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Edited by
Veerabhadran Ramanathan
Joachim von Braun

Resilience of People and Ecosystems under Climate Stress

Proceedings of a Conference held at
Casina Pio IV, Vatican City, 13-14 July 2022

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Beginning in the middle of the last century and overcoming many difficulties, there has been a growing conviction that our planet is a homeland and that humanity is one people living in a common home. An interdependent world not only makes us more conscious of the negative effects of certain lifestyles and models of production and consumption which affect us all; more importantly, it motivates us to ensure that solutions are proposed from a global perspective, and not simply to defend the interests of a few countries. Interdependence obliges us to think of one world with a common plan. Yet the same ingenuity which has brought about enormous technological progress has so far proved incapable of finding effective ways of dealing with grave environmental and social problems worldwide. A global consensus is essential for confronting the deeper problems, which cannot be resolved by unilateral actions on the part of individual countries. Such a consensus could lead, for example, to planning a sustainable and diversified agriculture, developing renewable and less polluting forms of energy, encouraging a more efficient use of energy, promoting a better management of marine and forest resources, and ensuring universal access to drinking water.

Pope Francis, Encyclical Letter *Laudato si'*, 164.

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Concept Note

A new initiative by the Pontifical Academy of Sciences to bring researchers, policy makers and faith leaders together to understand the scientific and societal challenges of climate change and develop solutions for enabling resilient people and resilient ecosystems.

We can no longer take comfort in just relying on climate mitigation. Adaptation to current weather extremes and related climate risks are upon us and should be considered as a central theme in climate policy actions. While we note that the field of climate resilience,[1] brings mitigation and adaptation under one common framework, this workshop has a focus on adaptation challenges, which are confronting the entire world population, but particularly the poorer segments of countries and societies. Our goal for this new PAS initiative is to bring resilience to center stage of climate summits and protect people and ecosystem from unavoidable climate extremes in the coming decades and to foster justice and the crucial good that is peace. One of our central concerns is the welfare of vulnerable populations, almost three billion, in the world.

Our approach is to acknowledge the multiple intersecting crises facing humanity: Climate Crisis, Biodiversity and Equity. While the primary focus is on the climate crisis, we will look for opportunities where addressing one benefits the other two crises. Following this guideline, our discussion of solutions will broaden the current focus on technology to include nature-based climate solutions that bring in oceans, mangroves, working lands and forests, which *de facto* will address the diversity and equity crises, as well as solutions with institutional innovations. In short, the primary focus will be on the two-way coupling between natural systems and social systems. Any approach to resilience building, must recognize the fact that it could take three to five decades to bend the global warming curve, and that climate will be changing from one decade to the next during this period without any norms.

[1] We adopt the IPCC definition for resilience as "the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity of self-organization, and the capacity to adapt to stress and change".

Scope

We are organizing this workshop for scientists in natural sciences, social sciences and humanities. The workshop is organized around two major themes of resilience, with the first being more briefly covered, while the main focus is on the second theme:

I. The likely climate change risks and trajectories: Under this theme we will consider:
   - Tradeoffs between social, economic and environment goals.
   - Unavoidable climate changes, disruptions, risks and threats.
   - We will distinguish between risks that are tolerable and acceptable from those which are intolerable.

II. Adaptation to Climate Risks and Threats. The highlighted topics are: Public Health including mental health; food and nutrition security; water and energy security; Climate refugees and mass migration; Urban and Rural resilience, including land use plans and protection of critical public assets and services; Coastal populations with emphasis on small island nations. Climate proofing critical infrastructure; financial and fiscal risks including climate financing for the vulnerable populations.

V. Ramanathan J. von Braun

Message of His Holiness Pope Francis to the Participants in the Conference on "Resilience of People and Ecosystems under Climate Stress"

From the Vatican, 13 July 2022

I offer cordial greetings to the organizers and participants in the Conference on *Resilience of People and Ecosystems under Climate Stress* sponsored by the Pontifical Academy of Sciences. I thank His Eminence Cardinal Peter Turkson, Chancellor of the Academy, His Excellency Bishop Marcelo Sánchez Sorondo and all those responsible for making this gathering possible.

The phenomenon of climate change has become an emergency that no longer remains at the margins of society. Instead, it has assumed a central place, reshaping not only industrial and agricultural systems but also adversely affecting the global human family, especially the poor and those living on the economic peripheries of our world. Nowadays we are facing two challenges: lessening climate risks by reducing emissions and assisting and enabling people to adapt to progressively worsening changes to the climate. These challenges call us to think of a multi-dimensional approach to protecting both individuals and our planet.

The Christian faith offers a particular contribution in this regard. The Book of Genesis tells us that the Lord saw that all he had made was very good (cf. *Gen* 1:31) and entrusted human beings with the responsibility of being stewards of his gift of creation (cf. *Gen* 2:15). In the Gospel of Matthew, Jesus reinforces the goodness of the natural world by reminding us of God's care for all his creatures (cf. *Mt* 6:26.28-29). In light of these biblical teachings, then, care for our common home, even apart from considerations of the effects of climate change, is not simply a utilitarian endeavour but a moral obligation for all men and women as children of God. With this in mind, each of us must ask: "What kind of world do we want for ourselves and for those who will come after us"?

To help answer that question, I have spoken of an "ecological conversion" (cf. *Laudato Si'*, 216-221) which demands a change of mentality and a commitment to work for the resilience of people and the ecosystems in which they live. This conversion has three important spiritual elements that I would offer for your consideration. The first entails gratitude for God's loving and generous gift of creation. The second calls for acknowledging that we are joined in a universal communion with one another and with the rest of the world's creatures. The third involves addressing environmental problems not as isolated individuals but in solidarity as a community.

On the basis of these elements, courageous, cooperative and far-sighted efforts among religious, political, social and cultural leaders on local, national and international levels are needed in order to find concrete solutions to the severe and increasing problems we are facing. I am thinking, for example, of the role that the most economically advantaged nations can play in reducing their own emissions and providing financial as well as technological assistance so that less prosperous areas of the world may follow their example. Also crucial is access to clean energy and drinkable water, support given to farmers around the world to shift to climate resilient agriculture, a commitment to sustainable paths of development and to sober lifestyles aimed at preserving the world's natural resources and the provision of education and healthcare to the poorest and most vulnerable of the global population.

Here I would also mention two additional concerns: the loss of biodiversity (cf. *Laudato Si',* 32-33) and the many wars being waged in various regions of the world that together bring with them harmful consequences for human survival and wellbeing, including problems of food security and increasing pollution. These crises, along with that of the earth's climate, show that "everything is connected" (*Fratelli Tutti*, 34) and that promoting the long-term common good of our planet is essential to genuine ecological conversion.

For the above-mentioned reasons, I have recently approved for the Holy See, in the name and on behalf of Vatican City State, to accede to the United Nations Framework Convention on Climate Change and the Paris Agreement, with the hope that "although the post-industrial period may well be remembered as one of the most irresponsible in history, nonetheless there is reason to hope that humanity at the dawn of the twenty-first century will be remembered for having generously shouldered its grave responsibilities" (*Laudato Si'*, 165).

Dear brothers and sisters, I am pleased that your work in these days is dedicated to examining the impact of changes in our climate and seeking practical solutions that can be implemented promptly in order to increase the resilience of people and ecosystems. In working together, men and women of good will can address the scale and complexity of the issues that lie before us, protect the human family and God's gift of creation from climate extremes and foster the goods of justice and peace.

With the assurance of my prayers that your Conference will bear good fruit, I invoke upon all of you the abundant blessings of Almighty God.

Francis

I. SETTING THE SCENE

Climate Resilience: Why, When and How?

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Summary and Recommendations

Summary of Data: Climate change is no longer a problem that is in the distant future; it no longer is a problem that affects just those in the margins of society. It has become a disruptive phenomenon affecting all aspects of society, including social, economic, and agricultural systems, and disrupting terrestrial and marine ecosystems. The number of weather/climate/water-related disasters has increased five-fold during the last 50-year period.

Recommendations:
- We can no longer rely just on mitigation of climate change but must broaden the framework of climate actions to include adaptation and transformation. In this broader framework of Climate Resilience, social and natural systems must be transformed to become climate resilient.
- Climate resilience actions must consider two other interrelated major crises: Unsustainable loss of biodiversity; and unsustainable inequality among people and nations.
- Championing and enacting mitigation actions to reduce climate risks needs to be the primary objective of the wealthiest one billion population, while implementing climate adaptation measures must be the primary focus of the poorest three billion.
- The planet will most likely cross the 1.5°C warming threshold in 8 to 12 years (2030 to 2034). Limiting warming to 2°C or slightly lower is still an achievable goal. Adaptation measures need to plan for warming of at least 2°C.
- A major effort focused on the poorest three billion people must be immediately initiated to adapt to the impacts of climate change and provide: 1) access to affordable clean energy and water; 2) help to farmers impacted by droughts and heat stress with improved governance and technical assistance to shift to drought-resilient agriculture; 3) integration of technological solutions with nature-based solutions; 4) improved access to health care to cope with mental as well as physical health effects.

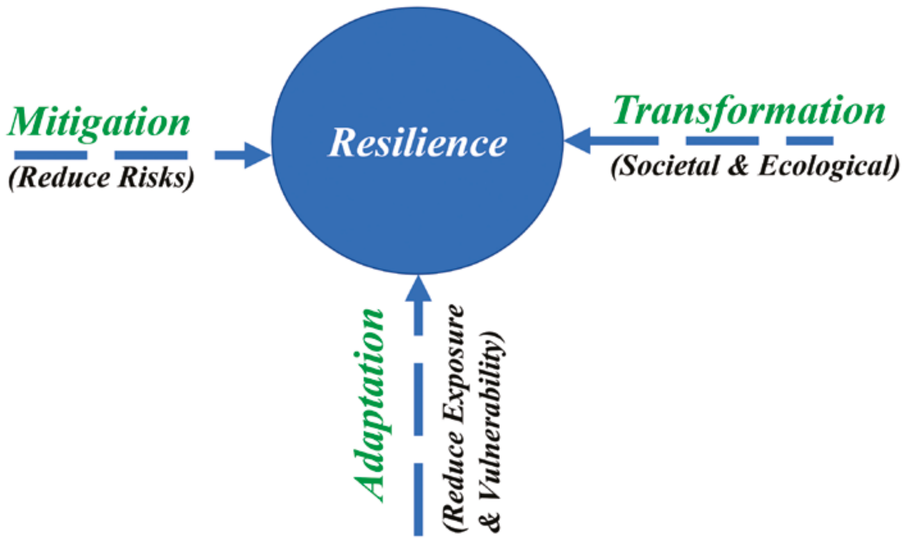
Resilience: What is it?

Resilience has a wide spectrum of interpretations. IPCC [1] goes on to define Resilience as follows:

> *Resilience in this report is defined as the capacity of social, economic and ecosystems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure as well as biodiversity in case of ecosystems while also maintaining the capacity for adaptation, learning and transformation.*

IPCC [1] elaborates on the above definition by stating: "Resilience as a system trait overlaps with concepts of vulnerability, adaptive capacity, and thereby risk, and resilience as a strategy overlap with risk management, adaptation, and also transformation".

Climate resilience needs to be built on three pillars: First Pillar – Mitigation to reduce climate change risks; Second Pillar – Adaptation to reduce exposure and vulnerability to climate changes that are unavoidable; and Third Pillar – Transformation of society to develop the capacity to prepare and plan for mitigation and adaptation. This transformation needs to happen bottom-up from the level of an individual and a community to national level.



Climate Resilience: Need for a new framework to address climate risks

- Climate change is no longer a problem that is in the distant future; it no longer is a problem that affects just those in the margins of society. It has become a disruptive phenomenon affecting all aspects of society, including social, economic, and agricultural systems and disrupting terrestrial and marine ecosystems. The number of weather/climate/water-related disasters has increased five-fold during the last 50-year period [2].
- Bending the warming curve quickly is a global imperative. Since we have delayed too long to bend the emissions curve, bending the warming curve requires more ambitious actions in addition to deep cuts in carbon emissions. Both the emissions and the warming curves are rising unsustainably. Fossil fuel emission of CO_2 reached its highest value in 2021.
- The warming crossed the 1°C threshold around 2014. The planet is currently warming at an unprecedented rate and is very likely to amplify by 50% (from 1°C) and cross the 1.5°C threshold in 8 to 12 years, during 2030 to 2034 [3]. This is likely to become the COVID moment for the climate crisis, affecting everyone on the planet directly or indirectly. Without deep emission cuts, the warming can cross the dangerous threshold of 2°C in about 25 years [1, 3]. The velocity of changes is already posing severe constraints and limits on adaptation [1]. Currently, 50% of the world population is subject to severe water shortages and 3.3 billion people live in countries with high climate vulnerability [1].
- We can no longer rely just on mitigating climate change but must broaden the framework of our climate actions to include adaptation. In this broader framework of *Climate Resilience*, social and natural systems must be transformed to become climate resilient.

Finally, climate resilience actions must consider two other interrelated major crises: Unsustainable loss of biodiversity [4]; and unsustainable inequality among people and nations. There are amplifying feedback effects between the three crises, such that solving one of them will have co-benefits for the other two.

Climate Resilience: Criteria setting Context

Inequality

There is a vast inequality among the global population in terms of income, wealth, access to energy, water, healthcare, and other resources. It is helpful for this discussion to divide the population into three groups [5]: The wealthiest 15% of the population, which is currently about 1 billion.

I refer to this group as the Top One Billion (T1B). The poorest 40% of the population, which is about 3 billion, referred to as Bottom Three Billion or B3B. In between the two, is the middle 45%, or about 4 billion, M4B. The uncertainty in these demographic statistics is at least 10%. For example, the 40% cited for B3B can range from 36% to 44%.

Per capita income of the poorest three billion, B3B, is less than \$10/day (US dollars) and that of the middle 4 billion is between \$10/day to \$30/day, i.e., about 85% of the population earns less than \$30/day [6]. The combined wealth of the B3B is about 2%, and that of the top one billion is 76% [6]. The poorest three billion rely on primitive fuels (wood, dung and solid coal) and technologies (mud stoves, open burning, kerosene) for cooking, heating, and lighting.

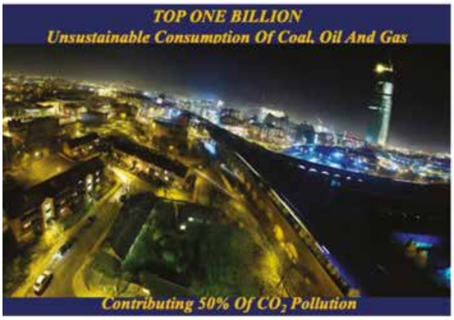


Image reproduced from Pixabay.

Photo Taken by Author (Ramanathan) in 2009.

The top one billion contribute about 50% or more of the climate warming pollution, such as CO_2, methane and HFCs. On the other extreme, the 3 billion in the B3B contribute only about 7%. Among the 3 billion in B3B, the poorest 0.7 billion emit just 0.5% of the CO_2 pollution [6].

On the receiving end of the climate risks, climate change impacts are felt disproportionately by the B3B, living mostly in rural areas. Over the last forty years, extreme weather has led to a cumulative 606,000 mortalities and 4.1 billion displaced people [7]. Global warming has decreased the GDP of the bottom three billion by 17% to 31% [8].

Globally, agriculture productivity decreased by 21% due to climate change and climate pollution [9]. An extreme case is India, where the warming and fossil fuel-related air pollution decreased wheat yield by 34% [10]. One of the main reasons is that the warming (and related drying) impacts those (most of the B3B population) living in hotter areas more than those (more than half of T1B population) living in equitable climates. In short, climate impacts act as force multipliers of the underlying socio-economic-cultural forces that cause inequality.

> *Global climate mitigation actions must be championed and enacted by the T1B group to limit climate risks to manageable levels, even for the B3B and M4B groups; implementing climate adaptation measures (through T1Bs technological/financial support) must be the primary goal of the B3B.*

Near and Long Term

Our main concern is the 21st century, although climate changes, once initiated, can last thousands of years due to the millennial time scales of ice sheets and ocean circulation. The near term applies to the period until 2050 and the long term beyond 2050. This categorization of the time scales is motivated by the fact that unchecked warming can exceed the 2°C guard rail for catastrophic climate risks by 2050, and deep reductions to the emissions of CO_2 and other heat-trapping gases to near-zero levels must happen by 2050. Beyond 2050, failure in drastic mitigation actions can lead to catastrophic/unmanageable warming levels of 3°C or more [1,3] that could lead to crossing of various tipping points in the social and natural systems.

> *The primary goal is to limit the warming below 2°C by 2050 and beyond, which is still an achievable goal.*

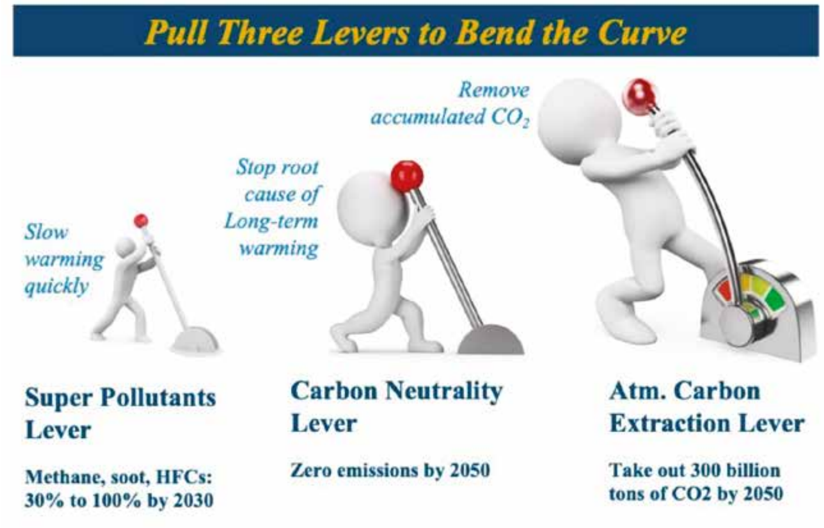
Inertia in the social and the natural systems

There are numerous sources of inertia which pose severe constraints on the efficacy of mitigation actions. Let us start with the inertia in the social system: 1) Time it takes for society to respond to scientific findings; 2) Time it takes for policy makers to respond to societal concerns; 3) Time to adapt available technologies and develop new ones for reducing emissions and the time for global scaling. Inertia from the above three sources can range from ten to fifty years. Next comes the inertia in the natural systems.

Once emitted, heat trapping gases stay in the atmosphere for about a decade (methane and HFCs) to several decades (CFCs) to a century (nitrous oxide) and even longer (carbon dioxide). The ocean-land-atmosphere system has thermal inertia such that about 1/2 to 2/3 of the projected warming (that results from today's emissions) is delayed by about 10 to 15 years and the remaining 1/3 to 1/2 will unfold over multi-decadal to longer time scales.

Because of these sources of inertia, the crossing of the 1.5°C warming in the next 8 to 12 years is mostly assured irrespective of the mitigation actions that are being contemplated currently.

> *We can still limit the warming below 2°C, provided we start bending the emissions curve in the next five years, which requires the entire global society to pull simultaneously on three levers (illustration below).*



Source: Ramanathan, Author.

Building Climate Resilience: The Three Pillars

The First Pillar

Mitigation. We have waited too long to make deep cuts. The T1B must reduce their own emissions and provide financial as well as technological assistance for the rest of the world to follow their example.

Bending the warming curve below 2°C by 2050 requires society to pull on three levers [11; 12] as illustrated above:

1) The Short-lived climate pollutants (methane, HFCs, surface and lower atmosphere ozone & Black Carbon soot) lever. With available technologies and current air-pollution governance mechanisms, we can cut the emissions of these pollutants by 40% to 100% within 25 years and cut the rate of warming by half.

2) The Decarbonization lever. We must bring down the fossil fuel-related emissions of CO_2 close to zero before 2050; This is the most important step for keeping the warming below 2°C for the rest of the century and beyond.
3) The Atmospheric Carbon Extraction (ACE) lever. The blanket of carbon dioxide is already too thick (it weighs 1.1 trillion tons already and we are emitting about 40 billion tons every year). From now to 2050, we must extract as much as 300 billion tons of CO_2 out of the air and thin the heat-trapping blanket sufficiently.

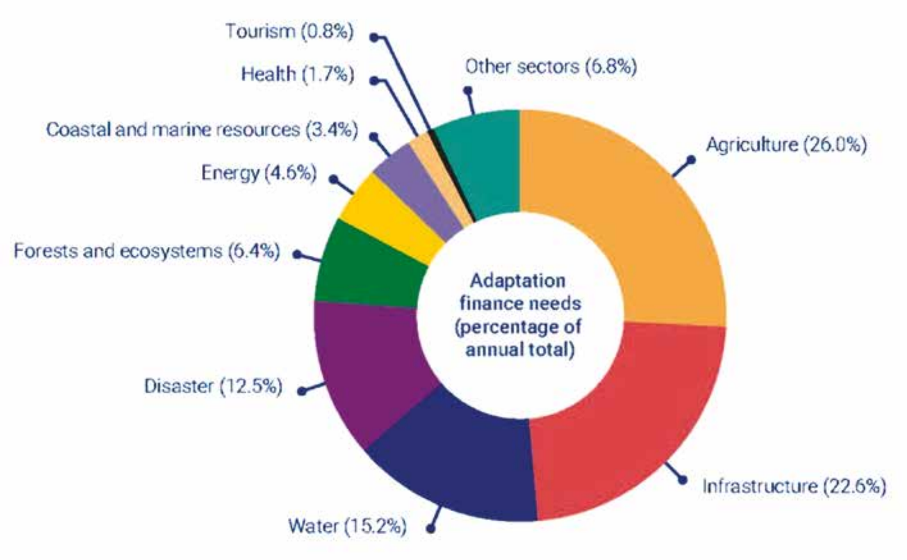


Figure. Adaptation financial needs by sectors based on data from 26 developing countries. Source: Gap report, 2021. UNEP report COP_26 Glasgow meeting.

The Second Pillar: Adaptation

The first step is to reduce vulnerability and exposure to weather extremes and other severe risks such as sea level rise and ocean acidity that are already occurring. Biodiversity loss and degradation of coastal and other ecosystems caused by climate change are also major risks. The next step, much more daunting, is to develop plans for future climate changes. To give but one example of its daunting nature, with unchecked emissions, the warming will progressively increase from 1.5°C to 2°C to 3°C etc. during the 21st century. Should adaptation planners, target 1.5°C, 2°C or 3°C or more? My best guess is that we should plan for 2°C warming for the time being and update it as needed, in about five to ten years from now.

While mitigation starts with and relies on top-down policies, adaptation measures require a different approach. It must start at the individual to local community level and integrate scientific knowledge with knowledge of local cultures and local governance mechanisms. Adaptation also must rely on top-down actions on a national to global level to deal with long-term risks such as sea level rise, ocean acidity and biodiversity loss. Several sectors are impacted (Figure above reproduced from [13]) with agriculture and infrastructure topping the list.

A major effort focused on marginalized and vulnerable populations, especially the B3B, must be immediately initiated to adapt to the impacts of climate change. It must provide: 1) access to clean energy and drinkable water for all; 2) help to farmers suffering from droughts and heat stress around the world with improved water and land governance, enhanced water storage and technical assistance to shift to drought-resilient agriculture; 3) integration of technological solutions with nature-based solutions; 4) cli-

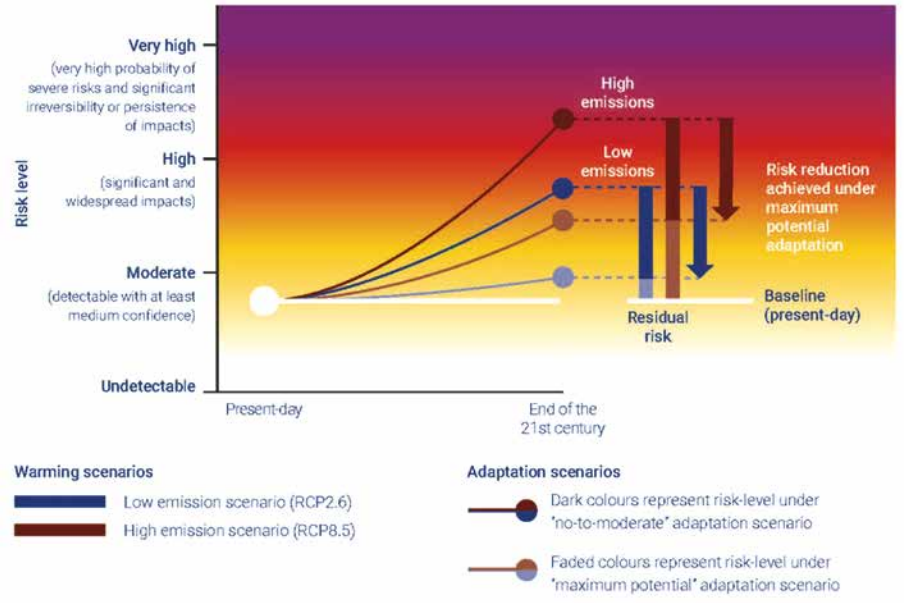


Figure. The real efficacy of mitigation and adaptation in reducing climate risks and increasing climate resilience. Source: Adaptation Gap report, 2021. UNEP report to COP26 Glasgow meeting.

mate change poses grave threats to human health, including mental health. Improved access to health care for the B3B and M4B should be prioritized.

The potential of adaptation for reducing risk exposure is huge. UNEP estimates (Figure above reproduced from [12]) that the risk reduction (through reduction in exposure) is as high as the risk reduction through mitigation. This does not, however, mean we can forego mitigation. What it implies is that adaptation actions are just as important as mitigation actions for protecting human and natural systems from climate risks.

The Third Pillar: Transformation

The third pillar of resilience is transformation of society and ecosystems. Transformation, instead of incremental transitions, can change the fundamental attributes of natural and social systems. To give but one example, growth in GDP is strongly coupled with energy generation and consumption. Transformation would involve decoupling energy consumption from economic growth, by increasing energy efficiency, reducing energy waste, and reducing the carbon intensity of energy consumption. On the social side, behavioral changes for reducing consumption and working for the common good are going to be essential attributes for climate risk reductions. Another example is a socio-economic transformation that will enable equitable access to renewable energy and natural resources for all and preserve the ecosystem and biodiversity for generations to be born. Such singular transformations require massive education of everyone from children to senior citizens, so that they will collectively support drastic and bold actions by their religious, cultural, social, and political leaders.

I will conclude with the most formidable challenge of all, which is uncertainty. There is uncertainty in societal will to bend the emissions curve; uncertainty in the magnitude of the future warming and resultant impacts, due to the multitude of feedbacks between and within the human and natural systems. Compounding all these uncertainties is the uncertainty in the optimal responses by society. We have an obligation not to let uncertainty paralyze us to inaction. Since uncertainty can go both ways (i.e., make it much worse or much better), use the uncertainty to catalyze rapid actions. It is going to require multiple iterations where we learn in the field by experimentation to sort out better actions [14]. Climate scientists have a special role to help society navigate through the uncertainties, provided scientists and scientific institutions form alliances with governments, private sector, faith-based institutions and NGOs who are on the front lines of climate actions.

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Uninhabitability, the Limits to Resilience, and a Passport to Safety

Kira Vinke and Hans Joachim Schellnhuber

Flooding events in the Pakistani Sindh province killed more than 1700 people over the summer of 2022, following extreme spring heatwaves. With 15% of the country's entire population affected by the water masses, several millions were displaced. Even those people well-adapted to the cycles of the monsoon had no options left to guard themselves from relentless rains and rising waters. The floods eventually subside, yet livestock losses and the vast destruction of fertile land will curtail economic development for years to come.

The situation in the South Asian country is no longer solely a tragic abnormality. As global warming is accelerating, high air temperatures can translate into unleashed precipitation. Overall, extreme events around the world are becoming more frequent and more intense, posing grave human security risks and requiring ever larger infrastructural adaptation.

Worst affected are *the bottom billions* of the human population – the globally deprived, whose active and institutional exclusion from growth and prosperity leave them without protection against the vagaries and hardships of the contemporary climate crisis. Intersecting vulnerabilities such as the marginalization of people of colour or the exclusion of women from decision-making bodies aggravate these inequalities and intentionally fortify group-specific limits to human resilience.

While current impacts at 1.2°C warming lead to loss of life and tremendous suffering, even more disastrous changes could be on the horizon. The scientific evidence indicates that further warming cannot be confined to below 1.5°C, while many recent studies conclude that greater dangers await human civilization beyond that lower guardrail of the Paris Agreement. Climate change can have truly catastrophic effects, such as a shut-down of the Gulf Stream System, which has already significantly weakened [1], or the melting of the Greenland Ice Sheet, possibly rendered irreversible by powerful feedback loops [2,3]. Worst-case scenarios accounting for interacting tipping dynamics have hardly been explored [4], so there is clearly a need for an appropriate research agenda. In fact, a Special Report by the IPCC would be a major step forward in this context.

Yet, the Earth System crisis is not only deepening due to climate impacts. Several planetary boundaries have been crossed already and many will be transgressed in the decades to come [5,6,7]. These include unprecedented biodiversity loss and disruptions of the nitrogen cycle.

The crises triangle of global warming and large-scale ecosystems collapse, the Covid-19 pandemic, and the Russian war of aggression against Ukraine are overstretching even the management capacities of prosperous societies. Climate impacts will most likely exacerbate the pressures on societal systems, thereby triggering cascading risks that range from food shortages to resource conflicts and forced migration [8]. Over the past decade, the annual new displacements due to "natural" disasters were consistently higher than those triggered by violence and conflict [9]. Disaster-related displacement is not fully attributable to climate change. But population growth in areas highly exposed to environmental disruption will undoubtedly lead to increasingly devastating humanitarian crises. Higher warming scenarios suggest that within the next 50 years, up to three billion people could be living outside the human climate niche, the temperature realm that enabled our civilization to flourish [10]. Because there are physiological and technological limits to the resilience of humans and their respective cultures, such extreme – albeit not implausible – scenarios need to be urgently prevented. We will elaborate on this below.

The international community is now tasked with a*voiding the unmanageable*, such as run-away global heating, and *managing the unavoidable*, i.e., the challenges arising from current and locked-in warming. The triad response to avert the most severe outcomes of the climate crisis therefore is: mitigation, adaptation, migration.

Mitigation

Climate change is a negative externality of economic and social systems that results from reckless over-use of natural resources and sinks. This grave imbalance in humanity's relationship with its environment is finally revealing its detrimental world-wide effects. The burning of fossil gas, coal and oil by middle- and upper-income groups, largely concentrated in industrialized countries, is eroding the livelihood base of lower-income groups, such as smallholder farmers in Pakistan, a country in which average per-capita emissions are approximately 1tCO_2/year. Since several decades it is clear that fossil-fuel use needs to be cut. But after a slump in global emissions due to the pandemic-related restraints in 2020, fossil business is reaching new highs as industrial activities return to their old normal.

Moreover, in the expectation of national economic setbacks in the context of the Russian war against Ukraine, wealthy countries like Germany seek to stabilize their energy supply by the short-term ramping up of coal-fired power plants. Other sectors, such as the emissions-intensive construction or shipping industries have barely seen any change towards bending their greenhouse-gas curves. In order to stay on the Paris pathway, global emissions would, however, need to be halved each decade, following the logic of a "carbon law" [11]. The current shocks to the international order and the economic make-up are watersheds for either deepening crises or the rebalancing of natural and social systems. Stimulus packages, which often seek to cement the status quo, rather need to be designed to improve or overcome locked-in economic models that rest on unsustainable practices. The latter have not only wrecked ecosystems around the world, but also imposed structural violence upon disadvantaged groups on all continents.

Adaptation

Intensifying climate impacts require adaptation measures applied to infrastructures, institutions and societies. Without adequate funding mechanisms, those already disadvantaged by industrial globalization will have to pay the highest price. Wealthy countries have agreed to provide 100 billion USD per annum in climate finance from 2020 to 2025 to developing nations. But even this minimum promise has not been held in the first years [12]. Also, most of the spending went into necessary, but largely profit-oriented mitigation measures, whilst adaptation finance fell short, as a rule.

Yet only through adaptive interventions can the most vulnerable be guarded from even moderate warming dynamics. Many smallholder farmers and fisherfolk have sustained their livelihoods in barren environments. But the disturbances of climate change render the upkeep of traditional practices in many places impossible for growing populations. Investments into insurance systems against extreme weather events or nature-based solutions such as Farmer Managed Natural Regeneration (FMNR) [13,14], which carries large co-benefits for mitigation, are tested ways forward to more resilient ecosystems-based livelihoods.

Migration

The latest report of the Intergovernmental Panel on Climate Change (IPCC) outlines the tremendous levels of risks some regions will have to face even at warming levels below 2°C [15]. Some areas may become too dangerous to live in, others may not sustain the same amount of people that are residing there today. Pessimistic scenarios of the World Bank estimate 200 million people moving internally until the middle of the century due to the anthropogenic changes in climate [16].

At this point, let us address a question, which most of us did not dare to ask for a long time, but which is becoming more and more pertinent as climate change progresses and precious time is lost by the nations of our world: *What magnitude of global warming would exceed humanity's ability to adapt to or recover from the resulting impacts?*

There is a robust expert consensus that a sustained increase of global mean surface temperature by more than 4°C could not be managed in any conceivable way. This conclusion is epitomized by Fig. 1, which summarizes the latest findings on tipping elements in the Earth's climate system.

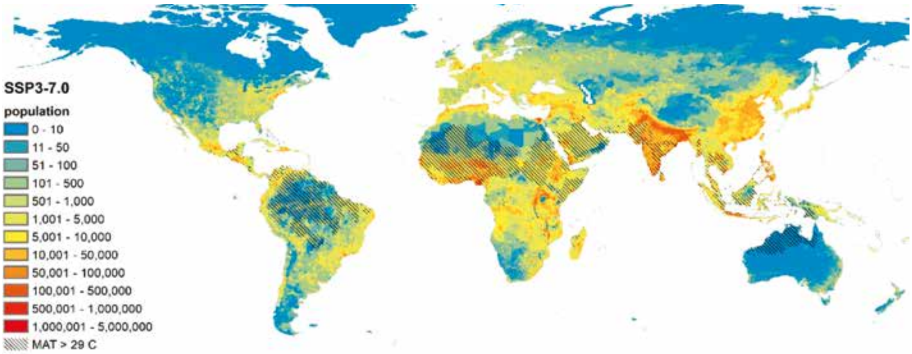

Figure 1 [17]. The location of climate tipping elements in the cryosphere (blue), biosphere (green), and ocean/atmosphere (orange), and global warming levels at which their tipping points will likely be triggered. Pins are colored according to our central global warming threshold estimate being below 2°C, i.e., within the Paris Agreement range (light orange, circles); between 2 and 4°C, i.e., accessible with current policies (orange, diamonds); and 4°C and above (red, triangles).

