

Planetary Boundaries and Electronics

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Agenda

- The usefulness of the planetary boundaries framework
- Project structure
- Milestone 1: How planetary boundaries are defined and measured
- Milestone 2: How human activities in general impact planetary boundaries
- Next steps

Planetary boundaries: more than just carbon

- As companies are beginning to move towards setting science-based sustainability targets, businesses still remain largely focused on their carbon footprint as their primary sustainability measurement
- While carbon emissions (and the resulting climate change) are indeed absolutely important to global environmental sustainability, there are other earth system processes that need to be supported, that are not captured through a carbon-only perspective
- In addition, looking at the earth systems processes themselves allows us to see the “lagging indicators” more directly reflecting the health of the planet
- The planetary boundaries framework—developed originally in 2009 by Rockström et al (and later updated in 2015 by Steffen et al)—remains an important holistic scientific framework for monitoring the resilience and stability of the planet’s ecosystem

*The purpose of this literature review
is to find scholarship linking
the lifecycle activities of electronics
to impacts on Earth's ecosystem,
specifically as viewed through the lens of
planetary boundaries framework*

How PB's are defined and measured

Milestone 1

How planetary boundaries are defined and measured

Milestone 2

How human activities in general impact planetary boundaries

Milestone 3

Links between the electronics product lifecycle and planetary boundaries

How planetary boundaries are defined and measured

We'll always have the Holocene

- The Holocene is a period of about 12,000 years of stable temperature and climatic conditions that supported humans in moving from a hunter-gatherer lifestyle to developing agriculture and settling in towns and cities
- It is assumed that keeping key earth system variables in the same range as that of the Holocene will continue to provide humans with three key ecosystem services:
 - A stable climate in which to live
 - Sinks for waste
 - Materials and energy needed for human life
- While in the past (during the Holocene) we had relatively few humans making little per capita impact on earth systems, now we have a much greater number of humans, also with larger per capita impacts
- This has moved the planet into a period called by many the Anthropocene, due to the significant impact of human activities on the planetary systems

Beyond just doing incrementally better

- Just as a car heading towards a cliff's edge must do more than to keep slowing its speed (specifically, it needs to completely stop before the edge), our collective sustainability efforts to “slow the car” through incremental improvements may not be enough to avoid tipping points in the planetary ecosystem
- The planetary boundaries framework addresses this need by putting quantitative limits on key variables related to earth system processes that should not be passed, or else we will risk the breakdown of the planetary system, creating conditions inhospitable to human life



The planetary boundaries approach

1

Identify the *primary earth ecosystem processes* that contribute to the stable functioning of the entire planetary system

