiatives across the organization.

- For further information, learn more at the IEEE Planet Positive 2030 Initiative website
- Get in touch at: PlanetPositive2030@ieee.org to get connected to and engaged with the IEEE Planet Positive 2030 community.
- Please, subscribe to the IEEE Planet Positive 2030 newsletter here.

If you're a journalist and would like to know more about the IEEE Planet Positive 2030 Initiative, please contact: Standards-pr@ieee.org.

Disclaimers

Strong Sustainability by Design is not a code of conduct or a professional code of ethics. Engineers and technologists have well-established codes, and the IEEE Planet Positive 2030 community respectfully recognizes the formative precedents surrounding issues of sustainability and the professional values these codes represent. These codes provide the broad framework for the more focused domain addressed in this Compendium, and it is hoped that the inclusive, consensus-building process around its design will contribute unique value to technologists and society as a whole.

This Compendium is also not a position, or policy statement, or formal report of IEEE or any other organization with which IEEE is affiliated. It is intended to be a working reference tool created through an inclusive process by those in the relevant scientific and engineering communities prioritizing sustainability considerations in their work.

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A Note Regarding Recommendations in This Document

Strong Sustainability by Design was created in two versions ("draft" and this current edition) that were iterated over the course of two years. The IEEE Planet Positive 2030 Initiative follows a specific consensus building process where members contributing content identify specific potential issues and proposed recommendations.

Membership

IEEE Planet Positive 2030, an initiative supported by the IEEE Standards Association as part of the Industry Connections Program, Sustainable Infrastructures and Community Development program (SICDP), currently has more than four hundred experts involved, and remains eager for new voices and perspectives to join in this work.

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GUIDING PRINCIPLES

Future Vision

It is 2030.

Greenhouse gas (GHG) emissions are significantly reduced, and the Earth's lands and ecosystems are on the way to recovery as imagined by the 2022 United Nations (UN) Convention on Biodiversity—a recovery that will enable planetary-scale environmental regeneration and resilience.

The catalyst for this transformation was a profound sense of urgency stemming from the looming *climate emergency* as the Earth moved closer to the climate tipping point (*the point of no return*; see UNU-EHS, "2023 Executive Summary"). The transformation has been driven by a reformed sense of leadership and planetary-scale collaboration informed by the notion of *deep care*—for the environment, for the Earth's biospheres, and for human dignity (ascribed to all people, including historically marginalized populations, equally).

Decision-makers have adopted caregiving and long-term sustainability as guiding principles for action to address both the need for reduction of GHG emissions and adaptation to the unavoidable impacts of climate change. The majority of global political, business, and community leaders, many of whom represent groups marginalized in the past, have more fully embraced the values of justice, diversity, equity, and inclusion in shaping new policies, new economic and business models, new tools for measuring growth, and new standards of practice.[1] Sustainable behavior that balances today's needs with the needs of future generations is now integral to cultures around the globe—for individuals as well as for organizations.

The concept of an economy based on the concept of "sufficiency" is finding more and more acceptance (Barbiroglio, 2022; Suski, Palzkill, & Speck, 2023; Schaffer, 2018).

Humans are sharing the planet's resources with a vast variety of other organisms. Emerging technologies, including responsibly developed artificial intelligence systems (AIS), are being applied to implement climate change mitigation and adaptation strategies. Humans have developed sustainable and regenerative practices and have recognized that they are caretakers of the planet. Change is driven by an increased awareness of the interconnectedness and interdependence among different types of stakeholders.[2]

[1] The UN "Guiding Principles on Business and Human Rights" contain three chapters, or pillars: protect, respect, and remedy. These pillars define specific, actionable steps for governments and companies to take to meet their respective duties and responsibilities aimed at preventing human rights abuses in company operations and provide remedies if such abuses occur. These guiding principles are valid for all kinds (and sizes) of businesses.

[2] Stakeholders, in this context, are human-centric and other lifeforms and the environment, including: the earth's biospheres, peoples, individuals, institutions, businesses, industries, governments, organizations, academia, and society at large.

Introduction

The goal of a long-term, flourishing planet Earth, planet Earth with a healthy planetary biosphere, can be attained if the current warming trend of the Earth's atmosphere is first halted and then reversed. Reduction of current and future GHG emissions as well as—in the longer term beyond 2050—reduction of the elevated GHG levels in the atmosphere is a paramount goal. Achieving this goal is imperative, but it is not sufficient to attain a long-term healthy planetary biosphere. While shifting from fossil fuel-based economies to largely GHG-free economies is the foremost agenda to address the looming climate crisis, it is equally important to transform the current, mostly linear, resource management into a circular economy (see Ellen MacArthur Foundation, "What is a Circular Economy" and "The Circular Economy in Detail), along with regenerative practices and environmental stewardship. Throughout, we, that is humans, need to observe a balance for all stakeholders between the urgency of today's environmental, biodiversity, and societal needs, the urgency of avoiding tomorrow's looming climate catastrophe and achieving a long-term, flourishing planet Earth.

Embracing complexity throughout the pursuit of this goal is vital. The increasing recognition of interdependencies between society and the environment, our home, means that the transition to a sustainable future is a complex or "wicked problem" (Rittel & Webber, 1973). The process of transitioning to a planet-positive society will not be easy or straightforward. Competing goals and problem sets, different cultural and/or governance approaches, and moving and/or unmeasurable targets imply that this journey will not be linear and will not be without political—or other forms of—disagreements or conflict. Indeed, addressing and responding to the realities of global warming may be the most important and complex problem humanity has ever faced. Failure to do so will have lasting harmful impacts and consequences for all stakeholders, including present and future humanity and the planetary biosphere. Honoring, recognizing, and including the large diversity in stakeholder cultures and in local, regional, and global conditions and needs requires flexibility and a diversity of approaches to creating a planet-positive society.

The very succinct **definition of planetary sustainability** by an unknown participant from Africa at the United Nations meeting in Johannesburg (Rio + 10), **"Enough for All—Forever"** can serve as a key guidepost. Individual, institutional, business, industry, government, organizational, academic, and societal stakeholders share the responsibility to "take care" of the planet Earth and its biosphere, humanity's—our—home.

The **guiding principles** of *Strong Sustainability by Design* are intended to provide a framework for the document's strategies and recommendations capturing both the desire for long-term planetary sustainability and the complexity that is inherent in fulfilling this desire. They embody the overall "impossible" goals of the IEEE Planet Positive 2030 Initiative.

The foundation: The need for a flourishing planet, human rights, and values

The foundation for the guiding principles is the need for a long-term flourishing planet Earth to sustain all life. The guiding principles are built upon the United Nations Universal Declaration of Human Rights; Declaration on the Rights of Indigenous Peoples; Declaration on the Rights of Disabled Persons; Declaration on the Right to Development; Rio Declaration on Environment and Development; Resolution on the Human Right to a Clean, Healthy and Sustainable Environment; Convention on the Rights of the Child; regional human rights declarations; and the IEEE Code of Ethics.

Human dignity and the human values of peace, freedom, social progress, and equal rights form the values basis underlying *Strong Sustainability by Design*. Enshrined within the UN's Charter and its Universal

Declaration of Human Rights for nearly three-quarters of a century, these broad values have guided the UN's efforts to fairly represent the world's diverse nations and cultures.

Alignment with UN values embraces a powerful declaration for universal human values that guide human societies. Having those values form the basis for *Strong Sustainability by Design*'s guiding principles provides a powerful, cultures-wide foundation for guiding the efforts of humans as caretakers and caretaker advocates of a flourishing planet.

Essential to the success of the guiding principles are awareness of the problem, accountability, transparency, freedom of expression, and protection of whistleblowers. The goal is a long-term flourishing planet Earth with a thriving biosphere—all nations, all peoples, all life, and all that supports life.

Ten Guiding Principles

These Principles are designed to provide high-level considerations and are not listed in any order of importance. This has been done purposefully so readers can provide recommendations including the potential ranking of these Principles by specific criteria that address the needs of their audience and stakeholders.

1. **Responsible and ethical leadership from governments, individuals, businesses, organizations, academic institutions, and communities**

   The responsibilities of individuals, organizations, academic institutions, and communities should be broadened to include an increased role in addressing the challenges of climate change, sustainability, and socioeconomic and environmental stewardship. New knowledge brings responsibility and demands action. Leadership requires collaboration and cooperation with all stakeholders impacted by decisions. Implementation of technology and policy development should always consider environmental flourishing and human wellbeing in accordance with specifics established by guidelines such as the United Nations Sustainable Development Goals (UNDESA, "The 17 Goals").

2. **Justice, diversity, equity, and inclusion**

   Championing justice, diversity, equity, and inclusion should be a part of sustainability, regeneration, and climate change strategies recognizing that climate change impacts are often felt most by those with the least resources. It is the responsibility of those with the most resources to support those who lack resources in an equitable manner. Addressing climate change impacts and environmental and sustainability challenges should reduce conflict, violence, and inequity.

3. **Global energy systems transformation**

   The transition from a fossil fuel-based energy system to a system that is based on clean and sustainable sources of energy should maintain energy accessibility, affordability, sustainability, reliability, and resiliency through all phases of the transition. This transition should also help ensure access for all to affordable, reliable, sustainable, and modern energy (UNDESA, Goal 7). A successful energy transition will enable GHG emission reductions not only in the energy/power sectors but in all sectors using energy, thereby supporting the decarbonization and electrification of these sectors.

4. **Climate change mitigation and adaptation**

   In responding to the challenge of climate change, and to prevent a climate catastrophe, society needs to both mitigate (that is, reduce) GHG emissions and adapt to the impacts of a changing climate. Both goals require urgent action. The goals of mitigation and adaptation may come into conflict, society will have to balance these conflicts.

5. **The regenerative imperative and a circular economy**

   Thinking, planning, and action must broaden beyond current economic, business, societal, and resource utilization models to achieve sustainability and for people and the Earth's biosphere to flourish for many generations to come. Future economic, societal and cultural, and business models should emphasize new public imperatives and values such as circularity, ecological regeneration, zero waste, and human flourishing and well-being.

6. **Balance between today's needs and the needs of the future**

   In the course of transitioning societies and the global economy toward a sustainable future, today's short-term needs must balance with the long-term, global aspirations for a flourishing planet. This balanced approach should address all human needs, including access to food and clean water, health care, and other essential goods and services necessary for a healthy standard of living, and the need for healthy ecosystems globally.

7. **Alignment of global goals with local goals and actions**

   The transition to a more sustainable future will be driven and implemented by local actions that should also produce positive global benefits. Local actions and global goals should support each other.

8. **Culture of sustainability**

   Strategies and actions should move societies toward building a culture of sustainability and "doing good" that is based on respect for all living beings and for the planet Earth. Sustainability efforts must move beyond minimizing harm to restoring and regenerating human and environmental systems.

9. **Responsible use of technology and technology labeling**

   The design, development, implementation, use, and handling/treatment at end-of-current-use of technology should be a dynamic ongoing process for evolving an appropriate, timely response to both negative impacts—the unforeseen consequences of technology on people and planet—and positive impacts—the opportunities to relieve suffering, increase flourishing and equity, and better steward the planet.

10. **Knowledge-based decisions, transparency, and accountability**

    Decisions should be based on metrics, sound data, relevant information, context, experience, and perspective; these factors all contribute to informed decisions, knowledge, and accountability. Knowledge-based decisions are thus made on the basis of good evidence and sound reasoning; this, in turn, can make hard decisions more defensible and accountable. Application of appropriate metrics and reevaluation of decisions should be carried out at appropriate time intervals to enable accountability, transparency, and corrective actions.

The following sections of this chapter discuss each of the guiding principles in more detail, including providing recommendations.

Guiding Principle 1: Responsible and ethical leadership from governments, individuals, businesses, organizations, academic institutions, and communities

The responsibilities of individuals, organizations, academic institutions, and communities[3] should be broadened to include an increased role in addressing the challenges of climate change, sustainability, and socioeconomic and environmental stewardship. New knowledge brings responsibility and demands action. Leadership requires collaboration and cooperation with ***all*** stakeholders impacted by decisions. Implementation of technology and policy development should always consider environmental flourishing and human wellbeing in accordance with specifics established by guidelines such as the United Nations Sustainable Development Goals (UNDESA, "The 17 Goals").

Background

Professional communities include technical and nontechnical professionals[4] who are committed to a sustainable future and who are experienced and knowledgeable regarding the paths toward this future. There is an imperative for leadership from this community to inspire global cooperation and collaboration at all levels of society.

This leadership imperative applies to both individuals and organizations. Individual responsibility includes the choices and actions of our lives and our roles in leading change within organizations. Organizations, including academic institutions, play a significant role in achieving long-term sustainability of the Earth's biospheres since their decisions and activities impact the planet on both community and global scales. Organizations should see themselves as both agents for increasing "collective good" and understanding imperatives to implement necessary structural and operational changes. In doing so, professional communities make key contributions towards achieving a flourishing planet, that is a flourishing planetary biosphere.

Increased engagement in public policy that is focused on creating a more sustainable world will be necessary. Professional communities will need to utilize technical knowledge and understanding of stakeholder concerns and leadership skills to help guide public investment decisions and promote necessary regulatory shifts.