The basic story told by this cartoon is that the Holocene environment, which has fostered the rise of human civilization, would be almost entirely destroyed in such a hot-house climate. In our view, the 3-4°C range is the *diabolical zone*: While breaching the 4°C-line can probably still be avoided by sub-optimal climate policies and measures, there are many realistic scenarios that could push our planet towards the 3°C-line or even beyond [18]. Just think of a world disunited by military conflicts such as the current Russian war of aggression against Ukraine or by increasing hostility between leading economies. Given the past failures to implement international agreements and rising international tensions can we safely assume that all countries will cooperate on limiting global warming? Therefore, a planetary temperature rise "well above" 2°C in the Anthropocene is not a far-fetched dystopia. Sea-level rise, water scarcity in the wake of alpine-glaciers melting, unbearable humid heat, or the expansion of climatic areas supporting tropical diseases could unfold in unprecedented ways for human civilization.

This is not the full story, however. Before the world population is supposed to peak at around 10 billion after 2050, roughly two billion human beings would be added by the demographic make-up around the world. To be specific, this population growth will mainly happen in the Global South, and most of these additional 2 billion humans will be born into a life of poverty. This means that they will join and expand the present-day "bottom billions" who are specifically vulnerable to climate change for mainly two reasons:

First, many are forced to settle in locations – flood-prone areas, unstable hill slopes, storm-exposed corridors, agricultural bad-lands, peri-urban areas without essential infrastructures, etc. – which are disproportionally exposed to extreme climate-related events. *Second*, they do not have sufficient capacities for resilience, i.e., they do not have the income or insurances which would allow them to recover after a disastrous event (such as a tropical storm or a long-lasting drought).

As a consequence, global warming in the 3-4°C range could deprive several billion people (!) of a safe place to live and prosper in the course of the 21st century. This mind-boggling finding is somewhat captured by Fig. 2, which is borrowed from a recent paper on the "climate endgame".

What would become of all these people? They would either stay where they are, trapped by social and natural forces, and many would be destined to perish. Or they would decide to move for survival – the majority along thousands of exhausting, pernicious, illegal, and often fatal roads. The mistreatment and human rights violations against refugees happening at quasi-impenetrable borders in various parts of the world already today would likely multiply into chaos on a hot-house planet.

We bluntly conclude that a 3-degree warmer world would become unmanageable and could not sustain a human(e) civilisation as we know it.

Therefore, the global community of nations needs to do everything to keep us as far away as possible from that hard limit to adaptation and resilience. Yet even in a, say, 1.8°C or 2.2°C warmer world, migration challenges

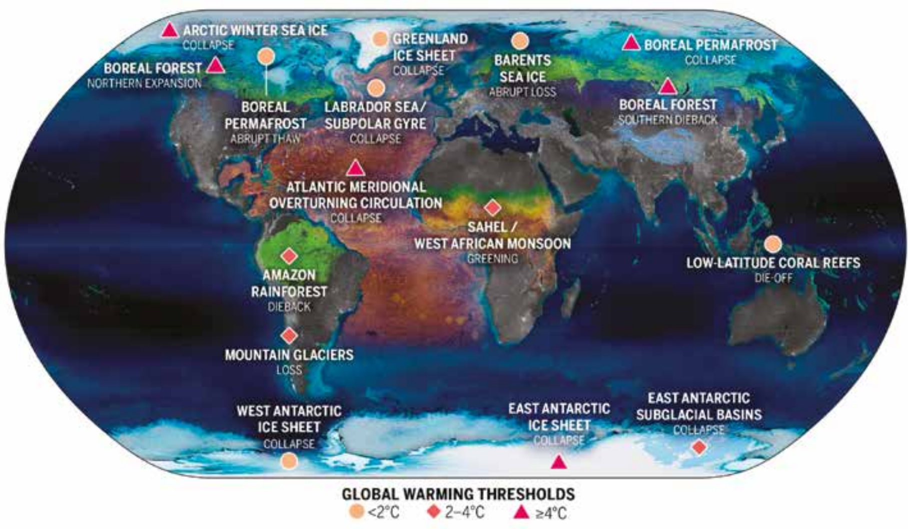

Figure 2 [19]. Overlap between future population distribution and extreme heat. CMIP6 model data [from nine GCM models available from the WorldClim database] [20] were used to calculate MAT under SSP3-7.0 during around 2070 (2060-2080) alongside Shared SSP3 demographic projections to ~2070 [21]. The shaded areas depict regions where MAT exceeds 29°C, while the colored topography details the spread of population density.

of unprecedented dimensions must be met, so conventional approaches will not suffice. Most importantly, significant population redistributions shall occur peacefully, even within and between densely populated countries.

We propose to consider, among other novel approaches, a scheme that has a historical analogue, invented for a different purpose and implemented under different conditions though: At present, international migration is strongly regulated through often forceful border regimes. Suffering climate change impacts confers no eligibility for asylum under the cornerstone of refugee protection, the Geneva Convention. If no legal pathways for migration are created for those severely affected by climate change, loss of life and human rights violations, as they are already taking place in the Mediterranean, the Sahara, the US-Mexican frontier, the India-Bangladesh border and elsewhere, will become rampant.

For this reason, we suggest as one of many necessary instruments to pre-emptively address the looming catastrophe the creation of a *climate passport* for people living in areas that are becoming uninhabitable due to anthropogenic global warming. This idea is inspired by the Nansen passport, a legal document that enabled people displaced by the First World War to legally reside and work in their host countries. It was initiated by the Nobel peace laureate and renowned polar explorer Fridtjof Nansen (1861–1930) and was eventually recognized by more than 50 states. The instrument of a climate passport intends to offer those whose agency has been curtailed by the extreme effects of global warming the freedom to choose where to continue their lives if their homelands have been destroyed [22].

We close this article with a climate parable:

Imagine a certain species of fish (say, cod) is driven out of its traditional marine habitat (say, the North Sea) by multiple impacts of anthropogenic interference with the climate system, such as thermal stress, ocean acidification, and depletion of oxygen and nutrients. As a consequence, instinctively and erratically, swarms of that species try to migrate to alternative domains (say, the Barents Sea), where they have a better chance of survival. Imagine also that those animals are stopped and sent back by naval border police at one of the lines separating national exclusive economic zones (say, the respective divide between Norway and Russia). The rejection is justified by the authorities by "the absence of asylum eligibility in line with the criteria of the Geneva Convention". Apart from its impracticability, such a scenario appears utterly cruel. Yet, many decision makers seem to be prepared to realize that very scenario, if instead of fish (crossing the Barents Sea) human beings were trying to migrate (crossing the Mediterranean on ramshackle vessels, for instance).

The preconditions for resilience under growing climatic pressures are mitigation, adaptation and the possibility of migration in the face of danger. Science confirmed what has long been known: the protection of nature goes hand in hand with the protection of our own kind. Only by addressing parallel crises holistically with a focus on prevention can Planet Earth continue to serve as our *common home*.

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II. GLOBAL CONTEXT AND PRIORITIES FOR RESILIENCE

Economic Options for Transformation and Resilience

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1. Introductory remarks on resilience

Every society clings to a myth by which it lives. Ours is the myth of economic growth. For the last five decades the pursuit of growth – a notion not to be confused with human integral development – has been the single most important policy goal across the world. As indicated by T. Jackson (*Prosperity without growth. The transition to a sustainable economy,* London, Routledge, 2011), the global economy is almost five times the size it was half a century ago. If it continues to grow at the same rate, the economy will be 80 times that size by the year 2100. This extraordinary ramping up of global economic activity has no historical precedent. It's totally at odds with our scientific knowledge of the finite resource base and the fragile ecology on which we depend for survival. And it has already been accompanied by the degradation of an estimated 60% of the world's ecosystems. Prosperity consists in our ability to flourish as human beings – within the ecological limits of a finite planet. The challenge for our society is to create the conditions under which this is possible. It is the most urgent task of our times.

An element of the living environment is resilient if it increases its capacity to adapt to Climate Change (CC), i.e., to limit, counteract, and reduce, with appropriate intervention, the effects of CC that may damage the environment. This resilience manifests itself in different ways, depending on the context that is considered. E.g., the resilience for a living being is its capacity for "self-repair" after damage. For an ecological system, resilience is the ability to return to its initial state after being subjected to a disturbance. For psychology, it is the ability to cope positively with traumatic events. To facilitate this adaptation to CC, resilience needs to be improved and promoted with appropriate procedures and technologies.

Two main strategies have been identified and implemented so far to cope with CC. The first is *mitigation*, acting on the causes of CC both by reducing Greenhouse Gas Emissions (GGE) and by reducing the use of fossil energy sources. The second is *adaptation*, to reduce the impacts of CC, i.e., implementing all those actions that can limit and counteract climate disruption, reduction of biodiversity, coastal fragility, etc. The mitigation strategy suggested by IPCC against CGE and their effects on CC, has not yet yielded the desired results. It is therefore necessary to focus on adaptation strategies, to immediately counter the effects of CC on the most vulnerable people and environments, by increasing their resilience through local interventions and targeted resilience actions. (M. Mammarella, G. Grandoni, "Resilience actions to counteract the effects of climate change and health emergencies in cities", *Ann. Ist. Sup. Sanità*, Rome, 55, 2019).

Our entire market economy has shown a lack of resilience. We essentially built cars without spare tires – to use a popular metaphor. Just-in-time inventory systems were marvellous innovations as long as the economy faced only minor perturbations; but they were a disaster, for example, in the face of COVID-19 shutdowns, creating supply-shortage cascades. As J. Stiglitz stressed several times (*Making globalization work*, 2006), markets do a terrible job of pricing risk, for the same reason that they don't price carbon dioxide emissions. Here lies the fundamental failure of neoliberalism and the policy framework it underpins. Markets on their own are short-sighted, and the financialization of the economy has made them even more so.

Precisely because markets do not account fully for key risks, there will be too little investment in resilience, and the costs to society end up being even higher. The commonly proposed solution is to "price" risk by forcing firms to bear more of the consequences of their actions. The same logic also dictates that we price negative externalities like greenhouse-gas emissions. Without a price on carbon, there will be too much pollution, too much fossil-fuel use, and too little green investment and innovation. But pricing risk is far more difficult than pricing carbon. The dire fact is that climate change represents the greatest market failure the world has seen. The year 2022 marks the 50th anniversary of the historic 1972 UN Stockholm Conference on the Environment. Yet the world has made very limited progress on the resilience issues since then.

2. Main reasons of the partial failure of the Glasgow Climate Pact

COP26 Conference (Glasgow, Nov. 2021) fell somewhat short of expectations for a plurality of reasons. One of the most relevant was the same lack of trust that has burdened global climate negotiations since COP1 (Berlin, 1995). Developing countries regard climate change as a crisis whose main responsibility falls on developed countries, which failed to honour their promise – dating back from COP15 in 2009 – to mobilize 100 BL $ per year for fair burden sharing in favour of the weakest countries. This fund could have been financed by adopting the Global Carbon Incentive (GCI) scheme proposed by Raghuram Rajan (31 May, 2021, *Project Syndicate*). The proposal is simple. Every country that emits more than the global average of around five tons per capita would pay annually into a global incentive fund, with the amount calculated by multiplying the excess emissions per capita by the population and the GCI. If the GCI started at $10 per ton, the US would pay around $36 billion, and Saudi Arabia would pay $ 4.6 billion. Meanwhile countries below the global per capita average would receive a commensurate payout.

This way, every country would face an effective loss of $10 per capita for every additional ton that it emits per capita, regardless of whether it started at a high, low, or average level. There would no longer be a free-rider problem, because poor countries would have the same incentives to economize on emissions as the rich ones. The GCI would also address the fairness problem. Low emitters, which are often the poorest countries and the ones most vulnerable to climatic change they did not cause, would receive a payment with which they could help their people to adapt. Moreover, the GCI would not snuff out domestic experimentation. It recognizes that what a country does domestically is its own business. Instead of levying a politically unpopular carbon tax, one country might impose prohibitive regulations on coal, another might tax energy inputs, and a third might incentivize renewables. Each one charts its own course, while the GCI supplements whatever moral incentives are already driving action at the country level.

A second reason of the partial failure of COP26 is the disconnection between climate models and macroeconomic models. Up to now, fiscal policies have been based on the assumption that the costs of climate damages would appear in an uncertain future, and should undergo a cost-benefit type of analysis, whereas the costs of transformation are now. This brings to underestimate the damages of extreme events and also the long-run benefits of climate policies. It would have been expected that COP26 would have advanced a radical revision of the principles and models utilized up to now to direct the choices of policy-makers. This was not the case. We urgently need a "green golden rule", whereby public investments for the transition do not contribute to the creation of so-called "bad" public debt.

Thirdly, to combat climate change, it is agreed that the most effective instrument is generalized carbon pricing. But this objective is difficult from several points of view, as the conditions of the countries participating in the COP differ both in terms of income levels and the energy mix adopted.

Accordingly, COP26 should have established an International Carbon Price Floor (ICPP) to accelerate emission reductions through effective policy action, whilst curbing the growing pressure to introduce border tax adjustments. To this regard, it should be noted that a group of 3,623 American economists has recently approved a document supporting the introduction of a Carbon Border Adjustment Mechanism (CBAM) supplementing the familiar carbon tax (See tinyurl.com/36krn3r2). ICPP should be based on two elements: a) it should be negotiated among a small number of key countries with high emissions levels; and b) the agreement should include the minimum carbon price that each of those countries commits to implement.

Fourthly, designing policy for climate change requires analyses which integrate the interrelationship between the economy and the environment. However, much of the standard economic modelling – including the celebrated Integrated Assessment Models (IAMs) – does not embody key aspects of the problem at hand. As J. Stiglitz and N. Stern ("The Social Cost of Carbon, Risk, Distribution, Market Failure: An Alternative Approach", NBER, 28472, Feb. 2021) have indicated, there are fundamental flaws in the methodologies commonly used to assess climate policy, showing systematic biases, with costs of climate action overestimated and benefits underestimated. The consequence is that using Integrated Assessment Models, with their choice of calibration, has led policy makers to conclude that societal optimization entails accepting an increase in temperature of almost 4°C, while the upper limit was set at 2°C already at the Paris Conference (2015). The Glasgow Conference should have underlined such a serious inconsistency and should have announced the constitution of a Global Working Group charged with the task of advancing an alternative methodology to direct the choice of policy-makers. S. Dietz et al. ("Are Economists Getting Climate Dynamics Right and does it Matter?", CESifo WP 8122, Feb. 2020) show that several of the most important economic models of climate change produce climate dynamics inconsistent with the current crop of models in climate science. These inconsistencies affect economic prescriptions to abate CO_2 emissions. This is a serious problem. Hence it is urgent to bring economic models in line with the state of the art in climate change.

3. Some measures to increase resilience

The option of reducing demand for emission-intensive goods and services has by far the highest potential for emission reductions in the industrialised world and it can be implemented immediately, although some aspects, such as adapting land-use planning to reduce travel distances, may take some time. To this regard, a useful tool of analysis is given by the Environmental Engel Curves (EECs), that plot the relationship between households' incomes and the pollution embodied in the goods and services they consume. These curves provide a basis for estimating the degree to which observed environmental improvements, which come in part from changing consumption patterns, can be attributed to income growth. These curves exhibit three characteristics. First, EECs are upward sloping: richer households are indirectly responsible for more pollution. Second, EECs are concave, with income elasticity less than one. Third, EECs have been shifting down over time: at every level of income, households are responsible for decreasing amounts of pollution. Most of this improvement is attributable to households consuming a less pollution-intensive mix of goods and services. This suggests the relevance of education and more generally of cultural investments (A. Levinson, J. O'Brien, "Environmental Engel Curves"; NBER, Jan. 2015).

A second measure to increase resilience is based on the following consideration. The costs of mitigation which are based on efficiency increases and technological change to stabilise greenhouse gas concentrations at levels corresponding to the 2°C limit will amount to less than three percent of the world-wide national product by 2030, if the concentration of greenhouse gases in the atmosphere is stabilised at a level corresponding to the 2°C limit. These costs rise significantly with every year in which action is delayed. Economic tools that encourage a market response to greenhouse gas emission reduction are urgently needed. There is an ongoing debate on the tools best suited – for example, a global trading system for emission rights or taxes on greenhouse gas emissions – but the essential point is that emission must be priced and that this price must be predictable. It is essential to keep in mind that climate change is but one symptom of the unsustainable way of life, modes of production and patterns of consumption that have evolved in the industrialised world. Reducing greenhouse emissions will not, by itself, solve the problem of sustainability and neither will geo-engineering solutions such as the suggestion of introducing sulphate aerosols into the stratosphere in order to reflect some of the solar radiation. As suggested by Pope Francis in *Laudato Si'*, without addressing the root problem we will sooner or later find ourselves face to face with other limits of the global ecosystem.

A further important measure to improve resilience requires us to rethink the indicators for human well-being, macroeconomic performance, and financial risks. Indicators must acknowledge human pressures causing the transgression of planetary boundaries. Macroeconomic performance indicators need to embed the deep uncertainty engrained in biosphere dynamics to ensure the preservation of natural capital. Financial institutions must recognize a wider set of planetary changes, and develop impact accounting as a core part of capital allocation decisions (V. Galaz, D. Collste eds., *Economy and finance for a just future on a thriving planet*, Beijer Institute Report, Stockholm, 2022).

There are those who claim that taking remedial measures on a case-by-case basis as impacts of climate change occur is economically more efficient than taking adaptation actions to stabilize the climate. In the very short term, and from a purely financial point of view, this may well be true since, due to the inertia of the climate system, the main climate benefits from mitigating and adaptive actions will not take effect within the near future. However, this approach is neither compatible with sustainable development, nor is it ethical. Lives lost in climate-induced disasters, or plant and animal species once extinct, cannot be restored whatever the amount of money made available. Even more importantly, inaction in the following years will almost certainly make it impossible to avoid crossing climate tipping points leading to, for example, changes in the monsoon dynamics in China or India; or melting of Himalayan glaciers that supply about one sixth of the global population with water; or sea level rises well above one metre. The consequent need to relocate millions of people makes monetary scales absolutely meaningless.

Inaction is unpardonable because the actions required do not demand unacceptable sacrifices by the industrialised world – on the contrary, they primarily require structural change that is affordable, and changes in social practices and habits; and these can be seen as the opportunity to return to the true values in life. Their costs in terms of money are well below the global annual expenditures on armaments. The choice therefore is not between fighting climate or poverty and illness, as is sometimes argued; on the contrary, climate protection is an essential contribution to fighting malnutrition, illness, and poverty.

4. In defence of a World Environment Organization

After COP26, it is clearer than ever that top-down pledges and policies are not enough. What we need is an institutional transformation from the ground up. Indeed, the lack of adequate international environmental governance (IEG) is a result of a fundamental injustice in the current state of global governance: tremendous power and resources have been concentrated in international finance and trade without a corresponding legal and institutional authority for the environment, social concerns and human rights. The increase in power and influence of major international finance and trade institutions such as the World Bank and World Trade Organization (WTO) that took place over the course of the 1990s contrasts sharply with a weakening of the, already-lesser, UN environment and development programs (UNEP, UNDP).

The existence of powerful international trade and financial regimes without comparable legal and institutional structures for social and environmental standards allows the World Trade Organization (WTO) to act as the *de facto* arbiter on environmental issues. However, the WTO is an institution that not only lacks a core competency on environmental issues and policy, but views the environment as a commodity to be exploited rather than a global Common Good, a resource requiring management and conservation. The result is that environmental social and human rights issues, treaties and commitments are trumped by finance and trade interests. Rather, it should be the case that these considerations get prioritized ahead of finance and trade (W. Pace, V. Clarke, "The case for a World Environment Organization", *The Federalist Debate*, 1, 2003). The governance of a Common Good cannot but be a common governance, in the sense of E. Ostrom.

Exactly for this reason, I believe one response for international environmental governance is to create a World Environment Organization (WEO) and to strengthen and upgrade the UN's social and development organizations so that these institutions can act as a counterbalance to the powerful finance and trade institutions. A WEO would be a designated and empowered advocate for the environment that could serve to ensure effective policy and decision-making and provide an adequate response to environmental management. That is precisely the aim of what has been called mission-oriented innovation policy. Of course, a World Environment Organization alone will not solve the problems of international environmental governance and global governance. There also needs to be fundamental reform of the WTO and of the IMF. However, establishing a WEO would be one step towards a more balanced, effective and accountable system of global governance.

5. A final remark

A changing planetary reality poses immense challenges and risks. Yet, a shift towards a just future for all on a thriving planet is possible, provided we get rid of the most powerful obstacle on the way to a new climate regime, i.e., the inability to imagine a different economic system or even just a new balance between market and society, and between humanity and the environment. Considering change impossible is the best way to perpetuate the existing. The difficulty in setting up an effective response to climate change is linked to the difficulty of imagining another economic order in which the economy constitutes a function of society, and not vice versa, in which humans are aware of the effects caused by the counteraction of non-humans and in which the fight against consumerism should not be interpreted through the lens of poverty.

I do not wish to hide the difficulties lurking in the practical implementation of a cultural project targeted at no less than a "paradigm shift" in economic thinking and a new model of economic development. As in all human endeavours, it would be naive to imagine that certain changes do not create conflict. The differences of vision and the interests at stake are enormous. It is no accident that a kind of widespread anguish about the future is running throughout society today. Some people and certain pressure groups are exploiting this anguish as a political tool, deriving from it, depending upon the circumstances, either a market-centred Machiavellianism or a State-centred Machiavellianism. It is precisely against this neo-Machiavellian culture and its underlying ethical relativism that the participants in this Conference are putting up a fight.

Sustainability and Climate Change Issues: Reducing Vulnerability Using Sustainomics & Balanced Inclusive Green Growth (BIGG)

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This lecture seeks to practically address two major global challenges – sustainable development and climate change. Developmental problems such as poverty-inequality, hunger, illness and resource scarcity are already formidable. Climate change is a potent risk multiplier, exacerbating the other crises too. It is highly inequitable that the worst climate impacts fall on the vulnerable poor who have emitted the least GHG. These multiple global problems driven by unsustainable activities, increase vulnerability and undermine resilience.

Inequality is a major driver that increases vulnerability and decreases resilience. The nexus of overuse of resources, inequality and poverty illustrates this point. Humankind is already over-consuming planetary ecological resources equivalent to 1.7 Earths. And by 2030, we will need the equivalent of two planets to sustain our current way of life. Secondly, it is the richest 20% of the world's population who consume more than 85% of planetary resources, which is 60-70 times more than the consumption of the poorest 20%. Furthermore, just 1% of the rich emit 175 times more greenhouse gases per capita than the poorest 10%. Third, we have not been able to eradicate poverty in the past, because the overconsumption of the rich uses up more than one planet, and there are no resources left to help the poor. This is a major reason why many promises to eradicate poverty by world leaders have not been kept.

The IPCC definition of resilience implies that what we need is to strengthen adaptation and mitigation capacity and build more resilience to restore socioeconomic and ecological systems to the existing state. Yet climate is only 1 out of 17 comprehensive sustainable development goals (SDG), and managing only climate risk is inadequate. Integrated solutions and multi-stakeholder cooperation that simultaneously address multiple sustainable development issues (including climate change) are urgently required, to lead us to a 21st Century Earth Eco-civilization. The global governance system needs to be changed and made more sustainable. The Sustainomics framework including the sustainable development triangle and balanced inclusive green growth (BIGG) path, first presented at the 1992 Rio Earth Summit, provides one effective solution.

Key elements of sustainomics start with the first principle for making development more sustainable that empowers everyone to take action now, without waiting for instructions from above. The second principle requires harmonization of the three dimensions of the sustainable development triangle – economic, social and environmental. The third principle encourages us to transcend traditional mental boundaries that limit us in terms of value systems, disciplines, time and spatial scales, stakeholder viewpoints, etc. The final principle sets out a practical implementation framework based on sustainomics tools and the BIGG path to sustainable development.

Sustainomics helps decision-makers to make the structure of development more sustainable, by going beyond the focus on economic growth (e.g., based only on material consumption or GNP). The BIGG path facilitates the incorporation of ecological and social concerns into the existing economic decision-making process. The first step in the BIGG approach is to integrate environmental issues into economic policies and projects, to achieve *green growth* – a win-win outcome. The second step, is to incorporate social aspects by selecting green growth paths that are more pro-poor, equitable and inclusive. This integrates the sustainable development triangle and completes *the BIGG model*, that will help implement the SDG and achieve the UN Agenda 2030. Ultimately, the Earth Eco-civilization will require responsible citizens to lead sustainable lifestyles based on sustainable consumption and production society.

Overall, the ongoing trend towards a multi-polar world will be helpful – based on many alternative economic (soft) power centres and multiple global currencies, which is gradually replacing the hegemonic uni-polar system based on a single militaristic (hard) power centre and one world reserve currency (US dollar). Such a multi-polar world could help reduce huge wasteful military expenses and wars to acquire scarce resources, while facilitating use of science, smart technology and social innovation to harmonize economic prosperity, environmental protection and social inclusion, built on multi-stakeholder cooperation among governments, businesses and civil society. This trend towards a more sustainable and conflict-free planet will be universally welcomed, given the depressing current realities. For example, the world in 2020 spent almost US$ 2 trillion on armaments, while only US$ 161 million (a fraction of that amount) was spent on development aid to help the poor. Furthermore, even while COVID-19 ravaged the world in 2020, the world's billionaires increased their wealth by 11%, while billions starved.

Switching resources from armaments to help the vulnerable poor will be a major step forward in increasing resilience. Most importantly, it will move us away from the threat of nuclear war – the ultimate catastrophe to be avoided at all costs, since it will destroy human society and make the very concept of resilience meaningless. Such trends need to be accelerated. Thus, competition for economic influence by different global power centres is already emerging that could benefit the poor and vulnerable countries – for example, the recently announced $600 billion assistance programme of the G7 would never have materialized if the $4 trillion Chinese Belt and Road Initiative (BRI), as well as the Shanghai Cooperation Organization (SC)), and the BRICS Group had not existed.

I have several concluding thoughts. First, we can be more effective by integrating climate adaptation and mitigation policies fully into overall sustainable development strategy, and improving resilience on a broader front. Second, we need to restructure international governance away from militaristic and punitive approaches, while encouraging trade, economic interactions, cultural understanding, and peaceful negotiations. In particular, nuclear war is an existential threat to humanity. Third, education worldwide should emphasize ethical values and sustainability principles, from an early age.

The presentation, with a detailed PPT, is on the PAS website at https://www.pas.va/en/publications/scripta-varia/sv152pas/munasinghe.html

Resilience as Development of the Real Potential of Nature and Scientific Discovery

Marcelo Sánchez Sorondo
Former PAS Chancellor

Despite Covid and other unfavourable circumstances, the activities of the Pontifical Academy of Sciences have continued in recent years, under the great impetus of its President, Joachim von Braun, to whom we wish to thank and pay tribute, as well as to Council Member Veerabhadran Ramanathan, who organised this meeting with such skill and discipline. Papers and meetings of experts on ecology, food, paleo-anthropology, oceanography, building ecology, scientific publications, cultural events, in person and virtual presentations, as well as Council Meetings and new members, are a brilliant demonstration of the vitality of this institution, which is decisive for the common good of humanity.

The PAS is currently studying the highly specialised issue of 'Resilience of people and ecosystems under climate stress'. As you can imagine, I will not go into the technical question, nor into the possibilities of its application. I prefer to stick to my studies and make a general consideration of virtuous attitudes that should guide resilience under the umbrella of sustainable development and climate stress.

Two attitudes for resilience

Let us highlight, in the more general field of scientific research on resilience, two attitudes that should characterise the scientist and the academic, and especially Christian scientists, or non-Christians who believe in the existence and providence of God.

On the one hand, scientists must honestly consider the question of the earthly future of humanity and of planet Earth, and, as responsible people, help to prepare for it, preserve it and eliminate the risks, in a resilient way, especially in the current situation of anthropic climate stress, wars, poverty, famine and threats of nuclear catastrophes.

I believe that this solidarity with present and future generations, properly understood, is a form of high charity and sincere love to which many human beings are sensitive today, within the framework of ecology. However, virtuous resilience with regard to this attitude must be ecological and not ecologist or, so to speak, "green". Exaggerating, such can be called the vices of "doing nothing" (*nihil agere*), i.e., considering nature as a kind of museum where the muses live and dwell, a museum to be preserved and guarded by a custodian who merely cleans the masterpieces. Nor is this attitude, which we may call passive, the meaning of Heidegger's imperative to "be custody of being".

At the same time, therefore, the scientist must be animated by the confidence that nature holds secret potentialities which it is up to science, intelligence and human love to discover and put at the service of humanity, in order to achieve the project that is in the Creator's mind. However, virtuous resilience with regard to this active attitude does not mean "doing just anything". If in the first ecological attitude of "green solidarity" the mistake was in "doing nothing", here the mistake is in doing without taking into account the real potential of nature and the work of human beings on it. In short, the virtuous attitude in resilience lies between two vicious extremes: that of doing nothing because it is considered that nature does not need the intervention of science, or that of considering nature as a material from which any development can be made to infinity, without taking into account its real potentiality and laws.

For a re-appropriation of act and potency

This leads me to consider resilience as an epistemic project and a form of truth, which can find a real foundation in the categories of being that Aristotle puts under the notions of potency and act. On the other hand, the IPCC definition of resilience uses the notion of capacity three times, i.e., "capacity of" a social system to absorb disturbances, "capacity for self-organisation", "capacity to adapt to stress and change". In short, the language of potency and action has not ceased to underlie the representation of human experience.

Aristotle observes in *Metaphysics* V [Δ] 12 and IX [θ] 1-10 that almost everything that falls under experience moves and changes; there is progress or return. Bodies change place and move in space; they change in magnitude and show increase or decrease in qualities, are destroyed or produced, i.e., begotten. In the living there is death and life, sleep and vigil; in those endowed with knowledge, ignorance and knowledge, memory and oblivion, etc.

From the analysis of these events Aristotle extracts the theory of act and potency, as the foundation of his whole philosophy, trying to solve the problems that had proved unsolvable to his predecessors, the Parmenidean physicists, and to Plato himself. Let's imagine a statue of the god Mercury.[1] There was a time when that wood or marble was not a statue or anything else with a shape; it became a statue, it received something in itself that it did not have before. Now, air or water are not statues either, nor do they have a stable shape. But neither can they have one: they are not susceptible of stable modification. Therefore, in the world of art and science some things are susceptible of artificial, stable and definite modification and others are not. Marble is not a statue, but it can become one. In the world of the living, the seed and the egg are not the oak or the chicken, but they can become them. An architect who is asleep does not build, but awake he can build.

Aristotle calls this capacity to act (or suffer) *dynamis* (δύναμις). The new reality in which the movement or development ends he calls act (ἐνέργεια).[2] In this way, being as potency (beginning in IX [θ]1-5) allows us to include change within being, contrary to Parmenides' prohibition. Because potentiality is a genuine mode of being, change, motion, and development are rightfully being. But when asked what sort of being is motion we are referred back to the dialectic definition of motion in the *Physics*, namely: 'the fulfilment (ἐντελέχεια) of what exist potentially (τοῦ δυνάμει ὄντος), insofar as it exists potentially'.[3] Aristotle thus succeeded in providing motion to a full-fledged ontological status, but at the cost of a real dialectical

[1] Aristot., *Metaph.,* IX [θ], 8, 1048 a 31.

[2] Book IX [θ] begins with the idea of potency in its relation to movement and introduces act (actuality) only in chap. 6: 'Actuality (ἐνέργεια) means the presence of the thing, not in the sense which we mean by potentially (δύναμις). We say that a thing is present potentially as Hermes is present in the wood, or the half-line in the whole, because it can be separated from it; and we even call a man who is not studying "a scholar" if he is capable of studying. That which is present in the opposite sense to this is present actually' (*Methap.* IX [θ], 6, 1048 a 30-35). Recourse to induction and to analogy is added to this apparent circularity, for lack of direct definition: 'What we mean can be plainly seen in the particular cases by induction; we need not seek a definition for every term, but must comprehend the analogy: that as that which is actually building is to that which is capable of building, so is that which is awake to that which is asleep; and that which is seeing to that which has the eyes shut, but has the power of sight; and that which is differentiated out of matter to the matter; and the finished article to the raw material. Let actuality be defined by one member of this antithesis, and the potential by the other' (1048 a 35 – b 5).

[3] Aristot., *Physica*, III [Γ], 1, 201 a 10 f.

situation, for it is neither act nor potency separately but implies a certain coexistence of both, an act that still retains potency.

At this point it seems important to me to highlight a first corollary that emerges from this realist approach, which is valid for our theme of development and resilience: for there to be movement or development, it is necessary to start from a real power or capacity and not from a logical or purely relational one, as certain philosophers, economists or scientists claim, which does not take reality into account. In other words, this means that for there to be development and resilience, one must start from a natural reality or "ecological system" capable of having the potential to develop, or from a mind or "social system" that has science in act capable of producing development or resilience in nature. In this sense the philosophical dictum of Parmenides is fully valid, "from Nothing comes Nothing" (οὐδὲν ἐξ οὐδενός; *ex nihilo nihil fit*). If nothing can come out of nothing according to Parmenides, nothing can do so without a real power according to Aristotle: without a real principle there is no movement, no development, no resilience.

On the other hand, in the Aristotelian interpretation, the subsequent instance of change, movement or development is generally identified with the end (τέλος), which sometimes represents the final cause or *that-for-which* it was produced: 'generation has as its object the end. And the actuality is the end, and it is for the sake of this that the potentiality is acquired; for animals do not see in order that they may have sight, but have sight in order that they may see. Similarly, men possess the art of building in order that they may build, and the power of speculation that they may speculate; they do not speculate in order that they may have the power of speculation'.[4] The change, movement or development takes place not in view of potency but in view of the act, which is the goal of the action, the act having therefore absolute priority, and the capacity posteriority. When it is said that animals do not see in order to have sight, but that they have sight in order to see, just as the builder or the thinker has science for its exercise and not vice versa, it is being pointed out that capacity is considered as such insofar as it is capacity for something, capacity being thus a function of the end (act).