2

Define *key control variables* for each of these processes

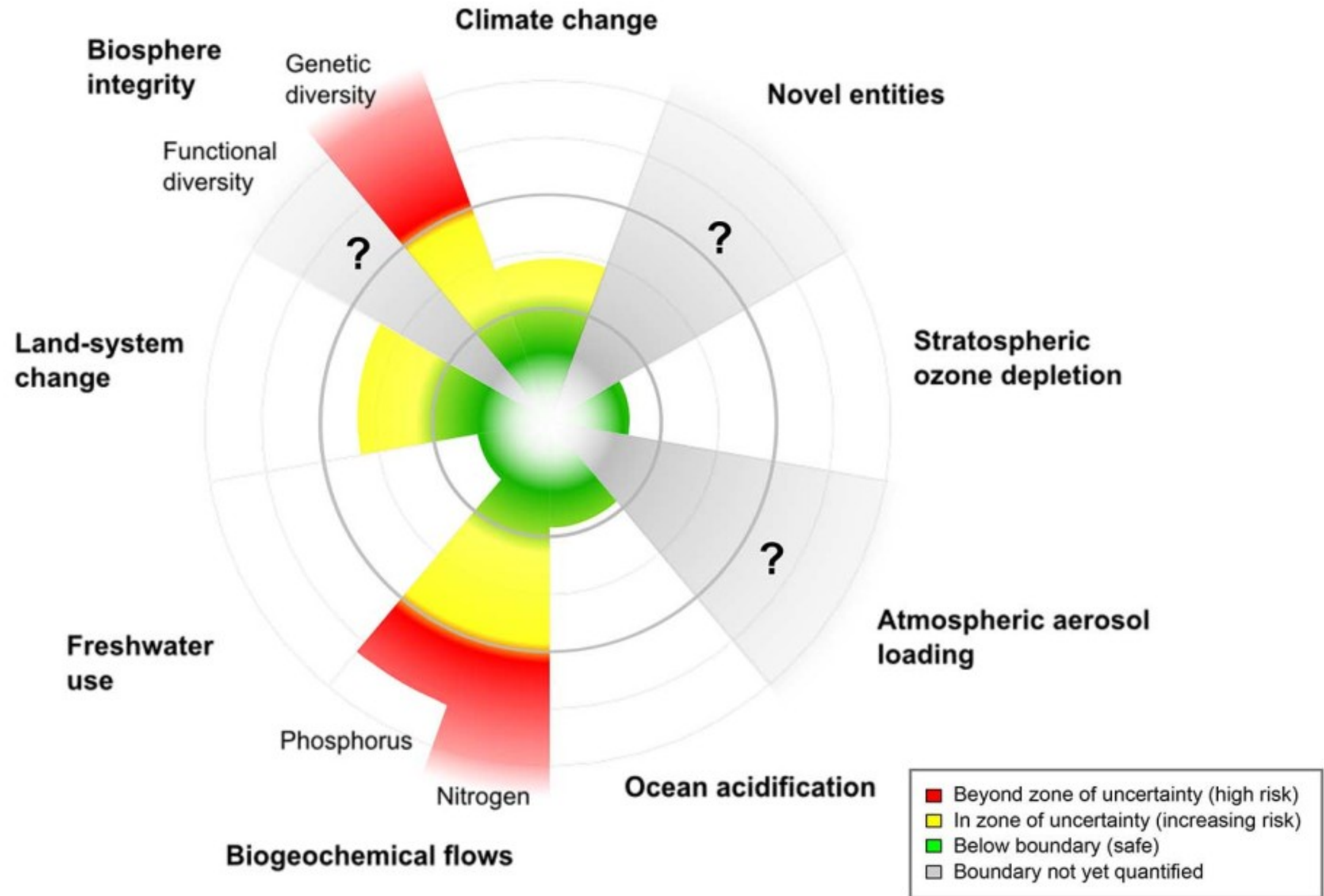
3

For the control variables, set:

- 1. *thresholds*** (tipping points where the process beyond which will likely to move into irreversible, non-stable behavior)
- 2. *boundaries*** (points before reaching a threshold that give some time for humans to reverse their activities, given the time delays inherent in complex systems)
- 3. *zones of uncertainty*** (band to indicate the space between the boundary and the threshold; reflects in part the uncertainty inherent in complex systems behavior and the areas where we may not have enough scientific knowledge to be more precise)

Planetary boundaries

- The boundaries are set independently of each other, even though there are important interdependencies between these processes
- Thus, breaching more than one boundary could cause a cascade of other boundaries being surpassed, too
- The boundaries contain an inherent opinion and assessment of what 'risk to human life' entails



The details (1 of 4)

Earth-system process	Control variable(s)	Planetary boundary (zone of uncertainty)	Current value of control variable
Climate change (R2009: same)	Atmospheric CO ₂ concentration, ppm	350 ppm CO ₂ (350–450 ppm)	398.5 ppm CO ₂
	Energy imbalance at top-of-atmosphere, W m ⁻²	+1.0 W m ⁻² (+1.0–1.5 W m ⁻²)	2.3 W m ⁻² (1.1–3.3 W m ⁻²)
Change in biosphere integrity (R2009: Rate of biodiversity loss)	<i>Genetic diversity:</i> Extinction rate	< 10 E/MSY (10–100 E/MSY) but with an aspirational goal of ca. 1 E/MSY (the background rate of extinction loss). E/MSY = extinctions per million species-years	100–1000 E/MSY
	<i>Functional diversity:</i> Biodiversity Intactness Index (BII)	Maintain BII at 90% (90–30%) or above, assessed geographically by biomes/large regional areas (e.g. southern Africa), major marine ecosystems (e.g., coral reefs) or by large functional groups	84%, applied to southern Africa only
	Note: These are interim control variables until more appropriate ones are developed		
Stratospheric ozone depletion (R2009: same)	Stratospheric O ₃ concentration, DU	<5% reduction from pre-industrial level of 290 DU (5%–10%), assessed by latitude	Only transgressed over Antarctica in Austral spring (~200 DU)

The details (2 of 4)