Recommendations

1. **Broaden the definition of professional responsibility.** Work with engineering and other professional organizations to broaden their definitions of professional responsibility to place greater emphasis on sustainability, climate change, environmental stewardship, and responsible technology. Associations of technical professionals globally should provide leadership.
2. **Individuals may, for example, contribute to the IEEE P7800™ Working Group's *IEEE Recommended Practice for Addressing Sustainability, Environmental Stewardship and Climate Change Challenges in Professional Practice*.**

[3] Individuals, organizations, academic institutions, businesses, governments, and communities will be referred to hereafter as stakeholders.
[4] Includes professionals from various technical, scientific, and nontechnical disciplines.

3. **Engage with the public with science-based information and conclusions.** Engage in activities focused on educating, communicating, and engaging with the public regarding the science behind climate change, the value that the natural world provides to society, and the future impacts of climate change. This would also include discussing and addressing out-of-date information and misconceptions.
4. **Raise awareness of the risks and challenges and potential impacts of climate change.** That is to raise awareness of the potential impacts of climate change to civilization and the planetary biosphere, the challenge of limiting climate change and the need for sustainability and environmental stewardship. Transparency is essential.
5. **Encourage and lead the development of an accountability system that is transparent and features external audits and verification.**
6. **Lead in the development of a cross-sectoral information system that links changes in climate, GHG levels in the atmosphere, ocean warming, and other indicators to countries' responsibilities, and compensatory mechanisms.**
7. **Include concepts of sustainability, climate change, and environmental stewardship in leadership and other professional training programs.** Support efforts to incorporate leadership in sustainability and programs of technical skills related to sustainability, climate change action, and environmental stewardship in the curriculum for professional education and other fields of study, including material within the IEEE Learning Network.
8. **Support the application of metrics, analytics, tracking and reporting.** Support efforts and highlight best practices related to the inclusion, application, tracking and reporting of sustainability, environmental, social, and governance (ESG) metrics, or equivalent/similar/improved metrics, for all types of organizations.
9. **Support the sustainability leadership initiatives of other organizations and collaborate with these organizations for increased impact.**
10. **Engage in public policy advocacy at all levels of government that supports the goals of the IEEE Planet Positive 2030 Initiative.**[5]

Case studies

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1. Engineering Change Lab—USA

   According to Engineering Change Lab—USA, there are two key elements to the leadership imperative:

   a. Stepping up to leadership roles:

      - Communicating, connecting, convening, and caregiving

[5] The Two "Impossible" Goals of the IEEE Planet Positive 2030 Initiative: 1) Transform society and infrastructure to achieve Planet Positivity; 2) Identify the technological solutions we need to design, innovate and deploy to reach Planet Positive 2030.

- Challenging the status quo and catalyzing change
- When necessary, taking the heat and holding steady

b. Building bridges:

- Collaborating across disciplines and with all other stakeholders
- Proactively reaching out across divides and between factions
- Managing polarities and resolving conflicts
- Committing to an open-source ideology that also recognizes sources
- Maintaining cultural awareness and empathy

Further resources

1. Annas, George J., Chase L. Beisel, Kendell Clement, Andrea Crisanti, Stacy Francis, Marco Galardini, et al. "A Code of Ethics for Gene Drive Research." *The CRISPR Journal* 4, no. 1 (19 Feb. 2021).
2. Engineering Change Lab USA (website).
3. Engineering for One Planet (website).
4. McMeekin, Mike. "Climate Change Noble Purpose for Engineering Statement." Engineering Change Lab, USA, 28 Oct. 2021.
5. Sustainable Development Technology Canada (website).

Guiding Principle 2: Justice, diversity, equity, and inclusion

Championing justice, diversity, equity, and inclusion should be a part of sustainability, regeneration, and climate change strategies recognizing that climate change impacts are often felt most by those with the least resources. It is the responsibility of those with the most resources to support those who lack resources in an equitable manner. Addressing climate change impacts and environmental and sustainability challenges should reduce conflict, violence, and inequity.

Background

Climate change, sustainability, and environmental challenges affect people differently based on factors such as location and resources. Some of these impacts can be direct, such as how extreme weather events and rising temperatures can disproportionately affect historically marginalized communities who may not have the resources to adapt to these changes. Those with fewer resources are often the most affected and have the least ability to respond to the impacts of climate change and other sustainability-related challenges.

The involvement of historically and currently marginalized populations allows for unique experiences and perspectives to contribute to the decision-making processes of government, especially concerning sustainability. For example, communities of color may face different environmental health risks and challenges compared to other groups, and their input on how to address these issues can be valuable and essential for successful change.

Therefore, it is beneficial for governments and organizations to actively engage with historically marginalized communities, listen to their voices, and take their experiences into account when creating policies and making decisions about sustainability. This will allow for the solutions developed to be more comprehensive, so everyone in society can benefit from a sustainable future.

More specifically, climate change can have a range of impacts on historically marginalized communities. These impacts include the health impacts of air pollution, lack of access to clean water and sanitation, rising sea levels, extreme weather events, and other climate-related events. These impacts have—and will—lead to a lowered quality of life (IPCC, 2022).

In addition, intersectionality includes multiple forms of social inequalities and vulnerability that interconnect and overlap with each other. Intersectionality addresses more than the categories of identities; it also includes the intricacies necessary to understand persistent social, political, and structural inequalities that, in turn, translate into various types of vulnerabilities and the unequal sharing of needs and responsibilities.

Technology plays a critical role in managing climate risks and impacts, but historically marginalized communities are often left out from benefiting from these technologies. The Technology for Climate Justice Reporting Framework in Figure 22.4, *Reporting Framework for Technology to Address Loss and Damage and Contribute to Climate Justice* (van den Homberg and McQuistan, 2018) aims to analyze technology needs to reduce losses and damages for decision makers. The framework includes two repositories of technologies: one for technologies currently used to address impacts and risks and another for planned technologies.

Tens of millions of people living in Africa have experienced/are experiencing acute food insecurity, hunger or famine (see The Africa Center for Strategic Studies, 2024). "*Drought…has devastated their living conditions.*

Climate change causes droughts to be more frequent and severe, which" will continue to negatively impact "*the lives of the African people*."

"Indigenous" …peoples, "who are especially reliant on their land for day-to-day survival, are leading the way with initiatives aimed at quelling the environmental disasters they suffer as a result of global warming and extreme weather conditions…

…And yet, despite the discrepancy in how different groups and countries are affected by climate change, many previous negotiations and policy decisions have excluded nongovernmental organizations, activists, civil society, and those most vulnerable to the effects of climate change. These groups, while present, are not allowed an equal opportunity to contribute to policy decisions" (text adapted from Fadahunsi, "Climate Change on the Front Line: Why Marginalized Voices Matter in Climate Change Negotiations"). Human rights should always be respected in the implementation of decarbonization, sustainability and "planet positive" strategies. Technically advanced, wealthier countries have a responsibility to respect the human rights of all people.

Climate change and its impacts are a global challenge that affects both developing and developed nations. While often perceived as a problem of the developing world, its impact is present in developed countries too, particularly among vulnerable communities such as people of color, women, children, the poor, and those with disabilities. (The Data Team, 2018; U.S. Global Leadership Coalition, 2021; Kermal Davis, 2007). For example, the devastation caused by Hurricane Katrina in 2005 highlights this reality. As humanity moves toward 2030, it becomes increasingly important to proactively tackle disparities resulting from climate change. We have an opportunity to collaborate, pooling our resources, technological advancements, and ideas, to support those most affected and to hear all voices in our collective journey toward an inclusive and sustainable future. The proactive discussions at the 28th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 28) regarding Loss and Damage remind us of the power of shared action and responsibility in shaping a world where diversity, equity, and inclusion are at the heart of our climate response (UN Climate Change, "COP 28," 2023).

Recommendations

1. **Utilize resources and disseminate climate information, proposed solutions, and best practices in formats that are accessible to communities** (Shaikh et al., 2021). For example, in Banke and Bardia district in Nepal, community information boards are used to explain "appropriate flood mitigation measures and the community-based early warning system." See Figure 22.1 in "Technology for Climate Justice" (van den Homberg and McQuistan, 2018).
2. **Develop climate change ambassadors.** Develop climate change ambassadors from different communities as messengers, prepared with leadership support, tools, training, and resources to communicate with and engage the public and community partners on their climate change issues (U.S. Fish and Wildlife Service, 2014).
3. **Integrate intersectional thinking.** Focusing on the areas of climate solutions, sustainability, and environmental stewardship integrate intersectional thinking, collaboration between communities, policymakers, and other key stakeholders through bridging traditional knowledge and climate science (Raygorodetsky, 2011) and active participation at each stage—from engagement in creating policy and developing technology to implementing solutions and strategies for climate change—and working in collaborative ways with all levels of community and government (Plant, 2021).

4. **Consider development of a minimal level of resource sharing system between nations**. Such a system could help avoid unarmed and armed conflict over natural resources and aid implementation plans for environmental protection and/or regeneration of ecosystems. Such a system could also help address highly varying local impacts of climate change and sustainability challenges.

Case studies

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1. Co-Designing Climate Services to Integrate Traditional Ecological Knowledge: Bali, Indonesia

   Biskupska, Natalia, and Albert Salamanca. *Co-Designing Climate Services to Integrate Traditional Ecological Knowledge: A Case Study for Bali, Indonesia*. Stockholm: Stockholm Environment Institute, Oct. 2020.

2. Climate Justice Case Studies

   Second Nature. "Climate Justice Case Studies." Accessed 15 Jan. 2023.

Further resources

1. Amorim-Maia, Ana T., Isabelle Anguelovski, Eric Chu, and James Connolly. "Intersectional Climate Justice: A Conceptual Pathway for Bridging Adaptation Planning, Transformative Action, and Social Equity." *Urban Climate* 41, art. 101053 (Jan. 2022).
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Guiding Principle 3: Global energy systems transformation

The transition from a fossil fuel-based energy system to a system that is based on clean and sustainable sources of energy should maintain energy accessibility, affordability, sustainability, reliability, and resiliency through all phases of the transition. This transition should also help *ensure access for all to affordable, reliable, sustainable and modern energy* (UNDESA, Goal 7). A successful energy transition will enable GHG emission reductions not only in the energy/power sectors but in all sectors using energy, thereby supporting the decarbonization and electrification of these sectors.

Background

In 2021, the International Energy Agency (IEA) published a roadmap to building a global energy sector with net zero emissions. The target date was 2050. In the roadmap, the agency called for a "complete transformation of how we produce, transport and consume energy," and that this process hinged "on an unprecedented clean technology push to 2030" (Bouckaert et al., 2021). Covering a broad and interconnected range of human activities (using energy)—power generation, transportation, heating and cooling, use of Information and communications technologies (ICT), industry, agriculture and more, all producing GHG emissions (Ritchie, 2020)—such a complete transformation of the world's energy infrastructure is a truly complex and difficult undertaking.

G20 world leaders, meeting in the United Arab Emirates for the COP 28 summit in 2023, pledged to "pursue and encourage efforts to triple renewable energy capacity globally through existing targets and policies, as well as demonstrate similar ambition with respect to other zero and low-emission technologies, including abatement and removal technologies, in line with national circumstances by 2030." At COP 28, commitments were made to:

- "Triple the world's installed renewable energy generation capacity to at least 11,000 GW by 2030, taking into consideration different starting points and national circumstances.
- Work together in order to collectively double the global average annual rate of energy efficiency improvements from around 2% to over 4% every year until 2030.
- Put the principle of energy efficiency as the "first fuel" at the core of policymaking, planning, and major investment decisions." (UN Climate Change, "COP 28," 2023)

These commitments provide important support towards *the* energy systems transformation and a new low emissions or, better yet, net zero energy systems infrastructure.

This energy system transformation is critically necessary considering that almost three quarters of the global GHG emissions are associated with the energy sector (energy for electricity generation for heating, cooling, transportation, manufacturing, agriculture, and other sectors like the ICT sector); see diagram showing global GHG emissions by sector for 2016 here (Ritchie, Rosado, & Roser, 2024) and the global direct primary energy consumption here, 2023 (Our World in Data, "Global Direct Primary Energy Consumption").

This energy system transformation is feasible as reported by researchers at LUT University and the Energy Watch Group in their report *Global Energy System based on 100% Renewable Energy* (Ram et al., 2019) and by Christian Breyer and team in *On the History and Future of 100% Renewable Energy Systems Research*

(Breyer et al., 2022). Other authors comment that wind and solar may not be enough, as "the only way in which wind/solar could meet all (or nearly all) global energy needs is if energy use is drastically curtailed" (Moriarty & Honnery, 2020). Many degrowth and limits-to-growth experts agree (Hansen, Narbel, & Aksnes, 2017). Nuclear power generation is one suggested fossil fuel alternative that can address baseload requirements for utility and/or power grids and make up renewable energy deficits (Hong Vo et al., 2020; Davis, 2022), but it faces concerns including accidents and nuclear waste management. More recent small modular reactor designs work to address some of these concerns (NEA, "NEA Small Modular Reactor Dashboard;" IEEE-USA, "Commercial Nuclear Energy and Technology Leadership"). And, in 2023, COP 28 leaders committed to mobilizing "investments in nuclear power, including through innovative financing mechanisms," to advance a global aspirational goal of tripling safe nuclear power generation by 2050 (U.S. Dept. of Energy, 2023). Yet the recognition remains that other emerging energy technologies, such as geothermal and negative emission biofuels, will additionally factor into production deficits. Most scenarios and projections predict it will take a combination of technologies to transition to a fossil-fuel-free global energy system.