In the framework of globalisation and the existence of only one planet to house all human beings, the need for development to be "sustainable"

[4] Aristot., *Metaph.* IX [θ], 8, 1050 a 5-13.

fits well with this Aristotelian idea of a goal or end. The adjective 'sustainable' means that development is able to maintain the potential use of natural resources for the satisfaction of human needs, especially for future generations. Instead, in the context of human development and Sen and Nussbaum's discussion of *capabilities*, an interpretation of the change in Aristotle would point out that their approach to capabilities lacks something: the consideration of actualisation as the end for which capabilities exist. In Sen's approach, the goal of development is the expansion of human capabilities. However, since 'animals do not see in order to see, but have sight in order to see', the expansion of human capabilities is only desirable and valuable if it is directed towards the actualisation of those capabilities.[5] In Aristotle, on the contrary, the goal is the human being's happiness, which must be reached through the development of his or her capacities by means of the virtues. The mere expansion of one's capacities does not produce the goal of happiness.

Difference within sustainable development and resilience

Let us now examine the difference between "sustainable development" and "resilience". According to the Philosopher, in I *De caelo*, the word virtue refers to "the extreme limit of a power".[6] Natural power is, in a sense, a principle of action, as stated in *V Metaphy.*, and in another sense, the "power of resisting corruptions". And since the first meaning is more common, we have reserved the term virtue or potency for the principle of sustainable development in the sense that it is what enables development. But insofar as denoting the extreme limits of power, the sense of which is more specific, it is applied to a special attitude or principle, namely resilience, which means standing firm against all kinds of disturbances and stress.

Thus, the term resilience can be taken in two ways. Firstly, as if it simply denotes resistance in development. In this sense, it is something general, or rather a condition of all development, since it is a requirement of all development to resist steadfastly in one's own movement. Secondly, and more pertinently, resilience can be seen as the wisdom and willingness to endure and sustain in those things where it is most difficult to be resilient and constant, i.e., in certain grave dangers such as global warming, war, famine and survival. Thus, the IPCC says resilience is "absorbing distur-

[5] Nussbaum, M., *Non-Relative Virtues: An Aristotelian Approach*, in M. Nussbaum, & A. Sen (Eds.), The Quality of Life, pp. 242-269, New York 1993.

[6] Τὸ κυρίως δυνατόν (*De caelo*, I, 11, 281 a 19 f.).

bances while retaining the same basic structure and ways of functioning, as well as self-organisation and adaptation to stress and change".

For a resilient science project

Over and above the different verification procedures, there is a founding act in a place – Sicily and Athens – and at a time – the fifth century BC – that initiates the very project of science (*episteme*) as a form of truth. By organising the observation of nature through mathematics, geometry, the theory of proportions, and the criteria of form, number and measurement, this act finds its identification as the basis of a scientific project that has forever distinguished Western knowledge from any other. A chain of thought events, all random, and all necessary after the fact, have transformed this project into a destiny. It belongs to the notion of a thought event to create the irreversible. This is not the place to describe the historical chain of decisive discoveries that have since come down to us under this scientific project. C. Allègre limits himself to summarising the discoveries of the last century, starting with the computer, passing through biology (the DNA double helix), computer science, quantum mechanics, the chemical explosion (its formulation), astrophysics, the order of chaos (evolution), neurosciences, and finally the sciences of the atmosphere and climate. The common denominator is the idea of *discovery* as an organised form of the *observation of nature*. I would like to insist on the term *nature*. Indeed, it has enabled us to put mathematics back in its slot as a discipline of forms, numbers and relations as rational constructs pursued for themselves and not as constituting *the* science of reference. As C. Allègre writes, 'contrary to the sciences of nature, mathematics does not develop by virtue of an oscillation between observation and theoretical model' (p. 429). This is probably the reason for the perhaps controversial title – *La défaite de Platon* – he gave to his overview of science in the 20th century.[7] With this scientific project what is at stake is the knowledge of what is real in nature. In this respect, the truth by observation of nature, with the asceticism of renouncing everything that is not number, figure, movement, delimits a sphere of truth that is obligatory, and it is the one to which all scientists conform. We believe that the scientist knows in part something that corresponds to the reality of nature. This partial correspondence between what science knows and the reality of nature is what we call scientific

[7] Claude Allègre, *La Défaite de Platon ou la science du XX^e^ siècle,* Fayard, Paris 1995.

truth. And it is this truth that qualifies the relation of theory to reality in these sciences. For example, Pope Francis is convinced of the truth of the scientific community when he says '*It is true* that there are other factors (such as volcanic activity, variations in the Earth's orbit and axis, the solar cycle), but several scientific studies indicate that most of the global warming of recent decades is due to the high concentration of greenhouse gases (carbon dioxide, methane, nitrogen oxides and others) released mainly by human activity'.[8] And this truth of the epistemic project is a participation of Truth, which comes neither from philosophy nor from the sacred texts of religion. As a participation in the truth, the Church listens to science, seeks it, supports it and loves it.

Faced with the tragedies of global warming, inequality, hunger and war, today the scientific community is called upon to discover in nature, through thought and scientific project, those potentialities that God has placed in the natural creation in order to act on them for the salvation of the planet and future generations. It is the Hour of Resilience.

This hope in the Author of nature and in the human spirit, created in his image, properly understood, is capable of giving a new, serene energy to the researcher in general but, in particular, on the new path towards resilience.

[8] *Laudato si'*, § 23.

III. CRY OF THE POOR AND THE YOUTH

Resilience: A Moral/Ethical Perspective

Joshtrom Isaac Kureethadam SDB

1. Introduction: Ethics as the weak link in climate discussions

While the ecological crisis, and the climate emergency, in particular, affects our common home, its impacts are felt by the members of our common household in starkly different ways. The crisis will affect first and most disproportionately the weakest and most vulnerable members of our common family. Still, such a concern is yet to become a burning moral issue in climate discourse. The debate over climate is often dominated by technical issues of carbon credits and emissions targets. But it is important to put people at the centre while talking about the ecological crisis, and precisely the poor who are worst affected by it.

In *Laudato Si'*, Pope Francis notes with sadness that while the worst impacts of climate change fall on the poorest, "many of those who possess more resources and economic and political power seem mostly to be concerned with masking the problems or concealing their symptoms". (*LS*, 26) We cannot sweep considerations of ethics, justice and equity any more under the carpet. As John Houghton points out, our current ecological predicament, and climate crisis in particular, raise deeper "considerations of morality, equity (both international and intergenerational), justice, attitudes and motivation – qualities that make up the *moral climate* that need to be put alongside the physics, chemistry, biology and dynamics that govern the equations describing the *physical climate*".[1] It is time to address seriously the question of "moral climate", if we are to succeed in responding to the current ecological crisis that threatens the very future of our civilization.[2]

2. A Moral Crisis: The Many Ecological Apartheids!

The contemporary ecological crisis is not just a physical problem but is also a profoundly 'moral' crisis as Pope John Paul II had noted already

[1] John Houghton, "Foreword" in Michael S. Northcott, *A Moral Climate: The Ethics of Global Warming* (London: Darton, Longman and Todd, 2007), vii. The italics as in the original.

[2] See in this regard the recent UN report: https://www.undrr.org/gar2022-our-world-risk

in 1990.[3] It is so precisely for the disproportionate impacts of the crisis on poor people and communities around the world. As Pope Francis points out in *Laudato Si'*,[4] "the deterioration of the environment and of society affects the most vulnerable people on the planet" (*LS*, 48).

> "Both everyday experience and scientific research show that the gravest effects of all attacks on the environment are suffered by the poorest".[5] For example, the depletion of fishing reserves especially hurts small fishing communities without the means to replace those resources; water pollution particularly affects the poor who cannot buy bottled water; and rises in the sea level mainly affect impoverished coastal populations who have nowhere else to go. The impact of present imbalances is also seen in the premature death of many of the poor, in conflicts sparked by the shortage of resources, and in any number of other problems which are insufficiently represented on global agendas.[6] (*LS*, 48)

The current ecological crisis, and the climate crisis, in particular, unmasks the many moral travesties of our times. It hides profound injustices: historical, social and generational. Let us briefly elaborate on each of these.

First of all, the climate crisis lays bare a huge historical injustice. The current climate crisis is brewed within the crucible of inequality with deep roots that go back in time.

> Climate change was manufactured in a crucible of inequality, for it is a product of the industrial and the fossil-fuel eras, historical forces powered by exploitation, colonialism, and nearly limitless instrumental use of 'nature'. The world's wealthiest nations, and the privileged elite and industry-owning sectors of nearly of all nations, have built fortunes and long-term economic stability on decades of unchecked development and energy consumption. By dumping

[3] Pope John Paul II, *Peace with God the Creator, Peace with All of Creation* (Message for the World Day of Peace, 1 January 1990), nn. 7-8, 15.

[4] *Laudato Si'* is, in fact, a social encyclical rather than one on climate change. "Climate" is mentioned just 14 times in the text, while "the poor", 59 times. See Mike Hulme, "Finding the Message of the Pope's Encyclical", *Environment: Science and Policy for Sustainable Development* 57/6 (2015), 17.

[5] Bolivian Bishops' Conference, Pastoral Letter on the Environment and Human Development in Bolivia, *El universo, don de Dios para la vida* (23 March 2012), 17.

[6] Cf. German Bishops' Conference, Commission for Social Issues, *Der Klimawandel: Brennpunkt globaler, intergenerationeller und ökologischer Gerechtigkeit* (September 2006), 28-30.

> harmful waste into the common atmosphere we have endangered everyone, including those who have contributed little or nothing at all to the industrial greenhouse effect: the 'least developed' nations, the natural world, and future generations.[7]

A historical perspective is important not only for attributing the cause of the current state of our home planet's climate, but also for assigning responsibility for its mitigation and adaptation. From the historical perspective, the rich and industrialized nations dominate the cumulative emissions account. It is estimated that rich countries are responsible for an estimated 92% of all excess historic emissions.[8] Historic emissions amount to around 1,100 tonnes of CO_2 per capita for Britain and America, compared with 66 tonnes per capita for China and 23 tonnes per capita for India.[9] Historically, fossil fuel energy has contributed to human development and improved health and survival. However, these benefits have largely been restricted to rich countries, while the adverse effects of the resulting emissions fall mainly on the poor. It is a situation of global injustice as denounced by Archbishop Desmond Tutu.

> While the citizens of the rich world are protected from harm, the poor, the vulnerable and the hungry are exposed to the harsh reality of climate change in their everyday lives. Put bluntly, the world's poor are being harmed through a problem that is not of their own making. The footprint of the Malawian farmer or the Haitian slum dweller barely registers in the Earth's atmosphere.[10]

In this regard, we may recall Pope Francis' condemnation of the "ecological debt". Such a debt is incurred by the exploitation and unequal consumption of natural resources from the part of rich communities and by the disproportionate emission of greenhouse gases leading to global warming and associated climate change. Pope Francis writes in *Laudato Si'*:

> A true "ecological debt" exists, particularly between the global north and south, connected to commercial imbalances with effects

[7] Chris J. Cuomo, "Climate Change, Vulnerability, and Responsibility", *Hypatia* 26 (2011), 693.

[8] J. Hickel (2020). Quantifying national responsibility for climate breakdown: an equality-based attribution approach for carbon dioxide emissions in excess of the planetary boundary. *The Lancet Planetary Health*, Vol. 4, Issue 9, e399-404, September 2020. https://www.sciencedirect.com/science/article/pii/S2542519620301960; Nabil Ahmed, et al. *Inequality Kills* (Oxfam, 2022), 33.

[9] United Nations Development Programme, *Human Development Report 2007/08*, 41.

[10] *Ibid*, 166.

> on the environment, and the disproportionate use of natural resources by certain countries over long periods of time. The export of raw materials to satisfy markets in the industrialized north has caused harm locally, as for example in mercury pollution in gold mining or sulphur dioxide pollution in copper mining. … The warming caused by huge consumption on the part of some rich countries has repercussions on the poorest areas of the world, especially Africa, where a rise in temperature, together with drought, has proved devastating for farming. (LS, 51)

As *Christian Aid* has pointed out, for their disproportionate contribution to the causes of climate change and its adverse effects, developed countries owe a two-fold "climate debt".

> For over-using and substantially diminishing the Earth's capacity to absorb greenhouse gases – denying it to the developing countries that most need it in the course of their development – the developed countries have run an 'emissions debt' to developing countries. For the adverse effects of these excessive emissions – contributing to the escalating losses, damages and lost development opportunities facing developing countries have run up an 'adaptation debt' to developing countries. The sum of these debts – emissions debt and adaptation debt – constitutes the 'climate debt' of developed countries.[11]

The injustice associated with the climate crisis is not just historical and between the global North and South. It is also intra-generational and it is getting ever more conspicuous.

We are used to highlighting the "anthropogenic" character of the climate crisis as caused by human activities. However, it is not the lifestyle of the whole of humanity *per se* that puts our home planet under pressure. There exist huge disparities in the consumption of natural resources across the globe which reveal scandalous differences in the ecological footprint of individuals and communities. In other words, there is a real 'apartheid' between the ecological debtors and ecological creditors of the world.

> If all of humanity lived like an average Indonesian, for example, only two-thirds of the planet's biocapacity would be used; if everyone lived like an average Argentinian, humanity would demand more than half an additional planet; and if everyone lived like an average

[11] Christian Aid, *Community Answers to Climate Chaos: Getting Climate Justice from the UNFCCC* (September 2009), 9.

resident of the USA, a total of four Earths would be required to regenerate humanity's annual demand on nature.[12]

The poor have benefited least from fossil fuels, and are first in line to suffer as the effects of global heating intensify. It is known that the world's poor contributes virtually nothing to global heating. According to Partha Dasgupta and Veerabhadran Ramanathan, the top "1 billion people are responsible for 50% of greenhouse gas emissions; a further 3 billion people for 45%; while the bottom 3 billion, who do not have access to affordable fossil fuels, are responsible for a mere 5%".[13] As the authors rightly point out, "although we all will soon be affected by climate change, it is the latter 3 billion who will, tragically, experience the worst consequences. Not only is their direct reliance on natural capital disproportionately large, they are also far less able to afford protection from extreme weather events".[14]

There are vast differences in emission and consumption levels within the same nations, both rich and poor. With regard to climate change, for example, some developing countries have their élite who are very high emitters, while in the developed countries there are persons who are low emitters and desperately poor.

Today we need to pay greater attention emissions inequality as over-consumption by the world's richest people is the primary cause of today's climate crisis.[15] At the core of the inequality crisis is a highly extractive economic model based on grossly carbon-intensive growth, which largely meets the needs of those who are already rich but is loading the greatest risks onto those living in poverty.[16] The wealthiest 1% of humanity are responsible for twice as many emissions as the poorest 50%,[17] and that by

[12] Global Footprint Network, et al., *Living Planet Report 2012*, 43.

[13] Partha Dasgupta and Veerabhadran Ramanathan, "Pursuit of the Common Good: Religious Institutions May Mobilize Public Opinion and Action", *Science* 345 (19 September 2014), 1457. See also V. Ramanathan, in *The Emergency of the Socially Excluded, Proceedings of the Workshop*, Vatican City, 5 November 2013; https://bit.ly/3gOlMIo

[14] Dasgupta and Ramanathan, "Pursuit of the Common Good", 1457.

[15] Here we refer to the per capita emissions of the richest 10% which in 2030 are set to be nearly 10 times higher than the global 1.5°C-compatible per capita level of emissions. From T. Gore (2021). Carbon Inequality in 2030, op. cit.; Nabil Ahmed, et al. *Inequality Kills* (Oxfam, 2022), 34.

[16] E. Berkhout, et al. (2021). The Inequality Virus: Bringing together a world torn apart by coronavirus through a fair, just and sustainable economy, op. cit.; Nabil Ahmed, et al. *Inequality Kills* (Oxfam, 2022), 34.

[17] T. Gore (2020). Confronting Carbon Inequality: Putting climate justice at the heart of the COVID-19 recovery, op. cit.; Nabil Ahmed, et al. *Inequality Kills* (Oxfam, 2022), 34.

2030, their carbon footprints are in fact set to be 30 times greater than the level compatible with the 1.5°C goal of the Paris Agreement.

> At the global level, the top 10% of global emitters (771 million individuals) emit on average 31 tonnes of CO_2 per person per year and are responsible for about 48% of global CO_2 emissions. The bottom 50% (3.8 billion individuals) emit on average 1.6 tonnes and are responsible close to 12% of all emissions in 2019. The global top 1% emit on average 110 tonnes and contribute to 17% of all emissions in a year.[18]

The rich who over-consume Earth's resources and over-pollute its common atmosphere are not limited to the developed world alone. The divide between the poor and the super-rich is conspicuous in most of the developing countries. In the city of Mumbai, the financial capital of India, the 27-story sprawling house of billionaire Mukesh Ambani sits uncomfortably with Asia's largest slum, Dharavi, with open sewers and crammed huts, home to more than a million people. Ultimately, the responsibility for the ecological crisis comes down to communities, households and individuals who constitute the human society. In the case of climate change, for example, the problem is basically caused by the high emission rates of approximately 1 billion high emitters of our common household. Significantly, a scientific study led by Shoibal Chakravarty of Princeton University has shown how global projected emissions can be drastically reduced by engaging the 1.13 billion high emitters.[19]

The great ethical tragedy about the contemporary ecological crisis is that a large majority of the members of our common household suffer on account of the greedy actions of a minority. As denounced by the Brazilian Archbishop Helder Camara, the ecological crisis is caused because "greedy or thoughtless people destroy what belongs to all".[20] Seen from the justice perspective, the contemporary ecological crisis clearly reveals the contours of an ecological apartheid into which humanity is drifting into.

[18] *Climate change & the global inequality of carbon emissions, 1990-2020*, Summary, Lucas Chancel (October 18, 2021).

[19] See Shoibal Chakravarty, et al., "Sharing Global CO_2 Emission Reductions among One Billion High Emitters", *Proceedings of the National Academy of Sciences* 106 (2009), 11884-11888.

[20] Helder Camara, *Sister Earth: Creation, Ecology and the Spirit* (New York: New City Press, 2008), 7.

The climate crisis and unprecedented wealth inequality are usually portrayed as separate issues. They are in fact joined at the hip. Climate crisis leads to greater inequalities and inequality also exacerbates climate change. There is a climate case for tackling inequality as well. The virus that threatens our survival as a global family is inequality. Inequality between nations, and within nations, is deadly for the future of our world. The pandemic has only highlighted it as, during this period, the wealth of the 10 richest men has doubled, while the incomes of 99% of humanity are worse off.[21] We all lose out as a result of the over-consumption by the richest people that is driving today's climate crisis, with the emissions of the top 1% double those of the bottom 50% of humanity combined.[22]

Among the most vulnerable groups affected by the climate crisis stand out children, women, minorities and marginalized groups, and indigenous communities. It is evident when we note the impacts of the climate crisis in basic areas of human welfare like food security, health and migration.

Almost 90% of the global burden of climate breakdown-related disease is borne by children under the age of five, for example, and 80% of climate refugees, forced from their homes by global heating, are women. Children bear the brunt of the climate-related impacts, while possessing the fewest resources to respond and cope. The climate crisis represents a shocking abdication of one generation's responsibility to the next, violating principles of intergenerational equity.[23] Indigenous people and racialized groups are disproportionally affected.[24] In the USA, Black, Hispanic or Native American people experience roughly 50% greater vulnerability to wildfires compared to other groups.[25]

[21] Nabil Ahmed, et al., *Inequality Kills* (Oxfam, 2022).

[22] T. Gore (2020). Confronting Carbon Inequality: Putting climate justice at the heart of the COVID-19 recovery. Oxfam. https://policy-practice.oxfam.org/resources/confronting-carbon-inequality-putting-climate-justice-at-the-heart-of-the-covid-621052/ 60 International Monetary Fund (2021); Nabil Ahmed, et al. *Inequality Kills* (Oxfam, 2022), 33.

[23] Combating climate crisis must be based on respect for human rights – World, ReliefWeb, https://reliefweb.int/report/world/combating-climate-crisis-must-be-based-respect-human-rights

[24] Oxfam (2019). *Forced from Home: Climate-fuelled displacement*. Media briefing. https://policy-practice.oxfam.org/resources/forced-from-home-climate-fuelled-displacement-620914/

[25] Environmental Justice Foundation | Inequality is worsening as climate... https://ejfoundation.org/news-media/inequality-is-worsening-as-climate-crisis-deepens-new-report

Another group who will disproportionately incur the costs of the current ecological degradation are the future generations. Pope Francis warns that "we may well be leaving the coming generations debris, desolation and filth". (*LS*, 161) According to Pope Francis, "our inability to think seriously about future generations is linked to our inability to broaden the scope of our present interests and to give consideration to those who remain excluded from development". (*LS*, 162) Leaving an uninhabitable home to the generations that come after us in indeed grossly immoral.

3. Weaving Justice into the Ecological/Climate Discourse: An Ethical Challenge

We live in a common home, our one and only home planet. But we live as a divided family. The present state of our home planet is totally unsustainable not only physically for the common biotic community of the Earth, but also socially for our common human family. The climate crisis not only threatens the physical foundations of our common home, but also tears apart the social bonds that unite our common household. As Pope Francis reminds us, "We are faced not with two separate crises, one environmental and the other social, but rather with one complex crisis which is both social and environmental" (*LS*, 139). In fact, "The human environment and the natural environment deteriorate together; we cannot adequately combat environmental degradation unless we attend to causes related to human and social degradation" (*LS*, 48). Given the deeply moral character of the ecological crisis, a true and effective response to it will have to be distinctly ethical. A physical response alone will not suffice. In order to rebuild our common home and reintegrate all the members of our common household, especially the most poor and vulnerable among them, we stand in need of an ethical vision built on the pillars of justice, equity and solidarity.

The first and most important pillar is that of justice. Justice demands paying back debts incurred. As *Caritas Internationalis* points out, the developed world has borrowed from the development potential of poorer countries and these 'loans' must be repaid.[26] In effect, nations that have grown rich in part by polluting without facing the costs of doing so – a subsidy by another name, one might say – must now repay their carbon debt. They have the moral responsibility to aid those whose rights have been violated

[26] Caritas Internationalis, *Climate Justice: Seeking a Global Ethic* (Rome: Caritas Internationalis General Secretariat, 2009), 4.

by dangerous climate change. In concrete terms such an exigency requires assistance for mitigation and adaptation as well as the right to compensation of the communities and nations affected. It is not conceivable to ask poor people to pay to solve a problem created by the wealthy, at least until they, too, have the ability to pay.

Vital to addressing the climate crisis is recognizing the inequalities that perpetuate it.[27] The climate crisis is only a symptom of a much larger crisis that needs to be addressed.

> The Climate Crisis is of course only a symptom of a much larger crisis. A crisis based on the idea that some people are worth more than others, and therefore have the right to exploit and steal other people's land and resources. It is very naïve to believe that we can solve this crisis without confronting the roots of it" (Greta Thunberg).[28]

Eco-justice demands that the right to development of poor, young and future generations and poverty alleviation be placed at the heart of a true moral response to the contemporary ecological crisis. It is morally unacceptable to constrain the right of poor nations to development by imposing upon them reductions of greenhouse gas emissions, while hundreds of millions of their citizens remain poor. Poverty eradication and the guaranteeing of dignified life standards for all members of our common household form an essential part of a moral response to the crisis of our common home.

> In a world with 2.4 billion people without secure supplies of fuel for cooking or heating, and 1.6 billion people without access to electricity, we also need to respect the primacy of poverty eradication. People who have to deal with the day-to-day reality of crushing poverty cannot be expected to focus their efforts on climate change. Countries with significant populations of poor people must have poverty eradication as their top priority.[29]

It is important to make an ethical distinction between 'luxury' emissions and 'survival' emissions as Anil Agarwal and others have pointed out.[30]

[27] Nabil Ahmed, et al., *Inequality Kills* (Oxfam, 2022), 33.

[28] H. Lock and K. Mlaba (September 30, 2021). 10 Powerful Quotes from Vanessa Nakate & Greta Thunberg at the Pre-COP26 Youth Summit. Global Citizen. https://www.globalcitizen.org/en/content/vanessa-nakate-greta-thunberg-quotes-cop26

[29] Christian Aid, *Climate Debt and the Call for Justice* (September 2009), 2.

[30] See Anil Agarwal, et al., *Green Politics* (New Delhi: Centre for Science and Environment, 1999). See also Henry Shue, "Subsistence Emissions and Luxury Emissions", *Law & Policy* 15 (1993): 39-60.

While all greenhouse gas emissions cause climate change, irrespective of where they come from, they do not have the same ethical standing. The emissions arising from living in large inefficient houses, flying for frivolous reasons, and driving inefficient vehicles are qualitatively distinct from those associated with poor households using wood burning stoves for cooking their frugal meals and kerosene for lighting.[31] We ought to clearly differentiate between emissions from profligate individuals or societies, whose wasteful lifestyle choices lead to high energy use, and those associated with energy uses for subsistence living. In this regard, "the methane emissions produced by an Indian subsistence farmer growing rice are not comparable with CO_2 discharges by the German owner of a big limousine. The former are "survival emissions", the latter "luxury emissions".[32] In a similar vein, "the emissions resulting from the efforts of a farmer in Africa as he attempts to feed his family are not on a par with the emissions resulting from the efforts of an American dermatologist as he attempts to get to Vegas for a weekend of gambling".[33] A clear distinction between luxury emissions and survival emissions is vitally important.

And the rights of the poor for survival emissions are indeed non-negotiable.

> ... If it turns out that there should be some sort of planetary limit on emissions, then you might think that everyone ought to be entitled to emit enough greenhouse gases as required for subsistence. Maybe those emissions are not negotiable. If subsistence emissions fall under the planetary limit, and we still have reductions to make, then we can only discuss reductions to luxury emissions.[34]

The imperative of poverty alleviation and the task of providing poorer populations with basic amenities like electricity and cooking gas cannot be put off in the name of mitigating climate change. It would be unethical to require people whose per capita emission rates hardly register in the global emission charts – to forego basic amenities so that the rich and affluent can carry on with their extravagant lives. It is estimated that providing basic

[31] Sujatha Byravan – Sudhir Chella Rajan, "The Ethical Implications of Sea-level Rise Due to Climate Change", *Ethics and International Affairs* 24 (2010), 244.

[32] Wolfgang Sachs, et al., eds., *Greening the North: A Post-Industrial Blueprint for Ecology and Equity* (London: Zed Books, 1994), 72.

[33] James Garvey, *The Ethics of Climate Change: Right and Wrong in a Warming World* (London: Continuum, 2008), 81.

[34] Ibid.

modern energy services for all would increase carbon dioxide emissions by only an estimated 0.8 percent. The projected annual investment to achieve universal access to modern sources of energy is less than an eighth of annual subsidies for fossil fuels, one of the principal sources of greenhouse gases in the first place.[35]

Efforts to curb over-consumption by the richest people are therefore vital to tackling the climate crisis. Indeed, solutions are not lacking in this regard, if there is political will.

> Wealth taxes, together with carbon taxes and bans on luxury carbon-intensive goods, are needed as part of a holistic effort to address outsize wealth, power, and consumption. Rich governments and corporations must reorient net zero targets as real zero targets that cut emissions significantly – and fairly – by 2030. They must invest in climate adaptation for low- and middle-income countries and phase out fossil fuels, while ensuring that climate adaptation finance directed to communities' efforts to survive is based on grants, not loans. They must also provide financial and technical assistance to low- and middle-income countries and poor communities who are already experiencing economic and non-economic damages and losses as a result the climate crisis. And we must see large-scale boosts to investment in clean energy and a just transition to low-carbon jobs that are accessible to marginalized groups, such as in the care economy, sustainable agriculture, and renewable energies.[36]

The contemporary ecological crisis in general, and climate change in particular, is ultimately about justice. It is about justice between communities of the same human generation (intra-generational), between current and future generations (inter-generational), and even between human beings and the rest of the biotic community (intra-species).

A second pillar on which the edifice of an ethical response to the ecological crisis needs to be built is the principle of *equity*. Equity follows close on the heels of justice. It is rather a precondition for justice. The principle of equity is based on the foundational value of human equality and dignity, namely, that that all persons are born equal and have equal rights to the resources of our home planet, our common habitat (*oikos*), and to its common atmosphere. The fact of living in our common home and being

[35] United Nations Development Programme, *Human Development Report* 2011, 9-10.

[36] Nabil Ahmed, et al. *Inequality Kills* (Oxfam, 2022), 35.

members of our common human family confers on each human person the right to equal ecological space. In the case of climate change, such a right means that "the Earth's atmosphere is a common resource without borders",[37] to which all have equal rights, precisely in being members of the common household. As the Earth's ability to absorb greenhouse gases is a "global common", it is vital this global common should be shared equally.[38]

The principle of equity as founded on basic human equality is vitally important. It is this same fundamental principle that lies at the basis of respect for human rights and the rejection of every form of discrimination. Equity is to be applied also when it comes to emission rights in the context of climate change. People in the developing countries are entitled for *per capita* emissions rights on an equal footing with the people of the developed world. As Dale Jamieson writes: "every person has a right to the same level of GHG emissions as every other person. It is hard to see why being American or Australian gives someone a right to more emissions, or why being Brazilian or Chinese gives someone less of a right".[39] So every person has 'equal' right when it comes to the ecological and climate space of our common home. To argue to the contrary would mean adopting a discriminatory logic which lies at the root practices like apartheid or racial or caste or other forms of segregation all of which go against the principle of basic human equality. In fact, the current ecological and ethical apartheids that we live through, and have tolerated for too long, are in fact a violation of the fundamental principle of equity and of fairness.

A third foundational pillar of an ethical response in order to build resilience in the face of climate crisis is solidarity. Solidarity is more than responsibility. It is co-responsibility for our common home and for all the members of our common household, especially the poor and most vulnerable. Solidarity springs from the profound conviction, as Pope John Paul II wrote in his social encyclical *Sollicitudo Rei Socialis*, that "we are *all* really responsible for *all*".[40] Solidarity is based on the truth of global commons, namely that our home planet and its common atmosphere, ecosystems and

[37] United Nations Development Programme, *Human Development Report 2007/08*, 39.

[38] Anil Agarwal – Sunita Narain, *Global Warming in An Unequal World: A Case of Environmental Colonialism* (New Delhi: Centre for Science and Environment, 1991), 13.

[39] Dale Jamieson, "Adaptation, Mitigation, and Justice" in *Perspectives on Climate Change: Science, Economics, Politics, Ethics*, eds. Walter Sinnott-Armstrong – Richard B. Howarth (Amsterdam: Elsevier, 2005), 231.

[40] Pope John Paul II, *Sollicitudo Rei Socialis*, n. 38.

natural resources are 'common goods', which belong to all. As Pope Paul VI wrote: "God intended the Earth and everything in it for the use of all human beings and peoples. … created goods should flow fairly to all".[41] In order to truly achieve eco-justice for all the members of our common household "we need to strengthen the conviction that we are one single human family". (*LS*, 52) Pope Francis speaks eloquently of solidarity and the preferential option for the poor as the best means to attain common good and build eco-justice.

> In the present condition of global society, where injustices abound and growing numbers of people are deprived of basic human rights and considered expendable, the principle of the common good immediately becomes, logically and inevitably, a summons to solidarity and a preferential option for the poorest of our brothers and sisters. This option entails recognizing the implications of the universal destination of the world's goods ... it demands before all else an appreciation of the immense dignity of the poor in the light of our deepest convictions as believers. We need only look around us to see that, today, this option is in fact an ethical imperative essential for effectively attaining the common good. (*LS*, 158)

Over half a century ago, Pope John XXIII had called for solidarity within the common family of humanity in the context of the increasing discrepancies between the poor and the rich. According to him it is "impossible for wealthy nations to look with indifference upon the hunger, misery and poverty of other nations whose citizens are unable to enjoy even elementary human rights" and denounced "as nothing less than an outrage of justice and humanity to destroy or to squander goods that other people need for their very lives".[42] These words today appear indeed prophetic. The need for solidarity is all the more urgent in our days. Solidarity also needs to be inter-generational.

> Intergenerational solidarity is not optional, but rather a basic question of justice, since the world we have received also belongs to those who will follow us. The Portuguese bishops have called upon us to acknowledge this obligation of justice: "The environment is part of a logic of receptivity. It is on loan to each generation, which must then hand it on to the next"[43] (159).

[41] Pope Paul VI, *Populorum Progressio*, n. 22.

[42] Pope John XXIII, *Mater et Magistra*, nn. 157, 161.

[43] Portuguese Bishops' Conference, Pastoral Letter *Responsabilidade Solidária pelo Bem Comum* (15 September 2003), 20.

The crisis of our common home is one of the greatest ethical dilemmas of our time, on account of the stark injustice and inequity masked by it. At the same time, the silver lining in the clouds is that acting against it in the spirit of solidarity, humanity has also a precious opportunity to create a more equitable and just world. It is up to our generation to rise to the occasion and respond to this unique challenge.

Building Climate Change Resilience Through Data Science

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Summary

In order to tackle climate change, we need to use all the available resources humanity has, and data is one of the most important assets humanity can count on. Therefore, it is imperative that every effort to build resilience is rooted in appropriate data-driven decision making. In this article I share two cases of cities that have failed to do this and give three broad but fundamental recommendations to change this for the better: 1) to invest in digital infrastructure that allows governments to collect and leverage data from its human and natural systems, 2) to make data professionals part of the efforts for climate resilience building, 3) and for all of us to become data champions who bring attention to the importance of data practices for the achievement of climate resilience.

Introduction

Climate change is possibly the biggest challenge humanity has ever faced, and in order to survive, we need to use all the resources we have. Today, one of the biggest assets humanity has is data. For instance, it is estimated that every day we generate 2.5 quintillion (i.e. 10 to the 18th) bytes of data, that by 2025 there will be 75 billion devices connected to the Internet of Things, and that by 2030 90% of people over 7 years of age will be digitally active [1]. Artificial Intelligence alone is projected to add 15.7 trillion USD to the global economy by 2030 [2]. There is a plethora of statistics that can prove the importance of Data Science. Nevertheless, the efforts made to integrate the leveraging of data into building resilience to climate change are very limited in comparison to other fields.

