Transforming human systems to safeguard the Global Commons

An integrated assessment of deep transformations in human energy, land use, and production and consumption systems towards keeping the Global Commons within the safe space of the Planetary Boundaries

March 2024

Potsdam Institute for Climate Impact Research

Center for Global Commons

This report was prepared by the **Potsdam Institute for Climate Impact Research (PIK)** and the **Center for Global Commons (CGC)** at the **University of Tokyo**. The analysis and report production were undertaken by **Gabriel Abrahão, Dorothee Keppler, Simón Moreno, Isabelle Weindl, Jessica Strefler, Bjoern Soergel, Lavinia Baumstark, Christoph Bertram, Michael Crawford, Jan Philipp Dietrich, Alois Dirnaichner, Robin Hasse, Jens Heinke, Florian Humpenöder, David Klein, Gunnar Luderer, Christoph Müller, Michaja Pehl, Robert Pietzcker, Franziska Piontek, Alexander Popp, Sebastian Rauner and Renato Rodrigues**, under the direction of **Elmar Kriegler (PIK), Johan Rockström (PIK) and Naoko Ishii (CGC).**

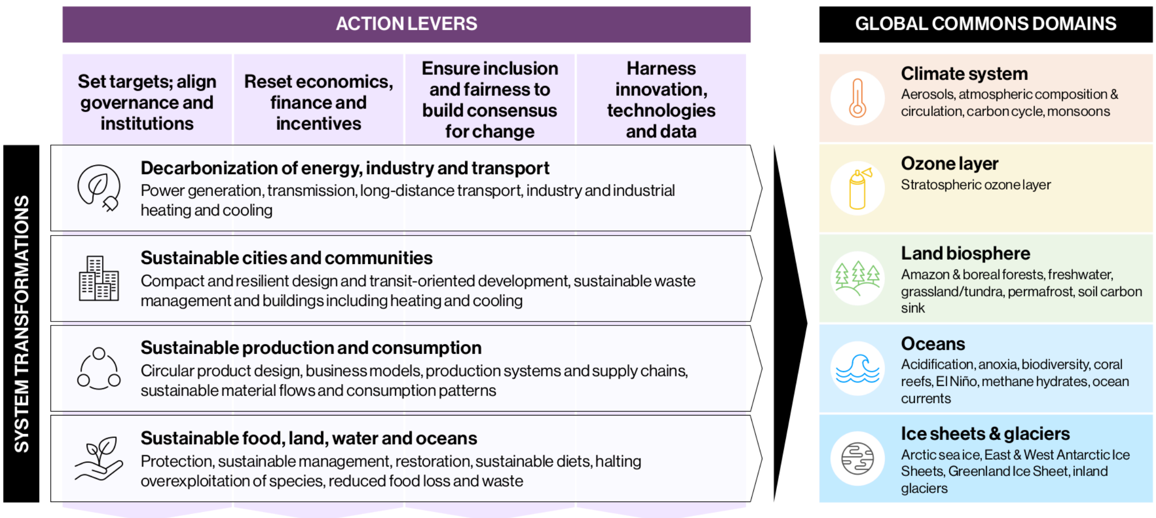
Please cite this report as:

Abrahão et al. 2024. Transforming human systems to safeguard the Global Commons: A report by PIK and CGC. Potsdam, Germany and Tokyo, Japan.

The Global Commons Stewardship Project

The Global Commons Stewardship (GCS) project, initiated and led by the **Center for Global Commons (CGC)** at the **University of Tokyo**, in partnership with **PIK, SDSN, WRI** and **SYSTEMIQ**, aims at the **development of a conceptual framework and strategies for Global Commons Stewardship.**

Within the GCS project, the **Potsdam Institute for Climate Impact Research (PIK)** is responsible for conducting **interdisciplinary modelling, performing a comprehensive assessment of how the system transformations identified in the GCS project can contribute to the stewardship of the Global Commons.**



The Global Commons Stewardship Framework

Executive Summary

Current policies and the Global Commons

Safeguarding the Global Commons requires a global perspective. The Global Commons, the biophysical systems that as a whole keep the Earth System stable and resilient, consisting of several global commons domains, are the foundation of human development and prosperity.. Currently, human activities have already pushed several of these systems outside the safe operating space of the Planetary Boundaries.