The energy system transformation is not limited to switching from GHG-emissions-producing fossil-fuel-based energy sources, it also requires energy efficiency measures and energy conservation. Energy conservation (e.g., turning a device off when not in use) and energy efficiency measures (e.g., replacing high-intensity discharge light bulbs with LED lighting for street lighting) are the low-hanging fruit. Furthermore, the energy systems transformation is expected to address new and additional energy demands, such as providing access to electricity to those who are currently without access (more than 700 million in 2023; see Statista 2024) and growing electricity demands anticipated by the expanding ICT sector, such as electrical power demands by a growing number of data centers and increasing use of AI processes.

It is essential that this transition addresses the disposition of the elements of the currently deployed energy system(s) through integration into the new system, reuse, and waste minimization. Depending on local and regional contexts, this may or may not be extraordinarily difficult for both technical and human or social reasons. It will be technically complex due to the interconnectedness of competing needs, often expressed as the *food/land-water-energy nexus*, for example for biofuels (SDSN/FEEM, 2021). Agriculture and solar panels may compete for land use or provide for new opportunities such as the development of agrivoltaics or agrovoltaic farming (Hall, 2022). Energy production may have significant water requirements (IEEE, 2010); for example, electrolysis to generate hydrogen (H_2) from electricity requires a minimum of 9 liters of water per kilogram of H_2.

During this energy systems transition, integrated systems planning should pay careful attention to the critical life-sustaining balance in the energy-water-food nexus. It is easy to focus upon one aspect to the detriment of other necessary components. Maintaining this balance should obey circular economy, regeneration, and sustainable principles (see Guiding Principle 5), and it should be based upon technical standards and regulations for the interoperability of regulations between jurisdictions. Examples for integrated systems planning include the following:

- Hydrogen is widely considered an energy carrier for transport and storage. IEEE SA has a program that considers the use of "Green Hydrogen" (IEEE SA, "Green Hydrogen). Many countries, such as Canada, have developed a hydrogen strategy (Government of Canada, 2020). *Planning considerations:* Hydrogen production requires water—depending on water quality, on the order of 9–20 or more liters per kilogram of hydrogen. On the other hand, when using fuel cell technology to generate electrical power from hydrogen, water is a co-product. Essentially, hydrogen transports not only energy, but also (virtual) water. Depending on the technology used, this water can be of drinking water quality.

- Another example is the increased use and application of ICT and the associated energy and water consumption in production and operation of the infrastructure (for example, data centers), balancing the increased application of ICT to potentially produce efficiencies, including energy efficiencies, in other sectors, like the energy sector.

These types of technical and economic relationships support regenerative and sustainable goals.

Perhaps more difficult will be the human and social challenges (Pasqualetti, 2011); political constraints (Bayulgen & Ladewig, 2017) and economic challenges (Dorian, Franssen, & Simbeck, 2006). Steering this transition through so many conflicting challenges will not be an easy task. But the cost of maintaining the existing energy infrastructure is far higher—the future of our planet's ecosystems. It is claimed that renewables-based energy generation use will be more cost-effective than current fossil-fuel-based energy systems (Ram et al., 2019). Depending on geographical location and associated technology performance, this cost prediction from 2019 has already been achieved (UN Climate Action, "Renewables: Cheapest Form of Power").

This difficult transition must balance between *short-term pain and long-term gain* AND between human and planetary needs—an *equitable* balance. That is, while it would presumably be most beneficial for planetary ecosystems to curtail human GHG emissions producing activities very quickly and severely, the energy transition should be a "just transition". A "just transition" as described by the Stockholm Environment Institute is "a transition that minimizes disruption for workers and communities reliant on unsustainable industries and energy sources" (Piggot et al., 2019). This transition provides for accessibility, ubiquitous access, affordability, sustainability, and reliability for the differing cultural and economic needs of diverse multitudes, as it develops and implements clean and sustainable energy sources for all.

Ultimately, despite these challenges and complexities, this energy system transformation is a *doable task.* According to Julia Steinberger, an ecological economist at the University of Lausanne, the process "is entirely doable, and it is doable fast, but it will come with a price tag which will then be repaid forever after in a prosperous and healthy society" (Meredith and Handley, 2021). There will be innumerable benefits. They will result in economic opportunities, particularly for less developed countries, as economies are built upon access to energy resources. Societies will experience a tremendous positive health impact in response to clean air and water (Gai et al., 2020), for example, preventing premature deaths and reducing health-care costs. There will be many others.

Models exist, such as leveraging innovations from the space industry and other environments where sustainability principles are critical (Deep Space Food Challenge). System inertia, e.g. thermal energy in the ocean, needs to be taken into account when modeling the impact of potential actions. There are other roadmaps and resources to help guide the way.

Most importantly, energy systems transformation is achievable—it is a *doable* task.

Recommendations

1. **Prioritize realization of energy efficiencies across all energy consumption as an early target.** Realizing energy efficiencies across all types of energy consumption, applications, and sectors is the low-hanging fruit regarding GHG emissions reduction. Note, best practices should be context specific. A couple of examples representing many ways of realizing energy efficiencies:
    a) **Replacing conventional street lighting** (e.g. high-pressure sodium) **with LED lighting.**
    b) **Avoiding losses due to standby power, also called *Phantom Power*** (IESO, "What's Phantom Power and How Can You Track It?")

2. **Employ digitalization and AI as appropriate to optimize energy systems efficiency and to track performance metrics as well as verify the level of attainment of key performance indicators** (KPIs).
3. **Address the energy transition from fossil-fuel-based to a no- or low-emission, clean electricity-based energy system as a priority and in a contextualized, sustainable way.** Low-emissions energy replacing fossil fuels, coal, natural gas, and oil is the enabler for other sector transitions as these sectors electrify. Associated water, food, and communications (i.e., connections to the internet and services) challenges will be easier to resolve as the new low-emissions or no-emissions energy generation and distribution system spreads across geographies and cultures, making clean, sustainable, mostly renewable, resilient electricity widely accessible. Context matters: for example, Kenya's electricity supply is generated to more than 40% from geothermal energy and to about 30% from hydro (IEA, "Kenya").

   Customer Benefit: Power customers purchasing no-emissions (very close to no emissions associated with the power generation) electricity can report effectively Scope 2 zero emissions, if electricity is the only energy purchased for (customer) operations.
4. **Observe new technology developments for incorporation into "energy planning scenarios."** Technologies under consideration should include geological hydrogen also called white hydrogen (USGS, "The Potential for Geologic Hydrogen for Next-Generation Energy"); modern nuclear fission technology, like small modular reactors; electricity generation, potentially, from nuclear fusion at some point in the future; and new technologies for harvesting energy from the ocean—the ocean represents a vast store of energy—among others. Technology development is ongoing not only with respect to electricity generation, but also with regard to energy efficiencies, circularity of infrastructure, and so on.
5. **Collaborate among all nations on the energy transition process, while factoring inequity differences between countries.** Consider all nations as being part of the energy transition process including nations that may not have the wealth or resources available to acquire renewable energy systems. All nations should feel confident that the international community will provide the necessary support, for example, knowledge, information, and best practices for transitioning their economies from fossil fuel dependence to renewable, sustainable, resilient energy-based systems. No nation should be excluded or unable to participate in this transition, nor should the transition pose too great an economic burden. Such a barrier would hinder active participation with the rest of the global community. This transformation should be economically affordable, technologically sustainable, reliable, and available to all nations regardless of their economic status.
6. **Implement the United Nations recommendations for the renewable energy transition** (UN Climate Action, 2022):
   a) **"Make renewable energy technology a global public good via radically increased actions in policy, education, media, and other venues"** (Komor & Bazilian, 2005; Groh & Möllendorff, 2020).
   b) **"Improve global access to components and raw materials via financial incentives, public-private partnerships, governmental and private sector support"** (Sovacool, 2013).
   c) **"Level the playing field for renewable energy technologies versus fossil fuel-based energy"** (Pershing & Mackenzie, 2006).
   d) **"Shift energy subsidies from fossil fuels to renewable energy"** (Merrill et al., 2017).
   e) Triple investments in renewables.

7. **Encourage and support government, industry, and business commitments to COP 28** (UN Climate Change, Summary of Global Climate Action at COP 28)
8. **Decentralize and diversify energy production as much as practical and feasible.** Distributed power generation increases resilience, reliability, and reduces transport (Grosspietsch, Saenger, & Girod, 2019) and provides opportunities for contextualization of approach to power generation.
9. **Encourage and incentivize energy conservation—energy not used, need not be produced—energy not used, need not be paid for**:
    - **a) Use widespread educational campaigns and possibly sharing metering devices for individuals to test power consumption of devices.**
    - **b) Incentivize energy efficient devices of all kinds, for example, from light bulbs to vehicles.**
    - c) **Give ownership "of energy consumption" to the user through education, data sharing and access, and choices, for example, the London Hydro Green Button program.** (London Hydro, 2022).
10. **Strongly enable participation by small- and medium-sized enterprises in the energy sector.** This will help decentralization and diversification as well as contextualization of energy production and development of energy-efficient devices and services and, at the same time, support economic development.
11. **Increase technical literacy in general and technical knowledge/know-how.** Encourage workforce retraining and development (Macdonald Fueyo, 1988) to support appropriate procurement and use of technology as well as safe, knowledgeable operation and maintenance of deployed technologies.
12. **Educate for a future literacy mindset** (Miller, 2015).
13. **Share best practices and know-how widely.** Easily accessible knowledge and knowhow for communities and businesses around the globe will foster implementation in parallel with communities (Owens, 2002).
14. **Communicate widely to share best practices and know-how.** Dispel misconceptions and address incorrect 'information' in an inclusive fashion. Individuals of all ages would like to be 'in the know' and be part of the solution. There are many public sources sharing current best practices that individuals can adopt.
15. **Develop technical standards that support "sustainability by design."** These technical standards should not only include considerations of the environmental impacts of implementation—potentially to scale—of the technology, but also the potential societal impacts (socio-technical standards). These standards would be expected to also provide a basis for the development of regulations by regulatory bodies and should lead to interoperability of regulations between jurisdictions.
16. **Design and implement new energy systems infrastructure such that the systems are "sustainable by design."** This includes component production, transport, deployment, storage, use and end-of-use processes from the outset such that the components enable a circular economy (as much as possible) (Desing et al., 2019) and incorporate regenerative design principles if at all possible.
17. **Provide for ubiquitous reliable access to resources. Strive** to provide ubiquitous reliable access to clean, affordable sustainable energy and access to water, clean air, food, and services around the globe as the transition completes.

18. **Observe and – for planning of any new facilities - take the implications of the water-energy-food nexus into account**, for example**:**

    a. Hydrogen (H_2) production using electrolysis requires 9 liters of water for the actual chemical process plus additional water for water purification to the level required by the electrolysis process and process cooling. The estimated total water consumption is a range between 20-30 L or more of water to produce 1 kilogram of H_2 (Turner et al., 2007). Hence, careful consideration should be given to the siting of green hydrogen production facilities to avoid putting pressure on potentially constrained water supplies.

       On the other hand, using a fuel cell to produce electricity from H_2 also produces water and heat as co-products (pulling oxygen from the air). Hence, this is an opportunity for delivering co-products: electricity and potable water (Pacheco, 2023; U.S. DoE, *Fuel Cells*).

    b. Some nuclear facilities require significant amounts of cooling water.

    c. Data centers require significant energy in the form of electricity as well as cooling. Both the electricity supply as well as cooling water (if cooling using water is the cooling technology deployed) could pose a potential issue to the water supply at the siting location.

Case studies

This information is given solely for the convenience of users of this document as examples of case studies that were known at the time of publication, and does not constitute an endorsement of any company, product, service or organization by the IEEE or IEEE Standards Association (IEEE SA).

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   Hentschel, Moritz, Wolfgang Ketter, and John Collins. "Renewable Energy Cooperatives: Facilitating the Energy Transition at the Port of Rotterdam." *Energy Policy* 121 (Oct. 2018): 61–69.

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Further resources

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Guiding Principle 4: Climate change mitigation and adaptation

In responding to the challenge of climate change, and to prevent a climate catastrophe, society needs to both mitigate (that is, reduce) GHG emissions and adapt to the impacts of a changing climate. Both goals require urgent action. The goals of mitigation and adaptation may come into conflict, society will have to balance these conflicts.

Background

Upon releasing a new IPCC report in February 2022, the IPCC noted in a press release:

> *The report clearly states Climate Resilient Development is already challenging at current warming levels. It will become more limited if global warming exceeds 1.5 °C (2.7 °F). In some regions it will be impossible if global warming exceeds 2 °C (3.6 °F). This key finding underlines the urgency for climate action, focusing on equity and justice. Adequate funding, technology transfer, political commitment and partnership lead to more effective climate change adaptation and emissions reductions. (IPCC, 2022)*

As of 2022, the Nationally Determined Contributions (NDCs) by countries to mitigate GHG emissions to limit warming to less than 1.5 °C (as agreed by the Paris Accord to be the target to protect the planet) is currently viewed as insufficient (Climate Action Tracker, 2023).