In this article I will present two *non-success* stories of cities that have failed to integrate data into their efforts to mitigate the effects and adapt to the challenges brought by climate change. After these cautionary tales, I will give some examples of already available technology that can be used in order to build climate change resilience in the short and long term. This is not meant to be a comprehensive, academic study of the implications that the absence or presence of data governance can have in efforts for climate resilience. Instead, this article is meant to share my own experiences and observations as a student, researcher and young data professional with the hope of bringing a different perspective to the discussion.

A TALES OF TWO CITIES: FREETOWN AND MONTERREY

Urban Water Resilience in Freetown, Sierra Leona

Four years ago I was a graduate student in the Engineering Faculty of University College London, and as part of a Master's degree I wrote a dissertation titled "Climate Change Resilience of The Urban Water System in Freetown" [3]. For this project I was granted funding and support from the university and its industrial partners to go to Freetown and develop a framework to assess the level of resilience to climate change and other natural hazards of the precarious water network of the capital.

The objective of the project was to bring together different dimensions and aspects of resilience and to develop a methodology to help the people in charge of the water systems to assess how resilient the system could be to different climate scenarios. The idea was that, with the help of this self-assessment tool, the relevant organisations could adapt to new climate conditions and address already existing challenges. Based on previous research and literature reviews I made beforehand, during my time in the city I conducted several interviews with different NGOs and grassroots organisations, talked to national and local authorities, had stakeholders and beneficiary workshops, visited water treatment plants, tested pipes, tracked water leaks and even learned the basics of water dam designs from a group of international engineers that at the time were working on renovating the water network. Back in London, I brought all of those learnings together into a very comprehensive evaluation framework for urban water systems called *ResUrb* [3].

At the time I did not know it, but the most important encounter I had in Freetown was with Mr. Clifford Coomber. Mr. Coomber had worked for the Guma Valley Water Company for over 18 years by the time we met. The Guma Valley Water Company was the government body in charge of keeping the water network that served Freetown and its citizens. Mr. Coomber was the main carer of the already worn-down Guma Valley water dam, the main water source of Freetown. He showed me the dam and the outdated working conditions in which its infrastructure was kept at the time. And the most remarkable thing he showed me was a notebook (see Figure 1).

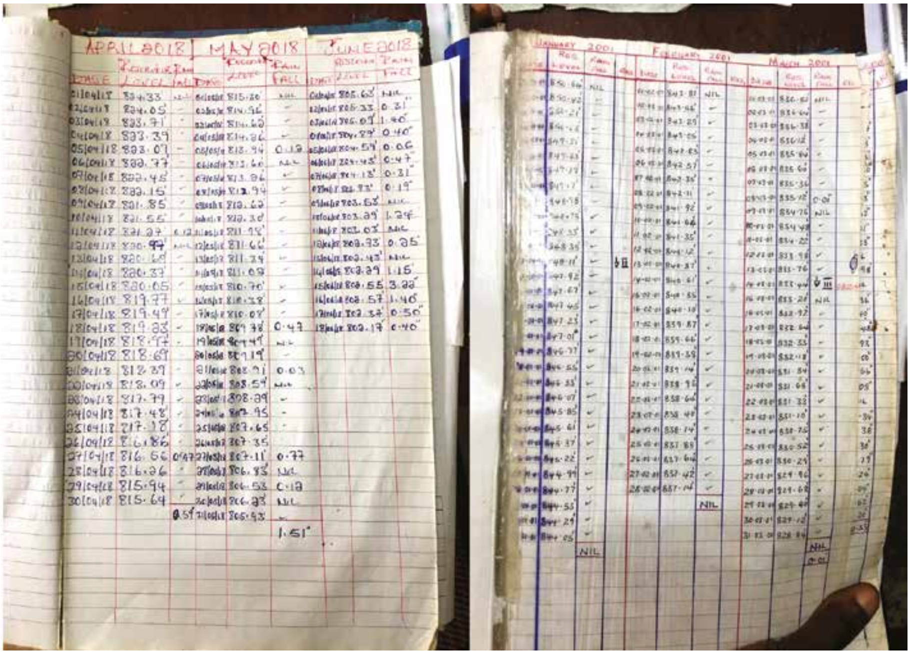

Figure 1. Last and first entry of Mr. Coomber's notebook in June 2018.

In this notebook Mr. Coomber had meticulously recorded by hand the volume of rainfall and the water reservoir levels that the dam had every single day between January 2001 and June 2018. In an urban setting with zero digital infrastructure for the tracking of any human activity or basic services like water and energy supply, Mr. Coomber had created a small but priceless, almost 20-year-old database with information that could serve as a proxy for the demand, use and availability of water in the whole city. He kept this record by his own initiative and without any clear objective. In his own reasoning, he just thought it was interesting to see the changes brought by time. This almost miraculous data wrangler made it possible for myself and the international team of engineers working on the water network to get insights like the following (see Figure 2).

With the registry of rainfall, we could see that there was a gradual and constant decreasing of the length of the rain season over the Guma Valley dam. This meant that the dam had about 15% less water available at the end of that 18-year period. We could also see that this had a visible effect on the way the water dam replenished itself every year. The yearly reservoir

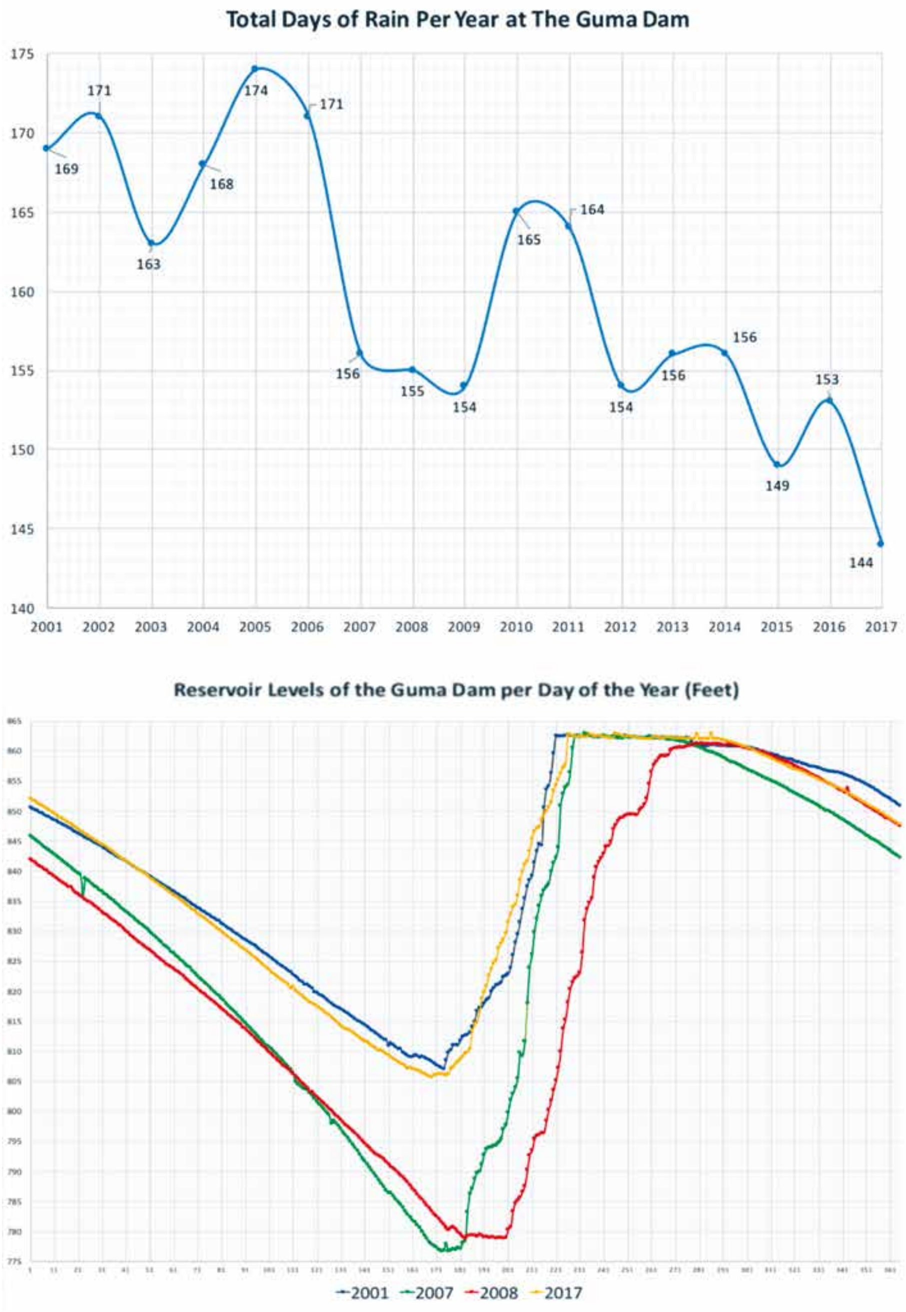

Figure 2. Total days of rain per year at the Guma Dam and Reservoir levels of the Guma Dam per day per year (feet).

levels showed that the dam lowered its levels consistently during the first half of the year, and then filled again during the rainy season. This pattern alone could have made us think that the amount of water available for the population stayed consistent, but interviews with the Guma Valley Company staff revealed that the reason why the 2017 line is so similar to 2001 was because they started having a set number of hours every day in which the dam was closed starting from 2008. In order to be able to reach maximum capacity in the dam after the rainy season, the city was left without water starting with a couple of hours every day. This daily closure became longer and longer with time, and by the time I was there in 2018 the city had water only around 9 hours a day. It took me a long time to understand this because, of course, I was staying in a privileged area of the city full of hotels with the infrastructure to sustain private water reservoirs.

In the end this framework achieved two things: First, it helped me gain my second Master of Science degree with a distinction. Second, and I believe more importantly, it became a nice, thick addition to the pile of forgotten books, papers and reports that no one ever reads on a shelf of Freetown's Guma Valley Water Company office. It may have helped someone to kill a mosquito or two, but I can neither confirm nor deny that assumption.

According to my professors' feedback, the framework I proposed in this project was a sound piece of academic work in the fields of Engineering and Climate Sciences. But in the end it amounted to nothing because, in order to be applied, it required the people in charge of the city's water to have a crucial and completely absent resource: data. Data about the changing levels of precipitation that fell into the main water dams. Data about the effect of erosion around the water dams due to deforestation and illegal human activities in protected areas. Data about the growing demand of water due to a growing population and migration. Data on the effects of fast spreading waterborne diseases. Data about loss of both water and active income due to leakages, illegal interventions to the pipes and missing payments of many users.

The data I was able to get from Mr. Coomber's notebook helped the engineers working in the renovation of the water system to better plan their work. It gave them insights to the water volumes available in different moments of the year and how these were changing with time. Nevertheless, to my knowledge, there were no subsequent efforts to keep data collections beyond Mr. Coomber's notebook. This means that whatever achievements in water infrastructure the international organisations working in Freetown could have, were doomed to have an ephemeral impact.

This was because the changing weather conditions were going to increase the system's vulnerability with time and the authorities lacked the information in order to adapt to these conditions.

Today, water access continues to be an overbearing challenge in Sierra Leone, where 60% of the population has no access to clean water and the level of vulnerability of the poorest keeps increasing with the changing weather conditions and the aftermath of the Covid-19 global pandemic [4].

Droughts in Monterrey, Mexico

Fast forward to the summer of 2022. Due to the Covid-19 pandemic I left London in 2020 and moved back to Mexico, my home country. My husband and I made this difficult decision so that our then-newborn son could interact with his family (and not only with his mother and father) during the long months and years we needed to isolate without knowing when or how we could have access to vaccines. It was only in June this year, 2 years and 3 months after the first lockdown was announced in the U.K., that the CDC approved the application of Covid-19 vaccines in kids of his age group (from 6 months to 5 years), and we still have to wait some months for our second baby to be able to be vaccinated [5].

We live in Monterrey, an industrial and prosperous city, home to one of the most important universities of Latin America [6], and the wealthiest borough in the country. Even though Monterrey's society is proud of its achievements, conservative values and work ethic, a couple of months ago life in Monterrey became a bit closer to what life in Freetown has been for decades. During the past 6 years our region has seen consistently lower levels of rainfall every year, and now we are in the middle of the worst drought ever recorded with the highest temperatures in the region registered since 2015. The 3 reservoirs that serve the city are at 45%, 8% and 2% capacity. Right now, the whole city only has running water from 4 a.m. to 10 a.m. every day, with some random days having shorter time windows, and with the most marginalised areas of the city getting no water at all [7].

Climate change has brought the hardest drought recorded, but the effects that this natural hazard is having on the population of my city could have been prevented if its authorities had had an appropriate, data-driven water management system in place. For instance, in the 1980s Mr. Alfonso Martinez, the then governor of the city, predicted that the city should not go beyond 4 million people in population to avoid extreme stresses in the water system [9]. Monterrey's population, however, is more than 5.5 million people today, and no major updates have been done to the urban water

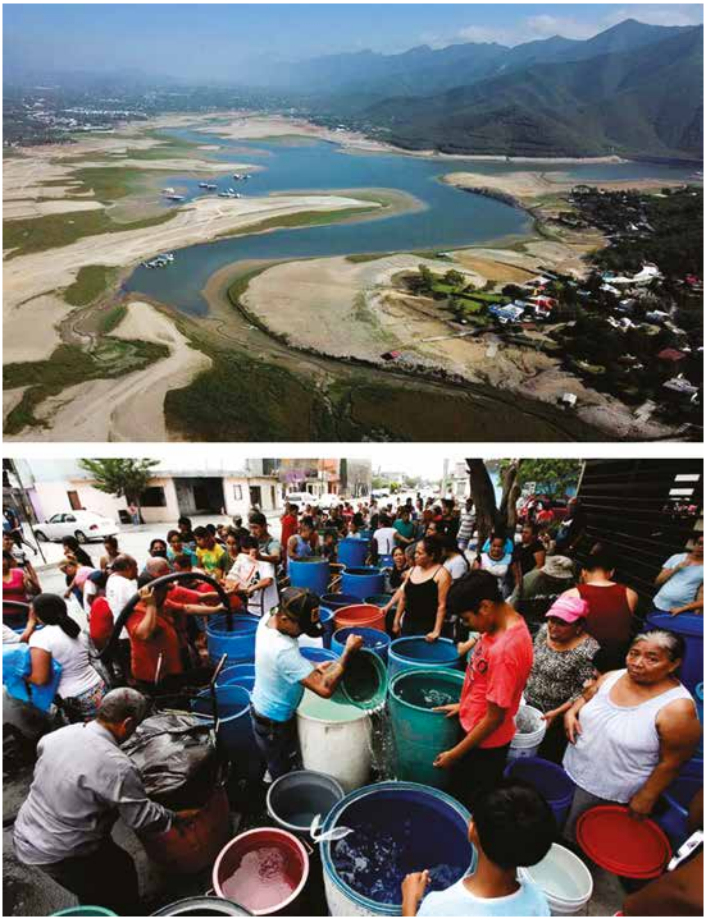

Figure 3. Images of the diminishing levels of water in La Boca dam and of people waiting for water trucks in Monterrey. Photos by Reuters [8].

network since his time. In addition, the water system has been exploited without regulation by private companies and industries that, theoretically, had agreed on respecting pre-established limits in their water consumption [7]. Major plans for the update and restructuring of the city have been in place since 2016 [10] but these lack clear pathways of data governance that would make their tracking and implementation transparent and, eventually, successful. There have even been talks of starting a smart monitoring of water usage in the city to achieve these objectives since 2017, [11] but these have not had any tangible results so far.

Lack of water has already made it harder to keep the hygiene measures necessary to keep Covid-19 at bay in the region. In the month of June alone, the weekly average for new cases in the state of Monterrey grew from 30 to over 850, meaning that we are well into the 5th wave of the pandemic for the city [12]. Moreover, water-borne diseases are at a rise, with a recent and severe spread of norovirus in the state [13]. I lack access to statistics for the number of cases that Monterrey has seen of norovirus in the past couple of months, but I can tell you that I had to take my 2-year-old toddler to the emergency room 3 times within the same week due to this public health issue, that for him meant sudden and unstoppable vomiting, diarrhoea and fever. It took him almost a month to fully recover. Now he is well and thriving, but again, not everyone has the same blessings and resources we do.

Data Science for Climate Resilience, Everywhere

I presented the antithesis of success stories of the use of Data Science to tackle the climate crisis because I wanted to illustrate how dangerous and neglectful it is to govern without insights brought by data nowadays. I still have not seen a fully successful case of a city or region taking data-driven decisions for the good of its people. Nevertheless, I believe it is possible. This is why my current work and education is aimed so I can be part of the new wave of data practitioners making this dream a reality. But action is needed now, more than ever. Therefore, I leave with you some recommendations on how to integrate data into our resilience building efforts.

The Internet of Things

The internet of things (IoT) is the network of devices producing and collecting data from a great variety of systems. It can be used to have smart and efficient water, energy and waste management in urban settings, to monitor and control air quality, and to track live networks like transportation and supply chains [14]. There are already successful companies developing accessible devices for different and specific objectives which could help governments achieve their resilience building goals [15]. It is imperative that cities and countries invest in IoT infrastructure in order to be able to build resilience for the human and natural systems they are responsible for.

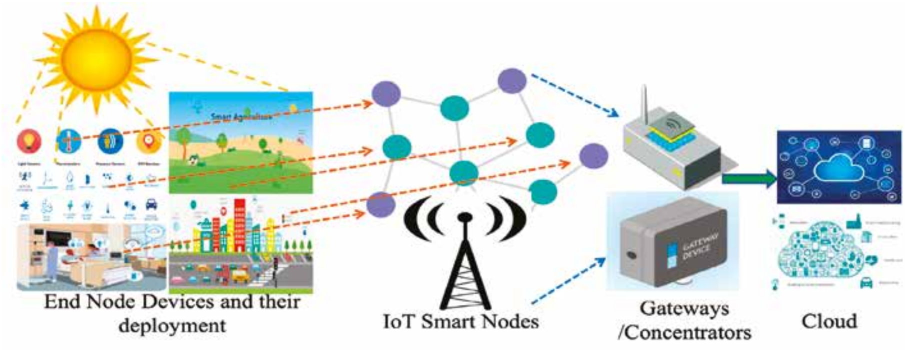

Figure 4. Sustainable IoT for Sustainable Smart Cities. Image taken from Ram et al. 2020 [16].

Complex Solutions for Complex Problems

Data Science could be thought of as a collection of methodologies to generate valuable insights from large and complex sets of data. The building of resilience to climate change is a multidisciplinary, multidimensional problem, and Data Science has a great but still under-used potential for it. Deep Learning is a prominent area of Data Science where data is processed by neural networks and high processing computing, algorithms and computational resources that mimic the way the human brain functions. Deep Learning makes it possible to achieve relevant capabilities for resilience building like predicting extreme weather events, localising and visualising climate distressed areas via satellite images, discovering new and more efficient materials, and designing and monitoring more efficient human and natural systems, like forestry, agricultural lands and buildings [17]. It is imperative that data professionals become part of the efforts of resilience building so this kind of knowledge and insights become assets for data-driven decision making of governments and public institutions.

Data Champions

As you can probably tell from my tales, it all boils down to free will. We can take all the data and technology of the world, and it will not be enough to solve the climate crisis if authorities, institutions and people are not willing to use them for the greater good. We need to have data champions in all levels and kinds of organisations and institutions that bring attention to the need for collecting and leveraging appropriate data to make smart decisions for resilience building.

Concluding Thoughts

The effects of climate change are already upon us. The most privileged will be able to adapt and maybe even thrive. But that will not be the case for the majority if climate action remains secondary in the world's leaders' agendas. We have to act now so our work does not end up in a pile of unread publications full of unheard cautionary tales of an imminent, bleak future for our already born children. Please help me clean up this world so that our kids can have a happy, joyful and peaceful life worth living.

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Adaptation Science for Least Developed Countries

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Summary

Climate change is a key determinant for sustainable development, with significant direct and indirect socio-economic and environmental implications on all sectors of the local, regional and global economies. Human activity has already warmed the planet by over 1°C since pre-industrial times, and the impacts of this warming have been felt at varying magnitudes in different parts of the world. Additional warming is expected to significantly amplify existing risks and associated impacts, especially in the most vulnerable parts of the world, including the Least Developed Countries (LDCs). Most of the LDCs' total population of 1.06 bn people, which account for 13.62% of the world's population, are in Sub-Saharan Africa.

So far, progress on adaptation is uneven and there are increasing gaps between action taken and what is needed to deal with the increasing risks. A key message from the 1IPCC WGII AR6 report is the recognition of the interdependence of climate, biodiversity and people and stronger integration of natural, social, and economic sciences (IPCC, 2022). The report also highlights the increasing evidence of maladaptation in many parts of the world. Therefore, there is a need for location and context-specific adaptation measures depending on levels of vulnerability, actors involved, resources etc. This paper seeks to highlight the current and projected climate risks, levels of vulnerability and exposure and regional tipping points in Sub-Saharan Africa in an effort to communicate the need for urgent action.

Current Climate Risks and Threats in Africa

In Africa, mean and extreme temperatures are rising. The rate of surface temperature increase has generally been more rapid in Africa than the global average, with human induced climate change being the dominant driver (IPCC, 2021). Extreme weather and climate events attributable to human-induced climate change include marine heatwaves (2x more likely) (Frölicher et al., 2018; Laufkötter et al., 2020; Oliver et al., 2018;

Seneviratne et al., 2021), multi-year droughts in West (Biao, 2017) and East Africa (Funk et al. 2018; Hoell and Funk; Liebmann et al., 2014) and Cape Town drought (3x more likely) (Otto et al., 2018), Eastern South Africa floods 2x more likely (Pinto et al., 2022). Africa has already experienced widespread losses and damages attributed to human-caused climate change. These include reduced food production, reduced water security, reduced economic output, loss of biodiversity, and increased human morbidity and mortality (Trisos et al., 2022). These impacts will become more severe with increased warming. An estimated 337 million people were affected by natural disasters in Africa between 2000-2019, in which floods accounted for 80% and droughts for 16%. Between 2018-2019, 6 million people were displaced by weather-related disasters in Sub-Saharan Africa and 46,078 deaths from natural disasters were reported between 2000-2019 (CRED, 2019). Globally, only Sub-Saharan Africa has reported the largest number of mortalities associated with floods since 1990 (Tellman, et al., 2021).

Figure 1. A region in Kenya that experienced severe flooding from the extreme rainfall event of March-April-May (MAM) 2018 season. Farmlands and some houses were submerged. Photo: Joyce Kimutai.

Vulnerability and Exposure to Climate Change in Africa

Socioeconomic, political and environmental factors drive vulnerability. Most people in Sub-Saharan Africa are employed in climate-exposed sectors: 55-62% of the workforce is employed in agriculture, and 95% of cropland is rain-fed (Ali, 2012). 66% of the urban workforce work in informal employment (ILO, 2018a; World Bank, 2020). There is growth in population, infrastructure and agriculture in areas exposed to climate hazards. Around 60% of urban dwellers in Africa live in informal settlements. There is rapid urbanization, growing informal settlements and mortality from disasters, which is 15x higher in highly vulnerable countries, especially LDCs (UNDESA, 2019b).

Climate Change has reduced economic growth across Africa. This has increased income inequality between African countries and countries in the global north, in more temperate climates (Diffenbaugh and Burke, 2019). This has particularly manifested through losses to agriculture, tourism, manufacturing, and infrastructure. GDP per capita on average declined by 13.6% (1991-2010 vs no climate change) across a number of African countries e.g., temperature impacts on GDP for Central African Republic, Democratic Republic of Congo and Zimbabwe and Kenya (Abidoye and Odusola, 2015). Reduced productivity leads to lower macroeconomic performance e.g., in a rural town in South Africa, 80% of businesses lost >50% of employees and revenue due to agricultural drought (Hlalele et al., 2016). In southern and eastern Africa, river flows mostly decreased from 1970-2010 leading to negative and cascading impacts on multiple sectors, including hydropower generation (Trisos et al., 2022).

Figure 2. Vulnerability and exposure are socially, culturally and geographically differentiated among climatic regions, countries and local communities across Africa. (a) informal settlements located along a river course (b) and (c) farmlands and homes prone to flooding (d) communities in drought prone arid and semi-arid areas. Photos: (a) Mike Tigas, (b,c,d) Joyce Kimutai.

Figure 3. Some economic losses from extreme weather events in Africa. (a) and (b) Landslides destroying crops resulting from over saturation of the soil from extreme rainfall. (c) and (d) Locust invasion of crops. (e) Roads rendered impassable due to damage from floods. Photos: Joyce Kimutai.

Projected risks

Figure 4 is the embers diagram for Africa adopted from (Trisos et al., 2022) illustrating risks and impacts at different levels of warming. The current level of global warming is 1.1°C. Above 1.5°C, there is a high risk of large regional crop losses, increasing poverty and inequality, increasing disease exposure, increasing drought, and increasing heat mortality. Above 2°C, the risks are even higher: high risk of widespread crop yield loss, widespread heat-related mortality risk, 7 to 18% of African species at risk of extinction, and over 30% decline in fisheries catch, and potential and severe risks of malnutrition. In scenarios with low adaptation, transition to high risk i.e., widespread and severe impacts have already begun for biodiversity loss. Improving the adaptive capacity of societies is key in mitigating the impacts of extreme events. In Africa, risks are expected to increase even when temperature change remains moderate or constant,

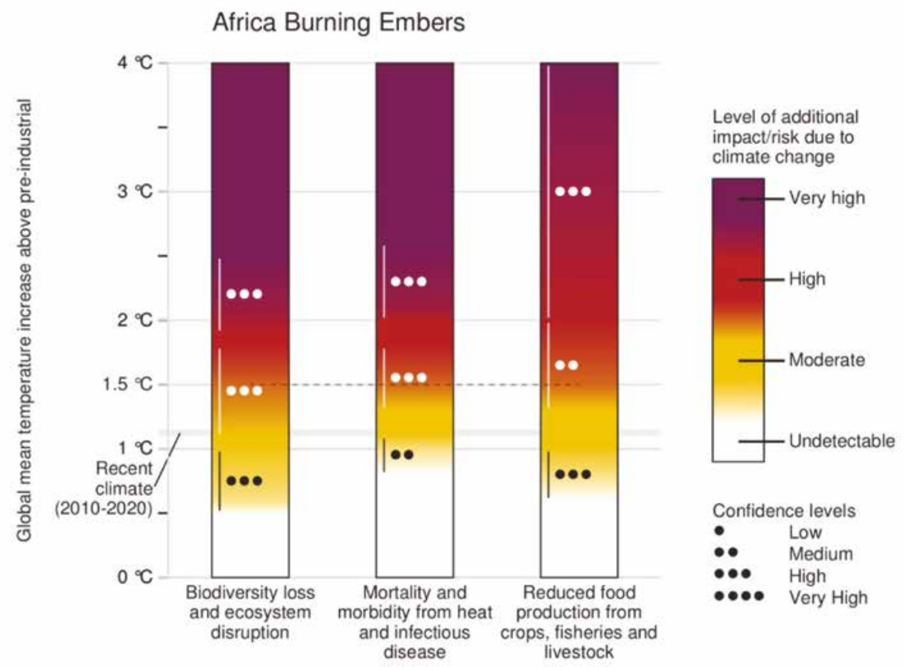

Figure 4. Embers showing increasing risk due to climate change for selected key risks in Africa. All the risks have transitioned to moderate-high risk by the recent level of global warming 2010-2020 (1.09°C) Source: Trisos et al., 2022.

since exposure and vulnerability to climate-related hazards are increasing significantly due to other human factors like population growth, urbanization, and migration (e.g., Thornton et al., 2010).

Adaptation to current weather extremes and related climate risks should be considered a central theme in climate policy actions, especially in the most vulnerable regions of the globe. Figure 5 shows the existing gaps in adaptation research, funding, and participation in the African continent. While adaptation is cost-effective, it is vastly under-funded in the region which greatly hampers implementation. Most African countries have low adaptation research, and most studies are carried out by researchers outside of Africa. Adaptation is intrinsically a local issue and therefore requires locally-led processes and interventions to improve resilience – African problems for African solutions. Only 3.8% of global climate change research funding is spent on Africa. Even as we emphasize the importance of evidence-based

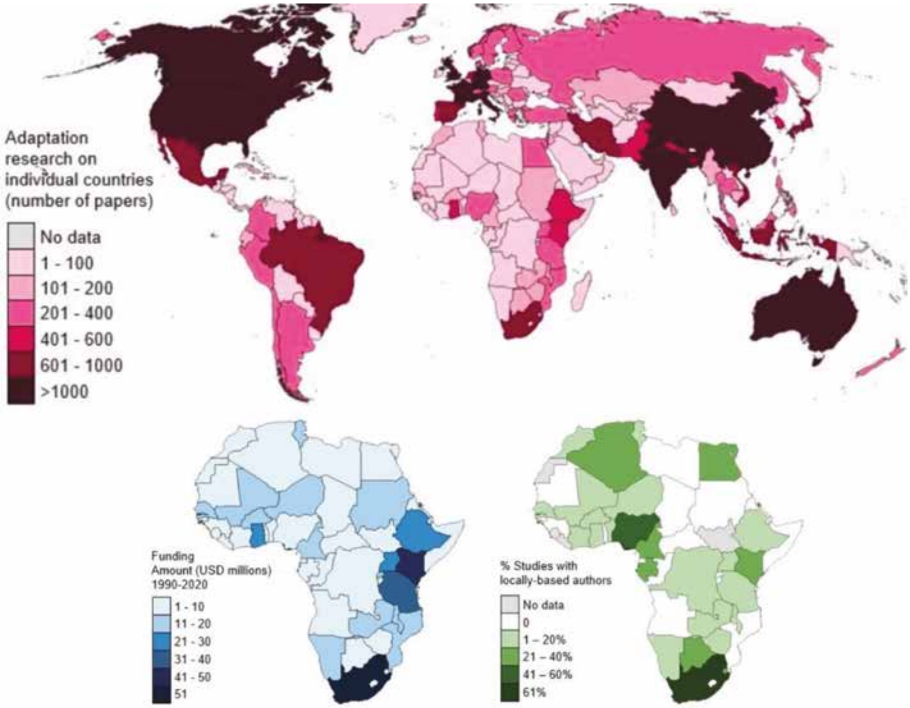

Figure 5. Gaps in climate change research funding, participation, and publication for Africa compared to the rest of the world. Source: Trisos et al., 2022.

climate change adaptation policy (e.g., to avoid maladaptation), the societally relevant questions should be: Are we doing our science in a vacuum? How different would the world be if scientific results were interpreted "as if people mattered"? "What is the impact of particular actions under an uncertain climate change". Science needs to be done holistically and implemented with compassion and empathy. Adaptation including loss and damage funding should be based on vulnerability to extreme weather and climate events rather than attributability. Failure to fund adaptation where it is needed creates global supply chain vulnerabilities.

Possible tipping points in Africa are rapidly approaching, with the question remaining as to whether they have already been reached. These include the disappearance of glaciers on Mt. Kenya, Mt. Ruwenzori, and Mt. Kilimanjaro; intense tropical cyclones (category 4/5) in various areas (reaching Maputo in Mozambique and Dar es Salam in Tanzania); the growing risk of day zero drought in cities; intense and frequent multi-years droughts (e.g., in East Africa) that severely impact maize crops and livestock, and heatwave that impact human health and increase mortality; and extirpation of species. Any further delay in concerted anticipatory global action on adaptation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future, especially for the most vulnerable regions (IPCC, 2021; IPCC 2022).

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IV. REGIONAL TO LOCAL RESILIENCE BUILDING

In Africa: Resilience and Adaptation in a Climate-Changed World

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Prologue

Resilience in the face of difficulty is a hallmark of the African experience over eons of time. Adaptation in the face of climate change has become a byword for Africa in the 21st century. Together – resilience and adaptation – will play a fundamental role in the continent's future as Africa confronts an endless array of dilemmas and uncertainties in an increasingly climate-changed world.

Africa is a huge continent with a land area covering nearly 30 million square kilometers. That's almost twice the size of South America and large enough to accommodate the U.S., China, India, Japan, and the 27 member states of the European Union (EU) inside its borders, with room to spare. It is home to 1.4 billion people – some 17% of the world's population. That's nearly twice the number of people living in Europe and more than four times the population of North America. In a world largely characterized by stable and even declining populations, Africa's population is growing rapidly in comparison – by 2.4% in 2021. That's almost twice the rate of population growth in Asia and nearly five times the rate of growth in Europe. This translates into a youthful citizenry. Sixty percent of Africa's population is under 25 and 75% is under 35. In contrast, less than one-third of the population in the EU is less than 30 years of age.

African countries are not only youthful, they are also rich in natural resources, ranging from rare minerals to oil to biodiversity. The continent is the world's largest source of gold and platinum. It possesses 95% of the world's diamonds and 60% of the world's cobalt, an alloy widely used in the manufacture of batteries and airplane engines. The continent, moreover, has more than 60% of the world's uncultivated arable land, a valuable commodity in an increasingly crowded and overdeveloped planet.

When people think of Africa, they are likely to think of endless sand dunes drifting across the Sahara Desert. While the desert is vast, covering 10 million square miles (an area three times the size of Australia), it is also true that Africa is home to 14 ecological zones, ranging from deserts to tropical oases. The deserts, while deeply challenging environments, are far from the dead zones they are often portrayed to be. They are, in fact, rich in silicates, phosphates and other minerals that, if properly managed, could provide a storehouse of wealth. These sun-drenched environments also offer vast opportunities for the generation of solar energy.

Yet, despite its demographic and natural resource advantages, Africa is the world's poorest continent. More than 40% of the population lives on less than US$1.90 a day, which the World Bank defines as extreme poverty, and more than 85% live on less than US$5 a day or $2000 a year. Thirty-nine of Africa's 54 countries are low-income countries; 34 are categorized as least-developed countries.

Food insecurity and malnutrition are widespread – an estimated 20% of the population is undernourished. In east Africa, the percentage of people who are undernourished rises to one-third. Beyond poverty and hunger, 60% of Africans do not have access to electricity and 40% do not have access to safe drinking water.

Climate Matters

It should come as no surprise that Africa is highly vulnerable to climate change. Its at-risk natural resource-based economy, its poverty, its poor infrastructure and weak financial systems and governance all conspire to undermine the continent's resilience and make adaptation difficult.

No continent – indeed no country or even community – is able to escape the relentless wrath of climate change. The changing climate is a global phenomenon that carries devastating consequences – intense heat waves, unprecedented hurricanes and typhoons, historic droughts and floods, and unpredictable weather patterns that hasten spring and prolong summer – now reach into every corner of the planet.