Earth-system process	Control variable(s)	Planetary boundary (zone of uncertainty)	Current value of control variable
Ocean acidification (R2009: same)	Carbonate ion concentration, average global surface ocean saturation state with respect to aragonite (Ω_{arag})	$\geq 80\%$ of the pre-industrial aragonite saturation state of mean surface ocean, including natural diel and seasonal variability ($\geq 80\%$ – $\geq 70\%$)	$\sim 84\%$ of the pre-industrial aragonite saturation state
Biogeochemical flows: (P and N cycles) (R2009: Biogeochemical flows: (interference with P and N cycles))	<i>P Global</i> : P flow from freshwater systems into the ocean	11 Tg P yr ⁻¹ (11–100 Tg P yr ⁻¹)	~ 22 Tg P yr ⁻¹
	<i>P Regional</i> : P flow from fertilizers to erodible soils	6.2 Tg yr ⁻¹ mined and applied to erodible (agricultural) soils (6.2–11.2 Tg yr ⁻¹). Boundary is a global average but regional distribution is critical for impacts.	~ 14 Tg P yr ⁻¹
	<i>N Global</i> : Industrial and intentional biological fixation of N	62 Tg N yr ⁻¹ (62–82 Tg N yr ⁻¹). Boundary acts as a global 'valve' limiting introduction of new reactive N to Earth System, but regional distribution of fertilizer N is critical for impacts.	~ 150 Tg N yr ⁻¹

The details (3 of 4)

Earth-system process	Control variable(s)	Planetary boundary (zone of uncertainty)	Current value of control variable
Land-system change (R2009: same)	<i>Global:</i> Area of forested land as % of original forest cover	<i>Global:</i> 75% (75–54%) Values are a weighted average of the three individual biome boundaries and their uncertainty zones	62%
	<i>Biome:</i> Area of forested land as % of potential forest	<i>Biome:</i> Tropical: 85% (85–60%) Temperate: 50% (50–30%) Boreal: 85% (85–60%)	
Freshwater use (R2009: Global freshwater use)	<i>Global:</i> Maximum amount of consumptive blue water use (km ³ yr ⁻¹)	<i>Global:</i> 4000 km ³ yr ⁻¹ (4000–6000 km ³ yr ⁻¹)	~2600 km ³ yr ⁻¹
	<i>Basin:</i> Blue water withdrawal as % of mean monthly river flow	<i>Basin:</i> Maximum monthly withdrawal as a percentage of mean monthly river flow. For low-flow months: 25% (25–55%); for intermediate-flow months: 30% (30–60%); for high-flow months: 55% (55–85%)	

The details (4 of 4)

Earth-system process	Control variable(s)	Planetary boundary (zone of uncertainty)	Current value of control variable
Atmospheric aerosol loading (R2009: same)	<i>Global:</i> Aerosol Optical Depth (AOD), but much regional variation <i>Regional:</i> AOD as a seasonal average over a region. South Asian Monsoon used as a case study	<i>Regional:</i> (South Asian Monsoon as a case study): anthropogenic total (absorbing and scattering) AOD over Indian subcontinent of 0.25 (0.25–0.50); absorbing (warming) AOD less than 10% of total AOD	0.30 AOD, over South Asian region
Introduction of novel entities (R2009: Chemical pollution)	No control variable currently defined	No boundary currently identified, but see boundary for stratospheric ozone for an example of a boundary related to a novel entity (CFCs)	

Human activities and how they impact PB's

Milestone 1

How planetary boundaries are defined and measured

Milestone 2

How human activities in general impact planetary boundaries

Milestone 3

Links between the electronics product lifecycle and planetary boundaries

*How human activities
in general impact
planetary boundaries*

Caveats

- The planetary ecosystem functions as a highly interconnected system
- Actions taken by humans can lead to a cascade of changes that ultimately impact planetary boundaries, and thus some are more proximal than others
- Note this is by no means an exhaustive list of human impacts on planetary boundaries but simply an initial review of causes found in academic literature
- Also, the actions are not necessarily equal; further literature review (if research has already been done) or even new field research would need to be conducted to understand the impact (quantitatively) of these actions

*The total weight of everything made by humans—
from houses and bridges to computers and clothes—
exceeds the mass of all living things on Earth*

Stokstad, E. (2020, December 9). Human ‘stuff’ now outweighs all life on Earth.
<http://www.science.org/content/article/human-stuff-now-outweighs-all-life-earth>

Change in Biosphere Integrity

- Biodiversity supports the resilience of the ecosystem in continuing to function in the face of shocks and changes (Folke et al, 2021)
- "Over the past 50 years of human acceleration, the capacity of nature to support quality of life has declined in 78% of the 18 categories of nature’s contributions to people considered by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services" (Folke et al, 2021)