In early 2023, the IPCC AR6 Synthesis Report stated in 2.1. under the headline: Observed Changes, Impacts and Attribution:

> *Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850-1900 in 2011-2020. Global greenhouse gas emissions have continued to increase over 2010-2019, with unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and between individuals (high confidence). Human-caused climate change is already affecting many weather and climate extremes in every region across the globe. This has led to widespread adverse impacts on food and water security, human health and on economies and society and related losses and damages to nature and people (high confidence). Vulnerable communities who have historically contributed the least to current climate change are disproportionately affected (high confidence). (IPCC, 2023)*

Mitigation

As soon as feasible, mitigate human caused GHG emissions. GHGs include carbon dioxide, which form the bulk of the problem, as well as methane and nitrous oxide, which also hold heat in the atmosphere. It is not possible to instantly stop all processes that create GHG emissions because they are intertwined with the daily lives of citizens. It is necessary to find and implement sustainable solutions that generate energy, products, and services without generating GHG emissions or, at the very least, significantly reduce GHG emissions. In some cases, this will require research, development, and innovation—very quickly.

Time is of the essence. According to a UN Intergovernmental Panel on Climate Change (IPCC) report finalized on April 4, 2022, to limit warming to 1.5 °C, global GHG emissions should peak before 2025 and be reduced by 43% by 2030. Methane must be reduced by 34% by 2030. Even if we are willing to tolerate warming of 2 °C, global GHG emissions must peak before 2025 and be reduced by 27% by 2030 (Shukla et al., 2022). At COP 28 (Nov. 2023) several major oil and gas companies promised to reduce methane leaks from their pipelines, but the UN Secretary-General Guterres said these "clearly fall short of what is required." As of September 2024, "the observed growth in methane emissions follows the Intergovernmental Panel on Climate Change's most pessimistic greenhouse gas scenarios, which predict global temperatures could rise above 3 °C by the century's end if such trends continue" (ESA, "The 2024 Global Methane Budget Reveals Alarming Trends").

All sectors of the economy will have to contribute. Key sources of GHG emissions are illustrated in Figure TS.6 of the IPCC mitigation report (Pathak et al., 2022). This figure illustrates direct plus indirect GHG emissions by end-user sector for 2019: industry 34%, agriculture/forestry/land use 22%, buildings 16%, transportation 15%, and other 12%.

It is not just about electricity production. Electricity and heating production contributes 23% of total direct carbon dioxide (CO_2) equivalent GHG emissions distributed across the sectors above (Figure TS.6 of the IPCC mitigation report). While ground transportation may be able to transition to electricity, innovations will be needed to transition food production, protect nature, and produce steel, cement, and other industrial processes. For example, much of the anthropogenic methane emissions come from agriculture and livestock production. Notably, rice contributes 1.5% of global GHG emissions and about 48% of GHG emissions from croplands globally, and rice production uses about 40% of the global freshwater resources (Food Forward NDCs, "Reducing Emissions from Rice Cultivation").

GHGs linger in the atmosphere for hundreds of years. While reforestation, biomass, and other natural systems can sequester carbon (ocean, land, soil sequestration), innovative breakthroughs are needed to achieve decarbonization—even if the mitigation goals are met. Carbon capture and storage is one of the approaches. Because carbon capture and storage require energy (endergonic systems), it is necessary to power carbon sequestration and storage with non-GHG "green" energy sources such as solar energy.

Adaptation

Adapt to the climate changes that people are and will be facing. In this document, adaptation is a method—or methods—for being resilient; that is, it is the ability of society to maintain essential functions and structures as well as to generate the capacity for its transformation. This adaptation will also require dealing with extreme weather events that climate change is making more frequent and more intense. Unfortunately, there is a significant gap between the current state of adaptation and the needed adaptations (IPCC, 2022).

Preparing for extreme weather. Climate change is making extreme weather more intense and more frequent. Reducing the risks caused by extreme weather requires planning, building resilient infrastructure, and strengthening natural systems like dunes and lagoons.

Preparing for extreme climate. Adaptive actions are needed to reduce vulnerability of natural and human systems. For example, changes in farming and land management practices will be needed, including the identification and development of species of crops and livestock with increased resilience.

Adaptations are usually planned and implemented as a response to extreme events and are focused on the specific risks they bring. For example, coastal flooding may result in new adaptation projects such as ecosystem replanting or building hard infrastructure such as levees. These projects may buy time to consider longer-term projects such as relocating people and structures from harm's way. The adaptations recommended below are organized by the specific risk they pose.

The 2022 IPCC report warns that "Available evidence on projected climate risks indicate that opportunities for adaptation to many climate risks will likely become constrained and have reduced effectiveness should 1.5 degree C global warming be exceeded" (Pörtner et al., 2022).

Our generation's responsibility to future generations. We must expeditiously solve the climate crisis so that we leave future generations a world that is supportive and nurturing.

Recommendations for mitigation of GHG emissions

1. **Electrify and/or use other GHG-emission-free energy for all land-based transportation.** Land-based transportation contributes about 10% to global GHG emissions.Passenger cars, trucks, and buses are the low-hanging fruit of the transportation sector for quick electrification. There are few technology problems to be solved. Government policy action could begin to mandate this as well as establish a recharging infrastructure. The Infrastructure Investment and Jobs Act (U.S. 117th Congress, 2021) allocated US $7.5 billion towards building a network of electric vehicles including public and private charging stations (IEA, "Infrastructure and Jobs Act: Nationwide Network of EV Chargers"), which is planned to be implemented by 2030. Hydrogen appears to be a viable fuel alternative for rail transportation.
2. **Reduce emissions from aviation and maritime transportation.** Reduce emissions from planes (1.8% of GHG emissions) *and ships* (1.6% of GHG emissions) and invest in research and development (R&D) for biomass fuels—provided they are sustainable, improved fuel efficiency, and electrification. Technology challenges around the latter include the weight and energy density of batteries. Other research and development (R&D) ideas include using hydrogen either as a fuel for combustion or as an energy carrier for energy transportation and storage to be converted using fuel cells into electricity, assuming hydrogen can be produced with green electricity or geological hydrogen (USGS, "The Potential for Geologic Hydrogen for Next-Generation Energy").
3. **Switch/transition the electricity grid (23% of GHG emissions globally) to use renewable, clean electricity generation.** There is little reason to delay this transition and continuation of building new fossil fuel power plants prolongs the carbon emissions. Further R&D is needed for energy storage and for building the necessary infrastructure to handle distributed generation (e.g., solar panels on houses and buildings). Consideration should also be given to electricity generation from nuclear power, geothermal opportunities, power generation from ocean-based technology, and potential new technologies under development.
4. **Electrify heating (5% of GHG emissions) *and cooking* (1% of GHG emissions).** There are no technological barriers to decarbonizing buildings and house heating and cooking.
5. **Reduce emissions from agriculture, livestock, and food supply (11% of GHG emissions).** This could be accomplished through demand-side changes (reducing eating of beef for example), improved efficiencies (e.g., **reducing food waste**), and technological changes to reduce emissions on the production side (e.g., lower energy methods of making fertilizer and changing the diet of cows and rice growing methods to reduce methane emissions).
6. **Cap abandoned oil and gas wells to prevent further methane gas emissions from these wells.**

7. **Reverse deforestation and protect the ocean.** Trees and the ocean store a tremendous amount of carbon. Oceans store approximately 6 billion metric tons of carbon per year, with trees/soil storing another 0.3 billion metric tons/year (Woods Hole, 2022; Café Thorium, "Ocean Twilight Zone").

8. **Reduce GHG emissions coming from industry, including from the production of cement, steel, plastic, and other manufacturing** (24% of GHG emissions). Using cement as an example, reducing emissions could include: replacing cement with other materials (e.g., wood), replacing the fossil fuels used in the production with renewable energy, process improvements to reduce the carbon footprint, and adopting different raw materials in the process. All of this requires further R&D and investment.

9. **Develop and/or deploy carbon dioxide removal methods to counter residual emissions.** While all the above recommendations will reduce the amount of new carbon in the atmosphere, it is still necessary to eliminate the carbon people have been generating since the industrial revolution. While some of this can be done by enacting policies to encourage tree planting, reforestation, and low-till farming, it is likely innovations will be needed to capture and sequester additional atmospheric carbon. Another option may be increased ocean-based carbon sequestration [marine Carbon Dioxide Removal—mCDR; see IEEE SA, "Marine Carbon Dioxide Removal (MCDR)"].

   While not all GHG-emitting industrial processes may be replaced by decarbonized processes in the short term, the emissions produced by these installations should be captured to avoid adding further to the atmospheric GHG levels (Buesseler, 2022, p. 90). To overcome obstacles to carbon capture and sequestration, financial incentives are needed to make existing methods viable, policy changes are needed to support the transport of carbon dioxide from where it is captured to where it can be stored (usually underground earth formations), and R&D is needed to create new technologies that may capture and store carbon at lower costs. Carbon mineralization and geological storage of CO_2 in basalt have been shown in recent years to be permanent and fast - in the order of days to less than 10 years. (Ferreira et al., 2024)

   Another path of carbon sequestration that is being pursued is carbon capture, including direct air capture, and the use of the captured carbon in new products.

   Carbon dioxide removal and sequestration has led/is leading to a new industry sector: the products are carbon credits. Associated with that is the new Monitoring (or Measuring), Reporting and Verification Sector (MRV Sector) (see Climate-KIC, "Monitoring, Reporting and Verification Sector").

10. **Clearly capture, analyze, and publicize actionable information on GHG contributions from products, services, and sectors to allow company, organizational, and personal decision-making to reduce GHG emissions.** See also Guiding Principle 9.

11. **Create a reporting system to measure progress, maybe globally confederated (hubs and spokes), to report on activities and achievements versus agreed upon GHG emissions reduction and other climate change mitigation KPIs**.

Recommendations for adaptation to climate change

Unlike mitigation responses, which have a global impact, adaptation tends to be done at the local level, in the local context, and focused on specific risks.

It is impossible to list all potential responses, but this list of recommendations provides examples of actions to address some of the common threats.

1. **Strengthen coastal socio ecological systems:**
    a. **Harden coastal defenses. Dikes, seawalls, flood barriers, and other hard infrastructure provide temporary protection but may worsen the problem in the long run by allowing unsustainable development** (an example of "maladaptation").
    b. **Implement integrated coastal zone management.** Ecosystem-based approaches (setting aside wetlands at the blue-green interface, replanting coastal grasses and salt marshes) provide additional space for coastal systems to migrate inland.
    c. **Plan coastal retreat when other approaches become insufficient or unaffordable**.
2. **Support terrestrial systems:**
    a. **Implement forest-based adaptation.** Implement sustainable forest management, forest conservation and restoration, reforestation, and afforestation, restoring natural vegetation and wildfire regimes.
    b. **Implement sustainable aquaculture and fisheries.** Eliminate overexploitation and reduce pollution and runoff.
    c. **Practice biodiversity management and ecosystem connectivity**.
3. **Help maintain water security:**
    a. Improve water use efficiency and reduce leaks in water systems.
    b. **Improve water resource management.** Set aside additional reservoirs, catchments, and wetlands to catch and maintain water during variable rainfall.
    c. Prepare for rationing and use of "gray water" in times of severe drought.
4. **Help maintain food security:**
    a. **Improve cropland management.** Implement earlier planting, changes in crop varieties, improvement in water management for crops, use of heat-and drought-adapted genotypes, soil improvements, soil moisture conservation, and agricultural diversification.
    b. **Implement efficient livestock systems.** Implement improvements in water management for livestock, genetic improvements for heat and drought varieties, and reduced intensification of livestock management to improve resilience.
    c. **Implement efficient fisheries management and aquaculture.** Include ecosystem restoration and regenerative practices.
    d. **Support R&D related to cultivating agricultural and livestock species with increased resilience to temperature, water, and other climate stressors.** Develop new practices, including regenerative practices, and promote existing practices, for example Indigenous-knowledge-based, to conserve food and live with weather extremes.

5. **Improve urban infrastructure to become more resilient:**
    a. **Implement green/blue urban infrastructure. Utilize urban agriculture, urban trees, green roofs, parks and open spaces, rain gardens, and watershed restoration.**
    b. **Create sustainable land use and urban planning.** Consider reforestation in and around urban areas, allocating additional land to sea level rise and disincentivizing development in vulnerable areas.
    c. **Require new buildings to be resilient and able to withstand extreme weather conditions.** Older buildings should be similarly renovated. Modify building codes to consider climate change risks locally to require energy backup systems, emergency water tanks, raising buildings above the flood protection elevation level, reinforcing roofs, and building in wildfire resistance, as appropriate.
    d. **Implement sustainable urban water and sanitation management.** Harden infrastructure to work during floods and droughts.
    e. **Improve knowledge at the local and regional levels (hydraulic studies, flood zones, risk assessments), raise awareness in local communities of the risks, create threat monitoring capabilities (e.g., stream and river monitoring), and establish plans to reduce vulnerability to existing and new buildings.** More specific data (hyperlocal) would help people and communities better understand the risks they face.
6. **Update energy systems to become more sustainable and resilient:**
    a. **Make community power systems more resilient to extreme weather events–for infrastructure critical to society and our economy.** With the transition to electric transportation vehicles, factories, heating, and so forth, the need for reliable energy systems becomes increasingly important.
    b. **Consider the potential impact to power systems of multiple risks simultaneously: extreme heat increasing demand, drought reducing cooling water for power systems, widespread heat waves reducing the ability to source power from neighboring areas.** In the southwestern United States and other drought-prone areas, hydroelectric systems are at risk of reducing power output, requiring other systems to shoulder increased loads. Electric vehicles are creating a new and significant demand on domestic power networks. Energy demand used for air-conditioning could triple by 2050 (Birol, 2023).
    c. **Enhance the electricity grid infrastructure.** Integrate distributed energy sources such as solar panels as well as storage systems to buffer the loads and provide more resilience.
    d. **Improve the efficiency of cooling equipment.** As cooling is increasingly needed in many locations around the planet, it will be important to improve the cooling provided per kilowatt of power.
7. **Protect human health:**
    a. **Develop health information systems.** Implement integrated risk management, early warning systems, and disease tracking and management (e.g., Lyme disease, malaria, new virus strains).
    b. **Create health system adaptations.** Implement vaccine development for existing and new disease coverage, mental health support, improved heat resistance of the built environment, and advanced water and sanitation systems.

c. **Prepare for heat stress.** Implement heat action planning, cooling centers, air-conditioning subsidies, and cooling suits for outdoor workers.

d. **Secure water quality/quantity.** Provide clean drinking water as local water resources dry up.

e. **Develop health emergency response plans**. Disasters and climate change-induced health issues require more emergency response capabilities.