Our integrated assessment results show that, with current policies, humanity is on track to worsen the state of most Global Commons domains and cross several Planetary Boundaries by mid-century (Fig A). The boundaries for Nitrogen Flow, Land System Change and Biosphere Integrity have already been transgressed today, and continuing current policies would not reverse the underlying trends by returning the associated indicators to a position substantially closer to their Planetary boundaries by 2050. With just the controls currently in place on emissions of CO_2 and other greenhouse gases, the Planetary Boundaries for Climate Change and Ocean Acidification would also be crossed by 2050.[1] **The only indicator that is set to improve is the one for the Ozone Layer, with the successful implementation of the Montreal Protocol** bringing ozone depletion back inside the Planetary Boundary.

A complete worldwide implementation of the Nationally Determined Contributions (NDC) on emissions reduction, land protection and afforestation by 2030 and the continuation of this level of ambition until 2050 would not substantially change the worsening trends under current policies. Only small progress back towards the Planetary Boundaries for Climate Change, Ocean Acidification and Land System Change would be made, **which is not enough to remain inside the Planetary Boundaries or even stop degradation at current values**. Furthermore, the pressures of increased land scarcity and a possible reliance on bioenergy for reducing emissions would lead agriculture to further **worsen the state of the Nitrogen Flow indicators.**

A holistic transformation pathway

A scenario in which transformations of energy use, land use, and production and consumption patterns are implemented jointly would allow humanity to reverse the degradation of the Global Commons domains to levels very close to or within the Planetary Boundaries by 2050. Although even these deep systems transformations would not be able to keep warming below 1.5°C without a small overshoot in 2050, a combination of CO_2 removal and continued reduction of non-CO_2 emissions would revert warming, so that global mean temperatures would stay below the Paris Agreement target by 2100 and beyond. However, CO_2 concentrations and radiative forcing would still

[1] As described in Section 2.3, we define the Planetary Boundary as 1.5°C warming over the preindustrial value, the target set by the Paris Agreement. As current warming is around 1.1°C, the target has not been crossed yet, but would be in 2050 if current policies continue. In this point we deviate from the Planetary Boundaries framework (Steffen et al. 2015) which defines Climate Change as an atmospheric CO_2 concentration of 350 ppm. Based on this indicator and value, the Planetary boundary for Climate has already been crossed, and even all the transformations investigated here cannot bring CO_2 concentrations back below that value.

only be stabilized at around current levels, at which changes in climate harmful to human and natural systems are already observed.

In the scenarios considered, the proposed interventions lead to dramatic changes in the energy, land and production and consumption systems. In our modeling framework, these changes are a combination of direct model assumptions and endogenous responses to them. Some of the most relevant are:

- The average global price on GHG emissions in both the energy and land sectors reaches around **90 U.S. dollars per ton of CO2eq in 2050**. These levels are relatively low, being enough to limit warming to 1.5°C by 2100 (with limited overshoot) only in combination with all other transformations. Prices are phased in more slowly in developing countries. In the absence of these other transformations, the prices required for the same temperature limit are over three times higher
- Diets worldwide move towards more healthy and sustainable patterns, along the lines of the **EAT-Lancet diet recommendations**, by 2050. **Global consumption of livestock products, which is currently increasing, decreases by around half**, especially moving away from ruminant meat. Most of this reduction comes from developed countries with meat-rich diets.
- **Food waste is halved by 2050**
- Global average **crop nitrogen use efficiency (NUE),** the fraction of nitrogen in fertilizer that is taken up by the crops, **improves from the current 50% to 70%.** .
- All areas currently listed as protected in the World Database of Protected Areas (WDPA) are effectively protected, plus all intact forest landscapes and biodiversity hotspots, in total **protecting around 30% of the global land environment by 2030**. This value is in line with the **commitments in the Kunming-Montreal Global Biodiversity Framework**. GHG pricing is applied to land use change to disincentive loss of carbon, natural vegetation and biodiversity in non-protected areas.
- The **share of electricity in the global final energy supply** increases from currently below 20% to ~25% in 2030, **to 45% in 2050**. A combination of reduction in the cost of renewables and carbon pricing leads to an almost complete **phase out of coal and oil use in electricity generation**, and reliance on gas falls below 2% of the electricity supply in 2050.
- The **per-capita demand for cement is reduced** by 20%, as a result of price changes in the energy system and through the promotion of higher material efficiency in the buildings sector.