Example Anthropogenic Actions	Details
conversion of land for agricultural purposes (both cropland and pasture)	Simplifies ecosystems and leads to a loss of biodiversity (Hautier et al, 2015) (McGill, 2015)
homogenization of crops and animals	Reduces resilience, making the system more susceptible to disease (Folke et al, 2021)
fertilizer application	Conversion of forest to cropland, increased use of nitrogen and phosphorus fertilizers, and increased extraction of freshwater for irrigation could all act together to reduce biodiversity more than if each of these variables acted independently. Many changes feed back into each other. (Steffen et al, 2011)
pollution	<p>Air pollution can lead to forest degradation due to acid rain (Duvic Paoli and Webster, 2020)</p> <p>Chemical pollution may influence the biodiversity boundary by reducing the abundance of species and potentially increasing organisms’ vulnerability to other stresses such as climate change(Rockstrom et al, 2009)</p>
removal and addition of species to local and regional ecosystems (including overharvesting)	Invasive species and diseases have been introduced to tropical forests driving species extinctions that have degraded pollination, dispersal, and predation functions that underpin forest health. Cascades of extinction often unfold. (Lewis et al, 2015)
freshwater use and consumption	Disrupts ecosystems by temporarily reducing water availability and has been a major driver for biodiversity loss. Includes surface water bodies and aquifers but also groundwater dependent ecosystems. (Pfister, 2015)

Novel Entities

- The central concept is that the Earth has a finite assimilative capacity for chemical pollution, which includes persistent, as well as readily degradable chemicals released at local to regional scales, which in aggregate threaten ecosystem and human viability. (Diamond et al, 2015)
- These are challenging to operationalize due to large number of commercial chemicals or mixtures causing myriad adverse effects to innumerable species, and the complex linkages between emissions, concentrations, exposures and adverse effects.

Example Anthropogenic Actions	Details
plastic pollution (including microplastics)	<p>The environmental impact includes: the injury and death of marine birds, mammals, fish and reptiles resulting from plastic entanglement and ingestion, the transport of non-native marine species to new habitats on floating plastic debris, and the smothering of the seabed, preventing gas-exchange and creating artificial hard-grounds, resulting from sinking plastic debris (Cole et al, 2011)</p> <p>Plastic litter with a terrestrial source contributes ~80% of the plastics found in marine litter (Cole et al, 2011)</p>
chemical pollution (air, water, land)	<p>Products from industrial, farming, and mining activities entering surface waters can contribute to biological consequences such as direct toxicity, mutagenesis, developmental disruption, and reduced primary production in aquatic environments (Carpenter et al, 2011)</p> <p>For example, chemical pollution can increase the vulnerability of ecosystems to species loss and land-use change, notably deforestation, can increase terrestrial-based chemical loadings to surface waters (Diamond et al, 2015)</p>
use of chemicals in production	<p>Chemical production today can result in future emissions, particularly for chemicals in infrastructure and goods with long lifetimes. It has been estimated that whereas ~ 10% of all chemical stocks are contained in waste deposits from primary production and ~ 10% are contained in landfilled waste, ~ 80% are contained in in-use and “hibernating” stocks. (Diamond et al, 2015)</p> <p>Plastics contain over 10,000 other chemicals, so their environmental degradation creates new combinations of materials – and unprecedented environmental hazards. (SRC, 2022)</p>
nuclear waste generation	(listed in Diamond et al, 2015)
raw material extraction	There are many ways that chemicals and plastics have negative effects on planetary health, from mining, fracking and drilling to extract raw materials to production and waste management (SRC, 2022)

Stratospheric Ozone Depletion

- The stratospheric ozone layer plays a critical role in regulating conditions on Earth, but has been substantially depleted by CFC (chlorofluorocarbon) and other halocarbon emissions. (Lane, 2015)
- Tropical ozone levels are expected to decrease below those of pre-industrial times, despite overall global ozone levels recovering strongly. Secondly, ozone layer recovery will be much more rapid in the mid-latitudes than in polar regions; and occur sooner in the northern hemisphere than in the south (Lane, 2015)