8. **Promote equitable living standards and equity:**

   a. **Provide education/reeducation to allow livelihood diversification as climate change eliminates some jobs.**

9. **Enable peace and mobility:**

   a. **Plan for relocation and resettlement**. Limits to adaptation are already being reached in some areas for both animals and humans. Some experts consider mobility to be a response rather than an adaptation, which approaching 2050, may be necessary as additional locations of the Earth become uninhabitable due to sea level rise, heat, or drought. Society must reduce the impacts of relocating vulnerable populations and infrastructure due to sea level rise, wildfires, heat, and drought.

   b. **Enable human migration for climate reasons*.*** Barriers to voluntary migration and resettlement should be addressed.

   c. **Support ecosystem migration*.*** Many species are moving to cooler climates where possible. Humans need to assist in this effort where necessary to help sustain the ecosystem on which we depend.

10. **Encourage cross-cutting solutions:**

    a. **Integrate climate change into all planning (e.g., federal, state, city, and company plans) and implementation of conservation and environmental management.**

    b. **Organize disaster risk management.** Society must prepare for extreme events caused by climate change, such as floods, heat waves, drought, hurricanes, tornadoes, wildfires, and insect and disease outbreaks. Companies, organizations, and communities must develop personnel disaster risk-management strategies to prepare for extreme weather and climate conditions.

    c. **Create early warning systems.** Speed the development of systems to forecast and warn of extreme events, provide situational awareness, and communicate important information.

    d. **Develop social safety nets.** Strengthen social services for extreme events and climate change-induced disruption such as food insecurity.

    e. **Create risk-spreading and cost-sharing systems.** Develop community seed banks, wells and water systems, and power systems.

    f. **Develop a systems-oriented approach to reduce the conflict and trade-offs between mitigation and adaptation and to support long-term resilience.**

    g. **Support research into solar radiation modification (SRM), which seeks to reflect more sunlight back into space, reducing the heating of Earth.** Further study is needed to understand its benefits and risks. See for example, "The Ocean Twilight Zone's Role in Climate Change."

h. **Support research and development in all areas of adaptation to speed adaptation and reduce costs.** The long-term goal is to flow investment into mitigation projects to reduce the GHG emissions and climate heating.

i. **Establish regional, national, and international cooperation capabilities to respond to extreme weather conditions**, for example, a regional transmission organization to share electric load and water system partnerships to improve water system reliability and system capability.

11. **Communicate, communicate, communicate.** Share success stories and current best practices. Engage people in discussion about misconceptions. Dispel misinformation in an inclusive fashion.

12. **Create a reporting system to measure progress, maybe globally confederated (hubs and spokes), to report on activities and achievements versus agreed upon climate change adaptation KPIs.**

Further resources

1. Doerr, John, with Ryan Panchadsaram. *Speed and Scale: An Action Plan for Solving Our Climate Crisis Now.* Portfolio/Penguin, 2021.
2. Engineering for One Planet (website).
3. Gates, Bill. How to Avoid a Climate Disaster: The Solutions We Have and the Breakthroughs We Need. UK: Allen Lane, 2021.
4. Pörtner, Hans, Debra C. Roberts, Helen Adams, Ibidun Adelekan, Carolina Adler, Rita Adrian, Paulina Aldunce, et al. *Technical Summary in Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK and New York, NY: Cambridge University Press, 2022.
5. Project Drawdown (website).
6. Stern, Nicholas. *The Global Deal: Climate Change and the Creation of a New Era of Progress and Prosperity*. PublicAffairs, 2009.
7. UN Climate Change Conference (United Arab Emirates: 30 Nov.–12 Dec 2023) (website).
8. Fifth National Climate Assessment 2023 (website).

Guiding Principle 5: The regenerative imperative and a circular economy

Thinking, planning, and action must broaden beyond current economic, business, societal, and resource utilization models to achieve sustainability and for people and the Earth's biosphere to flourish for many generations to come. Future economic, societal and cultural, and business models should emphasize new public imperatives and values such as circularity, ecological regeneration, zero waste, and human flourishing and well-being.

Background

THE REGENERATIVE IMPERATIVE

Embracing the regenerative imperative and circular economy imperatives in resource management offers a hopeful and actionable roadmap toward a sustainable and thriving planet Earth. This approach requires a paradigm shift in our relationship with the environment. Exploitation needs to transition to regeneration to reverse the Earth's biosphere degradation. Designing systems that model natural processes can create resilient, adaptive, and flourishing ecosystems that support biodiversity and provide for the needs of current and future generations.

Many interconnected factors have contributed to the declining health and resilience of the Earth's biological systems. Changes in land use, overexploitation of natural resources, and pollution of the environment are three major human activities driving this process.

Changes in land use over millennia have diminished the land's ability to support a burgeoning population. The conversion of forests into agricultural land, urban areas, and other uses has reduced carbon sequestration capacity—a significant factor in global climate change. It has also resulted in fragmented and lost habitats, making it more difficult for some species to survive. This resulting biodiversity loss has diminished ecosystem resilience and the ability of natural systems to adapt to environmental changes.

Overexploitation of natural resources has led to resource depletion, loss of biodiversity, and a reduction in ecosystem services essential for life on Earth. Unsustainable agriculture, overfishing, and illegal wildlife trade have further stressed the planet's ecosystems. For example, bottom trawling destroys ocean floor ecosystems and releases previously sequestered carbon on the ocean floor into the water and further—over a decade—into the atmosphere (Atwood, 2024; Atwood et al., 2024).

Pollution and GHG emissions (not all GHGs are pollutants, e.g. water vapor) have further compounded these problems. Releasing toxic substances into the air, water, and soil has adversely affected wildlife, ecosystems, and human health. Plastic pollution, chemical runoff from agriculture, and industrial pollutants have contaminated ecosystems, leading to degradation of water quality, soil fertility, and air quality of both land and the ocean.

Climate change is the ultimate result—through global warming—of this heavy burden on the Earth's ecosystems. In the face of the ongoing degradation of the planetary biosphere, adopting an approach rooted in the regenerative imperative, sustainability values, and the principles of a circular resource economy offers a transformative pathway toward long-term sustainability. This approach not only mitigates harm but can be net positive; it can renew, restore, and revitalize ecosystems and human, social, and economic systems.

THE CIRCULAR ECONOMY IMPERATIVE

Humanity faces an imperative: the need to transition from this wasteful linear economy to a system both sustainable and regenerative. A circular economic system is needed: a system in which finite resources are turned into items that not only have a history but a future.

This means taking a resources stewardship approach, which maintains resources indefinitely for future generations. As popularized in William McDonough's seminal book, *Cradle to Cradle: Remaking the Way We Make Things*, this necessitates moving from linear *cradle-to-grave* resource usage to *cradle-to-cradle* circular utilization in which nothing goes to waste (McDonough & Braungart, 2002). Resources are extracted once from the planet, and after extraction, they enter a circular, ongoing usage cycle. The end-of-life cycle for one item sees its components rebirthed in others. The planet does this naturally, as in nature, there is no waste. The by-product of one process is the feedstock for another process.

Waste management is one goal of an emerging circular economy. Waste is a major indicator of human impact and characterizes our linear economy. Single-use items from finite resources are discarded into landfills and float in vast ocean patches, wash onto beaches, spill across forests, and soil lakes and streams. Material waste produced by a throwaway economy is destroying entire ecosystems. Coupled with energy waste fueled by fossil fuels pumped from finite reserves, the damage is further compounded by material waste in many geographic locations/areas—even as other locations around the globe struggle with not having even basic energy needs met. The GHGs from these efforts, in turn, are warming the Earth's finite atmosphere and fueling a climate crisis that threatens the future of the planet—and life itself.

Governments should promote and support circular economies that manage waste toward zero, maximize resources, and incorporate "de-manufacturability." Common steps and targets in such transitions are available and known. Steps to taking a "circular economy" approach and ranging from smarter product manufacture to recovery of materials are detailed here (Morseletto, 2020). In 2022, a proposal for a new Ecodesign for Sustainable Products Regulation (ESPR) became a cornerstone of EU support for more environmentally sustainable and circular products. The proposal builds on the existing Ecodesign Directive, which currently only covers energy-related products. As part of that proposal a new "Digital Product Passport" (DPP) will provide information about products' environmental sustainability (EC, "Ecodesign for Sustainable Products Registration") and other information like repair records. The DPP is potentially a tremendous opportunity to enable sustainable procurement choices and, hence, foster a *sustainable supply system*.

> *Circular Economy has the potential to understand and implement radically new patterns and help society reach increased sustainability and wellbeing at low or no material, energy and environmental costs. (Ghisellini, Cialani, & Ulgiati, 2016)*

The challenges and successes are similar to implementing a space habitat such as the International Space Station or communities able to survive for generations in inhospitable (hot, cold, dry) environments. In the context of resources, experiences, knowledge, and so forth, space habitats are based on the premise of circular design closed-loop systems that minimize and utilize waste as much as possible.

Implementing these targets will not be an easy task. Technologies must be expedited to capture and reuse/recycle the many types of linear waste. Social structures will have to be developed to foster the transition from linear economics to a circular or no-waste economy counterpart. This is a complex and challenging undertaking with changes anticipated at most points in today's very complex global supply system.

Resource management is the second critical challenge. This requires the reuse of components of manufactured items either directly or, potentially reduced to the molecular level, as feedstock for new products. It also requires regeneration of the Earth's ecosystems and, hence, the biosphere that sustains life on Earth. This includes regenerative farming practices, restoring ecosystems like mangrove forests and coral reefs (to name a few), and reversing desertification in many places around the world.

Both the regenerative imperative and circular economy require changes in the way products and services are designed, used, and handled at the end-of-use. Design requirements for strong sustainability must include "design for de-manufacturability", in fact, design for strong sustainability needs to be strengthened to become Regenerative Design, where appropriate.

In December 2022, COP 15 adopted an equitable and comprehensive framework to address "overexploitation, pollution, fragmentation and unsustainable agricultural practices; safeguard the rights of indigenous peoples and recognize their contributions as stewards of nature"; and provide "finance for biodiversity and alignment of financial flows with nature to drive finances toward sustainable investments and away from environmentally harmful ones."

Recommendations

1. **Develop policies at all levels of government that encourage and support development and implementation of new innovations**. **Support should also be given to businesses and organizations who are applying these innovations and building circularity and regenerative practices into their business and organizational models, including their supply chains/systems/networks, products, and services.**
    a. Given the challenges and risks associated with these new features, businesses should be rewarded for their ambition and leadership whenever they succeed in proving that new economic and business models are both viable and profitable.
    b. The philosophy behind a circular economy is one that sees multiple, collaborative social segments as forces for good. **Business, government, academia, community, and society-at-large all should become domains in which innovative solutions can be created for tackling global problems and achieving planetary sustainability.**
2. **Devise policies and governance structures that support the shift towards regenerative and circular economies.** This involves creating regulatory frameworks that incentivize the restoration of ecosystems, the circular flow of materials, and the equitable distribution of resources. Financial instruments such as green bonds and environmental impact investing can fund regenerative projects. At the same time, participatory governance models should promote policies that are co-created with communities, aligning with local needs and ecosystems.
3. **Empower communities to lead regeneration efforts.** This involves education and capacity-building around the principles of circular economy and regenerative design, equipping individuals and communities with the knowledge and skills to innovate and implement sustainable practices. Community-led initiatives can pilot new approaches to circular living, creating models that can be scaled and adapted elsewhere.
4. **Integrate education for circularity, regeneration, and sustainability into all levels of education, fostering a new generation of thinkers and doers committed to sustainability.**
5. **Communicate best practices, knowledge, information and data on circularity, regeneration, and sustainability widely and easily accessible**. That should also include discussion of updated information, misinformation and misconceptions.

6. **Set targets, R&D milestones, and develop policies and resources to implement action plans**. For example:

    a. **Necessary social infrastructure around waste reclamation and reuse.** Paradoxically, waste reclamation often "ironically increases the risk of creating a demand for these waste streams, which thereby may become commodified" and increase linear economy path dependencies (Greer, von Wirth, & Loorbach, 2021)—an unintended consequence to be avoided.

    b. **Creation of future *economic and business models* expanding upon, and emphasizing, regeneration, human flourishing, and well-being** (Ghisellini, Cialani, & Ulgiati, 2016; Shrivastava & Zsolnai, 2022).

    c. **Natural ecosystem regeneration—both on land and in water—such as reversal of desertification, restoration of wetlands and coastal ecosystems,** and so forth.