Yet it is fair to say that both the risks and challenges posed by climate change have been greater in Africa than elsewhere. That's no consolation – or source of comfort – for those in the Americas, Asia or Europe – whose homes have been swept away by torrential floods, as was the case in Western Europe in July 2021, or scorched to the ground by intense and relentless wildfires, as occurred in the western United States in the summer 2021 and again in the spring 2022. Nor does the African climate change experience relieve the pain and anxiety of families in India and Pakistan whose lives were placed in dire straits by a protracted heat dome that brought temperatures reaching nearly 50° Celsius in April 2022.

But Africa's disproportionate vulnerability to climate change is nonetheless true – a consequence of its deeply rooted vulnerability to all kinds of economic and ecological risks and the difficulty it has had in responding to all kinds of emergencies, which have been compounded by its inability to deal with the wreckage and dislocation that have been left behind.

It should also be noted that climate change problems in Africa carry an inherent sense of unfairness. That's because Africa is responsible for just 3% of global greenhouse gas emissions, yet is shouldering a lopsided share of climate change impacts.

Impacts and Challenges

In Africa, as elsewhere, climate change impacts are coming from all angles and landing in all places, effecting both people and the environment in countless ways.

- Heavy rainfalls and unprecedented floods in eastern Africa in 2020 and southern Africa in 2022 upended the lives of more than six million people.
- In 2020, the Horn of Africa suffered its most punishing drought in four decades, seriously damaging the region's dominant agricultural sector. In 2021, the Nile River reached its highest point in 50 years, threatening the ecological stability of the riverbanks and causing major infrastructure damage to riverside communities. Too little water one year and too much the next reflects how unpredictable and variable the weather can be under a climate change regime.
- In 2019, Ethiopia and Somalia experienced their worst locust outbreaks in 25 years. For Kenya, it was the worst outbreak in 75 years. The swarming locusts dramatically reduced crop yields, placing additional stress on the agricultural sector, especially small landholders.
- Climate change aggravated dry conditions and gusty winds, together with intense desert storms, have accelerated and intensified sand movements in the African Sahel. Much of the airborne sand swirls about Africa but substantial amounts drift north across the Mediterranean Sea to Europe, damaging the environment and posing a serious public health threat. A portion of the dust is also carried west to the Atlantic Ocean (on average some 182 million tons each year). While a portion of the dust, during its cross-Atlantic journey, drifts to the ocean surface or is leached from the sky during rainstorms, more than 130 million tons reaches South America, the Caribbean and the United States, leaving behind a trail of phosphorous and other plant nutrients that turn Africa's loss into the Americas' gain. Sand transport both within and from

Africa illustrates how climate change, while largely a detrimental force, nevertheless can create winners and losers.

In sum, climate change impacts pose an enormous challenge for Africa beyond the challenges faced by the world at large. These are challenges not of Africa's making. And they are challenges that Africa does not have the financial resources or expertise to solve on its own. In this sense, Africa has simultaneously been a part of – and a part from – global climate discussions and actions that have taken place to address what is increasingly perceived to be an existential challenge for humanity.

Global Action

Over the past decade, the world has sought to lend a helping hand to Africa as part of a larger effort to combat climate change in low-income countries, under the growing realization that the challenge must be effectively addressed everywhere if progress is to be made anywhere. Assistance has been largely guided through decisions rendered at the Conference of the Parties (COP), held under the auspices of the United Nations Framework Convention on Climate Change's (UNFCC).

In 2010, at COP16, in Cancun, Mexico, delegates adopted the Cancun Adaptation Framework, designed to help LDCs, and poorer countries more generally, formulate national climate adaptation plans. One year later, at COP17, in Durban, South Africa, steps were taken to strengthen this measure through the approval of the National Adoption Plan Global Support Program. This initiative, established jointly by the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP), with financial support from the Global Environmental Facility (GEF), sought to identify climate-related technical and financial needs in low-income countries and to weave national adaptation plans into their broader economic development strategies. In effect, it sought to mainstream climate adaptation efforts by placing them on a level playing field with infrastructure investments and support for agriculture, industry, tourism and other critical issues. Forty-five low-income countries have signed onto this effort, including eleven countries in Africa.

At COP21 in Paris, held in 2015, the Paris Accord called upon each country to voluntarily prepare, maintain and share Nationally Determined Contribution (NDC) targets. The intent was to create country-specific pathways to reduce greenhouse-gas emissions and provide a detailed blueprint for constructing effective adaptation strategies based on the scope of the problem as defined by each nation. NDCs have been prepared by each of Africa's 54 nations, creating country-specific blueprints for climate action. In 2021, at COP26, in Glasgow, UK, the conference called for global adaptation funds to rise to US$40 billion a year by 2025 and to ultimately reach US$100 billion a year. These aspirational goals were accompanied by a pledge to provide US$350 million to LDCs to bolster their adaptation efforts. African nations themselves committed US$6 billion in support of utilizing NDC targets as a framework for policy action and they requested that Northern countries provide an additional US$27 billion to meet the projected US$33 billion needed for adaptation on a continental scale. Recent discussions in advance of COP27, scheduled to take place in Sharm El-Sheikh, Egypt, in November 2022, have focused on the need to create specific financial mechanisms to help Africa adapt to climate change – although an exact amount of monetary assistance has yet to be announced. Increasingly, climate change adaptation discussions have moved from planning to finance.

It is fair to say that international fora have viewed climate change challenges in Africa with a greater sense of urgency over the past decade and that several encouraging steps have been taken to assist the continent in this effort. But it is also true that these steps, however well-intended and designed, have been largely hesitant and sporadic and that the determined rhetoric heard at conferences and summits has often exceeded the discordant reality taking place on the ground (and in the air).

In this sense, efforts to assist Africa in meeting the continent's climate challenges are not that different from the way that rich nations have approached their own climate change challenges. Good intentions and aspirational thinking have often failed to be turned into durable policy and programmatic actions that are capable of meeting the scope of the problem – both in Africa and beyond.

Action in Africa

In addition to international efforts, Africa has also pursued climate change adaptation policies and strategies that have often been wrapped within larger efforts to protect the environment and strengthen the prospects for economic growth.

- The African Ministerial Conference on Environment (AMCEN), launched in 1985, seeks to coordinate environmental policies across the continent. Climate change issues have become an increasingly important part of its remit.

- The Committee of African Heads of State on Climate Change (CAHOSCC), created by the African Union (AU) in 2009, strives to nurture common positions on climate change issues to help ensure that Africa speaks with one voice.
- The African Group of Negotiators on Climate Change (AGN) seeks to forge common regional positions on climate issues.
- The African Climate Policy Centre (ACPC) helps to improve the capacity of African nations to effectively participate in international climate change negotiations.
- The African Green Infrastructure Investment Bank (AfGIIB), an AU-convened, African investor-led global financial initiative, is designed to catalyze private capital for Africa's "green" transition. The initiative, announced in 2021, calls for $25 billion in capital investments derived from African and international sources. AfGIIB, which would oversee these investments, is designed as an independent, commercially operated institution.

There have also been on-the-ground, site-specific initiatives in Africa devised to stem climate change and adapt to its impacts. Although these efforts are largely designed to address mitigation strategies, they are well aligned with the continent's broader efforts to strengthen its resilience to climate change impacts and advance the SDGs.

- Africa Great Green Wall (GGW), an initiative sponsored by the AU, is designed as an expansive 8000 kilometer-long and 15-kilometer-wide ecological corridor running from Senegal to Djibouti. The project is dedicated to reforestation, resilient agriculture, ecosystem renewal and biodiversity protection. The goal is to restore 100 million hectares of degraded land, sequester 250 million tons of carbon and create 10 million "green" jobs by 2030. The project is projected to cost US$33 billion. The Great Green Wall Accelerator is a companion international initiative, launched by French President Emmanuel Macron and other world leaders in January 2021 at the One Planet Summit, with the specific purpose of coordinating, monitoring and measuring GGW progress. International donors have pledged US$19 billion to the project.
- Desert to Power, an initiative sponsored by the African Development Bank (AfDB), is intended to install 10 gigawatts of solar power by 2030 through an array of photovoltaic systems comprised of both public and private central grids and off-grid installations. When completed, it will be the Sahel's largest solar project, connecting 250 million people to clean power.

– The Africa Adaptation Acceleration Program (AACP), a joint initiative launched by the African Development Bank (AfDB) and Global Center on Adaptation Africa (GCA) in 2021, aims to mobilize US$25 billion within the next five years to accelerate and expand adaptation efforts across the continent. AfDB has committed US$12.5 billion to the project. A primary aim is to empower millions of African farmers by providing them with digital climate services and climate adaptation technologies to enhance resiliency and increase productivity. Another principal goal is to ultimately train one million young Africans for jobs related to climate adaptation and resilience.

From Strategies to Solutions

Significant strides have been made in formulating climate change adaptation strategies and policies designed to strengthen Africa's resilience in the face of a climate-changed world. International organizations have played a key role in these efforts, as have bilateral agreements with other nations and funding from foundations and investments by private corporations.

Increasingly, however, the effort has been led by Africa itself, whether through projects initiated by AfDB, continental and regional groups dedicated to climate and sustainable development issues such as AACP, individual African nations, or African-based non-profit organizations and private-sector firms. Individual initiative has played a role as well. Climate action in Africa has its admirable share of champions.

Progress is undeniable. Yet wide gaps remain between aspirations and reality – between plans and their implementation. Insufficient funding, despite progress on the financial front, continues to slow the response to climate impacts and risks. While large showcase projects at both the regional and national levels are encouraging, the scale of the adaptation efforts continues to lag behind the scope of the challenge. Similarly, while recent investments by Northern benefactors and African governments and organizations are welcome, substantial additional financing will be necessary to build both a robust adaptation infrastructure and propel the energy transformation that will be necessary to secure a sustainable future across the continent.

Partnerships and synergies remain the keys to progress – in terms of both institutions and ideas. Domestically, African nations need to integrate their adaptation strategies into their broader economic and environmental policies – aligning their climate goals with their overall goals for development. As part of this effort, National Determined Contributions (NDCs) targets should serve as roadmaps designed to guide climate change adaptation policies and programs. The more seamless these alignments become, the more likely progress will be made in meeting both climate change challenges and other critical social and environmental issues. For the same reasons, adaptation strategies should be closely aligned with climate change mitigation strategies and, more broadly, the SDGs.

There is much to admire and praise in Africa's recent efforts to meet the challenges of adaptation and resilience posed by climate change. The continent – both on its own and in concert with others – has taken important steps in addressing what has become a global existential problem unlike any previous problem that the world has faced. But the sum of the parts of these broad-ranging actions – however well-meaning and impactful – has yet to match the whole of the challenge.

Africa's history speaks to its resilience in the face of difficulty. But there are limits to what resiliency can accomplish when confronting a challenge as complex and all-embracing as climate change. Adaptation is critical but the need to respond at a scale and at a pace commensurate with the challenge cannot be underestimated. And, when it comes to climate change – both in Africa and elsewhere – time is running out.

To meet Africa's climate change challenges in terms of their immediacy and depth – and to translate African-led climate strategies and policies into tangible results on the ground – we recommend the following actions be taken:

- Each African country should produce and implement a National Adaptation Plan (NAP) fully integrated into its National Development Plan (NDP) and Nationally Determined Contributions targets (NDC).
- Each African country should continue to increase financial support for its NAP and to design innovative strategies to encourage adaptation financing and investment from the private sector and international financial institutions.
- Adaptation actions should be aligned with both mitigation actions and the SDGs to deliver co-benefits (for example, through the Great Green Wall Initiative and efforts to tap the vast potential for solar energy production in northern Africa).
- African universities should integrate climate change adaptation and resilience into their curriculum to help prepare students for future "green" jobs. In-person and virtual courses should be developed with this goal in mind.

- Emerging technologies, including artificial intelligence, climate change data and information systems, digital agriculture, drones and robots should be deployed to help drive collaborative actions that address adaptation, mitigation and the SDGs.
- African-based and global partners should provide the financial support needed to implement the actions launched by the African Adaptation Acceleration Program (AAAP). The program promises to extend benefits to both the economy and the environment across Africa that will remain in place for generations to come.

Ecological Environment Management in China

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Summary and Recommendations

Ecological environmental protection is important for everyone and the future of the world. Since China's reform and opening up, great achievements have been made in economic development and great progress has been made in ecological environmental protection. China has incorporated the construction of ecological civilization into the Five-sphere Integrated Plan (to promotes coordinated economic, political, cultural, social, and ecological advancement), which refers to China's overall plan for building our beautiful motherland. China has carried out a series of actions to prevent and control pollution. As a result, the environmental quality has improved significantly. The proportion of days with good air quality in cities, the proportion of surface water sections (sites) with good quality, and the safe utilization rate of polluted farmland, increased significantly.

In order to protect the ecological environment, it is recommended that the international community should cooperate to promote global ecological and environmental governance, actively carry out pollution prevention and control, actively include the role of science and technology in improving energy efficiency and resource production and utilization efficiency, and increase the proportion of clean energy.

The Industrial Revolution led to an acceleration of the development of human society. With the surge of world population and the rapid development of industry and economy, the impact of human activities on the ecological environment has become more and more acute. Therefore, the "Anthropocene" epoch has been proposed. Global problems of ecological destruction and environmental pollution have become increasingly serious. For example, the Antarctic ozone hole, global acid deposition, and global-warming resulting disasters constitute global environmental problems, which obviously endanger the survival and reproduction of all human beings, and have attracted great attention from the international community. Ecological Environment protection has become a central issue related to the development of all human beings. The term *Anthropocene* was popularised by scientists to illustrate how human impact has made our world so vastly different from the world we inherited.

On June 5, 1972, the United Nations held the first world conference on the human environment in Stockholm, adopted a series of principles and set out the Stockholm Declaration and Action Plan for the Human Environment. In June 1992, the United Nations Conference on Environment and Development was held in Rio de Janeiro, Brazil, where the future destiny of the earth was discussed, and Agenda 21, the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity were signed. The 2030 Agenda for Sustainable Development was adopted at the 70th session of the United Nations General Assembly in 2015, with its 17 Sustainable Development Goals (SDGs), serving as the overall framework to guide global and national development action. In 2015, the Paris Agreement was adopted at the 21st United Nations Climate Change Conference, providing a framework for global actions to address human induced climate change.

The signing of a series of important international conventions shows that the international community's awareness of ecological and environmental protection has been greatly enhanced and international cooperation has been strengthened. The international community's joint efforts to address global ecological and environmental problems and build a shared future for all life on earth, have brought great hope for the harmonious development of human and nature.

1. Background and policy of Ecological Environment Management in China

Between 1972 and 1988, a Leading Group of Environmental Protection of the State Council was established and later upgraded to the State Bureau of Environmental Protection (SBEP, an independent organization) (Xie, 2020).

During the period from 1989 to 1998, the government implemented the "33211" and "one control and two compliances" environmental pollution control programme. The SBEP strengthened the environmental protection. ("33211" refers to: the three rivers: Huai River, Hai River, Liao River, and three lakes: Dianchi Lake, Taihu Lake, Chaohu Lake; "2" is dual-control area: sulfur dioxide and acid rain control area; "11" is one city (Beijing) and one sea (the Bohai Sea); "one control and two compliances" refers to: by 2000 the country's total pollutant discharge should be controlled at the level of 1995, the pollutant discharge of industrial pollution sources as well as environmental quality of the environmental function zones of key cities should comply with the standards).

During the period from 1999 to 2008, China continuously intensified its efforts in energy conservation, in emissions reduction, and the control of the total discharge of pollutants, and the Ministry of Environmental Protection (MEP) was established (Xie, 2020), greatly strengthening pollution prevention and control.

Since 2009, China has carried out a series of actions to prevent and control pollution, launched air, water and soil Pollution Prevention and Control Action Plans, and implemented the nationwide battle to prevent and control pollution (three major actions to keep the sky blue, water clear, soil clean). China's ecological environment protection is entering a critical period in which carbon reduction is the key strategic direction, green transformation of economic and social aspects is being promoted. (The State Council, 2013, 2015, 2016; The CPC Central Committee, The State Council, 2018, 2021; Xie, 2020). Increasing, attention has been directed to conservation of China's biodiversity.

2. China's achievements on Ecological Environment Management

2.1 Ecological Environment Protection System

China has set up and improved systems for ecological environmental protection including ecological conservation performance assessment and accountability, ecological compensation, and the designation of river, lake and forest chiefs. China has formulated and revised a series of laws and regulations regarding environmental protection, forming a relatively comprehensive legal system for ecological environment protection. China has strengthened the administrative law enforcement team for ecological environment protection, and established the system of central inspection on eco-environmental protection, conducted supervision of the central government in 31 provinces to deal with major typical cases of ecological environment destruction. (Ministry of Ecology and Environment, QIUSHI, 2022). All these provide an institutional and legal guarantee for ecological environment protection.

2.2 Great achievements in land greening programs

China has carried out large-scale land greening programs. The country's forest coverage and forest stock volume have been increasing over the past 30 years. After more than 70 years of afforestation, China's forest cover rate increased by 2.6 times. By the end of 2020, the forest cover area of China reached 23.04%, and the forest area was 220 million hectares. The forest stock volume has increased from 15.137 billion cubic meters in 2016 to 17.56 billion cubic meters in 2021 (Ministry of Ecology and Environment, The People's Daily, 2021). As shown in Figure 1. China has also increased the amount of conservation areas.

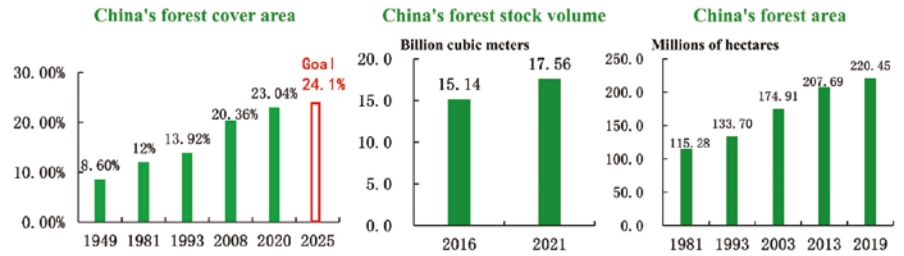

Figure 1. China's forest coverage rate, forest stock volume, forest area.

2.3 Air pollution control

Through large-scale air pollution control, air quality has continued to improve. The proportion of days with good or excellent air quality in cities at or above prefecture level increased year by year from 2015 to 2021, and reached 87.4% in 2021, 10.7% higher than that in 2015; the concentrations of major air pollutants decreased gradually: $PM_{2.5}$ decreased by 40%; SO_2 decreased by 64%; NO_2 decreased by 23% (Ministry of Environmental Protection, 2016; Ministry of Ecology and Environment, 2018, 2020, 2022) (Fig. 2).

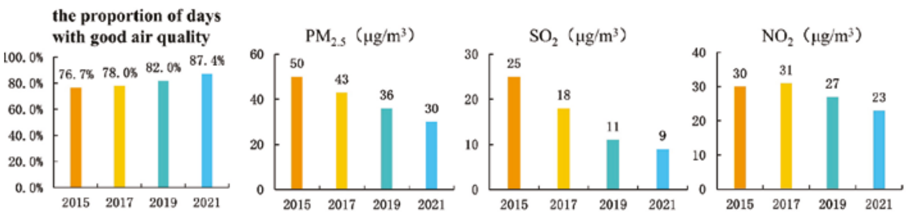

Figure 2. Proportion of days with good or excellent air quality and the concentrations of major air pollutants ($PM_{2.5}$, SO_2, NO_2) in cities at or above the prefecture level in China from 2015 to 2021.

2.4 Water pollution control

From the 1980s to the 1990s, China carried out large-scale pollution control actions. Since the 21st century, the efforts to control water pollution have been stepped up. Water quality has improved significantly. The proportion of surface water sections (sites) with excellent and good water quality increased from 66% in 2015 to 83.4% in 2020. The proportion of nearshore marine water with excellent and good sea water quality increased from 73.4% in 2016 to 81.3% in 2021. The proportion of monitoring sections for rivers that flow into the Sea with excellent and good water quality increased from 46.8% in 2016 to 71.7% in 2021 (Ministry of Environmental Protection, 2016, 2017; Ministry of Ecology and Environment, 2021) (Fig. 3-4).

2.5 Soil pollution control

China has gradually incorporated soil pollution prevention and control into the key work of environmental protection, and has carried out a series of basic surveys and pollution control actions (Liu et al., 2021). Over the past decade, obvious progress in the prevention and control of soil pollution

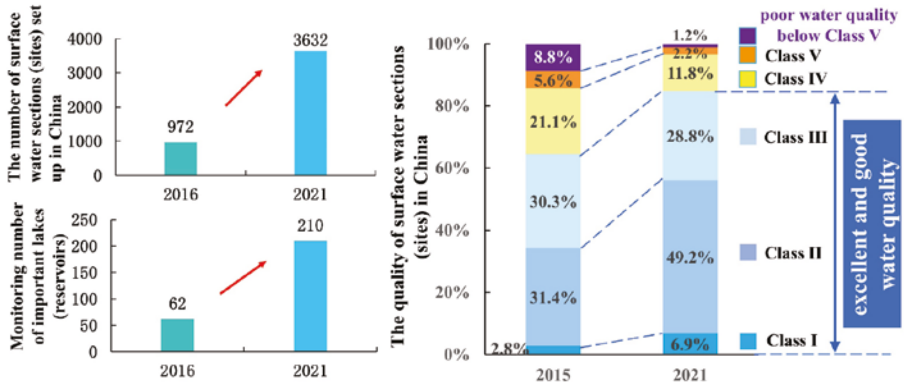

Figure 3. The number of surface water sections (sites) set up in China in 2016 and 2021, the general surface water quality in China in 2015 and 2021.

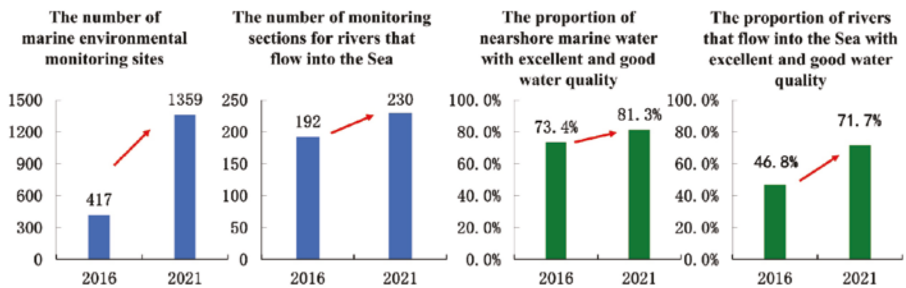

Figure 4. The number of marine environmental monitoring sites, sections for rivers that flow into the sea set up in China (2016-2021), the proportion of nearshore marine water, rivers that flow into the sea with excellent and good water quality in China (2016-2021).

has been achieved. By the end of 2020, the safe utilization rate of polluted farmland reached about 90% (Ministry of Ecology and Environment, 2021), successfully fulfilling the objectives set out in the soil pollution action plan.

2.6 Comprehensive utilization of solid waste

China attaches great importance to the resource utilization of solid waste. During the period from 2016 to 2020, about 13 billion tons of bulk solid wastes have been comprehensively utilized, which reduced over 0.0667 million hectares of land occupied by solid waste and produced new products (State Statistics Bureau, 2022; Ministry of Ecology and Environment, Statistical Bulletin, 2020). In 2021, "Guiding Opinions on the Comprehensive Utilization of Bulk Solid Wastes in the 14th Five-Year Plan" was issued, proposing that by 2025, the comprehensive utilization rate of newly added bulk solid waste should reach 60%.

3. China's "dual carbon" strategy

China attaches great importance to its response to climate change, and formulated and released the National Strategy of "peaking carbon emissions and achieving carbon neutrality" (dual carbon). In 2020, China announced new targets and measures. China aims for peak carbon dioxide emissions before 2030 and to achieve carbon neutrality before 2060; to increase the share of non-fossil fuels in primary energy consumption to around 25 percent by 2030.

Since the "dual carbon" strategy was put forward, China has taken actions to reduce carbon emissions and has made great achievements in energy conservation, emission reduction and new energy development (Fig. 5).

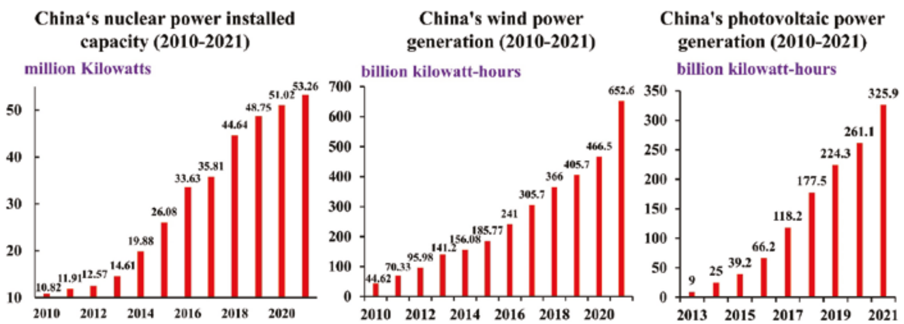

Figure 5. China's nuclear power installed capacity, wind power, photovoltaic power generation.

4. Technology boosts ecological environment protection

4.1 Conducting long-term monitoring program of tracing atmospheric CO2ff by 14C to provide scientific data for the evaluation and control of carbon emission reduction

Based on accurately understanding of the levels and spatial-temporal variation characteristics of atmospheric fossil fuel derived CO_2 (CO_{2ff}), we can provide scientific data for the evaluation of carbon emission reduction. Radiocarbon is a unique tracer for the identification of atmospheric CO_2 emitted from fossil fuels, because ^{14}C is depleted in fossil fuels due to their great age, in comparison with the ^{14}C half-life of 5730 $\pm$ 40 years. The marked difference in ^{14}C content can be used to distinguish between atmospheric CO_{2ff} and CO_2 from other sources. Usually, ^{14}C in air samples has been used to quantify the CO_{2ff} with different time-resolution. Plants assimilate carbon from the atmosphere during photosynthesis and preserve a record of atmospheric ^{14}C during their growth period, so ^{14}C measurement of plant material is an alternative way to monitor atmospheric CO_{2ff} on large-spatial scales and long-time scales.

My research team proactively carried out monitoring program of quantitatively tracing atmospheric CO_{2ff} by radiocarbon from 2010 in Xi'an, the largest city in northwestern China, and then the atmospheric ^{14}C observations gradually expand to more major Chinese cities and background sites, such as Beijing, Shanghai, Guangzhou and so on. In the past decade, our team has obtained a series of basic atmospheric ^{14}C data by air samples, annual herbaceous plant samples and tree rings. Based on those data, model simulation and source analysis have been carried out to figure out the transportation and main source of CO_{2ff}. Through those efforts, we have obtained a general picture of Chinese urban CO_{2ff} and characteristics of its spatio-temporal variations at different scale, and established an effective atmospheric ^{14}C monitoring system.

The multi-year (2011-2019) observation in Xi'an showed that CO_{2ff} has higher value in winter than that in summer. The annual averages of CO_{2ff} concentrations decreased from 40.1 $\pm$ 3.8 ppm during 2011-2013 to 25.7 $\pm$ 1.1 ppm during 2014-2016 (a decrease of 35.9 $\pm$ 6.6%), due to the implementation of the Action Plan on Prevention and Control of Air Pollution from 2013 (Fig. 6). The model and source analysis results showed that local CO_{2ff} inputs from coal combustion was the main contributor in Xi'an (Feng et al., 2018; Zhou et al., 2020). Using tree ring ^{14}C archives, we reconstruct an historical CO_{2ff} time series in Xi'an. CO_{2ff} concentration increases from both urban and rural sites during 1991-2015,

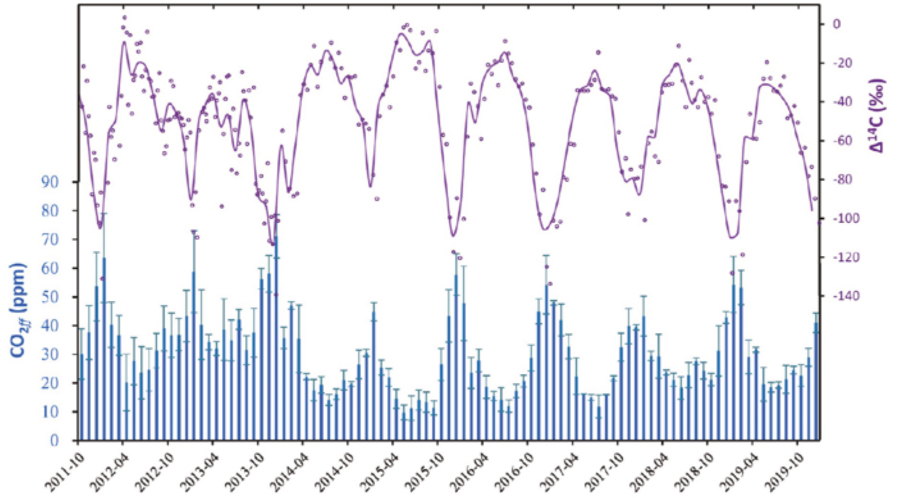

Figure 6. $\Delta 14CO_2$ (purple dots) and CO_{2ff} (blue bars) variations in Xi'an during 2011-2019.

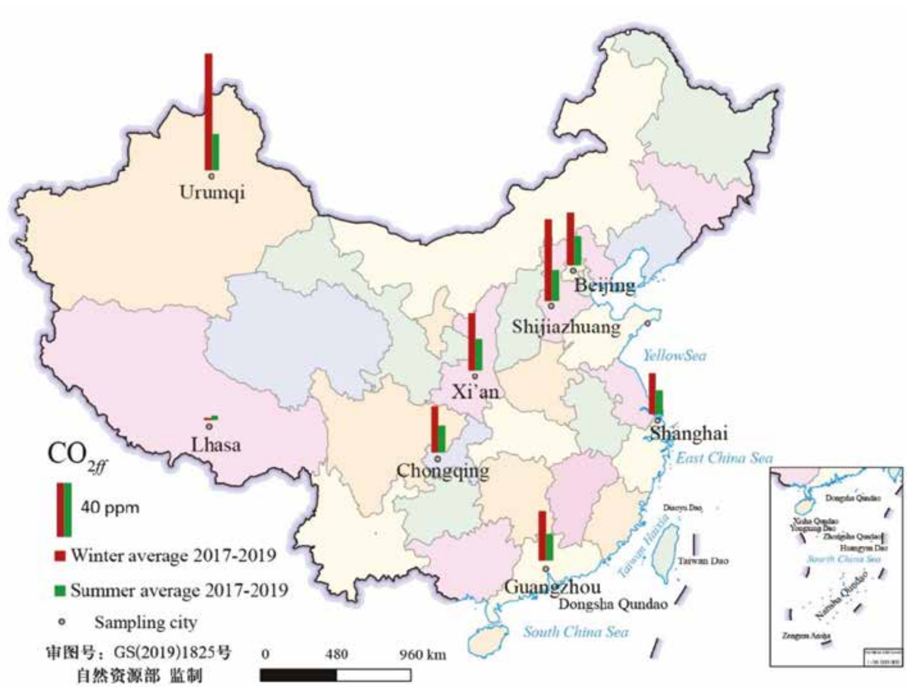

Figure 7. The comparison of fossil fuel CO_2 concentration in winter and summer in some Chinese cities (2017-2019).

with more significant increases among urban sites. The persistent rise in CO_{2ff} was attributed to increasing energy consumption caused by regional socio-economic development, which are corroborated by strong correlations between CO_{2ff} and socioeconomic parameters (Hou et al., 2020).

Observations in major Chinese cities showed that the northwestern cities have relatively high CO_{2ff} concentrations in winter (Fig.7), thus they are the key points to reduce carbon emissions, especially the emissions from coal consumption. We also found significant correlations between $PM_{2.5}$ and CO_{2ff} in Chinese cities, which imply the feasibility of reduction of both carbon and atmospheric pollutants in China through similar policy measures (Zhou et al., 2020; Zhou et al., 2022).

4.2 Reinforcing scientific research to comprehensively utilize industrial solid waste and develop new technologies for tailings utilization

Our group has developed a new method for the utilization of solid waste with catalyst as the key, and the recovery rate of major elements in the tails can reach 90%. For example, two 600,000 KW power plants could produce about 1 million tons of fly ash, and all the fly ash could be comprehensively utilized to extract 440,000 tons of alumina and 375,000 tons of silica gel, 22,000 tons of red iron oxide, 55 tons of gallium, and consume 510,000 tons of CO_2. By the technology zero emissions of solid waste and CO_2 could be achieved.

5. Summary

1) Ecological environmental protection, a critical issue for the world, the countries, and the people, mainly depends on the government's governance and input. It requires the government to issue relevant laws and policies, and implement ecological environment protection actions. Meanwhile, arouse public awareness is also indispensable;
2) The technology advancement and technical exchanges are the key to solving global ecological environment problems, such as new technology for coal utilization in an efficient and low-emission way. They will make important contributions to energy conservation and emission reduction;
3) The international community should strengthen cooperation and build a beautiful world.

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Ending Energy Poverty

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Introduction

Energy poverty results when people lack affordable and reliable access to modern forms of energy. It may be chronic or temporary, and like poverty itself, it occurs everywhere. Indeed, it is both a symptom, and cause of poverty – one that has been made worse by the Covid-19 pandemic, and the unfolding war in Eastern Europe. This paper describes the challenges along with new ideas, recent progress, and reasons to be optimistic about ending energy poverty in the developing world without accelerating climate change. It makes the following recommendations directed at the international community and the leaders of low access countries:

1. Governments should develop structured programs when pursuing universal electricity access following the core principles set out in the Integrated Distribution Framework (IDF) adopted by the Global Commission to End Energy Poverty, including a focus on economic impact and the use of on- and off-grid technologies.
2. In partnership with international experts and institutions, governments should use modern computational geospatial tools to plan resilient and affordable energy infrastructure to enable universal access and drive equitable economic growth.
3. To help reduce consumer energy costs, increase system resiliency, and encourage investment in low carbon generation, governments of small low-access countries should more aggressively pursue cross-border trade and regional integration of their electricity systems.
4. To enable 1-3, the international community must be far more generous in supporting access programs with greatly expanded concessional lending and grant-making to poor countries. Governments in turn must commit to efficient business models that encourage greater private sector investment in access and service reliability. Absent this large increase in wealth transfers, the SDG7 goal of achieving universal access cannot be achieved, and energy poverty will persist.