Example Anthropogenic Actions	Details
CFCs and other halocarbon emissions	This has increased transmission of UVB radiation to the surface, and been implicated in a range of negative human and ecosystem health impacts. (Lane, 2015)
N2O, CH4 and CO2 emissions	Atmospheric modelling studies consistently indicate that ongoing growth in CO2 emissions will expedite ozone layer recovery; then deliver a ‘super recovery’ whereby global ozone abundance goes over and above pre-industrial levels. By the year 2100, atmospheric CO2 is expected to be the strongest anthropogenic influence on ozone layer status. (Lane, 2015)

Atmospheric Aerosol Loading

- Primary aerosols are atmospheric particles that are emitted or injected directly into the atmosphere, whereas secondary aerosols are atmospheric particles formed by in situ aggregation or nucleation from gas-phase molecules (gas to particle conversion). (Colbeck et al, 2014)
- The Global Burden of Disease WHO GBD project concluded that that 3.2 million people die prematurely every year from cancer, heart disease and other illnesses that are attributable to particulate air pollution; 65% of these deaths occur in Asia. (Colbeck et al, 2014)

Example Anthropogenic Actions	Details
<div>direct aerosol release</div> <div><ul style="list-style-type: none">• transportation• electricity production• heating• industry• forest burning• desertification</div>	<p>Anthropogenic aerosols include particulate matter (PM), emitted directly as a ‘primary’ aerosol, and nitrogen oxides, sulphur oxides, volatile organic compounds, and ammonia which can react in the atmosphere forming ‘secondary’ aerosols. (Duvic Paoli and Webster, 2020)</p> <p>The acidifying effects of atmospheric deposition of nitrogen and sulphur are well-known: causing major damage to plants, water bodies and buildings, contributing to water and ocean acidification, and affecting nutrient and carbon cycles. (Duvic Paoli and Webster, 2020)</p> <p>The increasing severity of droughts/floods and worsening air quality from increasing aerosols in Asia monsoon regions are the two gravest threats facing over 60% of the world population living in Asian monsoon regions. (Li et al, 2016)</p>

Ocean Acidification

- Beyond a threshold concentration, this rising acidity makes it hard for organisms such as corals and some shellfish and plankton species to grow and survive. Losses of these species would change the structure and dynamics of ocean ecosystems and could potentially lead to drastic reductions in fish stocks. Compared to pre-industrial times, surface ocean acidity has already increased by 30 percent. (Stockholm Resilience Centre)

Example Anthropogenic Actions	Details
CO2 emissions	<p>Around a quarter of the CO2 that humanity emits into the atmosphere is ultimately dissolved in the oceans. Here it forms carbonic acid, altering ocean chemistry and decreasing the pH of the surface water. (Stockholm Resilience Centre)</p> <p>This boundary is intimately linked with one of the control variables, CO2, for the climate change PB. The concentration of free H+ ions in the surface ocean has increased by about 30% over the past 200 years due to the increase in atmospheric CO2. This, in turn, influences carbonate chemistry in surface ocean waters. Specifically, it lowers the saturation state of aragonite (Ω_{arag}), a form of calcium carbonate formed by many marine organisms. (Steffen et al, 2015)</p>

Bio-geochemical Flows (N and P)

- Beyond a threshold concentration, this rising acidity makes it hard for organisms such as corals and some shellfish and plankton species to grow and survive. Losses of these species would change the structure and dynamics of ocean ecosystems and could potentially lead to drastic reductions in fish stocks. Compared to pre-industrial times, surface ocean acidity has already increased by 30 percent. (Stockholm Resilience Centre)
- Other flows such as silicon and carbon are also of concern (Steffen et al, 2015)

Example Anthropogenic Actions	Details
fossil fuel combustion	<p>All the nitrogen used in food production is added to the environment, as is the nitrogen emitted to the atmosphere during fossil-fuel combustion. In the 1990s, these two sources of anthropogenic nitrogen to the environment amounted to more than 160 teragrams (Tg) N per year. On a global basis, this is more than that supplied by natural biological nitrogen fixation on land (110 Tg N per year) or in the ocean (140 Tg N per year) (Gruber and Galloway, 2008).</p> <p>The relative size of the modification of the nitrogen cycle by human activity (all actions) is far greater in magnitude than the parallel modification of the carbon cycle. (OECD, 2018)</p>
industrial nitrogen fixation	<p>Humans have doubled the annual flow of nitrogen following the discovery of the Haber-Bosch process a century ago, which allowed us to convert molecular nitrogen from the air into usable nitrogen for fertiliser (80%) and industrial uses (20%). (OECD, 2018)</p>
fertilizer use	<p>Nutrient-enriched runoff from agriculture and urban land is a major cause of eutrophication, i.e., the overenrichment of aquatic ecosystems with nutrients or organic matter, leading to harmful blooms of algae, deoxygenation, loss of economically valuable species, and human health problems (Carpenter et al, 2011)</p>
biomass burning, land clearing and conversion, drainage of wetlands	<p>Human activity liberates N from long-term biological storage pools, and thereby contributes further to increasing the biological availability of N. The major pathways of mobilization include biomass burning; land clearing and conversion; and the drainage of wetlands and consequent oxidation of their organic soils. Moreover, the loss of wetlands removes a significant sink for fixed nitrogen (denitrification, the conversion of nitrate to N₂ under anaerobic conditions), further increasing the mobility of N to and through streams and rivers. (Vitousek et al, 1997)</p>