7. **Set policy for and practice contextualized regenerative farming and food production.** Circular agriculture focuses on creating closed-loop systems that recycle nutrients, minimize waste, and regenerate soil health. Practices such as permaculture, agroecology, and holistic grazing integrate food production with ecosystem restoration. Emphasizing soil regeneration, these practices enhance soil carbon sequestration, support water retention, and rebuild biodiversity. By viewing waste as a resource—much like our ancestors' and indigenous peoples' practice—circular agriculture utilizes agricultural by-products as inputs for other processes, fostering resilience and productivity.

8. **Prioritize restoration and the creation of self-sustaining ecosystems that provide economic, ecological, and social benefits in forest management**. This includes reforestation and afforestation and the integration of permaculture principles to design forest systems that mimic natural forests. Such practices enhance biodiversity, sequester carbon, and support local livelihoods while harmoniously producing food, fiber, and other materials with nature.

9. **For regenerative water and ocean management, involve designing systems that learn from natural hydrological cycles, enhancing the quality and availability of water.** This includes creating landscapes that capture, store, and purify water through natural processes, such as constructed wetlands and biofiltration systems. Rainwater harvesting, graywater recycling, and restoring natural water bodies are integral to creating resilient water systems that support human and ecological needs. This includes regeneration of ocean ecosystems such as coastal areas, mangroves, wadden seas (see UNESCO, "Wadden Sea"), salt marshes, and coral reefs.

10. **Prioritize natural ecosystem regeneration—both on land and in water—such as reversal of desertification, restoration of wetlands and coastal ecosystems.** This should help limit further loss of wildlife (WWF, 2024) and biodiversity (Alves, 2024).

11. **Expedite research, development, deployment, and adoption of technologies promoting ten common circular economy strategies** (Morseletto, 2020).

    a. ***Refuse*.** Eliminate unnecessary single-use products.

    b. ***Rethink*.** There are two aspects: 1) production of multipurpose "widgets" rather than a number of single-use "widgets" and 2) develop a sharing economy (equipment rental) and/or sharing community (neighborhood sharing).

    c. ***Reduce*.** There are two aspects: 1) using less resources in production of "widgets" and 2) reduction of consumption of goods.

    d. ***Reuse*.** Develop a sharing economy, passing items from one user to another.

e. ***Repair*.** The right to repair should be inherent with every product.

f. ***Refurbish*.** Rebuilding, refurbishing with repaired or improved parts.

g. ***Remanufacture*.** De-manufacture “widgets” into reusable parts for other products or the same type of product.

h. ***Repurpose*.** Innovative use of widgets for purposes other than originally intended—as a whole or in part or with additional parts.

i. ***Recycle*.** Sorting end-of-life items for reuse of materials.

j. ***Recovery*.** Recovery of materials through separation of materials into feedstock streams for the “next” semi-permanent product.

12. **Design systems and products from the outset for circularity, regeneration, and sustainability.**

    a. Design, implement, and operate installations and/or devices to include end-of-use plans for circularity.

    b. **Design systems for zero waste** (minimizing waste) and maximizing efficiencies. In the circular economy, waste is designed out of systems. This perspective transforms waste management practices, focusing on the recovery and regeneration of materials as feedstock for new production. Circular waste management strategies include industrial symbiosis, where one industry’s waste becomes the input/feedstock for another, and the development of biodegradable materials that can be composted to regenerate soils. Innovations in recycling technologies also play a crucial role in keeping materials in use for as long as possible, reducing the need for raw materials and minimizing environmental impact.

    c. Design for modularity, repairability, high efficiency, and long service.

    d. Design for net-positive societal and environmental impacts.

13. **Make accounting more encompassing regarding values*.*** Move forward from gross domestic product (GDP) accounting toward accounting inclusive of other metrics (environmental, biosphere, well-being, etc.). GDP does not capture unpaid work of caregivers and other aspects of the caring economy; volunteer efforts that contribute to the economy; leisure time; and other aspects that are important to human well-being.

14. **Include externalities into the accounting systems.** For example, IEEE P3469™ inspired by a concept of the E-Liability Institute to include GHG emissions as part of the accounting ledger (Kaplan & Ramanna, 2021).

15. **Develop “Technical Standards” to include sustainability, regenerative, social and circular economy values/principles “by design.”** Also referred to as socio-technical standards.

16. **Develop and deploy tools that will provide sufficient information and access to data to permit knowledge-based sustainable procurement**. That is, tools such as the Digital Product Passport, a tool that will show extensive product information along with information about the associated supply system, including the suppliers’ “sustainability performance.” The Digital Product Passport is part of the EU Ecodesign for Sustainable Products Regulation.

17. **Transition to regenerative energy systems.** Transitioning to regenerative energy systems—in addition to renewable and net zero energy systems—should include moving beyond merely reducing emissions to designing energy solutions that positively impact the environment. This includes the widespread adoption of renewable energy and other clean sources that regenerate local ecosystems, such as bioenergy with carbon capture and storage (BECCS), and the development of energy systems

that mimic natural processes to improve resilience and biodiversity. Energy systems should be decentralized and designed to empower communities, enhancing energy democracy and resilience. And the systems infrastructure should support a circular economy—no waste at end-of-use.

Case studies

This information is given solely for the convenience of users of this document as examples of case studies that were known at the time of publication, and does not constitute an endorsement of any company, product, service or organization by the IEEE or IEEE Standards Association (IEEE SA).

1. Singapore Turns Sewage into Clean, Drinkable Water, Meeting 40% of Demand

   "The tiny island nation has little in the way of natural water sources and has long had to rely principally on supplies from neighboring Malaysia. To boost self-sufficiency, the government has developed an advanced system for treating sewage involving a network of tunnels and high-tech plants."

   Agence France-Presse. "Singapore Turns Sewage into Clean, Drinkable Water, Meeting 40% of Demand." VOA News. 10 Aug. 2021.

2. Zero-Waste Communities Across the Globe

   "Eight cities in Asia, Europe, and North and South America, along with four online communities, showcase approaches to zero waste."

   "Zero Waste Communities Across the Globe." *Zero Waste* (blog). 3 Mar. 2021.

3. Nine Examples That the Transition to a Regenerative Economy is Underway

   "Southface Institute has created the following series of case studies to share success stories from regenerative economy pioneers. Each case study examines its subject through the interdependent lenses of the natural environment, the social environment and the built environment."

   Shea, Bailey, and Shane Totten. "Nine Examples That the Transition to a Regenerative Economy is Underway." *Southface Institute* (blog). 23 Mar. 2021.

4. 9 Ways to Create a Local Regenerative Economy

   "Nine steps towards creating decentralized cooperative local economies that emphasize local production with local resources to meet local needs to build local wealth."

   Bjonnes, Roar. "Nine Ways to Create a Local Regenerative Economy." Shareable, 11 Aug. 2021.

5. Achieving One-Planet Living Through Transitions in Social Practice: A Case Study of Dancing Rabbit Ecovillage

   "This article examines DR's extraordinary energy and resource savings through the lens of social practice theory, which focuses on the meanings, competencies, and materials that individuals combine to form everyday practices."

   Boyer, Robert H. W. "Achieving One-Planet Living through Transitions in Social Practice: A Case Study of Dancing Rabbit Ecovillage." *Sustainability: Science, Practice and Policy* 12, no. 1 (2016): 47–59.

6. The EU's New Digital Product Passport

   The EU's new Digital Product Passport *"will provide information about products' environmental sustainability. This information will be easily accessible by scanning a data carrier and it will include attributes such as the durability and reparability, the recycled content or the availability of spare parts of a product. It should help consumers and businesses make informed choices when purchasing products, facilitate repairs and recycling and improve transparency about products' life cycle impacts on the environment. The product passport should also help public authorities to better perform checks and controls"*

   European Commission. "Ecodesign for Sustainable Products Regulation." Energy, Climate Change, Environment; Standards, Tools and Labels; Products, Labeling Rules and Requirements; Sustainable Products.

7. Circular Economy of digital devices

   The APC's "Guide to the Circular Economy of Digital Devices" includes the right to repair.

   Association for Progressive Communications (APC). "A Guide to the Circular Economy of Digital Devices."

Further resources

1. Awasthi, Abhishek Kumar, Jinhui Li, Lenny Koh, and Oladele A. Ogunseitan. "Circular Economy and Electronic Waste." *Nature Electronics* 2 (Mar. 2019): 86–89.
2. Barreiro-Gen, Maria, and Rodrigo Lozano. "How Circular is the Circular Economy? Analysing the Implementation of Circular Economy in Organisations." *Business Strategy and the Environment* 29, no. 8 (July 2020): 3484–94.
3. Bennett, Nathan J., Jessica Blythe, Andrés M. Cisneros-Montemayor, Gerald G. Singh, and U. Rashid Sumaila. "Just Transformations to Sustainability." *Sustainability* 11, no. 14 (July 2019).
4. Capital Institute (website).
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Guiding Principle 6: Balance between today's needs and the needs of the future

In the course of transitioning societies and the global economy toward a sustainable future, today's short-term needs must balance with the long-term, global aspirations for a flourishing planet. This balanced approach should address all human needs, including access to food and clean water, health care, and other essential goods and services necessary for a healthy standard of living, and the need for healthy ecosystems globally.

Background

At the heart of sustainability is the understanding that our resource utilization cannot surpass the rate of resource availability and reuse. There is only one Earth in our planetary system. If the Earth's biosphere gets destroyed, there is no new home for life on Earth. With this in mind, the aim is to reduce resource waste through an understanding of current needs and needs of the future to avoid Earth Overshoot Day (the point at which our consumption outstrips the planet's biocapacity in each annual cycle) (https://overshoot.footprintnetwork.org/). Therefore, a required understanding of our present socioeconomic capacity contextualized among individuals and communities—locally to globally—is needed while integrating the multifactorial conditions that determine resource utilization, availability, and rate and the effects of these on our environment.

Another way of expressing this imperative is that decisions should follow the *Seventh Generation Principle* in which "decisions made today should result in a sustainable world seven generations into the future" (Indigenous Corporate Training, 2022). This intergenerational mindset should see all people concerned for the health and well-being of future generations, that is, all people's children's children and the generations beyond, just as much as people are concerned for their own health and well-being today.

Healthy humanity depends upon a healthy planetary biosphere, both directly through the ecological services that it offers and indirectly through the positive impacts of the living environment on stress and mental health. It also requires an understanding of how needs differ across demographics and how climate change may influence these needs, while accounting for future adaptations and changes. For example, if consumption outstrips production, people today impoverish their children. Overconsumption is not the only issue; for example, a lack of recycling of wastes that contaminate the environment will also have direct and indirect population effects. There is no return from extinction!

We need to develop adjustment mechanisms that allow us to constantly improve our social and economic systems such that we can provide for our short-term needs with one hand while working on the long-term transformation process with the other—with the goal of achieving a long-term healthy planetary biosphere for all.

Recommendations

1. **Consider stakeholder needs and the impacts of projects in the short, medium, and long term.**
2. **Design for maintainability, sustainability, repair, reuse, recycling, and end-of-use material reuse as feedstock for new widgets.**
3. **Maintain the right to repair and the right to tinker.**
4. **As much as possible, avoid creating single-use products.**
5. **Develop collaborations between programs, organizations, and institutions (e.g., government, academic, and nonprofits) that have an understanding of and data available for individual and community needs.**
6. **Develop and use a predictive information system (or systems) for prognosis and planning to achieve this "balance" between today's needs and the needs of the future for all stakeholders: the Earth's ecosystems and humans.**

Case studies

This information is given solely for the convenience of users of this document as examples of case studies that were known at the time of publication, and does not constitute an endorsement of any company, product, service or organization by the IEEE or IEEE Standards Association (IEEE SA).

1. Balancing Socioeconomic Development with Ecological Conservation towards Rural Sustainability, China

   Li, Qirui, Hua Ma, Zhuqing Xu, Hao Feng, and Sonoko D. Bellingrath-Kimura. "Balancing Socioeconomic Development with Ecological Conservation towards Rural Sustainability: A Case Study in Semiarid Rural China." *International Journal of Sustainable Development & World Ecology* 29, no. 3 (Oct 2021): 246–262.

2. Quantifying the Sustainability of Water Use Systems: Calculating the Balance between Network Efficiency and Resilience

   Li, Y., and Z. F. Yang. "Quantifying the Sustainability of Water Use Systems: Calculating the Balance between Network Efficiency and Resilience." *Ecological Modelling* 222, no. 10 (May 2011): 1771–1780.

3. Sustainable Linear Infrastructure Route Planning Model to Balance Conservation and Socioeconomic Development

   Wu, Shuyao, and Binbin V. Li. "Sustainable Linear Infrastructure Route Planning Model to Balance Conservation and Socioeconomic Development." *Biological Conservation* 266, art. 109449 (Feb. 2022).

Further resources

1. Hisano, Masumi, Eric B. Searle, and Han Y. H. Chen, "Biodiversity as a Solution to Mitigate Climate Change Impacts on the Functioning of Forest Ecosystems." *Biological Reviews* 93, no. 1 (July 2017): 439–456.
2. Rastelli, Eugenio, Bruno Petani, Cinzia Corinaldesi, Antonio Dell'Anno, Marco Lo Martire, Carlo Cerrano, and Roberto Danovaro, "A High Biodiversity Mitigates the Impact of Ocean Acidification on Hard-Bottom Ecosystems." *Scientific Reports* 10, no. 1 (Feb. 2020): 1–13.
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Guiding Principle 7: Alignment of global goals with local goals and actions

The transition to a more sustainable future will be driven and implemented by local actions that should also produce positive global benefits. Local actions and global goals should support each other.