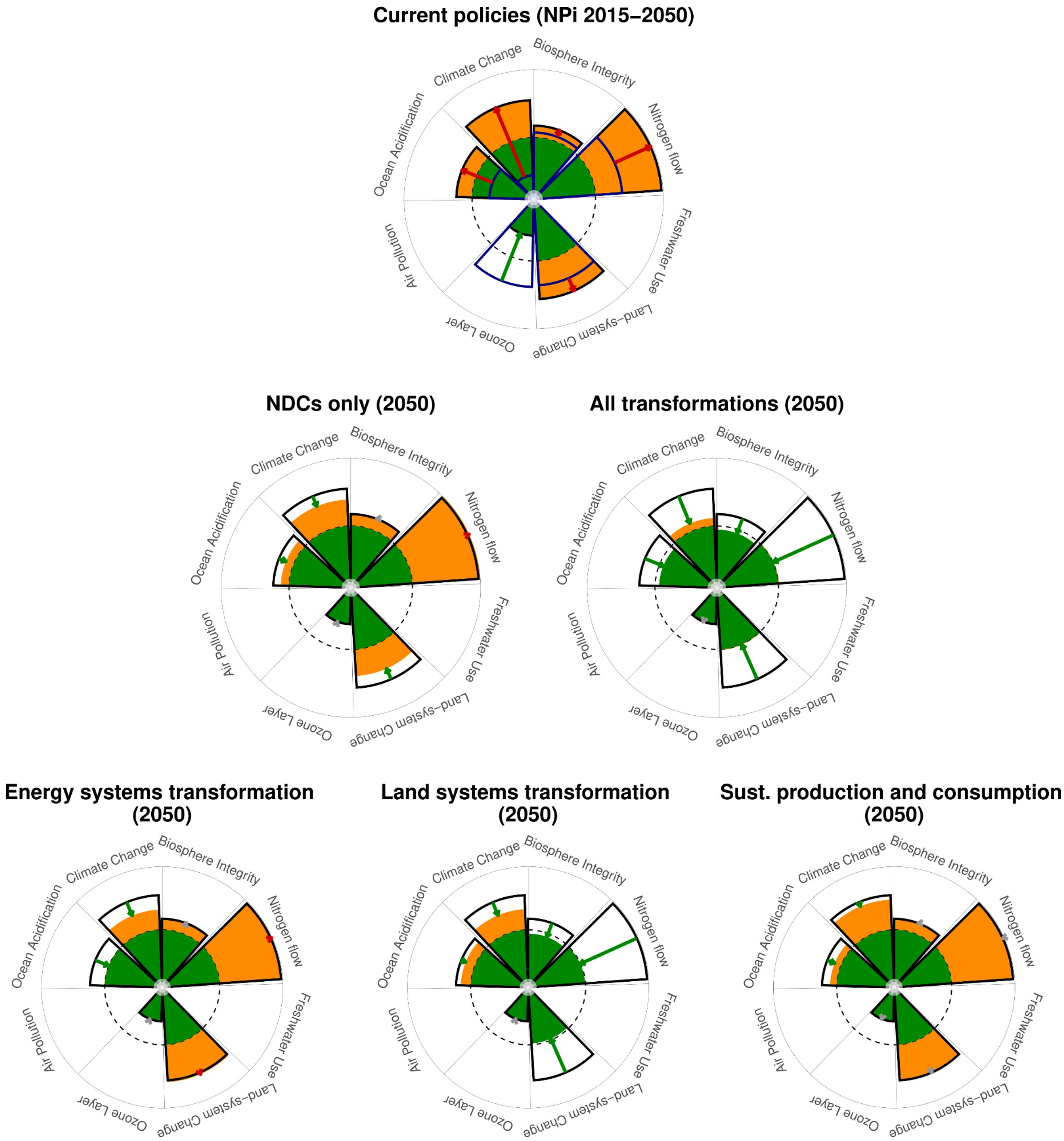


Fig. A: Effects of the continuation of current policies (from 2015 to 2050, top row) and of various transformations (in 2050) on keeping the Global Commons domains within selected the Planetary Boundaries. Inner dotted lines mark the Planetary Boundary value (or the 1.5C global mean temperature change limit in the case of the Climate Change boundary). Green (red) arrows indicate an improvement (worsening) of an indicator due to a certain transformation in 2050 in relation to either 2015 (blue lines in NPi) or to the current policies continued scenario in 2050 (black lines). Wedges show the relative value of each indicator, with green (orange) portions showing the part inside (outside) the defined safe space. The starting points of the wedges at the center were chosen so as to visually emphasize the effects and their relation to the Planetary Boundary value, and are not comparable across indicators. Effects on the Air Pollution and Freshwater Use boundaries were not explicitly quantified in this study.