Background

The concept of *energy poverty* was first introduced in the 1970s in relation to "fuel poverty" in the UK, and the need to shape public policy that would ensure that home heating fuel was available and affordable universally (Isherwood 1979) – a narrowly defined, but important objective. Contemporary usage has largely maintained this connection with *residential* consumption. Indeed, *ending* energy poverty has become virtually synonymous with *achieving universal residential access* to modern energy, and in particular, to electricity and clean cooking fuels (such as liquified petroleum gas) that can displace so-called traditional fuels such as firewood and dung. Thus, the United Nations has prominently identified achieving "universal access to affordable, reliable and modern energy services" among the objectives of Sustainable Development Goal 7 (SDG7). As shown in Figure 1a, progress in expanding electricity access has been rapid over the past two decades, with only 10% of the global population living without electricity services as of 2021, or some 759M people – 84% of them in rural areas (IEA 2021), and the vast majority in sub-Saharan Africa. Progress over the same period has been slower for clean cooking fuels (Fig. 1b), with less than a 15% reduction in the population lacking access since 2000. Notably, the effect of the Covid pandemic has so far been to stall continued progress on both fronts. Here we will focus on the electrification problem, noting that electrification also provides a potential pathway to clean cooking that can significantly improve the economics of grid electrification.[1]

Electricity access is not defined uniformly from country to country. For modeling purposes, the International Energy Agency (IEA) uses a uniform minimum level of consumption of 1250kWh per year per *grid connected* household, or 250kWh per capita (IEA 2020). As an alternative to grid service for rural households, so-called off-grid alternatives are increasingly used. These include *mini-grids*, that is, isolated self-contained grids serving tens to thousands of dwellings with aggregated generation (diesel, or solar with battery back-up), and *solar home systems* for individual dwellings. The latter come in a range of configurations comprising a small solar array and battery bundled with a number of pre-wired LED light fixtures, and possibly a phone charger, fan, or small television. Mini-grid service is typically

[1] For countries with excess generating capacity, including many in Africa, electric cooking represents an important potential load that can help to offset fixed generation costs. This can have a beneficial impact on consumer costs if the savings are not overwhelmed by any additional cost associated with upgrading the distribution network.

provided by small firms that design, build and operate systems configured to meet community requirements, which may vary widely depending on the level of wealth and economic activity. Users either pay a fixed monthly fee, or according to metered consumption. Solar home systems, on the other hand, are either purchased for a single up-front price, or on a rent

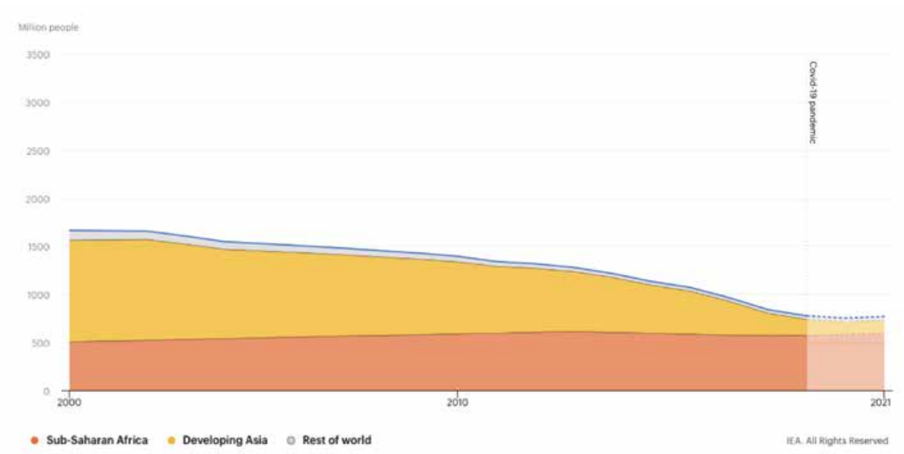

Figure 1a. IEA, Global population without access to electricity by region, 2000-2021, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-population-without-access-to-electricity-by-region-2000-2021-2 used with permission.

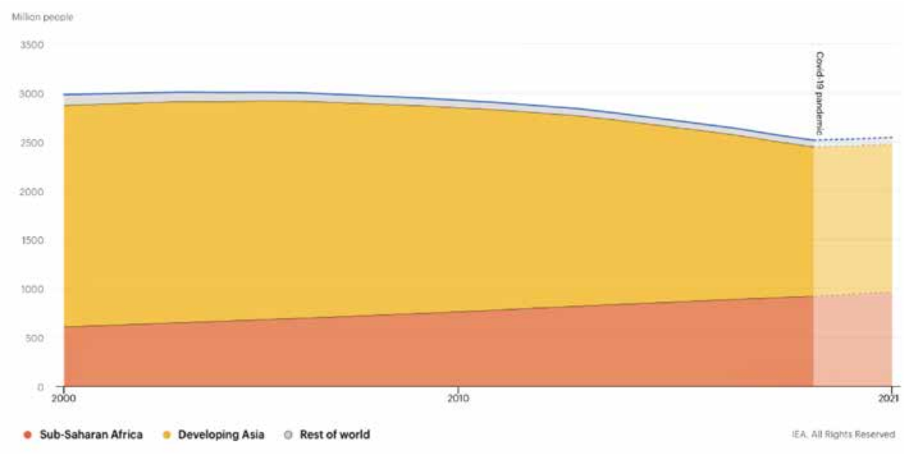

Figure 1b. IEA, Global population without access to clean cooking by region, 2000-2021, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-population-without-access-to-clean-cooking-by-region-2000-2021 used with permission.

to own, or Pay-as-You-Go (PayGo) basis, with a two- or three-year purchase period (Jacquot 2021). In its modelling work, the IEA defines the minimum level of service to be 50kWh per capita per year for off-grid rural households, and 100kWh for urban households (IEA 2020). The cost of service in either off-grid mode is high on a $/kWh basis compared to typical grid service – however, the economics of extending and maintaining grids in rural areas to serve dispersed populations of small residential consumers are very unfavorable for utilities, which given the choice resist such investments. Off-grid technologies therefore represent a more *feasible* option for many rural consumers in developing countries, rather than one that is necessarily inexpensive.

Nevertheless, we emphasize that the attainment of a high level of residential access economic development may be fleeting if not accompanied by economic development. To draw attention to the much larger electricity investment gap that still must be addressed throughout the broader economy in many unindustrialized countries, a Modern Energy Minimum (MEM) was recently proposed (Moss 2021). This economy-wide level of consumption is some four times more than the IEA's minimum grid service level, and ten to twenty times more than its off-grid minimum.[2] Therefore, although achieving universal access to modern energy is a precondition for ending energy poverty, it must be emphasized that access alone will not end energy poverty – the scale and use of energy is also crucially important.

Universal Access and Climate Change in India

India's rapid electrification in the past two decades serves as a hopeful and informative beacon, and a counterpoint to the African story (IEA 2020(2)). In addition to massively expanding its electricity distribution network during this period, India also increased its generation capacity (with a substantial share coming from renewable sources), and created a synchronized national transmission network. To be sure, India has many advantages relative to other developing countries that enabled this success, including the sheer size of its electricity market which provides considerable economies of scale

[2] Taking $2,500 as a target minimum household income level (roughly in line with the median household income in a lower middle-income country), the MEM offers per capita consumption of 1,000 kWh per year as an appropriate minimum benchmark based on the established correlation between household income and economy-wide electricity consumption.

that help to keep electricity prices low. India also has deep domestic capital markets, as well as a large tax base, and substantial technical capacity within government and industry to tackle large programs and projects. Thanks to the determined efforts of successive governments, and especially the present one, over 700M have gained access to electricity since 2000, many of them within the last five years. While the vast majority of new connections were via grid extension, off-grid technologies remain important in India for the relatively small number of those who live in deeply rural and itinerant communities where grid access is infeasible.

Concerns have been raised that rapidly developing countries like India will come to dominate global greenhouse emissions as their wealth and consumption continue to increase in the coming decades. However, it is far from clear that this is inevitable. A recent study (MIT 2022) modeled plausible growth scenarios for the Indian power sector through 2050, and concluded that even under relatively conservative cost and performance assumptions, the Indian grid can continue to expand at its present annual rate of roughly 5% through mid-century by making extensive use of solar and wind energy, with significantly lower emissions than today by 2050 – even *without an assumed price on emitted carbon*. The study concludes that similar outcomes are possible in other emerging economies in South and Southeast Asia.

Challenges for Sub-Saharan Africa

As we have noted, access levels in sub-Saharan Africa are low, hovering in the range of 25-50%, and they are expected to remain so for decades as the rate at which new connections are made lags population growth. But even with its growing population, Africa remains relatively sparsely populated, and African electricity markets are small, depriving them of India-like economies of scale. African economies and financial markets are likewise small. These factors weigh on energy infrastructure investment, and contribute to relatively high bulk grid electricity costs, compounded for consumers by the high cost of distributing electricity in its sparsely populated rural areas.

Off-grid technologies therefore play a more prominent role in sub-Saharan Africa than India. Many governments have incorporated off-grid elements into their overall electrification strategies – assisted by professional planners, some using sophisticated geospatial planning platforms.[3]

[3] See for example, WAYA Energy, https://waya-energy.com

The Integrated Distribution Framework

In 2019, to help inform energy access policy and programs in sub-Saharan Africa and elsewhere, the Rockefeller Foundation, in partnership with MIT, assembled the Global Commission to End Energy Poverty.[4] Focusing initially on electricity because of its close connection to economic development, the Commission has sought to identify successes in ending energy poverty from around the world, analyzing best practices and building a consensus for global action. Among other things, it has promulgated a set of principles under the banner of the *Integrated Distribution Framework* (IDF) (GCEEP 2020) to help shape policy in low access countries.

The IDF focuses on the *electricity distribution segment* rather than transmission or generation. This is the part of the electricity system that consumers interact with in their daily lives comprising meters, wires, and the short connecting lines that carry power from the transmission network, and the generating stations that supply it. Transmission and generation investments are generally self-contained and carefully planned, and investor returns are relatively predictable – and are therefore they are typically paced not by a lack of investor appetite, but rather by investor confidence in distribution utilities to be a reliable downstream off-takers. In developing countries, where utilities commonly experience government pressure to expand into rural areas while providing service at unrealistically low tariffs, they seldom are. Indeed, stretched thin under such pressure, the majority are unable to invest adequately in either expansion or maintenance, and their customers, dissatisfied with the low reliability and quality of service they receive – or simply too poor to pay – complete a destructive cycle that ensures the chronic failure of the segment. Distribution is therefore the persistent access bottleneck, and making distribution work is therefore central to achieving universal access to electricity, and ultimately to ending energy poverty. The so-called *viability gap* between the total remuneration that distributors (including the providers of off-grid technologies) require in order to deliver reliable service and the revenues they can expect to receive from their customers, some of whom cannot pay anything – must be

[4] The Commission is co-chaired by Rockefeller President, Raj Shah, Emeritus MIT Professor and former US Secretary of Energy, Ernest Moniz, and Akinwumi Adesina, the President of the African Development Bank. Its members include CEOs of major international firms, the heads of many of the world's leading bilateral and multilateral development agencies, as well as the leaders of multilateral agencies leading global energy-related programs, including Power Africa, the IEA, UNECA, IRENA and SEforALL. The author is also a member, and serves as secretary and co-director of research.

somehow filled for the utility to be viable. This generally requires a combination of two things: that utilities raise additional revenues from mainly industrial and urban customers (in order to cross-subsidize rural service), and governments provide grants or very low-cost loans (thereby directly subsidizing service) to utilities and off-grid providers to offset what would otherwise be unsustainable losses. To help reduce the subsidy burden as much as possible, lower cost off-grid connections should be used where grid service is too expensive.

The IDF rests on four deceptively simple principles designed to guide governments in the process of expanding service to the poor without undermining service overall:

(1) A commitment to universal access that leaves no one behind, and includes permanence of supply and the existence of a utility-like entity with ultimate responsibility for providing access to everyone irrespective of wealth, in a defined territory.
(2) Efficient and coordinated integration of on- and off-grid solutions (including grid extension, mini-grids and stand-alone systems) linked through integrated planning and appropriate business models for all types of consumers whether rural, urban, industrial or residential.
(3) A financially viable business model for the overall distribution system combining on- and off-grid approaches typically in the form of a concession that provides legal security and ensures the participation of external, mostly private investors, and may include subsidies for viability gap funding.
(4) A focus on economic development to ensure that electrification produces broad socio-economic benefits including expanded access to critical public services such as health and education, and economically beneficial end-uses.

With help from the Commission, the IDF has now been incorporated into the plans and programs of numerous countries.[5]

The IDF helps to dispel the unhelpful perception of a competition between on- and off-grid approaches – both are needed, and in a measure that will change over time as wealth increases and needs change. The overall conception is that coexistence should be encouraged to enable rapid service expansion at the least possible cost, but coordinated by a single utility-like entity to avoid wasted investment. The IDF also posits that

[5] See for example (Abajo 2020).

service *permanence* must be back-stopped, so to speak, by the utility in the sense that if a private off-grid supplier fails to offer or maintain reliable service, then the utility must assume responsibility for providing it (by on- or off-grid means). Moreover, as *default-provider* and *provider-of-last-resort*, the utility must clearly exist within a financially viable regime – when necessary, receiving additional remuneration from the government to cover the cost of extending service to rural areas, and meeting obligations that are not covered through billing, such as providing free or below-cost service to economically disadvantaged consumers. Under the IDF, the government and utility further assume joint responsibility for planning service expansion in a way that provides for both residential service, and service to economically productive industry in rural areas.

One implication of such a cooperative arrangement is that the continued viability of the utility depends on the financial capacity and good behavior of the government itself. Implicitly, if the government lacks the financial resources to subsidize, or otherwise cannot be relied upon, then the shortfall, or *viability gap*, must be guaranteed in some way by a third party such as a development bank with concessional funding in the form of a concessional loan, or grant to the government. A key finding of the Global Commission to End Energy Poverty is that the amount of funding made available by wealthy countries to developing countries with high levels of chronic energy poverty is far too low.

Measuring the Financial Gap

To shed light on the overall and relative scales of private, government, and concessional funding required, the Global Commission recently developed a multi-dimensional *Electricity Access Index* (Perez-Arriaga 2022). On its financial axis, the index compares a country's rate of historical investment in distribution with the rate that would be needed, based on a model calculation, to achieve universal access by 2030 – referred to as the "adequacy" of investment.[6] The model calculation includes the share of private, government and concessional capital that must be deployed. To date, this has only been done for a small number of countries – but it is clear from these that the present level of investment, and notably the concessional portion, is far below the required level. An unavoidable conclusion is that the international donor community must be far more

[6] On a second axis, the index measures investment "efficiency" based on an expert assessment of measures linked to the IDF.

generous in supporting access programs. As noted above, to help minimize the burden on donors, planners should use modern geospatially referenced tools to help plan resilient, and affordable energy infrastructure using a combination of on- and off-grid technologies.[7]

Regional Cooperation for Resilience and Security of Supply

The affordability of the bulk electricity supply (i.e., the electricity that it produced by generators and delivered to distribution utilities via the transmission network), which depends strongly on market size and the economies of scale that it provides, also clearly influences the level of support that governments and external partners must provide to ensure end consumer affordability. To achieve economies of scale, small countries must engage in regional trade in electricity by connecting their transmission networks with their neighbors in bilateral arrangements, or via multi-country power pools (GCEEP 2020). This also naturally engenders diversity of supply as different countries develop resources such as hydro, solar, and wind according to their unique access to such resources, and increases supply resiliency. Diversity and scale of supply and demand also lessen the need for energy storage on the grid, and thereby further help reduce supply cost in solar- and wind-intensive systems. Despite this, and despite the extensive positive experience in other parts of the world, progress in establishing cross-border trade in electricity in Africa has been much slower than elsewhere.[8] Governments of small low-access countries should more aggressively pursue cross-border trade and regional integration of their electricity systems to support access programs and prepare them for a low carbon, electrified future.

The ongoing work described briefly here, as well as other private, multilateral and government initiatives cast a hopeful light. Despite recent Covid and war-related reversals, and the financial stress created by deglobalization,

[7] It must be acknowledged that while geospatial tools can help to minimize the cost of achieving universal access to electricity, political leaders must also account for public opinion, and other socio-political factors in ways that may shift the relative roles played by on- and off-grid technologies. A preference for grid-electrification is common, and often well-justified in terms of physical permanence and economic impact, if it is within the government's capacity to provide it. If not, then off-grid technologies should be considered, recognizing that they may displaced by the grid in the future.

[8] Regional, including international and subnational trade via power pools is well-established in North America and Europe, and Latin America, for example, where it plays a vital role in maintaining price stability and system resilience.

progress over the long term globally in ending energy poverty in the developing world has been uneven, but also unmistakable. Over the past two decades, the number of people lacking access to electricity outside Africa has been reduced by nearly a billion to roughly 200m. Within Africa over the same period, however, the number of unelectrified has continued to increase as population growth steadily outpaces new, mainly rural connections. The introduction of off-grid solar technologies has helped to slow this increase, but to reverse it will require a massive expansion of access programs making use of these technologies, as well as grid extension. Our essential point is that electricity is essential to modern life and living standards, and cannot be thought of as optional for the poor. It is essential for *everyone* and embedded in our economies, and must be provided in such a way that ensures that service is reliable, affordable and viable in the long-term *everywhere*. We have offered a guide to governments in the form of the IDF.

Although we have not emphasized it here, despite recent gains in electricity access in most parts of the world, access to clean cooking technologies has increased at an unacceptably slow pace owing mainly to a lack of affordable options to so-called traditional fuels such as wood and dung. We note, however, that the rapid advance of electrification, and declining renewable generation costs are making electrified cooking a new option for many. We see this as an important recent development, especially for developing countries with abundant renewable energy resources where many now depend on traditional fuels with grave consequences for their health and safety.

We also emphasize that, as evidenced by the rapid growth of renewable generation in developing countries, the objective of providing modern energy to all humanity, and along with it, prosperity and hope for the future, does not have to be in conflict with climate change mitigation efforts. A low carbon global economy with universal access to modern energy is clearly possible. Bringing it about, however, will require a mix of discipline on the part of political leaders and unprecedented generosity on the part of the international community to ensure that affordable low-carbon electricity service is made available to all.

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People-Centred Approaches to Deliver Nature-Based Solutions: A Perspective for Resilience in the Amazon

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1. Introduction

There is growing evidence that it could take three to five decades to bend the global warming curve.[1] Therefore, it is an ethical imperative to mobilise the scientific and practical knowledge to develop resilience pathways for humanity.[2] Special attention must be given to the most vulnerable peoples so as to reduce climate injustice.[3]

Nature-based climate solutions applicable to oceans, native terrestrial ecosystems and anthropogenic land-use systems can play an important role as they can be economically efficient.[4] In addition, nature-based solutions can deliver social equity benefits. The challenge is how to enhance social benefits of nature-based solutions, given high and increasing rates of inequalities worldwide.[5] This is a theme that requires new advances for both science and practice.

People-based solutions to climate change offer a promising approach to link social inclusion goals to nature restoration and protection goals.[6]

[1] IPCC 2021, Special Report: Global Warming of 1.5°C. https://www.ipcc.ch/sr15/chapter/spm/

[2] *Laudato Si'*. Pope Francis, June 18, 2015. https://www.vatican.va/content/francesco/es/encyclicals/documents/papa-francesco_20150524_enciclica-laudato-si.htmll

[3] Climate Justice. United Nations, May 31, 2019. https://www.un.org/sustainabledevelopment/blog/2019/05/climate-justice/

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[5] Nature-based solutions and their socio-economic benefits for Europe's recovery. Institute for European Environmental Policy, February 24, 2021. https://ieep.eu/publications/nature-based-solutions-and-their-socio-economic-benefits-for-europe-s-recovery

[6] Viana, V.M. People-based solutions as a strategy to deliver nature-based solution to biodiversity and climate emergencies. In: *Nature-Based Solutions Workshop: Measuring Impact on a Triple Bottom Line and Scaling it Through Public Policy.* PreCOP25, October, 8, 2019, San José, Costa Rica.

People-based solutions can be defined as practical approaches to tackle climate change adaptation and mitigation agendas through labour-intensive and culturally appropriate activities. Job creation for less-educated workers can reduce inequalities, while culturally appropriate activities can improve livelihoods and mobilise ethnoecological knowledge of local communities and specially of indigenous peoples. These solutions have the potential of being more cost-efficient in delivering climate resilience goals together with multiple sustainable development goals than other approaches. This paper will bring evidence from science and practice to back this approach with a perspective from the Amazon.

The Amazon is one of the most important biomes on earth in delivering ecosystem services that are essential to increase resilience of global systems to climate change. The Amazon stores 176 billion tons/CO_2 (25% of global storage in terrestrial ecosystems),[7] 16% of global surface freshwater, 10% of plants, and over 2,300 species of fish, more than can be found in the entire Atlantic Ocean.[8] There is evidence that deforestation in the Amazon can have regional impacts in rainfall regimes for South America,[9] with major impacts for food production systems, hydroelectricity power generation, and urban water supply.[10] There is also evidence that deforestation in the Amazon can affect extreme drought events and forest fire frequency in distant areas such as California.[11] The Amazon is also home to over 300 indigenous peoples that have played a key role in forest protection, but are highly vulnerable to the impacts of climate change. These peoples represent a clear case of climate injustice.

This paper will analyse how people-based solutions can be applied to the challenge of building resilience to climate change, with a perspective from the Amazon. The paper will provide evidence from a case study,

[7] The State of Forests in the Amazon Basin, Congo Basin and Southeast Asia. A report prepared for the Summit of the Three Rainforest Basins Brazzaville, Republic of Congo. May 31-3 June, 2011. www.fao.org/3/i2247e/i2247e00.pdf

[8] Science Panel For The Amazon. *Amazon Assessment Report 2021.* https://www.theamazonwewant.org/

[9] Amazon Tipping Point. Science Advances. February 21, 2018. https://www.science.org/doi/full/10.1126/sciadv.aat2340

[10] The Amazon and the national interest. *Journal Política Externa*, v. 19, n. 1, jan. 2011. https://silo.tips/download/a-amazonia-e-o-interesse-nacional-virgilio-viana-1-summary

[11] How the Amazon's fires, deforestation affect the U.S. Midwest. NBC News. August 23, 2019. https://www.nbcnews.com/news/world/how-amazon-s-fires-deforestation-affect-u-s-midwest-n1045886

drawing practical solutions and making recommendations based on concrete actions.

2. Case study

This paper will summarise indicators of community-based sustainable development programs carried out by Foundation for Amazon Sustainability (FAS) in 583 communities of traditional and indigenous peoples that live in a network of 16 protected areas of Amazonas state in Brazil. Amazonas is Brazil's largest state, with 1.5 million square kilometres, 97% remaining forest cover and with more tropical rainforests than other tropical country, including Congo, Indonesia and Colombia. The economy of these communities is based on fisheries, agriculture, forest extraction and community-based tourism.

Since 2008 these protected areas have received investments by Foundation for Amazon Sustainability (FAS) based on the concept of people-based solutions for climate change and sustainable development. These investments were prioritised on the basis of a participatory planning meth-

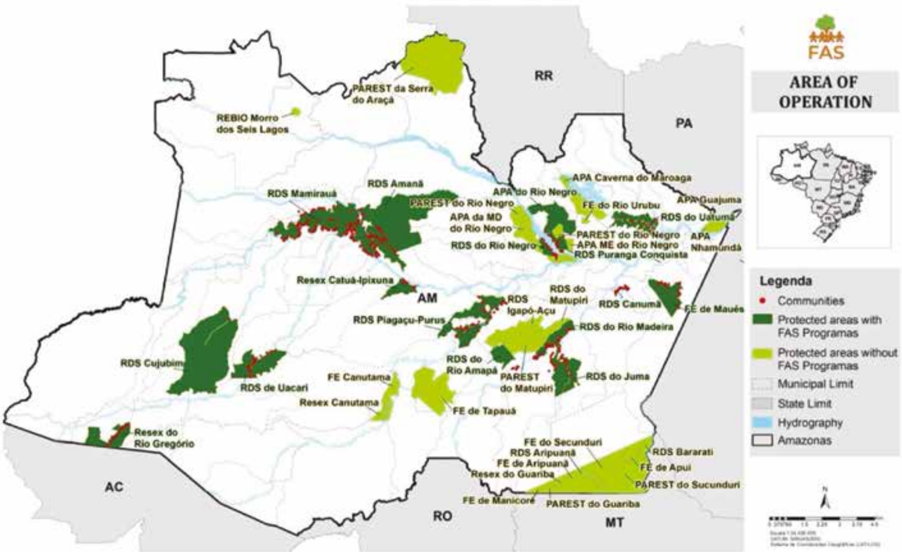

Figure 1. Map of state-protected areas of Amazonas State that have received investments made by Foundation for Amazon Sustainability (FAS) through people-based solutions for climate change and sustainable development and those that have not received these investments. Source: Foundation For Amazon Sustainability https://fas-amazonia.org/novosite/wp-content/uploads/2022/06/mapa-bf-sembf-scaled.jpg. Accessed in June, 2022.

odology developed by FAS and used in over one thousand workshops carried out throughout the Amazon. Investment management and evaluation also used FAS' social technology.[12] Investments were based on a systemic approach that included all 17 Sustainable Development Goals, which were grouped into 8 workstreams and 2 priority thematic focal areas (Figure 2).

On the basis of this systemic approach, a total investment of 62,913,072.9545 USD was made in the 2008-2021 period (and 53,721,311.66 USD from 2008 to 2019). These investments were made on the basis of participatory decision making at the community level.

Figure 3. Investments made in 582 Amazon communities from 2008 to 2022 divided in to different priorities identified through over one thousand participatory planning workshops.

In addition to the investments described in Figure 3, FAS has also been responsible for co-implementation of the Bolsa Floresta Program, which is the largest program for payment for environmental services in tropical rainforest areas. The program has benefited 582 communities, in an area of

[12] Bolsa Floresta (Allowance for Forest Conservation) Guide. Foundation For Amazon Sustainability (FAS). February 03, 2022. https://fas-amazonia.org/publicacao/programa-bolsa-floresta/

11 million hectares with benefits for about 40 thousand people. The program has paid cash benefits to mostly (86%) women, totalling 61 million Reais in historic values.

Results of the investments made include an increase in average income of over 200%[13] from 2009 through 2019. This was a result of investments in income generation based on sustainable use of forests and fisheries as well as small-scale agriculture and community-based tourism. These investments were co-designed with local communities so as to reflect their priorities and mobilise local resources as co-funding (not accounted for in Figure 3).

The people-based approach for participatory decision making has been a key ingredient for success. People were usually engaged and highly motivated as these were "their" projects, and not "someone else's" projects. This subtle difference represents one of the key explanations for the suc-

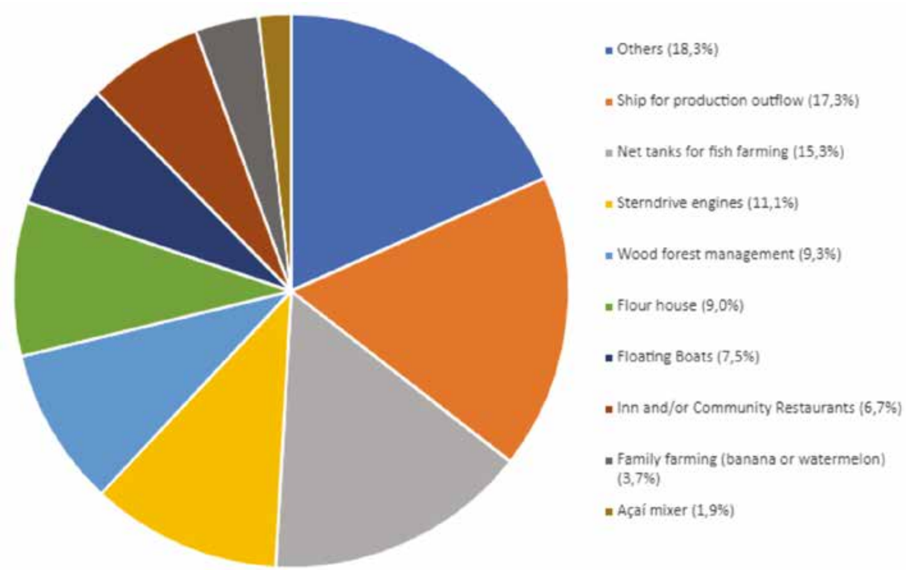

Figure 4. Investment priorities identified for income generation in 41 communities for three protected areas (Rio Negro Sustainable Development Reserve, Puranga Conquista Sustainable Development Reserve and Rio Negro Environmental Protected Area). This survey was used to back the participatory decision-making process at the community level, based on 970 respondents, with 5% error. Numbers are averages for three surveys (2011, 2015 and 2019).

[13] Viana, V.M. Systems approach to sustainable development in Amazonia. *Tempo do Mundo* Journal 2022.

cesses documented here. This people-based approach also explains the reasons for a high proportion of failures of governmental investments in the Amazon that tend to be top down and not bottom up.[14]

People-based investments made on community infrastructure identified 11 categories of priorities. Similarly to income generation, investments on community infrastructure were co-designed with local communities so as to reflect their priorities and mobilise local resources as co-funding (not accounted for here).

A major reduction of deforestation rates was observed in the areas that received the benefits of the investments aimed at promoting sustainable development. Overall, there was a 43% reduction in deforestation rates in the 2008-2020 period when compared to the five-year baseline (2003-2007).

An analysis comparing areas that benefited from investments aimed at promoting sustainable development with areas that have not received such

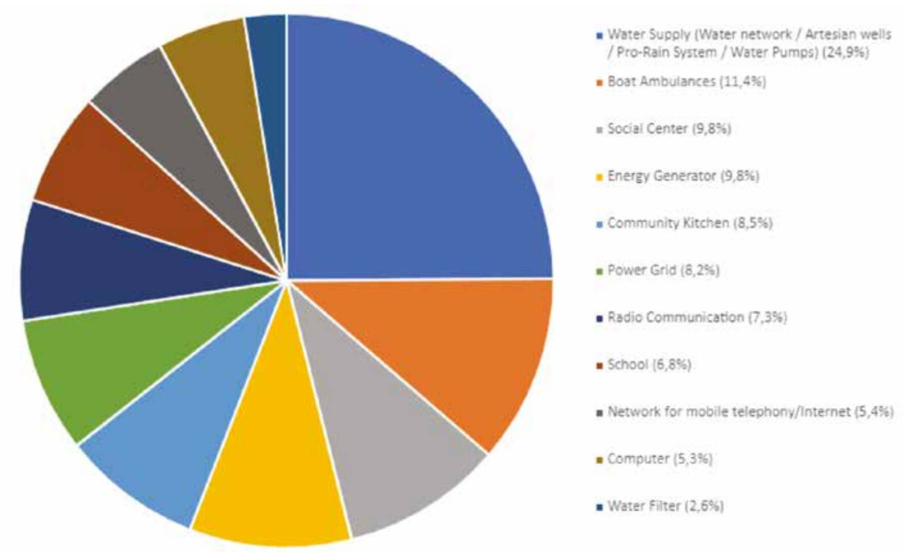

Figure 5. Priorities identified for investments in social infrastructure by 41 communities for three protected areas (Rio Negro Sustainable Development Reserve, Puranga Conquista Sustainable Development Reserve and Rio Negro Environmental Protected Area). This survey was used to back the participatory decision-making process at the community level, based on 970 respondents, with 5% error. Numbers are averages for three surveys (2011, 2015 and 2019).

[14] *Sustainable Development In Practice: Lessons Learned From Amazonas.* Virgilio Viana, June 2010. https://pubs.iied.org/17508iied

Figure 6. Deforestation reduction in 16 protected areas that benefited from investments aimed at promoting sustainable development. Data based on public access satellite data from INPE. http://www.dpi.inpe.br/prodesdigital/prodesuc.php. Source: Foundation For Amazon Sustainability's Activity Report 2021. https://fas-amazonia.org/publicacao/activities-report-2021/

benefits shows a major difference in deforestation patterns. While there was a reduction of 55% in 2021 compared to 2020 in areas with people-based investment, there was an increase of 28% in deforestation rate in areas that did not receive these investments. Similarly to the results observed in income generation, people-based approaches also explain the reasons for success in reducing deforestation and greenhouse gas emissions. This shows a major contrast to areas that received only conventional top-down activities of the state government.

The people-based approach for participatory decision making resulted in improving livelihoods. While 54% said that their livelihoods had improved

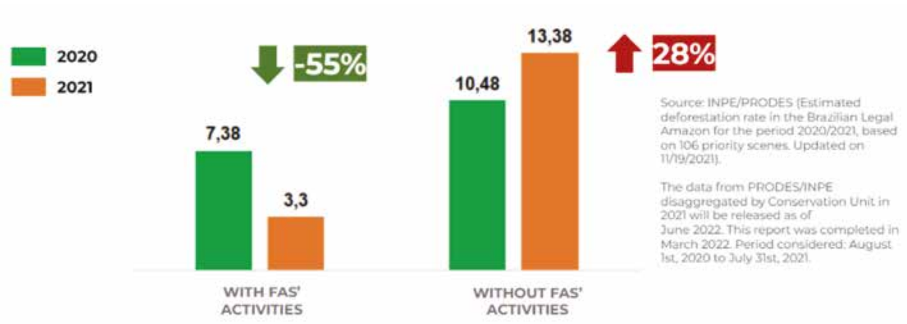

Figure 7. Comparative deforestation between protected areas that benefited from people-based investments for sustainable development and climate change with areas that did not receive such investments by FAS. Source: Foundation For Amazon Sustainability's Activity Report 2021. https://fas-amazonia.org/publicacao/activities-report-2021/

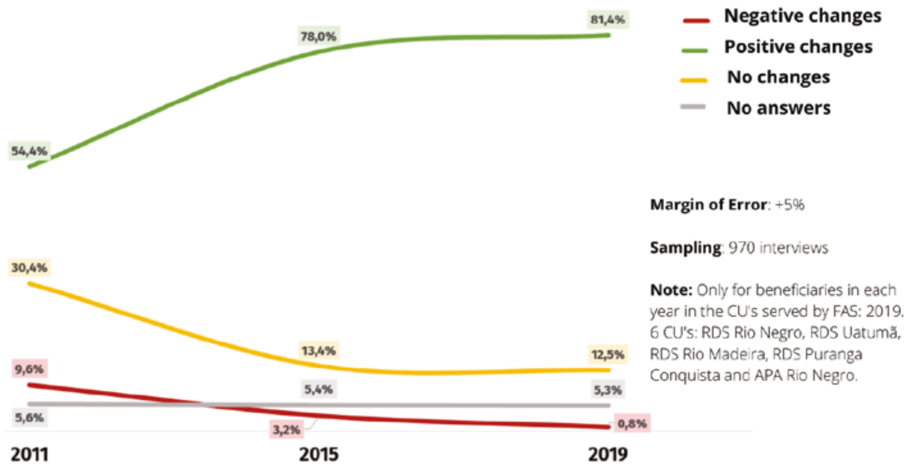

Figure 8. This survey was used to back the participatory decision-making process at the community level, based on 970 respondents, with 5% error in 153 communities for three protected areas (Rio Negro Sustainable Development Reserve, Puranga Conquista Sustainable Development Reserve and Rio Negro Environmental Protected Area).

by 2011, 78% and 81% considered that there were positive changes in 2015 and 2019, respectively. Similarly to income generation activities, people were highly engaged and motivated as investments were made on their priorities. This is one of the key explanations for the successes documented here.