Background

Ultimately, local actions and local implementations of local, regional, and global plans are at the pinnacle of addressing climate change adaptation and mitigation as well as long-term planetary biosphere sustainability goals. The more that local societies align their own goals and actions with global goals and objectives, the greater the likelihood we—that is, *humanity*—will achieve a fundamentally sustainable planet. Local communities across the globe have been, are, and will be impacted directly and indirectly by climate change. Moreover, there are local differences across communities: at the individual level; family level; housing level; neighbor and community level; village, town, and city level; and at the county, state, and national level. At *all* levels, we—*society*—will benefit by integrating relevant data and information from diverse sources that contextualize, weigh, and evaluate outputs that educate our decision-making to produce positive global benefits. From this approach, local actions will match and move towards our global goals.

This is significant and beneficial, as this approach accounts for the diverse and multifactorial effects of climate change. The people of communities most impacted by climate change may also be poor, disadvantaged, or underserved and, therefore, less able to respond appropriately and effectively. These may also include agricultural, fishing, manufacturing, and environmental goods communities, where climate events can directly and indirectly lead to socioeconomic impacts that have global implications.

An example of a conflict is bottom trawling. Trawling the seafloor may provide much nutrition for many people while harming the ecosystem on the ocean floor, discarding unwanted fish species, leaving damaged equipment behind and stirring up sequestered carbon from the ocean floor. The amount of freed up carbon is globally in the order of the entire CO_2 emissions amount reported annually by Great Britain. Thus, locally or regionally, bottom trawling may provide food, while on the global scale it damages ecosystems and frees up carbon (Horn-Muller, 2024).

Thus, the impacts of climate change are expected to lead to increased competition and conflict, lower general quality of life and health, and increased inequities. By balancing socioeconomic factors globally through technological means—and in a manner that is also beneficial for distributed local communities in need—not only can climate change be successfully addressed, but socioeconomic issues faced by communities across the world as well—such as poverty, lack of education, and lack of socioeconomic mobility and support—while also addressing potential conflicts and inequities. In turn, this can lead to improved human rights, well-being, competence, and accountability as well as improved outcomes in response to climate change. This strategy is expected to make the best use of resources and collective capacity for the well-being of future generations and to promote a shared and heightened understanding of human cultures and experiences in a technology-supported world.

Recommendations

1. **Organize and/or research local to global relationships.** Organize and/or research local to global relationships accounting for differences in a multifactorial approach of human (e.g., demographic, health, occupation, and education) and environmental factors (e.g., temperature, humidity, flora, and fauna), independently and dependently, regionally, and across time (past, present, and future).
2. **Connect low-income, high-risk, and high-need communities with programs and organizations that can provide immediate, short-term, and/or long-term support.**
3. **Engage organizations and communities to foster the use of sustainable technologies and programs.** Organize, develop, guide (from preexisting initiatives, new initiatives, and also, ideally, integrated collaborations), and engage relevant technologies and communities—for example, government, organizations, academia, and industry—that address and support recommendations 1 and 2, with emphasis and priority given to technologies and programs that apply sustainable practices and knowledge that are inexpensive, simple, approachable, relevant, and long-lasting and that minimize resource utilization and waste.
4. **Share diversity, equity, inclusion, and accessibility information in support of sustainable programs.** Organize details and share diversity, equity, inclusion, and accessibility information that is adapted for and empathetic toward individual, cultural, and socioeconomic differences and circumstances in support of sustainable programs.
5. **Develop action plans.** Develop timelines and objectives that are adaptive in real time and in the short and long term and are based on priorities and factors related to local and global contexts from the above recommendations and that balance, align, and integrate local and global goals and initiatives.
6. **Develop knowledge sharing and communication mechanisms that connect across backgrounds and professions.** Develop knowledge-sharing and communication mechanisms that teach—both technical and nontechnical—actions and outcomes across backgrounds and professions, realizing that the current intellectual property protection system can pose barriers to sharing solutions.
7. **Develop solutions that address actions with conflicting outcomes such as bottom trawling and limiting the GHG levels in the atmosphere**. Bottom trawling, a somewhat local activity, provides significant amounts of protein—food—and employment while releasing carbon back into the ocean waters and furthermore back into the atmosphere as carbon dioxide.
8. **Develop and support community networks**. There are many community networks and networks of networks around the globe with goals aligned with achieving sustainability and addressing climate change related issues. Community networks offer important alternatives for connectivity based on local, low-cost, and environmentally aware solutions. (IEEE, “The Role of Community Networks in Advancing Universal Access to the Internet”, 2021; The Internet Society, “Connecting the Unconnected”).

Case studies

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1. Interconnected Place-Based Social–Ecological Research

   Balvanera, Patricia, Rafael Calderón-Contreras, Antonio J. Castro, María R. Felipe-Lucia, Ilse R. Geijzendorffer, Sander Jacobs, Berta Martín-López, et al. "Interconnected Place-Based Social–Ecological Research Can Inform Global Sustainability." *Current Opinion in Environmental Sustainability* 29 (Dec. 2017): 1–7.

2. Stockholm Royal Seaport

   Holmstedt, Louise, Nils Brandt, and Karl-Henrik Robèrt. "Can Stockholm Royal Seaport be Part of the Puzzle towards Global Sustainability? — From Local to Global Sustainability Using the Same Set of Criteria." *Journal of Cleaner Production*140 (Jan. 2017): 72–80.

3. Systems Integration for Global Sustainability

   Liu, Jianguo, Harold Mooney, Vanessa Hull, Steven J. Davis, Joanne Gaskell, Thomas Hertel, Jane Lubchenco, et al. "Systems Integration for Global Sustainability." *Science* 347, no. 6225 (Feb. 2015).

4. Earth System Science for Global Sustainability: Grand Challenges

   Reid, Walter V., Davidson Chen, Leah Goldfarb, Heide Hackmann, Yuan-Tseh Lee, Khotso Mokhele, et al. "Earth System Science for Global Sustainability: Grand Challenges." *Science* 330, no. 6006 (Nov. 2010): 916–917.

5. Community Networks

   Munshi, Kaivan. "Community Networks and the Process of Development." *Journal of Economic Perspectives* 28, no. 4 (Fall 2014):49-76.

   Clark, A. "Understanding Community: A Review of Networks, Ties and Contacts." ESRC National Centre for Research Methods, 2007.

Guiding Principle 8: Culture of sustainability

Strategies and actions should move societies toward building a culture of sustainability and "doing good" that is based on respect for all living beings and for the planet Earth. Sustainability efforts must move beyond minimizing harm to restoring and regenerating human and environmental systems.

Background

Actions are most powerful and effective when individuals or groups have a clear understanding of what is being done, how it is done, and, perhaps most importantly, why the actions are necessary and important. The more societies understand how human civilization is impacting and changing the world, the more capable and confident we, as a global community, can be to make necessary changes. These changes must be made not only in personal lives but also within the technological systems that underpin societies and the global economy. Indeed, the more we individually and collectively understand the significance of individual choices and the immense power of collective, international actions, today's global problems and challenges should become less threatening and more manageable, if not resolvable. We, individually and collectively, must therefore understand that every action we take should lead us one step closer to achieving a sustainable future.

Many great sustainability initiatives and purpose-driven organizations have been launched in recent years, with the UN SDGs one of the most well-known. Recent research (see Biermann et al., 2022) has shown, however, that while the SDGs have had positive effects in terms of generating global discussion as well as shaping some isolated policy reforms, "there is little evidence that goal setting at the global level leads directly to political impacts in national or local politics." This suggests that goal setting is largely ineffective unless it is also accompanied by a *commitment and willingness to act* at the local level in accordance with the stated goals such as the SDGs.

Acting sustainably, therefore, starts with individuals, communities, organizations, and nations making an explicit commitment to live, work, grow, and prosper in accordance with the necessary courses of action that promote the long-term health and well-being of all living beings and ecological systems on our planet. This commitment needs to be made not only at the level of individuals but also within systems at local, national, and international levels. This commitment then needs to be written into actionable policies. Culture also plays a key role in embedding this commitment to act sustainably within the social psychology of organizations and other large collectives.

This is a global problem, and societies and individuals are all interconnected; therefore, we cannot rely on each nation or region to cease unsustainable actions or implement sustainable ones in isolation. Although poorer countries may be impacted more severely by climate change, they did not contribute the most to the current crisis. Similarly, they may be less able in terms of resources, technology, and time to take significant actions.

Recommendations

1. **Commit to act to achieve long-term planetary health.** We, that is, business, academia, government, society, organizations, communities, and individuals, must recognize and acknowledge that talking about sustainability is futile unless we also seriously commit to taking the necessary actions to achieve long-term planetary health and well-being—actions speak louder than words. That includes transparency, broad communication, and education.
2. **Develop and implement guiding documents like policies and mission statements.** To act sustainably, businesses, industries, governments, institutions, international, and other organizations should inscribe and/or embed their commitment to long-term planetary health and well-being into their policies, codes of conduct, mission statements, and other governing doctrines/documents/regulations.
3. **Establish an ecological consciousness and code of conduct in industry and business.** Businesses and industries need to recognize that they play a central role in how natural resources are either used and/or impacted by their business activities. Businesses and industry need to establish an ecological consciousness. They need to take a proactive role in overseeing how their business is impacting the environment, combined with methods and procedures that not only aim to minimize environmental impact and achieve best practices and optimal use of resources while doing business but also aim to be circular and regenerative. These actions should be consistently invested in and applied to every aspect of business—not just in building design or supply chains but also in artificial intelligence (AI), in work-from-anywhere versus commute policies, and in building, site plans, and employee travel requirements, event-planning practices.
4. **Verify there is no discrepancy between public business claims and advocacy.** Businesses should hold the advocacy groups that lobby governments on their behalf to the same standards that they claim to apply to themselves publicly. Advocacy groups should not lobby for weaker policies or longer implementation periods or greater subsidies on behalf of any organization that is making potentially unsubstantiated sustainability claims.
5. **Encourage businesses to qualify to become ethically certified.** Certification examples are B-Corp, Fair Trade International, Climate Neutral, and People for the Ethical Treatment of Animals (PETA) (Christian, 2022).
6. Develop an accountability framework for ethical business certification and labeling. This should include independent 3rd party verification.
7. **Deliver on treaties, generate and implement action plans to achieve climate, sustainability, and biodiversity targets.** Governments need to make national commitments and develop action plans to deliver on their commitments to treaties such as the Paris Agreement and Kyoto Protocol and to global climate summits such as the Conference of the Parties (COP). Such commitments can be further accomplished by passing climate targets into law.
8. **Practice integrated systems planning at all levels of government to avoid unintended and unanticipated impacts of actions.**

9. **Develop strategic plans and pursue policies at local and other government levels.** Examples are included below.
    a. **"Shift energy subsidies from fossil fuels to renewable energy"** (Merrill et al, 2017).
    b. Encourage major economies to donate sustainable materials for renewable energy and regenerative agriculture to economies that cannot afford them.
    c. **Invest in "carbon-sucking" concrete** (Clancy, 2021).
    d. Address the use of "tax havens" and other strategies to avoid contributing to the tax base needed to fund these initiatives.
    e. **Heavily invest in water recycling and reuse** (Visram, 2021).
    f. **Plant more trees,** especially in neighborhoods where pollution is higher and where residents are less likely to have air conditioning (temperatures rise significantly higher in areas with no trees) and where residents are more likely to have underlying health conditions.
    g. Restore/regenerate ecosystems and biodiversity.
    h. **Restore the ocean and waterways** (Johnston, 2022).

Case studies

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1. Corporate Mission Statements

    There are many corporations with inspiring mission statements including sustainability, climate change, biodiversity and/or other similar goals.

2. Finland's Plans: It Aims to be Net Zero by 2035 and Net Negative by 2040

    Lo, Joe. "Finland Sets World's Most Ambitious Climate Target in Law." *Climate Home News*, 31 May 2022.

3. "Aiming for Sustainability Isn't Good Enough—The Goal Is Much Higher"

    Former CEO Paul Polman Says "Aiming for Sustainability Isn't Good Enough—The Goal Is Much Higher". Companies should "take responsibility for that total impact in the world. I call it the total handprint, all consequences intended or not."

    Polman, Paul. "Former Unilever CEO Paul Polman Says Aiming for Sustainability Isn't Good Enough—The Goal is Much Higher." By Adi Ignatius. *Harvard Business Review,* 19 Nov. 2021.

4. How to Make Supply Chains/Systems More Sustainable

    "More intractable sources of a company's carbon footprint, Scope 3 emissions, include everything outside of direct operations, such as travel, waste, and supplies."

    Lapan, Tovin. "How Salesforce Wants to Make Its Supply Chain More Sustainable." *Fortune*, 22 June 2021.

5. Carbon Emissions

   McKibben, Bill. "Could Google's Carbon Emissions Have Effectively Doubled Overnight?" *The New Yorker*, 20 May 2022.

6. IoT Emissions

   Freedman, Andrew. "First Look: Salesforce Teams Up with AT&T to Cut Emissions." *Axios*, 23 June 2022.

7. The World's Most Sustainable Companies

   Annual rankings since 2007 by Corporate Knights

   Mc Carthy, Shawn. "The Global 100 List: How the World's Most Sustainable Corporations Are Driving the Green Transition." Corporate Knights, 17 Jan. 2024.