Modelling transformations

In this study, we used the REMIND-MAgPIE integrated assessment framework to simulate scenarios that implement different combinations of these transformations in addition to existing policies. Results show how they affect the future development of five Global Commons Domains, (Climate, Cryosphere, Oceans, Ozone Layer and Land Biosphere) relative to the Planetary Boundaries over the course of the next century.

Due to the high relevance of the land and industry sectors for the pressure on several planetary boundaries, special sets of scenarios also offer insights into the effects and trade-offs of dedicated land- and industry-specific transformations. In the land sector, options for changing current food systems, improving resource efficiency in agriculture, and land-based solutions for climate change were investigated. In the industry sector, reductions in the demand for materials, the introduction of carbon capture and storage (CCS) technologies, and widespread use of hydrogen were analyzed in combination with GHG pricing in the sector. Additionally, the potential of circular economy strategies in the plastics sector was examined in relation to the planetary boundaries of climate change and the introduction of novel entities.

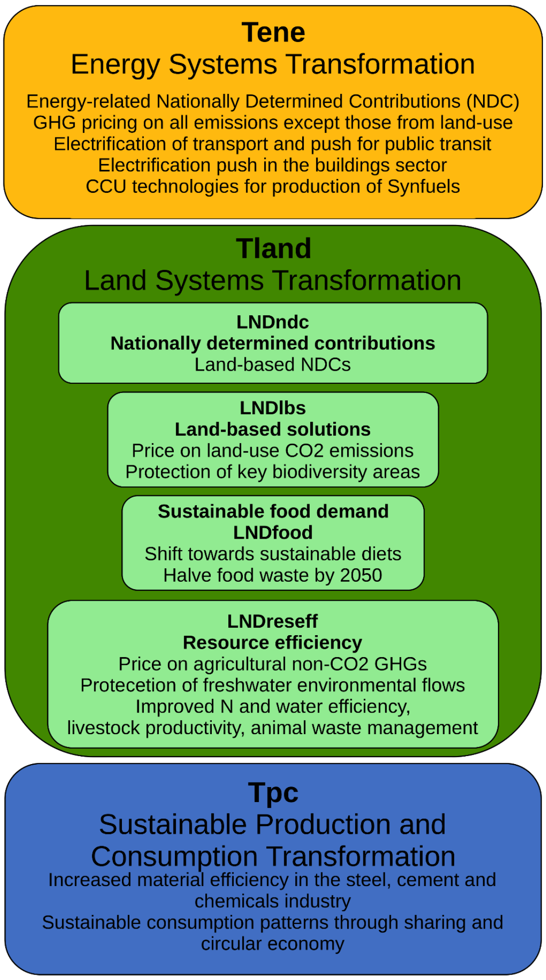


Fig. B: System Transformations implemented in the REMIND-MAgPIE modelling framework

Effects of individual transformations

Implemented individually, the transformations of energy use, land use, and production and consumption patterns have different effects on safeguarding the Global Commons. Most but not all of them are positive.