3. Lessons learned

The results from investments guided by people-based approaches using participatory social technology developed by FAS resulted in a number of positive outcomes, including other outcomes not reported here due limitations of space. These results yield lessons learned that can be summarised below.

– People-based approaches for participatory decision making is a key ingredient for success for reaching climate change and Sustainable Development Goals in the Amazon and other tropical rainforest areas.
– People-based approaches with participatory management practices result in engagement and motivation of local communities so that they see actions as coming from "their" projects and not from "someone else's" projects. This subtle difference is key for success as a result of engagement of local communities.

- Engagement of local communities in action towards their own priorities mobilises local resources (mostly labour) and rich ethnoecological knowledge that can be blended with conventional science and technology. This is particularly important to develop nature-based solutions as ethnoecological knowledge can complement and fill gaps in scientific knowledge.
- The lack of people-based approaches helps explain the reasons for a high proportion of failures of governmental investments in the Amazon that tend to be top down and not bottom up.

4. Conclusions

Considering that some impacts of climate change are inevitable and are already affecting human societies, there is an urgent need to speed up action towards resilience building. This urgent call for action should be based on science and lessons learned from practice.

There is mounting scientific evidence that nature-based solutions can be more efficient than conventional technological solutions.[15] Lessons learned from practical action reported here point to the potential of people-based solutions in increasing the efficiency and efficacy of nature-based solutions. People-based solutions incorporate local knowledge and resources and this plays an important role in building long-term resilience.

People-based solutions can play an important role in resilience building not only in the Amazon. Other tropical rainforest landscapes can equally benefit from people-based approaches. Nature-based climate solutions can be delivered more efficiently through people-based solutions for resilience building. People-based solutions for resilience building can also offer a promising approach to mitigate climate injustice in the Amazon.

There is a need to mobilise resources to invest in resilience building in the Amazon as there is a clear case of climate injustice. Indigenous peoples that have done the least to contribute to global climate change are now suffering the impacts in their livelihoods.

People-based approaches have been found to be successful to deliver Sustainable Development Goals and can be used to deliver resilience-building goals. Therefore, people-based solutions should be developed and improved through science and innovation to increase efficiency and efficacy of practical action.

[15] Seddon, Nathalie. *Global recognition of the importance of nature-based solutions to the impacts of climate change.* Cambridge University Press.

People-based solutions provide a promising approach for a two-way coupling between natural systems and social systems as they can deliver both nature and social benefits. People-based solutions should use a systemic approach and include goals to improve public health; food and nutrition security; water and energy security, among others. Education and sustainable management of natural ecosystems can play a central role.

People-based solutions can reduce migration to urban areas which are overcrowded throughout the developing world, with high levels of extreme poverty and violence. Investment in rural resilience can have indirect effects for urban resilience.

People-based solutions can also reduce deforestation and therefore greenhouse gas emissions. This can protect critical public assets and ecosystem services such as carbon sequestration and storage, protection of water cycles, biodiversity conservation and other co-benefits.

There is a need of bridging the gap between science and practice in order to speed up action towards resilience. There is also a need of valuing and incorporating ethnoecological knowledge of local communities and specially of indigenous peoples.

Climate Action to Protect and Promote Health: Sharing Knowledge Among Regions for Adaptation Solutions

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Summary

A recent project on climate change and health from the InterAcademy Partnership (IAP), the global network of academies of science, engineering and medicine, shares evidence to inform policy at national, regional and global levels. Capturing diversity within and between regions in assessing the adverse effects on health helps to identify common challenges and guide solutions for urgent action, prioritised for those who are most vulnerable.

Both mitigation and adaptation are vital and must be better coordinated. Different approaches to adaptation must be better integrated between sectors and levels of governance, involving communities in co-design and implementation, avoiding those actions that jeopardise public health and environmental sustainability or may lead to maladaptation, and recognising the continuing need to clarify impact measurements and the potential limits to adaptation.

Specific examples from the IAP project include assessment of adaptation to the threats of heat, wildfires, flooding, infectious disease, forced displacement, and malnutrition. While adaptation is often at a local scale, there are wider connotations including cross-border implications of threats to health, which may require regional action. There are many inequities in the current global response to climate change and other health crises. Transformative change in developing, financing and progressing solutions is essential to deliver objectives for health equity and climate justice and this requires the scientific community to generate robust evidence on the impact of adaptation actions in order to guide financing and implementing of solutions. Academies can help to address current imbalances and methodological weaknesses in research generation and use by communicating the voices from those who have not always been heard in the processes whereby evidence informs policy.

Introduction to the challenges for the shared global agenda

Climate change is a global health crisis as well as an environmental and financial crisis (Willetts et al., 2022) and the World Health Organization has emphasised that climate change is the single biggest health threat facing humanity. Climate change poses serious threats now to human physical and mental health and health risks will increase over time (Haines and Ebi, 2019). People and ecosystems least able to cope are being hardest hit (IPCC, 2022).

Until recently the adverse health effects of the climate crisis had been relatively neglected by policy-makers but that is beginning to change. Although the scale, nature and timing of adverse effects of climate change on physical and mental health, via both direct and indirect pathways, vary within and between regions of the world, there are common challenges. Rapid and decisive action could greatly reduce the long-term risks to health from climate change and bring near-term benefits to health and the resilience of health systems. To achieve objectives for health equity and climate justice, an increased focus on the most vulnerable groups in marginalised and disadvantaged communities is essential. There are unprecedented threats but also unprecedented opportunities to use scientific knowledge to inform policy and practice. Much can be done now to use the evidence already available: solutions for adaptation and mitigation are within reach using present knowledge, but action requires political will.

Framing the scope and scale for academies' collective work on adaptation for health

This paper draws on the work of a project by the InterAcademy Partnership (IAP), the global network of more than 140 academies of science, engineering and medicine – including the Pontifical Academy of Sciences – enabling the voice of science to be heard in addressing societal priorities. This inter-regional, inclusive, project encouraged academies to capture diversity in evaluating evidence from their own countries on climate change and health issues. Project design encouraged expert participants to use a transdisciplinary, systems-based, planetary health approach to inform policy options for collective and customised action. Working groups from four regional academy networks were constituted: in Africa (the Network of African Science Academies, NASAC), Asia (the Association of Academies and Societies of Sciences in Asia, AASSA), the Americas (the Inter-American Network of Academies of Science, IANAS) and Europe (the European Academies' Science Advisory Council, EASAC). The networks agreed on the overall scientific scope and project design and on priority questions to address as the common starting points. Publication of the reports (EASAC, 2019; AASSA, 2021; IANAS, 2022; NASAC, 2022) was accompanied by engagement with the science and policy communities in the regions and at national level. The four regional reports and the feedback on them were then also used as a resource to prepare a fifth, global report (IAP, 2022).

Clarifying multiple pathways to inform the policy response

The pathways of climate change exposure are complex and health impacts are modified by social determinants. Although there are uncertainties in attribution and extrapolation, it is clear that climate change affects health and health systems in multiple ways, see Figure 1. While climate change affects everybody, a focus on solutions for the most vulnerable in society can help to stop hazards becoming disasters (Kelman, 2017; Ismail-Zadeh, 2022).

Climate change also intersects with other major health crises, in particular those occasioned by COVID-19 (Wyns and van Daalen, 2021) and the Ukraine war. For example, the three concurrent crises are leading to

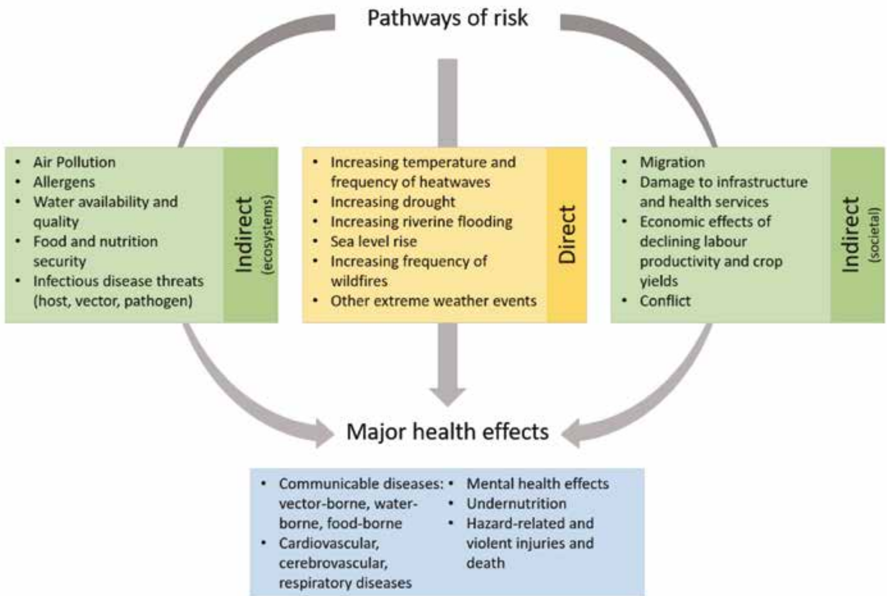

Figure 1. Diverse pathways of climate change risk and potential health effects. For detailed discussion see EASAC (2019), AASSA (2021), IANAS (2022), NASAC (2022) and IAP (2022).

an amplification of pressures worldwide on food and nutrition security (Kornher and von Braun, 2022) and hence on health.

Both mitigation and adaptation approaches are essential as solutions to tackle climate change and its drivers and develop climate-resilient health systems (Blom et al., 2022), but they have often been applied in a fragmented way and they should be better integrated with the aim of achieving resilient, net-zero emission societies. Adaptation becomes more feasible when there is decisive mitigation and there will be limits to adaptation beyond which adverse impacts cannot be prevented. Some key issues for evidence generation and use for guiding selection and implementation of solutions are summarised in Box 1, drawing on the IAP project reports.

What is the current status of policy responses worldwide and their underpinning by evidence? Many countries have developed National Adaptation Plans, and establishing linkages with Nationally Determined Contributions is important to support integrated mitigation and adaptation interventions, increase accountability and avoid duplication of governance structures. While an increasing number of countries have identified climate-related health risks and started to implement early-warning systems for adaptation, the focus is usually narrow and has mostly pertained to heat-related impacts and (vector-borne) infectious disease risks. Other threats, for example from water-borne diseases, malnutrition and the multiple impacts of climate change on mental health have often been relatively neglected. Concerns

Box 1. Recommendations on evidence generation and use to guide decisions on selecting and implementing solutions, from IAP global and regional reports

- Using the evidence base already available to inform policy and practice with greater urgency and ambition.
- Filling knowledge gaps by transdisciplinary research, including clarifying intersections between climate change and concurrent global health crises such as COVID-19.
- Strengthening monitoring and surveillance activities that link health and climate.
- Improving evaluation of impacts of climate mitigation and adaptation actions to assess and quantify benefits, trade-offs and costs, and document facilitators and barriers to action.
- Effective health risk communication, including countering misinformation and addressing equity in climate-health responses.
- Expanding academy roles worldwide in support of science as a public good.

remain about the low level of political commitment and lack of ambition in developing national responses; limited allocation of human and financial resources; poor linkages with the Sustainable Development Goals; lack of prioritisation; poor use of evidence to inform policy-making; and low level of implementation. There is progress: the health services in more than 80 countries are now connected with the corresponding national meteorological services to assist in using knowledge for health adaptation planning, including through heat-health early-warning systems.

Cross-sectoral action informed by stakeholder engagement (Oktari et al., 2022) is essential to realise the health potential for both mitigation and adaptation (Buse et al., 2022). This includes integrating interventions on health infrastructure, urban planning, housing and building design, nature-based solutions, early-warning systems, policy and management, and perception and behaviour.

Progress also depends on better integration of currently disconnected global policy initiatives, for example to tackle both climate change and biodiversity loss together. This requires coordination at the level of the intergovernmental institutions (UN Framework Convention on Climate Change and Convention on Biological Diversity) (Willetts and Grant, 2022) and by the corresponding international advisory bodies (IPCC and IPBES).

Setting the overall context for adaptation strategies

There will likely be complementary adaptation approaches to a given hazard. For example, adaptation to heat can be technical (e.g., insulation, green walls), societal (e.g., urban greening), physiological (e.g., individual acclimatisation), institutional (e.g., within public health services), economic (e.g., subsidies for building and renovation) and behavioural (e.g., seeking cooler environments). Integrated adaptation preparedness and responsiveness require decision-makers to address both shorter-term (e.g., education and awareness-raising) and longer-term (e.g., city planning) interventions, involving different levels of governance, including local authorities. However, literature surveys demonstrate that for many local adaptation initiatives, for example in medium-sized cities worldwide, the extent of cross-sectoral involvement, including the public health sector, varies greatly and planning may be unbalanced (Gopfert et al., 2019).

In addition to integration between sectors and different levels of governance, there are a number of other general considerations to be taken into account when devising and implementing adaptation plans (Figure 2). Achieving "triple win" objectives necessitates prioritisation of those adaptation solutions that are value-creating and sustainable, avoiding practices and business models that jeopardise public health and environmental sustainability (Guerriero et al., 2020). The framework for assessing such interventions requires transdisciplinary support (Bell et al., 2019). The measurement of impact of adaptation actions is challenging and, unlike mitigation where the effectiveness of action can be measured in terms of "GHG emissions reduced", no universally accepted metric for assessment of adaptation effectiveness exists – we emphasise that health indicators must be at the core. Evidence for adaptation success in national adaptation plans, is mixed (Watts et al., 2021) and the evidence base, for the *ex-ante* evaluation of adaptation responses is particularly limited in low- and middle-income countries (LMICs) (Scheelbeek et al., 2021).

Without impact measurement it is difficult to know whether an intervention is appropriate for sharing more widely as good practice or, indeed, if there is potential for the intervention to worsen the situation. Some internationally-funded interventions in LMICs may inadvertently reinforce, redistribute or create new sources of vulnerability to climate change (maladaptation in Figure 2), particularly if community stakeholders have not been involved in co-design and implementation of the action (Eriksen et al., 2021).

Limits to adaptation (Figure 2) will apply to the exposure to various hazards. For example, in seeking adaptation to flooding there may be physical limits (e.g., low-lying islands or other localities), behavioural limits (e.g., for populations living in vulnerable areas), technological limits (e.g., nature of flood defences) and financial limits (e.g., who pays and what are the cost-benefit considerations). An evaluative approach using the IPCC 'burning ember' representations, to illustrate risk (Ebi et al., 2021), recently characterised limits to adaptation to heat-related morbidity and mortality, O_3-related mortality, malaria, dengue and Lyme disease, if temperature increases were to exceed 2°C.

Responses to reduce the risk of the negative burden on health may be implemented at several levels: by specific individual or population level adaptation interventions or by strengthening the resilience of the system that enables it to respond effectively to a perturbation (Figure 2). Some of the approaches for developing effective near-term adaptation solutions are summarised in Table 1; further detail and references, including discussion of successful adaptation in response to each of these hazards, are provided in the IAP project reports. There is much work still to be done to clarify the positive effects of health adaptation (Rocklov et al., 2021). And, to maximise impact, specific adaptation solutions must be accompanied by

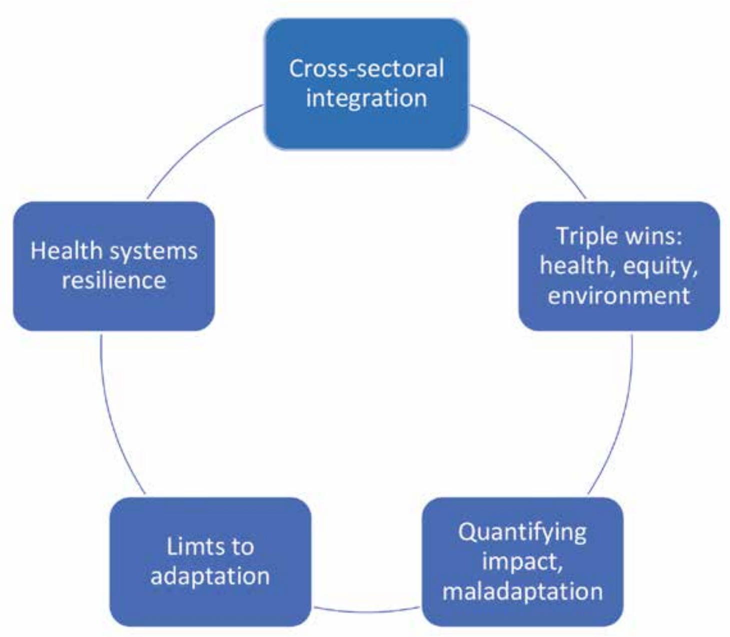

Figure 2. The context for identifying and implementing health adaptation strategies in responding to, and preparing for, climate change.

action to understand and address the social determinants of disadvantage in vulnerable populations. For example, recent research reviewing data from 32 LMICs shows that the extent of adverse climate-health effects of infectious disease-precipitation relationships in young children were dependent on the degree of deprivation in household living conditions (Dimitrova et al., 2022). Academies and their networks are well-placed to help lead the scientific community to generate robust, validated and contextualised, evidence on the impact of adaptation actions in order to guide policy decisions

While many of the adaptation actions may be customised at a local scale, there are often wider connotations including cross-border implications of health threats, such as those arising from air pollution, infectious disease and forced displacement. Moreover, there may also be wider regional implications for adaptation and maladaptation if national action leads, inadvertently or not, to adverse consequences elsewhere. For example, many nations are currently exporting their lack of environmental sustainability (Wiedmann and Lenzen, 2018) by importing food, feed and biomass generated unsustainably elsewhere. Regional coordination can also help if there is a lack

Table 1. Adaptation approaches discussed in the IAP regional reports.

Hazard	Examples of issues to consider in devising adaptation actions
Heat	Improving effectiveness of early warning systems; supporting advances in regulation as well as technologies for green structures and infrastructure; introducing more sustainable cooling solutions; scaling up interventions for sustainable cities; addressing occupational health issues
Wildfires	Improving advice to public, including targeted plans for vulnerable groups, incorporating knowledge e.g., from Indigenous Peoples; better understanding of health effects of different wildfire pollutants; avoiding use of fire to remove crop residues; concerted international action to reduce consumer demand for food commodities whose production is based on land clearance by fire
Flooding	Nature-based solutions and physical engineering measures, enlisting community participation; better integration of climate change and disaster risk management so that policy making becomes more anticipatory and prioritises those who are most vulnerable
Infectious diseases	Understanding value of early-warning systems, surveillance and other interventions to improve public health and sustain economic output; accompanying research priorities include supporting fundamental research in advance of a crisis, new business models for public-private partnership for novel diagnostics, therapeutics and vaccines, and collaboration between public health and veterinary sectors
Migration	Addressing multiple problems in migrants' country of origin and strengthening host country health and other systems to be climate-resilient and migrant-inclusive
Malnutrition	Opportunities for climate resilient agriculture (e.g., new crop varieties) and rebalancing of objectives to attain environmental sustainability and nutrition security

of data for a particular country: academies and their regional networks can advise national policy makers to consider relevant data from elsewhere.

Focusing on climate justice

There are many inequities in the global response to climate change (Romanello et al., 2021) and the IAP reports highlight the imperative for implementing solutions that focus on vulnerable groups in different regions. The present inequality in climate change impacts and in implementation of solutions brings major costs for society: transformative changes require a fundamental shift from a current emphasis on individualist lifestyles to a sharing economy based on equitable, inclusive, sustainable development paths (Anon. 2022).

These solutions also depend on transforming the present funding pathways. Global finance for adaptation across all sectors is only a small fraction of the finance for mitigation actions and finance flows to the health sector are particularly low (less than 1% of climate adaptation finance (Watkiss and Ebi, 2020). This neglect of health adaptation solutions must be corrected. Furthermore, current spending on harmful subsidies for fossil fuels or unsustainable agriculture, should be redirected to support universal health coverage, public transport, affordable healthy food choices and other policies that improve health, reduce GHG emissions and promote equity. This reform could be key to achieving public and political support for climate change action (Buchs et al. 2021; Watkiss and Ebi, 2022).

In tackling health inequities and pursuing climate justice, academies can play an important role by taking account of local health profiles, ecosystems and cultures in research using validated methodologies to quantify adaptation solutions, and linking local action with the national, regional and global pathways of change as these emerge. Collectively academies can help to highlight the imperative for climate justice worldwide and to articulate to decision-makers the human cost of failing to meet ambitious and equity-related goals. The very wide geographical coverage of IAP, both in terms of its evidence gathering and analysis, and its subsequent reach-out with key messages, is valuable in representing the voices of those from LMICs and other vulnerable populations who are not always heard during the processes whereby evidence informs international policy. We emphasise the need to correct the current global imbalances, by engaging with vulnerable communities in the design and use of research and in clarifying and scaling up the implementation of effective adaptation interventions. There is much still to be done to embody health equity and climate justice in the evaluation and implementation of adaptation solutions.

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V. BUILDING ADAPTIVE CAPACITY FOR HUMANITY

Nature-Based Solutions

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The aim of this article is to demonstrate how nature-based solutions can contribute to climate change mitigation by reducing energy consumption and, in the long term, by building resilience of ecosystems in a planned multi-dimensional way. The focus is on nature-based solutions in the context of climate-resilient buildings and cities. The built environment is currently facing a number of challenges that can be solved by contemporary technology, but this usually results in excessive energy consumption. Alternatively, these issues can be successfully addressed with nature-based solutions. The building's adaptation to the ambient conditions resembles biological models, in which such factors as body temperature, humidity, gas and fluid exchange, shape and colour modification, allow organisms to adjust to the environment without harmful effects or resource over-consumption. Natural models enable active metabolism, including air- and water-quality improvement, pollutants filtration, energy and waste management, circularity. At the building and city scale this enables carbon sequestration, natural cooling, humidification and air purification. To increase the resilience of humans and ecosystems it is necessary to change the principles of their coexistence with a view to achieving symbiotic homeostasis beyond 2050. Hybrid interaction of biological processes and technology should become a prototype for climate-resilient development.

Introduction

Dynamic development of technology, including all kinds of electronic devices, in addition to positive effects, contributes to a strong dependence on electricity. This refers in particular to the built environment, responsible for around 40% of global GHG emissions and similar levels of energy consumption. In view of the massive demand for energy, humanity under climate stress must take measures to:

- Accelerate the transition from non-renewable to renewable energy sources (RES);
- Increase synergies of RES combined with efficient energy storage methods;
- Reduce dependence on electricity and fossil fuels for heating and cooling purposes through bioclimatic strategies and nature-based solutions;
- Transform building skins from carbon-emitting to carbon-sequestrating bio-based envelopes or living ecosystems;

- Maximise energy efficiency in buildings, neighbourhoods, urban and rural areas by re-greening them and increasing biodiversity through green ventilation networks connected to water bodies;
- Eliminate AC for cooling public recreational spaces in favour of nature-based solutions (natural ventilation, evaporative cooling, shading, greening).

Searching for methods of climate risks mitigation, we turn to nature-based solutions due to their high potential for resilience and efficiency (European Commission 2015). To increase the resilience of people and ecosystems, it is important to understand that currently their interactions are mostly based on parasitism (a correlation in which one partner benefits at the expense of the health of the other). It is critical to enhance the transformation towards neutralism and commensalism with the minimum requirement of achieving a level of well-balanced competition which can also be described as *sustainability*. The basic principle of the relationship between people and other species inhabiting the same ecosystem should be to minimise the negative impact of our activity on the environment, taking into account the long-term effects, and in particular the climate change. The optimum scenario beyond 2050 is to achieve homeostasis on the basis of symbiosis (Widera 2018).

In-depth analysis of the natural systems behaviour allows for a knowledge transfer from biology to architecture, with the purpose to implement natural processes in structures designed by human (Gruber et al. 2011, Anthony et al. 2014). This involves several exchange mechanisms between the external and internal environments (including light, energy, gases and liquids) as a part of nature-based solutions applied in the built environment to solve the problems related to climate change (Widera 2016; Naumann et al. 2014). This refers in particular to excessive energy consumption for heating, cooling and ventilation, but also to the production and transportation of construction materials.

Thermoregulation

One of the most remarkable features of the natural world is the ability to respond adequately to dynamic environmental conditions. Nature-based solutions used in the built environment combine functions allowing for system resilience and carbon storage, and increased user comfort and safety, simultaneously enhancing ecosystem's health and biodiversity (Fig. 1). An excellent example of a natural system designed to selectively store and distribute energy is the fat concentrated in the camel's hump, which enables effective cooling through sweat evaporation on the remaining surface of the body. Under conditions of dehydration, the animal's mass acts as a heat buffer and regulates body temperature. Comparable thermoregulation in buildings can be provided through the thermal massing strategy. Affordable and effective heat storage is possible with earth building techniques such

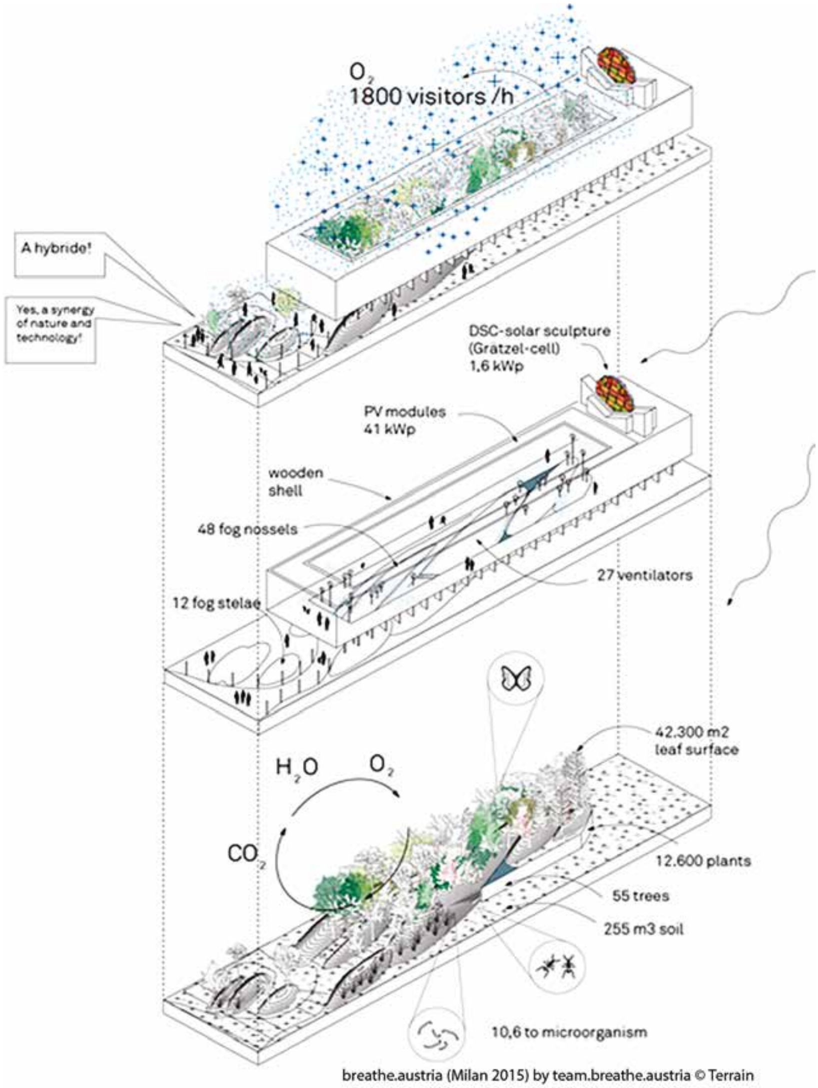

Figure 1. Biodiversity scheme of Breathe Austria Pavilion at Expo Milan (2015) by team.breathe. austria. ©Terrain.

as stabilized earthen blocks, *superadobe* (earthbags plastered with clay and lime) or hempcrete. Advanced concepts of building envelopes are designed for active adaptation to external conditions through monitored gas and liquid exchange comparable to evapotranspiration. Heat storage and passive night radiant cooling are very efficient in combination with Phase Change Materials (PCM), such as Passive Infrared Night Cooling technology developed by ZAE Bayern and tested in Center for Advanced Research in Building Science and Energy in Würzburg (Lang, Rampp, Ebert 2014).

Gas and liquid exchange

Nature-based solutions for indoor comfort are based on a symbiosis with green plants which absorb carbon dioxide and produce oxygen through photosynthesis. In addition to vegetated façades, green zones should be introduced into buildings through internal courtyards that further improve daylight distribution and natural ventilation. Correctly designed buildings can serve as carbon sinks and the amount of CO_2 absorbed by green surfaces in the built environment is increased 50-100 times when the natural processes, such as evapotranspiration and photosynthesis, are hybridized with technological solutions (Widera 2018). Abundant green zones were introduced into the breathe.austria Pavilion at Expo Milan (2015) as a testbed of efficiency of natural and technological processes. Fans, sprinklers and vapour diffusers, powered by minimal amounts of photovoltaic electricity (including dye-sensitised solar cells), enhanced natural processes to lower the temperature, raise the humidity and sequester the maximum amount of carbon dioxide (Fig. 2). It has been proven that the hybridisation of nature and technology allows the indoor space to be cooled by 5 to 7°C thus replacing conventional air conditioning. The tests carried out in the breathe.austria pavilion showed that green plants in a 560 m2 surface produce 62.5 kg of oxygen per hour, while sequestering 86.9 CO_2. This rate of photosynthesis is the equivalent of a 3-hectare natural forest (team.breathe.austria 2015). The built environment serves as a breathing 'photosynthesis collector' that contributes to global oxygen production and carbon dioxide sequestration.

Bio-filtration façade systems with appropriately-chosen green plants improve air quality by absorbing pollution. Nature-based hybrid façades with building-integrated or building-applied modules (organic PV cells or microalgae bio-façades) combine sustainable energy production with thermoregulation, recovering the part of solar energy not converted to electricity (Arup 2014).

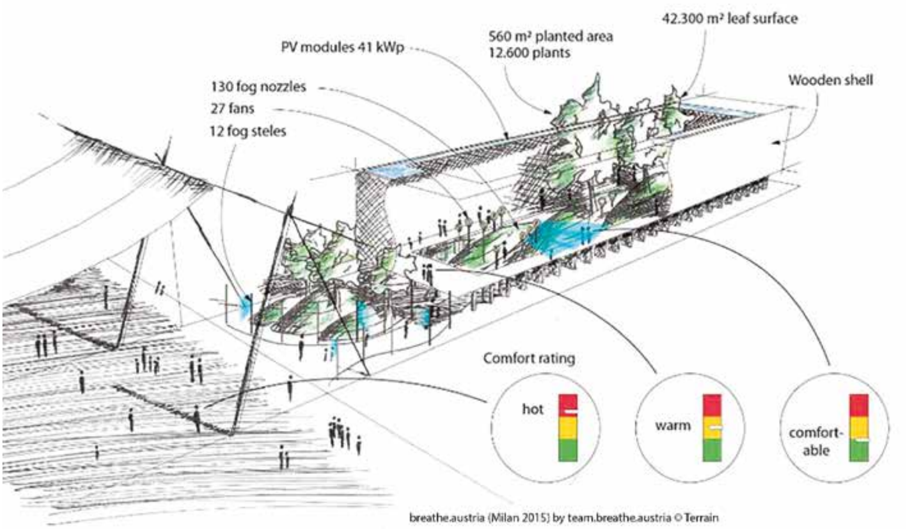

Figure 2. Hybridized natural and technological processes in Breathe Austria Pavilion, Expo Milan (2015) by team.breathe.austria. ©Terrain.

Flows and mobility

Organization patterns observed in nature are based on mobility and flows of air, water, energy and matter. Under natural conditions, animals and plants developed the ability to adapt to winds or sea currents. By drawing conclusions from organism responses to the phenomenon of movement we can design buildings which save energy through reduced resistance, like fish, whose body is shaped to minimise the flow-blocking surface in the aquatic environment and which, when exposed to strong currents, position themselves to face the tide. A similar building setting with appropriately designed ventilation ducts can save up to 30% of energy. The analogous application of knowledge about flows in urban design results in improved comfort due to cooling effect and better air quality. Urban cooling is enhanced when correctly combined with water bodies introducing water particles into ventilation channels and cooling the urban structure through evaporation. Trees and other plants embedded in the urban tissue provide chilling shade, carbon sequestration and increased humidity. Due to the lack of space in city centres, pocket parks, green façades and roofs, as well as planted terraces, are recommended.

Nature-based techniques established the basis for passive downdraught evaporative cooling (PDEC). This method has been successfully applied in several buildings, e.g., Frontier Project (2009, Rancho Cucamonga, CA, USA) by HMC Architects or De Anza College (2019, Cupertino, CA, USA) by Winkleman Designs. In arid climates, structures inspired by termite dens with vertical ventilation channels are advisable for buildings and districts, using a combination of ground heat exchangers, ventilation chimneys and cooling towers. Double-layered ventilated roofs with projecting sections for shading contribute to façade temperature reduction and significant energy savings while preventing heat radiation.

Nature-based solutions for energy flows include daylighting, heat harvesting and storage, and electricity production. A distinct feature of plants is their ability to follow the sun and optimise the amount of energy intake by opening up to receive more light and heat, and closing down to avoid overheating or excessive cooling. A direct application of heliotropism is found in the Heliotrope building (1994, Freiburg im Breisgau) by Rolf Disch. The structure rotates to track the sun, gaining the maximum amount of sunlight and warmth. This is combined with energy generation including a dual-axis solar photovoltaic tracking panel, a geothermal heat exchanger, a CHP (heat and power) unit and solar-thermal balcony railings for water heating.