Further resources

1. "The Business Guide to Carbon Accounting." Salesforce, 9 May 2022.
2. CK Staff. "Global 100 Resources." *Corporate Knights*, 3 Apr 2021.

Guiding Principle 9: Responsible use of technology and technology labeling

The design, development, implementation, use, and handling/treatment at end-of-current-use of technology should be a dynamic ongoing process for evolving an appropriate, timely response to both negative impacts—the unforeseen consequences of technology on people and planet—and positive impacts—the opportunities to relieve suffering, increase flourishing and equity, and better steward the planet.

Background

Each wave of new technology has also resulted in unforeseen consequences: fire, language, writing, printing, electricity, computing, transistors, AI, and more. The responsible design, development, use, and disposal of technology is a dynamic cyclical process, not a two-step binary dance of *backlash* followed by *laws and regulations*. Drug and nutrition labeling recognized the need to alert customers about how they would be affected by what they consume. Today people consume technology 24/7, and it affects both their health and their lives.

Advanced technologies such as AI and machine learning present great opportunities for enhancing our own human capabilities for tackling climate change and other global problems. These same technologies also pose serious risks and dangers to the health, well-being, and dignity of human life and to the broader fabric of our societies and the environment. Advanced technologies will not lead to nor generate beneficial outcomes automatically. It is therefore up to those who are technologists to decide how technology is designed and developed and whether technologies are being built to work and serve in the best interests of humanity.

All technologists bear some degree of responsibility in the production process of the technologies that they are working to create. Should instances of irresponsible or unethical uses of technology occur, those involved in their creation and development should be able to raise concerns in a way that can help prevent any risks or dangers from occurring downstream, in the real world. The technology industry and the community of technical professionals needs to be receptive to these concerns and be brave enough to call out instances where technology is not being developed in a responsible way.

Responsible use of technology also applies to the way in which organizations and businesses use technology for their own purposes; industrial use of technology should not perpetuate activities that are inherently unsustainable and that work against our ultimate objective of creating long-term sustainability. Responsibility requires, first, an awareness of what constitutes “good and bad” actions and behaviors and, second, the willingness to encourage and promote “good” actions and behaviors while also preventing or calling out “bad” actions and behaviors when they are noticed. Failing to develop and use technology ethically and responsibly will result in risks and dangers occurring in the world that could have otherwise been prevented.

Recommendations

1. **Accompany technology development by a responsible technology checklist. This responsible technology checklist should attest if the development and deployment of the technology is:**
    a. **Centered on the person or people;**
    b. **Respectful of the natural environment and stewardship of the planet;**
    c. **Sustainable by design;**
    d. **Preserving desired privacy and security by design;**
    e. **Protecting personal information with timely, specific informed consent on the private or public use of data;**
    f. **Accountable to the people who use it and to the planet—in addition to the people who fund and manage it;**
    g. **Ethical;**
    h. **Deployed in solutions that are appropriate to the context of the problem (not all problems need technology);**
    i. **Deployed where a human is in the loop with respect to overseeing and managing technological systems; and**
    j. **Developed with due respect for justice, fairness, the law, and public interest.**
2. **Implement a standardized feedback process for technology innovation with checkpoints to catch dangerous or irreconcilable issues.** Development of technology should take into account feedback; track and measure deployment of technology at the innovation and experimentation stage; and filter out technology that triggers undue backlash.
3. **Develop "responsible technology" standardized labels for robustly tested technology and certification of responsible technology**. For example, see the Digital Product Passport initiative in Europe and Guiding Principle 5, case studies. These types of labels are expected to enable sustainable procurement and support/lead to sustainable supply systems.

Case studies

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1. Drug/Pharmaceutical Labels

    Drug labels came into widespread use in the 1800s. Early pharmacy labels can be found on the website of the Bristol-Myers Squibb European Apothecary here and the AIHP "History of Drug Containers and Their Labels here.

    Wallace Janssen discusses the history of US laws regarding the Food and Drug Act of 1906.

> *"The United States was slow to recognize the need for a national food and drug law. Frederick Accum's "Treatise on Adulterations of Food and Methods of Detecting Them" had been published in London and Philadelphia in 1820, and Great Britain's first national food law was passed in 1860. A variety of U.S. state laws dated from colonial times." (Janssen, Wallace F. "The Story of the Laws Behind the Labels." FDA Consumer. June 1981. page 1.) "Changes from an agricultural to an industrial economy had made it necessary to provide the rapidly increasing city population with food from distant areas. But sanitation was primitive compared to modern standards".*

Janssen, Wallace F. "The Story of the Laws Behind the Labels." FDA Consumer, June 1981, pg. 3.

2. The 1962 drug amendments

> *"The Drug Amendments of 1962, passed unanimously by the Congress, tightened control over prescription drugs, new drugs, and investigational drugs. It was recognized that no drug is truly safe unless it is also effective, and effectiveness was required to be established prior to marketing—a milestone advance in medical history. Drug firms were required to send adverse reaction reports to FDA, and drug advertising in medical journals was required to provide complete information to the doctor—the risks as well as the benefits."*

Janssen, Wallace F. "The Story of the Laws Behind the Labels." FDA Consumer, June 1981, pg. 12.

3. Vehicle Information Labels

Vehicle information labels in the United States include the 17-digit vehicle identification number (VIN) and also some or all of these: the vehicle emissions label, the certification (safety) label, tire information label, service parts identification label, air-conditioning label, coolant label, and belt routing diagram.

U.S. Tape & Label (USTL). "The Complete Guide to Automotive Labels."

Tiberio, Guy. "Vehicle Information Labels: The Stickers You Need to Know!" Slide Presentation.

4. The Trend Toward Prevention

One theme in the FDA's history is the change from primarily "criminal statute—protecting consumers through the deterrent effect of court proceedings—to" laws that are primarily "*preventive,"* including "informative regulations and controls before marketing" can begin. "The laws requiring approval" before marketing formed important changes in the FDA's methods regulating food and drugs in the United States (www.fda.gov). "They specifically required the agency to issue regulations explaining the requirements and procedures. The 1962 Drug Amendments" (see above) "called for current good manufacturing practice" (GMP) "regulations to set standards for plant facilities, maintenance," and l"aboratory controls," and to help "prevent errors or accidents" that "could harm consumers." In 1969, the first GMPs for food establishments were issued based on actual industry practices.

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The Nutrition Labeling and Education Act of 1990 (NLEA) “marked the culmination of a groundbreaking effort to provide information on food labels to help consumers make better choices and encourage food companies to produce healthier food.” “The NLEA required food packages to contain a detailed, standardized nutrition facts label with information such as: serving size; the number of calories; grams of fat and saturated fat; total carbohydrate, fiber, sugars, and protein; milligrams of cholesterol and sodium; and certain vitamins and minerals.” The 2020 Nutrition Facts label required “the largest food manufacturers (those with over $10 million in annual food sales) to use the revised label after the U.S. FDA announced an extension to its 27 May 2016 final rule.”

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Guiding Principle 10: Knowledge-based decisions, transparency, and accountability

Decisions should be based on metrics, sound data, relevant information, context, experience, and perspective; these factors all contribute to informed decisions, knowledge, and accountability. Knowledge-based decisions are thus made on the basis of good evidence and sound reasoning; this, in turn, can make hard decisions more defensible and accountable. Application of appropriate metrics and reevaluation of decisions should be carried out at appropriate time intervals to enable accountability, transparency, and corrective actions.

Background

The IEEE Planet Positive 2030 Initiative sets goals that require new designs, models, and ongoing discovery of processes that support coherent strategies and build collective knowledge of our entire ecosystems—putting the emphasis on contextual parameters, "systems," and "systems of systems." Metrics and accountability are essential for charting progress towards goals.

Information-based systems require meaningful metrics that measure the impact of the entire system on people and the planet, while developing new models for organic growth. Such information-based systems rely on metrics and measurements and, thus, build confidence and trust in our reporting. Furthermore, such accountable systems enable meaningful communications, inform new models for transitioning to performance improvement, and leverage technology to provide scenarios for transformation to sustainable systems.

To achieve sustainable and equitable outcomes, decision-making processes require refinement and precision based on scientific, data-driven methodology, including contributions by nontechnical disciplines (e.g., culture, history, education, communication, and policy). All stakeholders are accountable and have a responsibility as caretaker advocates to speak up about and share findings that may be expected to be impactful to the environment and biospheres—whether they are positive or negative impacts.

Technology is essential to achieving knowledge-based decisions, transparency, and accountability. There are real or perceived technology gaps and/or opportunities for significant improvements and technology development in a number of technology areas. For example, these may include sensors for data collection, information handling and information reliability, analysis, data security, data governance, AI, and AI explainability as well as tools—modeling tools, prediction and prognosis tools, communications technology, blockchain, and other collective intelligence processes as they are being developed.

There is a huge variety of sensors as part of the Internet of Things (IoT). Comprehensive data collection is one of the first goals for knowledge-based decision-making. The ever-increasing need for data requires tremendous amounts of sensors with different capabilities, sizes, functional life, power-requirements, and other features. For example, one area where there is a profound lack of data collection is in the ocean. One of the issues associated with ocean-based data collection is the limited life of the batteries powering sensors and associated transmitters and the lack of opportunity to replace or recharge these batteries.

As stated above: The IoT provides an increasing array of sensors for data collection, however the arena is problematic as there are gaps in labeling, licensing, IoT authorized/certified identity, and device registration over the lifecycle of the device. Data collection is especially hindered due to lack of interoperability between some of the IoT device and sensor types. The lack of Label, License, Identity, Interoperability (LLII) means that manufacturers design proprietary tests and descriptions while the procurers must rely on these (“Caveat Emptor”) unless they are large enough to do their own quality assurance (QA) and testing on acceptance of the device, and during device operation on the data that is collected.

The European Union (EU) Digital Product Passport (DPP) initiative may address some of the LLII when the DPP gets designed and implemented for electronic devices. See also Guiding Principle 9.

Recommendations

1. **Determine organizational actions, behaviors, and public policy based on firstly comprehensive data, reliable information, and knowledge-based decision-making.** The increasing complexity, nonlinearity, and rapid pace of change in societies and environments render the transition to a sustainable future a “wicked problem” (Rittel & Webber, 1973). The planetary biosphere, ecosystems, and human societies are approaching tipping points. Transparency—at least—should be vital to any decision-making process.
2. **Involve multidisciplinary, interdisciplinary, and transdisciplinary teams in developing climate change, regenerative, circular economy, and sustainability policies for all jurisdictions and at all levels: at the business, academic, governmental, and political levels.**
3. **Show how data and analysis can help minimize errors and inaccuracies.** All organizations should be able to show and describe how data collection and the use of data (e.g., models, simulations, projections) have minimized inaccuracies and errors (e.g., bias, discrimination, race/gender skews) or at least account for variation, which can produce false or inaccurate outputs/reports. These may be from poor, biased, or insufficient data, poor methodology, lack of contextualizing, poor leadership, unethical behavior, and inaccurate representation.
4. **Practice and apply careful oversight and consideration with regard to the technological systems used for generating data-driven knowledge and outputs.**
5. **Engage an appropriate independent party to scrutinize decision-making processes for verification and validation with respect to relevant guiding principles.**
6. **Develop and implement policies about transparency, accountability, reporting, and decision-making processes. This is a request to all organizations.**
7. **Provide education and training about transparency, accountability, reporting, and decision-making processes throughout all organizations.**
8. **Continue to address the need for ever more inexpensive sensors with long functional life.** These sensors need to be designed for a circular economy; that is, at the end of use, the materials used to build any given sensor should be reusable as feedstock for new devices or, potentially, be biodegradable.
9. **Ensure source and validity of any data and information including accuracy, completeness, and process of and limitations on the data collection.** Associate a tracking record with data and information to be able to duplicate/verify said data and information. For critical information/data and information handling processes, a registry may be a tool to ensure reliability of the data, information, and associated processes.
10. **Develop standards for data analysis, data security, data governance, AI, and associated processes.** A majority of data collection, handling, reliability tests, analysis, security procedures for data, how

the data is governed, and the algorithms and pattern recognition incorporated in AI models may not be well regulated, and not subject to third party oversight.

11. **Develop interoperative regulation between different jurisdictions to address all aspects of information and data handling, governance, security, modeling, and AI**. For example:
    a. *Information handling:* Decision-makers need to be able to rely on trustworthy information and data. Standardized formats, processes, and oversight should be researched, developed, and implemented. An independent registry for" information handling" for information and data may be an option.
    b. *Information reliability and accuracy:* The user needs to know how reliable and accurate the data and/or information is. For example, the same type of data collected over time and/or across many jurisdictions around the globe will most likely have been collected using different sensors, thus leading to different data quality and accuracy. Data and information needs to be accompanied by process and accuracy information to attest to its reliability and accuracy. Furthermore, alteration needs to be prevented.
    c. *Data and information security and ownership:* It is essential that data governance be clear to all stakeholders and that security is a priority. Data privacy and security matters.
    d. *Education of the stakeholders of data, information, analysis, modeling, and AI:* Technology is being developed very fast—for example AI. It is essential that technologists, researchers, government examiners—for example patent officers—and users are well informed on all aspects of developing and implementing new technologies to enable them to critically evaluate technologies and their applications. This elevated level of training should also enable stakeholders and communities to engage early on as new models and modeling tools are developed.

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