- **The Energy Systems Transformation has strong effects on safeguarding the Climate, Cryosphere and Oceans, but can have detrimental effects on the Land Biosphere Global Commons domains.** Transforming the energy systems towards sustainable energy sources and shifting towards more sustainable transport modes would reduce GHG emissions by 39 Gt CO_2eq/year in 2050, a 60% reduction relative to a scenario with only the currently implemented policies. This would prevent around 0.19°C of warming. Most of the avoided emissions would be of CO_2, keeping **Ocean Acidification at relatively safe levels inside the Planetary Boundary** throughout the century. However, an **increased reliance on bioenergy ultimately has detrimental effects on the Land Biosphere**, leading to higher deforestation rates, use of nitrogen fertilizers, agricultural consumption and degradation of biodiversity.
- **The Land Systems Transformation is fundamental for preserving the Land Biosphere, but also has substantial positive impacts on the other Global Commons domains.** By 2050, it would halt the loss of natural forest, reduce agricultural water consumption and improve human-induced nitrogen fixation and biodiversity intactness to conditions superior to those of today. This would bring Land System Change, Nitrogen Flow and Biosphere Integrity back within their Planetary Boundaries. **These effects are more than enough to counteract negative effects from the Energy Systems transformation in these Global Commons domains.** The combination of land interventions would also reduce GHG emissions by 19 Gt CO_2eq/year. Methane emissions would be particularly reduced, preventing 0.18°C of warming in the medium term (2050) and **minimizing overshoot of the 1.5°C Paris Agreement target.** The avoided CO_2 emissions would have positive impacts on Ocean Acidification, but not enough to prevent it from degrading to levels outside the Planetary Boundary.
- **Individual components of the Land Systems Transformation focusing on resource-efficient production, reduction of GHG emissions, and dietary changes, differ in terms of their individual impact on safeguarding the Global Commons domains, and exhibit synergies and tradeoffs between them and with other transformations.**
    - **Transitioning to resource-efficient production systems** is a key supply-side intervention to reduce human-induced nitrogen fixation and agricultural water use. However, reducing water consumption by limiting irrigation can increase pressures on Land System Change and Biosphere Integrity, as replacing irrigated systems with relatively lower-yielding rainfed ones requires more land area.
    - **Pricing GHG emissions from land use change** can prevent leakage effects from other interventions, including those that can occur if regulation-based land protection or afforestation schemes like current NDCs miss sufficient coverage in terms of regional distribution and types of included ecosystem.,
    - **Each of these land protection measures are of paramount importance if interventions in other sectors further increase biomass demand**, e.g. for energy use. On the other hand,

land-based solutions alone can push unsustainable intensification practices and can create tradeoffs with water use.

  - **In contrast, transforming food demand towards more sustainable diets and reducing food waste leads to strong beneficial impacts across most Global Commons domains. It can combine synergistically with other land interventions, leading to more than additive outcomes in Land Systems Change and Biosphere Integrity**, as reduced demand for food frees more land to be used for mitigation and conservation. Its beneficial effect on reducing emissions and the use of nitrogen and water are slightly diminished when evaluated in conjunction with the other land interventions, which ultimately make the food system more environmentally efficient and therefore reduces the burden of additional food demand. However, it still **positively affects economic variables such as food and bioenergy prices**, which are mostly negatively influenced by the other land interventions. It is also key to facilitating a multi-dimensional transformation to sustainability that also **addresses human well-being and development**.

- **The Sustainable Production and Consumption Transformation has some effects on safeguarding the Climate, Cryosphere and Oceans, but is not enough to protect them on its own.** The improvements in material efficiency and more sustainable consumption habits ultimately lead to lower industrial production and energy demand, which reduces GHG emissions by 16 Gt CO_2eq/yr relative to current policies in 2050. These reductions can prevent 0.09°C of warming overshoot in 2050 and have benefits for Ocean Acidification. When combined with other transformations, Sustainable Production and Consumption can further limit peak warming, facilitate the Energy Systems Transformation and ease the pressure on the Land Biosphere.
- **The transformations have little to no effect on the Ozone Layer beyond the Montreal Protocol.** With continued compliance to the Montreal Protocol on the emissions of ozone-depleting substances, the ozone layer should return to pre-1980 levels between 2030 and 2050.

The role of demand reductions

Interventions that reduce demand for goods and services, be it for industrial materials (such as the Sustainable Production and Consumption Transformation), or for unsustainable food products (Sustainable Food demand) **can have very substantial effects on safeguarding the Global Commons. But even within our deep transformations, demand-side interventions alone will not be sufficient to reach any of the assessed targets.** Furthermore, when coupled with structural changes in the systems themselves, such as the decarbonisation of energy supply and more resource-efficient agricultural production, these demand-side interventions tend to have a smaller effect than when considered alone. This arises from the fact that these transformed production systems can fulfill the same demand with less impact on the Global Commons.

However, reductions in demand can be fundamental in reducing the socioeconomic burden of these production systems transformations, making the same targets achievable with lower prices for food, energy and GHG emissions for example. Since most of the demand reductions assessed require deep behavioural changes, implementing them is posing a major policy challenge.