Freshwater Use

- Transformations include changes in the morphology of rivers and lakes, hydrology, biogeochemistry of nutrients and toxic substances, ecosystem metabolism and the storage of carbon, loss of native species, expansion of invasive species, and disease emergence (Carpenter et al, 2011)
- Beyond drinking water, freshwater supports human well-being in many ways related to food and fiber production, hydration of other ecosystems used by humans, dilution and degradation of pollutants, and cultural values. (Carpenter et al, 2011)

Example Anthropogenic Actions	Details
water withdrawal	Water withdrawals by humans are used for agriculture, in various industries, and within domestic households. However, most of the water withdrawn for agriculture is consumed (transferred to the atmosphere as water vapor), whereas most of the water withdrawn for industrial and domestic use is returned to surface flows.
hydrologic flow modification	Dam construction has shifted from developed to developing regions, especially China, India, and South America in the past 20 years. Floodplains are among the most dynamic, productive, and diverse ecosystems on Earth. In developed regions, most rivers have been channeled and leveed, floodplains have been converted for agricultural and urban use, and natural flow regimes have been altered through river regulation. (Carpenter et al, 2011)
land-use change	Land-use change affects freshwater flows by changing the fates of precipitation among ET, runoff, and groundwater recharge. Conversion of natural ecosystems to cropland or urban uses generally increases runoff as well as flood frequency and intensity, and it decreases ET and groundwater recharge. (Carpenter et al, 2011)
aquatic invasive species	Invasion by terrestrial plant species (such as Tamarix in the western United States) with high ET rates has the effect of decreasing runoff to surface waters (26). (Carpenter et al, 2011)

Land System Change

- Land-use dynamics constitute about a dozen processes: urbanization, conversion of forest to cropland, conversion of grassland to cropland, change of crop on existing cropland, more intensive use of croplands, incorporation of trees into cropland, conversion of cropland to forest, conversion of forest to pasture, conversion of cropland to pasture, more intensive use of pasture, incorporation of livestock into cropland, and, finally, conversion of pasture to cropland. (Geist et al, 2006)

Example Anthropogenic Actions	Details
conversion of land for agriculture use	At the level of proximate causation, the broad category of agricultural expansion, for example, falls into cropping and livestock activities with further subdivisions such as shifting cultivation and sedentary cropping, to be further subdivided into large-scale versus smallholder farming. (Geist et al, 2006)
wood extraction and deforestation	<p>Likewise, the broad category of wood extraction falls into commercial timber logging, fuelwood and polewood extraction for domestic uses, and charcoal production, with further subdivisions possible between clear-cutting, selective logging, state-run versus private company activities, etc. (Geist et al, 2006)</p> <p>Deforestation and degradation also cause biophysical changes, including albedo, surface roughness, and evapotranspiration. Deforestation leads to warming (Lewis et al, 2015)</p>
infrastructure construction	Proximate (or direct) causes involve a physical action on land cover and are usually limited to a recurrent set of activities such as agriculture (or agricultural expansion), forestry (or wood extraction), and infrastructure construction (or the extension of builtup structure). (Geist et al, 2006)
human-caused fires	Natural fires are extremely rare in moist tropical forest, but anthropogenic fires are common today. Following logging and fragmentation, fuel loads (woody debris, ongoing tree mortality), conditions (drier, warmer in canopy openings), and ignition sources (people) all promote fires. (Lewis et al, 2015)

Links to the electronics product lifecycle

Milestone 1

How planetary boundaries are defined and measured

Milestone 2

How human activities in general impact planetary boundaries

Milestone 3

Links between the electronics product lifecycle and planetary boundaries

No research found on this topic.

Thank you

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