Industry transformation

Industry-specific modelling shows that carbon pricing is essential for reducing the sector's environmental impacts, but implementing industry-specific policies enables faster and deeper de-carbonization of the sector.

Reducing the material demand of the economy through sustainable production and consumption practices **offers significant reductions of the pressure that industry puts on the Global Commons domains**. However, the feasibility of deep dematerialization remains uncertain.

Carbon capture and storage (CCS) is important for deep decarbonization of the global industry to tackle process emissions, as these cannot be mitigated by means of low-carbon energy carriers. However, **CCS technology is not a viable replacement for phasing out fossil fuels for energy use**. Robust policy making for deep decarbonization cannot be avoided.

The adoption of hydrogen-driven technologies in the industry sector should concentrate on the specific applications where electrification is not feasible, as it is generally not the most cost-effective solution .

Circular approaches for plastic waste mitigation can help mitigate the introduction of novel entities in the earth system while avoiding putting further pressure on the climate and the energy transition but further research is required that defines the technical, economic, and environmental limits of this alternative.

Policy recommendations

An integrated, comprehensive design of policies is needed for a Global Commons stewardship: Global Commons stewardship needs combined and comprehensive policy settings, targeting transformations on multiple sectors at the same time. To protect and preserve the Global Commons and planetary integrity, such an integrated approach is of utmost importance. The interventions considered in our scenario analysis are mutually supportive in preserving the Global Commons in many cases, and can avoid or compensate for policy trade-offs if applied together. This is of particular importance between and within the Energy and Land Systems Transformations, to avoid trade-offs between land-based mitigation, growing bioenergy crops and nature conservation.

Current policies and commitments need to be substantially strengthened and increase their coverage of the broad set of changes and transformations required for safeguarding the Global Commons: Current commitments should not only be implemented, but strengthened with more ambitious targets in terms of emissions reductions by 2030 and 2050, but also of land and biodiversity protection. The recently adopted Global Biodiversity Framework represents a major step in this direction. Policy measures should also have a more comprehensive focus on multiple sectors and producer and consumer-facing interventions. This could help fill gaps in policy coverage, for example, with regard to better taking into account the effects of agricultural systems on the water and nutrient cycles, inducing a change towards more sustainable consumption patterns, and increasing the material efficiency of production.

An emissions pricing scheme to safeguard the Global Commons should play a critical role to penalize actions that lead to more GHG emissions and reward those that reduce emissions. It should be designed to cover all emitting sectors, have prices that rise over time, and explicitly address its own equity and distributional impacts: Measures that effectively put a price on emitting GHGs can have large positive effects on many Global Commons domains. Actual measures can include direct carbon pricing or taxation, but also carbon markets (such as the EU Emissions Trading Scheme) or regulations. Emission pricing directly targets the protection of the climate, and thus also the preservation of ice sheets and glaciers and the prevention of further Ocean Acidification. It also discourages the use of coal and other fossil fuels, thus improving air quality especially in cities and communities. Including the **land use sector** in such a pricing scheme creates incentives to protect and expand forests. It also **disincentivizes** an **excessive reliance on bioenergy** for decarbonizing the energy sector. Including **GHGs other than CO_2** in the pricing scheme also favours **less meat consumption** and fosters a more **sustainable use of nitrogen fertilizers**. However, GHG pricing should be **accompanied by specific land protection measures** to alleviate the pressure that some climate mitigation options such as bioenergy use and afforestation can cause on natural and semi-natural land, which is critical for halting and reversing biodiversity loss. GHG pricing instruments should **address their equity and distributional impacts by design** to ensure their acceptance, directing their revenues to lower income regions and households and phasing in prices more slowly in developing countries.

The GHG price levels required for safeguarding the Global Commons domains, especially the Climate, depend crucially on all other measures implemented: In the absence of any other measures, energy system GHG prices in our scenarios would have to reach around 350 U.S. dollars per ton of CO_2 equivalent by 2050 to reach the 1.5°C climate goal. Combining it with other policies, especially **encouraging the reduction of total demand for high emissions products and services,**

such as industrial materials, energy and animal-source foods, and pricing emissions in the land sector lowers the GHG prices necessary to achieve the same climate target. Demand reductions, although difficult to implement, ease the cost of transition and have several co-benefits for the land biosphere. Combined with strong levels of demand reduction, a comprehensive GHG pricing scheme in the energy and land use could achieve the 1.5°C climate goal with prices as low as 90 U.S. dollars per ton of CO_2 equivalent by 2050.

The role of bioenergy in decarbonising the energy system should be limited and coupled with land conservation policies: Bioenergy production can lead to severe trade-offs, threatening the integrity of the land biosphere and increasing food prices. Many of these effects could be counteracted by very ambitious conservation policies and a shift towards more sustainable food consumption behaviour, which are challenging to implement at a global scale. Therefore, a mix of regulations on energy markets to limit their reliance on bioenergy and comprehensive conservation policies on bioenergy producing regions is recommended.

Foster sustainable production and consumption of industrial goods: A reduction in per-capita production of material goods in high-income countries facilitates the decarbonization of the energy supply, thus contributing directly to the protection of climate, cryosphere and oceans, as well as to a reduction of air pollution and associated health effects and the amount of waste to be disposed of. Part of these reductions can be achieved through material efficiency measures and technological improvements in the producing industries. But promoting a shift to more sustainable consumption patterns, with a focus on sharing and circular economies, could also lead to massive benefits.

A sound strategy for the sustainable transformation of the global industry requires a set of sector-specific policies to overcome potential bottlenecks and carbon lock-ins. Incentives that speed up the development and rapid scale-up of Carbon capture and storage technologies are needed to mitigate process emissions in industry. However, **deploying CCS is not a license to continue to use fossil fuels, as it cannot provide full decarbonization**. Robust policy making for the industry transformation should hedge against the deep uncertainties underlying both new technologies and reductions in demand. **More research must be done to define the techno-economic boundaries of dematerialization and material efficiency**, as well as advancing the understanding of cross-sectoral interactions. Incentives that foster the scale-up of **hydrogen** are needed, but should be **targeted to applications where electrification of processes is technically constrained**. Subsidizing the deployment of hydrogen beyond the necessary scope risks triggering additional transformational challenges which can hinder the transformation of industry.

Promotion of healthy and sustainable diets and a reduction of food waste: The food system is one of the key drivers for environmental degradation. A transition to lower meat and dairy consumption, as recommended by the 'Planetary Health' diet of the EAT-Lancet expert commission, improves human health and has far-reaching positive consequences for the Global Commons. Together with a reduction of food waste, an adoption of the Planetary Health diet reduces food sector emissions of CH_4 and N_2O drastically. By reducing land requirements for food production, in addition to inputs for agriculture such as irrigation and nitrogen fertilizer, sustainable diets are key to facilitating ambitious climate targets and preserving biodiversity.

Pull all levers to make land and food systems more sustainable: Although supply-side measures to make agricultural production systems more resource-efficient, demand-side transitions to healthy diets and low food waste, and systemic solutions to disincentive land system change and associated

GHG emissions are each yielding substantial progress on some Global Commons domains, none can on their own achieve - despite their ambitious design - the vision of returning within those Planetary Boundaries that are closely tied to land use and agriculture. Thus, policy coherence is key to harnessing the many synergies between individual strategies and is likely to have many co-benefits in other areas, such as nitrogen-related air and water pollution and public health.

Beyond the physical dimensions of the Global Commons domains assessed, we also recommend to further take into account measures that primarily target societal development goals and that can also have substantial impacts on the Global Commons. Many of these interventions can directly or indirectly affect the justice, acceptability and feasibility of policies targeting the Global Commons domains, such as improving global justice in sharing the burden for implementing transformations, gender equality and access to education.

The feasibility of the implementation of such ambitious measures will depend on well-working governmental institutions and strong international cooperation. Although each government should control its own transformation strategy, coordination and compensation mechanisms at the global level are critical given the significant challenges arising from the profound transformations in the energy, agricultural and industrial systems, particularly in the global south. International cooperation and strong regional institutions will be needed to prevent leakages in the impact of policies, especially in the land sector and between the Global South and Global North. Moreover, due to the non-predictability of all impacts of certain measures, monitoring and readjustment strategies will be necessary and should be included in the conception of governance strategies aiming to keep the impacts of human activities on the Global Commons domains within Planetary Boundaries.

To access the full report, visit

https://cgc.ifi.u-tokyo.ac.jp/wp-content/uploads/2024/03/GCS_report_2024.pdf

Or scan the QR Code below

PIK

Potsdam Institute for
Climate Impact Research

CENTER FOR
GLOBAL
COMMONS