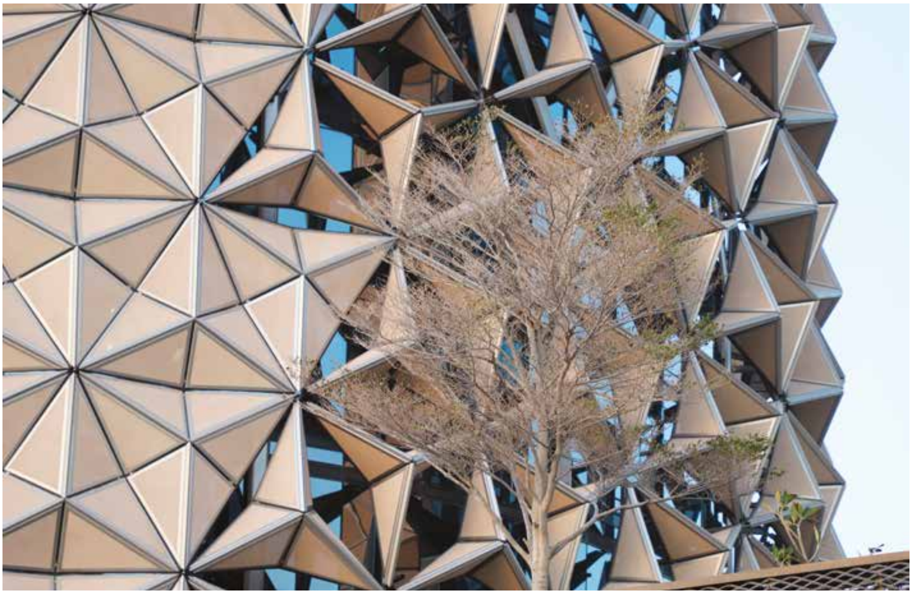

Figure 3. Kinetic façade system in Al Bahar Towers (2012), Abu Dhabi by Aedas Architects. Photo: B. Widera.

The concept of climate-responsive screens inspired by nature is used in kinetic façade systems such as Al Bahar Towers (2012, Abu Dhabi) by Aedas Architects (Fig. 3). This results in a 50% reduction of solar gain and a significantly reduced demand for air conditioning. An even better performance of a kinetic building inspired by a falcon's wings being a "symbolic interpretation of the flow of movement" (Stouhi 2021) was achieved in the UAE Pavilion (Expo 2020 Dubai, UAE) by Santiago Calatrava. The roof hybrid system, between a shell and a portal frame, consisted of 28 movable carbon fiber wings which, when open, allowed daylight penetration to fully expose the photovoltaic panels beneath them to solar radiation, and when closed, protected against wind and sandstorms. Cantilevered wings created a pleasant ambience around the pavilion, with water ponds naturally cooling the air and native greenery enhancing biodiversity and reducing reflected heat (Calatrava 2021) (Fig. 4).

Circularity

The solutions encountered in the natural environment are based on circular economy principles. They are characterised by a lack of waste, since the metabolic products of some organisms are part of the food chain

Figure 4. Kinetic building designed for optimal performance and inspired by a falcon. UAE Pavilion at Expo Dubai (2020), UAE, by Santiago Calatrava. Photo: B. Widera.

for others. In today's construction sector, a zero-waste approach is extremely important for reducing a negative environmental footprint. The most efficient nature-based concepts use technologies that can be found in nature. They include phytopurification, soaking and aerating applied to the conservation of soil, water, woodlands and wetlands. To save drinking water sources, rainwater should be fully utilised and the use of salt water maximised, especially in conditions where freshwater is limited. Rainwater harvesting and phytopurification were successfully applied in the Children's Center (2011-2012, Um al Nasser, Gaza Strip) by Arcò and Mario Cucinella Architects. Coastal desert areas can benefit from salt water for plantations using biological desalination methods (e.g., quinoa) and farming such as fish ponds for water purification and fertilization.

Efficiency

Natural structural systems (e.g., spider webs) are characterized by high efficiency and performance, being thin, lightweight and fully fit for purpose. A similar approach was used by Gaudí, Fuller and Nervy, and nowadays it is supported by parametric design. Genetic algorithms apply a repeated trial-and-error method based on the evolutionary process experience. Natural-based performance optimisation of structural systems diminishes consumption of raw materials and resources, contributing to a significant reduction in CO_2 emissions.

Structures such as beehives or anthills inspire optimal use of materials, space organization and building operation. Animals build their homes from organic materials available in the immediate vicinity and adapt their operation to the shifting external conditions. Climate adaptation and resilience of the built environment can be enhanced by responsive façade systems (kinetic, green or PCM modules) which can be combined with food production adding to the most efficient use of space (Fig. 5).

An observation derived from ecosystem organization is that species share the territory using only as much as they need. Contemporary preference for large open space in buildings may be satisfied through inclusive, shared facilities. A nature-based approach should promote green areas and the extra space can be provided through gardens, green atria, shaded terraces or similar carbon-absorbing zones. Moreover, gardens and green façades can be transformed into semi-public areas cultivated by those who can dedicate their time and resources to benefit from sustainable urban farming.

Figure 5. Kinetic green façade for sustainable food production. American Food 2.0 at Expo Milan (2015) by James Biber. Photo: B. Widera.

Inclusiveness and Symbiosis

Examples of inclusiveness and symbiosis can be found in numerous ecosystems. One of these is the coral reef which, when healthy, represents an exceptionally rich biodiversity. Corals are marine animals that form colonies secreting calcium carbonate skeletons hosting algae living within coral polyp cells. Algae absorb the sunlight and use it in photosynthesis, providing energy for the coral. Symbiotic algae protect the coral from excessive ultraviolet radiation (Baptista, Parker, Conant 2021). The coral reef is home to millions of fish, anemones, crabs and shrimps defending their corals from predators such as starfish. This ecosystem is as complex as the city, but also very sensitive. The negative effects of climate change, which threaten the safety of the planet, are lethal for reefs. The process begins with coral bleaching caused by sea warming. When temperatures rise, symbiotic algae produce oxygen at toxic levels and are expelled or die, revealing white skeletons. Corals can recover if conditions improve and they are repopulated by algae. If conditions do not change, the corals will starve and eventually die, and so will the reef. A temperature rise of +1 to 2°C can stress corals. Currently, water temperature equal or higher than 30°C represents a threat to most coral species (Hughes et al. 2018). Moreover, ocean pollution results with the lowered pH. As oceans absorb a quarter of anthropogenic CO_2 and water becomes acidic, the coral structure weakens and the skeletons break. The warning from this observation is that humanity must not allow the temperature to exceed a critical limit. However, the latest observations show that this process is reversible. In 2020 and 2021 the amount of CO_2 emitted into the atmosphere by plane and car travels was significantly lower due to the COVID-19 pandemic limitations and lockdowns. Research performed in September 2021 on the coral reefs in the Indian Ocean, on Northern Atoll in Maldives, revealed that the average annual water temperature at a depth range of 1 to 30 meters dropped to 29°C, which was 1°C lower than the temperature measured in the same area for 3 consecutive years. This resulted in the improvement of the ecosystem's health and the scientists noted that previously bleached corals restarted their growth processes reaching about 5-8 mm of annual increment. Experimental attempts to increase the biodiversity of local ecosystems showed that microalgal symbionts with improved thermal tolerance also increase coral resilience and bleaching tolerance (Buerger et al. 2020). While further research is necessary, it is initially estimated that coral growth in symbiotic relation with heat-evolved algae can be 30-40% faster than under conditions of limited biodiversity. This leads to the conclusion that improving biodiversity has a positive impact on reversing the negative effects of climate change.

The temperature rise beyond 2°C that causes lethal stress to coral reefs is exactly the same as the critical temperature limit calculated for global climate change (IPCC 2022). The author of the paper believes that in nature there are parallels rather than coincidences and, since the sources of negative change in ecosystems are the same – increasing temperatures and acidification of the environment due to excessive carbon dioxide emissions

– then the effective countermeasures observed in the ocean environment may also be key to tackling global climate change. The nature-based resilience model assumes that the surface of the coral resembles a building covered with vegetation that provides shelter for other species in the city biotope. This kind of symbiosis needs to be developed in conjunction with a model for carbon dioxide sequestration and air pollutants bio-filtration, simultaneously contributing to the increased energy efficiency of buildings, and sustainable vertical urban farming.

Conclusions

Climate-responsive building adaptation to ambient conditions resembles biological models in which temperature, humidity, gas and fluid exchange, shape and colour modifications allow organisms to naturally adjust to the environment. This enables active metabolism, including the improvement of air and water quality, pollutants filtration, energy and waste management, and circularity. Building functioning on the basis of solar technologies and active metabolism results in CO_2 absorption, oxygen production, natural cooling, humidification and air purification. Hybrid interaction of biological processes and technology should become a prototype for climate resilient development. This approach perfectly complements the philosophy of transforming the built environment in the context of the New European Bauhaus: sustainable, beautiful, together.

Interdisciplinary research and knowledge transfer from underwater biology to the built environment and climate science allows us to understand that a limit of 2°C on global temperature increase, which has been identified as critical to the survival of civilization in its current form, is also the limit beyond which coral reef ecosystems in tropical waters will be destroyed. Moreover, the factors disturbing the stability of the system are the same, namely increasing temperatures and acidification of the environment due to excessive carbon dioxide emissions. The author of the paper argues that the effective countermeasures observed in the ocean environment may also be key to tackling global climate change. This leads to the conclusion that symbiotic relations and biodiversity conservation and restoration, combined with effective carbon sequestration, are the most important elements in the process of combating climate change.

The nature-based resilience model for the built environment assumes that living building surfaces provide symbiotic shelter for other species in the city biotope and can be combined with sustainable food production, thus contributing to climate change mitigation.

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Resilient Food Systems

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Abstract

The world food system has drifted into a complex crisis and climate change is a main force among the causes. Climate change affects all the components of the food system, usually in ways that exacerbate already existing vulnerabilities and inequalities between social groups and regions of the world. Climate change also amplifies other risks to food systems resilience and may add unknown risks, that is, uncertainties. Numerous practices, food production and processing technologies, knowledge, collective actions, social capital, as well as market and trade policies, already exist for strengthening food systems resilience, with multiple synergies with other important sustainable development goals such as mitigating and adapting to climate change, conserving biodiversity, safeguarding ecosystem services, and reducing social and gender inequalities. Hence, a wide-scale proactive application of these resilience-building actions would create benefits well beyond food systems. Many of these actions are presently being applied at local scales worldwide, but need to be scaled up where they are already known and scaled out to new areas. Synergies and tradeoffs between these actions require in-depth and context specific research. Maintaining and strengthening food systems resilience under these conditions calls for going beyond usual risk management paradigms, incorporating approaches that help deal with uncertainties. Investment in science and innovation is critical for developing solutions that help strengthen food systems resilience against future climate change uncertainties.

Keywords: climate change, resilience, food systems, food security and nutrition

1. Introduction: Food systems are losing resilience

The world food system is both significantly contributing to climate change, with about 30% of green-house gas emissions, and also suffering from climate change (IPCC 2019). Global and many national food systems are currently facing major crises with strong indications of increasingly limited resilience and even failures of resilience. These food systems crises are driven by multiple, often overlapping, reasons. Firstly, the COVID-19 pandemic has disrupted food production, food markets and trade. It has also reduced employment in many countries, reducing household incomes. Facing these challenges, most governments have expanded social protection expenditures, widening budget deficits and accumulating foreign and domestic debt. This now constrains the capacities to respond to further crises. Secondly, international food prices have become more volatile and have risen sharply, adding further hardship for the poor. The Food Price Index by the Food and Agriculture Organization of the United Nations (FAO) has risen to new highs (Figure 1).

Moreover, Russia's military attack on Ukraine is further driving up food prices. Together the two countries account for 20% of global maize exports and 30% of global wheat exports (Kornher and von Braun, 2022). The

Figure 1. FAO Food price index. Source: FAO. Note: 2014-2016=100.

hampered trade flows directly affect major importing countries, for instance in the Middle East and Africa, and indirectly poor people in many other countries too. This will increase hunger. The rise in food import bills and pandemic-related interventions have affected markets and value chains in food systems. Rising input prices (fertilizer and energy) and higher transport costs have made agricultural production significantly more expensive.

Food prices are not expected to fall to pre-crisis levels anytime soon. In the context of increasing climate risks and rising number of extreme weather events, which are projected to exacerbate global and regional food security (Figure 2), these market and price risks are here to stay with us into the foreseeable future, and also present serious threats to political stability. Many countries already have unsustainable levels of foreign indebtedness and lack domestic fiscal space to finance social protection in order to alleviate these negative effects for the most vulnerable. As a consequence, a significant part of the progress that the world has achieved in terms of reducing instances and impacts of famines (Table 1) may be undermined in the future.

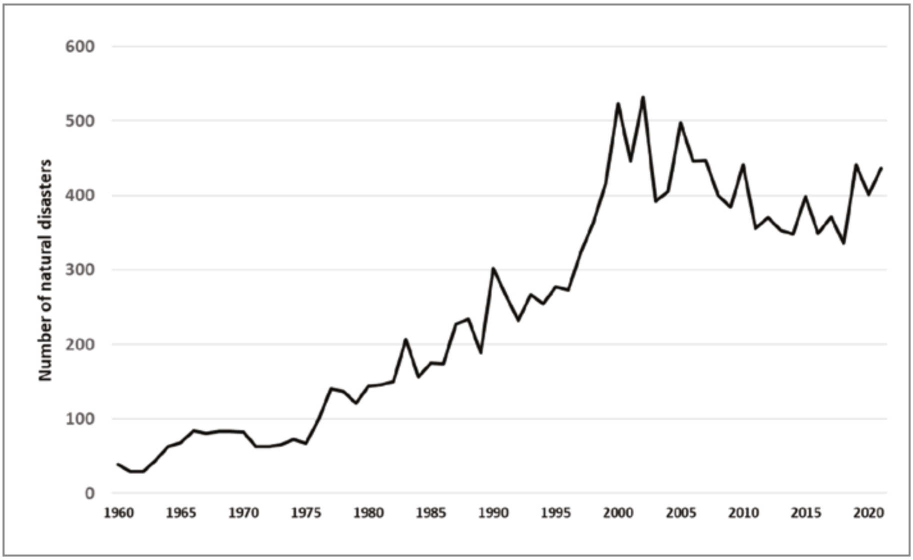

Figure 2. The number of severe climatic disasters with human life losses. Source: EM-DAT.

Time periods	Countries affected by famine	World Food Summits	Number of people killed by famine	Cereal yields, tons per hectare
1900-1920	India, Cape Verde, Spain, China, Lebanon, Rwanda, Burundi, Tanzania, Iran, Turkey	–	8 million	0.5-2.0
1920-1940	Kazakhstan (2), Russia, China (2), Rwanda (2), Ukraine	–	28.2 million	0.5-2.0
1940-1960	Cape Verde (2), Morocco, Russia (2), Greece, Ukraine, China (2), Iran, India, Rwanda, Yemen, Oman, Saudi Arabia, Indonesia, Netherlands, Germany, Malawi, Ethiopia.	–	27.5 million	0.5-2.0
1960-1980	China, Nigeria, the Sahel region, Ethiopia, India*, Bangladesh, Cambodia	1974	20 million	1.5-2.3
1980-2000	Mozambique, Ethiopia, Sudan (3), Somalia, North Korea, Afghanistan, Ethiopia	1996	2.8 million	2.3-3.1
2000-2020	Democratic Republic of the Congo, Sudan, Somalia (2), West Africa, Yemen, South Sudan, Ethiopia, Madagascar	2002 2009 2021	3.1 million	3.1-4.1

Table 1. Past failures of food systems resilience: countries with major instances of famine and the number of people killed by famine between 1900-2020. Source: compiled from various sources. *Refers to the situations in Bihar (1966-67) and Maharashtra (1970-73), see e.g., Dyson and Maharatna (1992), Hazell and Rozer (2013).

2. Concept of Food Systems and Theory of Resilience

Before analyzing food systems resilience in this context, the concept of food system needs to be introduced, and theory of resilience discussed.

Food systems embrace the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption, and disposal incl. loss or waste (von Braun et al. 2020) of food products that originate from agriculture (including livestock), forestry, fisheries, and food industries, and the broader economic, societal, and natural environments in which they are embedded (von Braun et al., 2021). A *sustainable food system* is one that contributes to food security and nutrition for all in such a way that the economic, social, cultural, and environmental bases to generate food security and nutrition for future generations are safeguarded while preventing any losses to biodiversity (von Braun et al., 2021). Food systems are connected to other systems such as health, ecology and climate, economy and governance, and science and innovation (Figure 3). A conceptual framework of food and nutrition systems should capture delivery of health and well-being while being embedded in the transformation towards a sustainable circular bioeconomy. Science and innovation impact the functioning of the system as a whole and within its building blocks and the interconnections among them. While addressing climate stress for food systems, our main focus in this paper is on people and communities, and their resilience.

Resilience is defined as "the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity of self-organization, and the capacity to adapt to stress and change" (IPCC, 2018).

The *concept of resilience* has been primarily associated with the idea of successfully dealing with emerging risks, i.e., when we know all potential outcomes of these risks and their likelihoods of occurrence, and based on that knowledge can elaborate policies that provide optimal responses to these risks. However, this concept of resilience now needs a revision through integrating uncertainties. Uncertainty means that we are dealing with situations when we don't have the knowledge of what will happen and with which likelihood. Climate change will increasingly result in unprecedented impacts, also with cascading and compounding factors playing together for which there is little past knowledge enabling us to deal

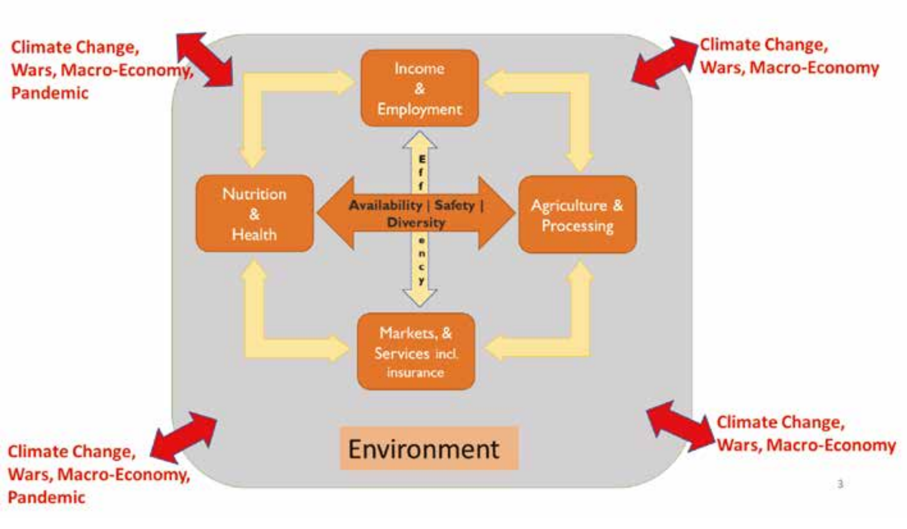

Figure 3. Food systems conceptual framework. Source: adapted from von Braun et al. (2021).

with them in a business-as-usual way. Maintaining and strengthening food systems resilience under these conditions requires going beyond usual risk management paradigms.

Economic models of expected utility cannot fully account for human decision-making in the context of emerging climate change risk which also involve intertemporal choices. Climate change risks are different from standard risks because there are uncertainties associated with them and available knowledge is not sufficient to attach reliable probabilities for their occurrence. Human decision-making when faced with uncertainties can fall back to intuitive risk judgments, i.e., perceptions, rather than rational expected utility maximization (Kahneman, 2011; Tversky and Kahneman, 1986). With climate change risks, involving unprecedented changes in the frequencies, severity and magnitudes of extreme weather events due to climate change, heuristic decision-making can lead to sub-optimal outcomes. As a result, required changes in institutions and technological adoptions may often happen only ex post as a response to shocks, rather than ex ante for the prevention of shocks or building resilience to shocks (Zilberman et al., 2011), which is inefficient and would involve much higher social costs. To avoid this, human decision-making under climate change risks would need to be informed by precautionary approaches and the Prospect theory (Kahneman, 2011; Tversky and Kahneman, 1986), i.e., models of economic behavior that account for both risks and uncertainties. However, there has been limited applied research using these rich elements of behavioral economics to explain human decisions in the context of climate change adaptation and resilience building.

The concept of resilience is multifaceted and highly interdisciplinary; hence, it is challenging to quantitatively *measure food systems resilience*. The analysis of three quantitative indicators of resilience that are currently widely used found that it is "unclear what these measures capture and what value they add" (Upton, Constenla-Villoslada, and Barret, 2022). Quite often, qualitative descriptions are used for food systems resilience. Resilience assessments and conceptualization have so far been primarily conducted – at the household level – separately from analyses or conceptualisations of systems level resilience. Ideally, the measurement of people's resilience needs to be embedded inside the measurement of resilience of systems, accounting for whole system functioning.

Resilience is also understood as a desirable capability of people to deal with shocks without significant loss of livelihood, health, and nutrition (von Braun and Thorat, 2014). This means that resilience is the capacity of individuals and groups to anticipate, prevent, adapt to, cope with, and recover from shocks and stressors. Resilient individuals, groups, or communities tend to share the characteristics of having sufficient physical, financial, human, and social capitals to absorb, adapt to, and transform shocks (von Braun and Thorat, 2014).

In this paper, we combine these lines of thought and conceptualize food systems resilience as a function of hazard, exposure and vulnerability (Figure 4). Increasing food systems resilience means reducing risks to food systems and being prepared for successfully dealing with uncertainties. Actions to reduce food system vulnerabilities, lower exposure to food systems risks, and reduce climate change-induced hazards to food systems help strengthen food systems resilience. These actions to build food system resilience could target individual components of hazard, exposure, and vulnerability, but could also have cross-cutting effects across two or three dimensions, e.g., sustainable management of natural vegetation, soils and land.

Actions to reduce hazards mean measures that help mitigate climate change and also, whenever possible, reduce extreme weather events under the current climate.

In practice, actions to reduce vulnerabilities mean measures to build up five capitals: human, financial, social, natural, and physical. Food systems resilience involves maintaining and developing social (e.g., collective action, social protection, human rights and dignity), human (e.g., education, skills), natural (e.g., preserved ecosystems and healthy soils), physical (e.g., water infrastructures) and economic capitals with the help of enabling policies and institutions. This "five capitals" framework is currently emerging as a major analytical framework in the sustainability sciences (Hendriks et al., 2021 for food systems; Dasgupta 2021 for biodiversity). Household-

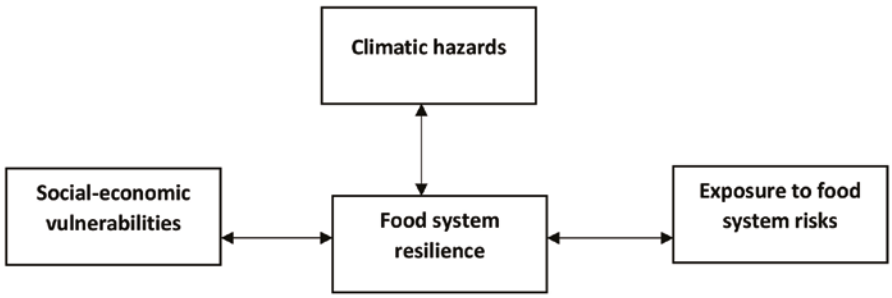

Figure 4. Food system resilience framework. Source: modified from the IPCC risk framework in Abram et al. (2019).

and community-level studies from across diverse settings found that building up these five capitals is the essential approach to strengthen resilience against uncertain future shocks, both climatic and non-climatic (Mirzabaev, 2013 – Central Asia; Rakib, 2015 – Bangladesh; Ngigi, 2017 – Kenya; Boansi, 2019 – Ghana; Kankwanba 2020 – Malawi).

Actions to reduce exposure to food system risks involve all measures that help reduce exposure to both climatic and non-climatic risks to food systems resilience, such as conflicts, pandemics, trade barriers and food export bans, and others. These measures need to be taken proactively. Resilience is a forward-looking notion; it is about facing future shocks. Proactive measures for strengthening food systems resilience increase the ability to absorb future shocks without losing the long-term potential for development (Figure 5). Households that are below some normative threshold, e.g., poverty line, or food security line, are not considered resilient even if their position is stable with regard to this normative line (Barret and Constas, 2014). This means that households which are trapped in poverty and food insecurity cannot be considered resilient even if their poverty and food insecurity levels do not increase following a shock (Barret and Constas, 2014). Proactive measures to strengthen resilience are also less costly than reactive disaster relief measures (Gerber and Mirzabaev, 2017).

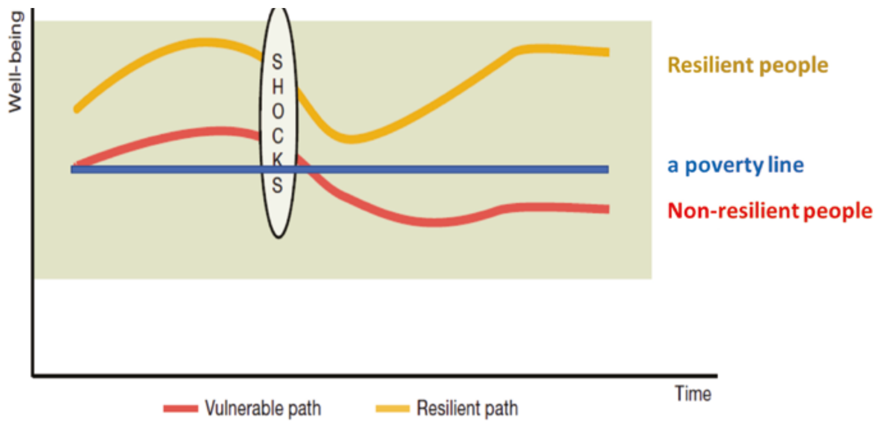

Figure 5. Vulnerable vs. resilient food systems. Source: adapted from von Braun and Thorat (2014).

3. Impacts of climate change on food systems resilience

Climate change-induced extreme weather events, such as droughts, floods, heatwaves, extreme precipitation, hurricanes, and cyclones, are projected to pose severe risks to the resilience of food systems globally, but particularly more so locally, especially in developing countries (O'Neill et al., 2022). Climate change usually works as a risk amplifier, exposing already existing underlying weaknesses of local to global food systems, and interacts with other sources of risks to the resilience of food systems, such as conflicts (FAO et al., 2021), global pandemics, or more chronic underlying factors shaping food systems resilience such as social inequality and marginalization, bad governance, cultural attitudes, public policies, and others.

The effects of climate change on food systems resilience are mediated through a complex web of mechanisms (Mirzabaev et al., 2021; Figure 6). Impacts of climate change on food systems occur through changes in water availability and quality, in pests and disease environment (Mbow et al., 2019;

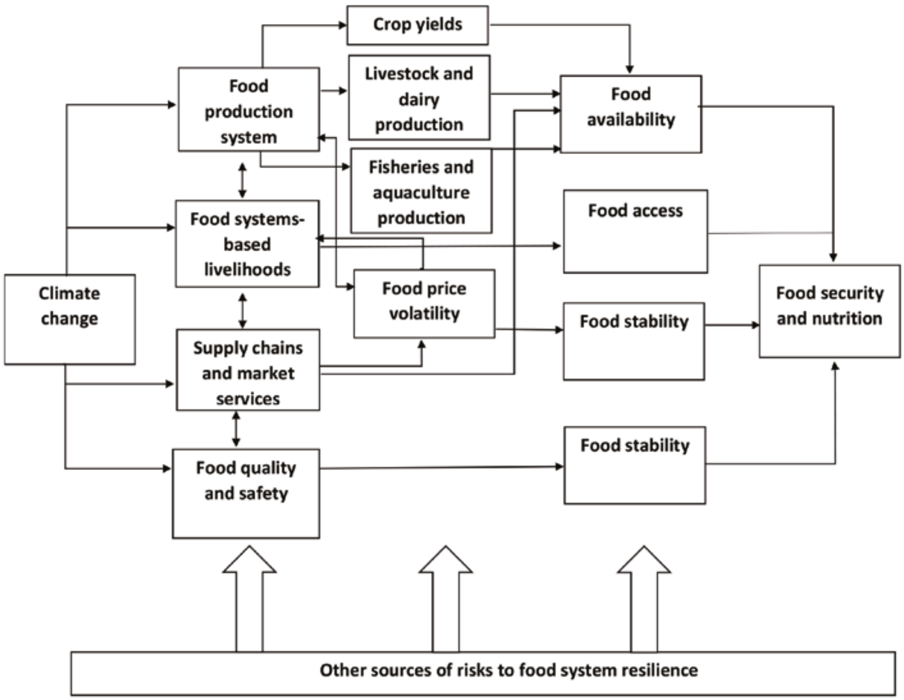

Figure 6. Climate change impacts on the food systems. Source: Adapted from Mirzabaev et al. (2021) and von Braun (2020).

Bezner Kerr et al., 2022), harvest failures and infrastructure damage. Heatwaves, droughts, and floods harm food security, health and nutrition, and lower labour productivity affecting livelihoods and incomes, especially for those engaged in climate-sensitive sectors or working outdoors. This exposure can strongly affect more vulnerable low- and middle-income countries and particular social and economic groups, e.g., smallholder farmers and farmworkers, low-income households, the elderly, women, and children.

Growing competition for land and water resources due to climate change impacts can also lead to deforestation and loss of biodiversity. The ways food systems operate are already inflicting a heavy toll on biodiversity. Loss of biodiversity is by itself a significant threat to the resilience of food systems, e.g., through the loss of genetic diversity enabling resistance to climate change impacts on agricultural production or loss of marine fisheries (Bezner Kerr et al., 2022).

Although in this paper we emphasize climate change-induced risks to food systems resilience, it is important to bear in mind that, in reality, we usually need to deal with a number of risks occurring at the same time, compounding each other or cascading from each other, such as political and conflict risks (e.g., the consequences of the war in Ukraine), unsustainable land management and soil fertility loss, or changes in food and agricultural policies.

4. Strengthening food system resilience

Actions for strengthening food system resilience can be classified into those which 1) reduce food system vulnerabilities, 2) lower the exposure to food systems risks, and 3) reduce climate change-induced hazards to food systems (Table 2). Specific actions building food systems resilience can fall under more than one of these categories at the same time. The key purpose of these actions is to transform food systems towards climate-resilient development pathways (Zurek et al., 2022). Below, we discuss some of the examples of these resilience-strengthening measures for illustration. We also emphasize that these three categories of measures not only help to be resilient against known risks, but also increase resilience to uncertain impacts of climate change.

Sustainable land management (SLM), including sustainable water management, safeguards and nurtures ecosystem health, raises agricultural productivity, supports climate change adaptation and mitigation, and also contributes to the protection of biodiversity (Mirzabaev et al., 2019; Olsson et al., 2019). For these reasons, SLM needs to be widely promoted by providing incentives, such as payments for ecosystem services (Daily and Polasky, 2019). Boosting nature-based solutions (Jensen et al., 2020) and nature-positive production calls for a wider application of agroecological and livestock management practices that are economically viable and environmentally sustainable (Neufeld et al., 2021; van Zonneveld et al., 2021). Nature-positive food systems will contribute to climate-resilient development (Schipper et al., 2022) through implementing greenhouse gas mitigation and adaptation options in the food systems in order to support sustainable development (Danso, 2015).

Efficient social protection programs that include job creation and a variety of *nutrition programs* including school feeding programs strengthen resilience (Bundy et al., 2018). To mitigate the risks of poverty and hunger, low- and middle-income countries should be supported to strengthen crisis-resistant and flexible social protection programs and, where such programs do not exist, to build them up, e.g. cash transfer programs and employment programs, as well as nutrition programs through school and health systems.

Actions to reduce hazards	Actions to reduce vulnerability	Actions to reduce exposure
· Sustainable soil, land, and water management · Avoiding deforestation · Climate change mitigation	· Social protection · Protect (agro)-biodiversity · Insurance · Reduce loss and waste of food · Market information · Livelihood diversification · Collective action · Regional grain reserves · Reducing poverty and social inequality · Education, capacity building, agricultural services, local and indigenous knowledge · Early warning systems · Sustainable soil, land, and water management · Rural-urban labor mobility · Migration	· Open and equitable international food trade · Infrastructure development · Irrigation expansion · Diversification of food import sources · Conflict prevention and resolution · Good governance · Early warning systems · Migration

Table 2. Actions for strengthening food system resilience (*inter alia*). Source: Hertel et al. (2021), Mirzabaev et al. (2021).

Trade and market policies. Ensuring free and open food trade will require a reinvigoration of multilateral trade negotiations. In addition, to avoid panic-induced world price spikes, transparent information on production, stocks and government interventions around the world is critical and must be made publicly available, e.g., through the Agricultural Market Information System (AMIS) (Zimmermann et al., 2021). Investment in trade facilitation, e.g., through improved infrastructures and also (digital) technology for managing customs systems, is increasingly important. Availability of market and trade facilitating hard and soft infrastructures was found to significantly reduce food insecurity in Malawi (Kankwamba, 2020) and increase farmer incomes in Georgia and Armenia (Pkhikidze, 2021).

Diversification. Diversification of agricultural production, diversification of incomes (including through rural-urban migration), and diversification of food supply sources are some of the most widely used and recommended options for building food systems resilience. At the same time, diversification is not free: it has costs, such as reduced opportunities for specialization, economies of scale, and related transaction costs. A key part of the definition of resilience is not only to withstand shocks, but also to maintain the capacity for future development. If diversification helps withstand shocks, but limits future development opportunities, it will not be fully conducive to resilience building.

Insurance. Another widely-used tool to strengthen food system resilience is insurance. Insurance helps spread the risks of negative shocks and the costs of damages among a larger pool of people, thus building resilience at the level of individuals. At the same time, insurance does not reduce and remove climate change risks to food systems. In the worst cases, it can be seen as a maladaptation to climate change, if insurance incentivizes the continuation of activities and practices that are not resilient to climate change impacts. Insurance works particularly well with idiosyncratic shocks, but works much less with covariate shocks (such as extreme weather events).

Migration is both a response to climate change and to its outcome. In some cases, migration can be regarded as a form of livelihood diversification (Mirzabaev et al., 2019), with remittances sent by migrant workers contributing to household resilience. However, in other cases, climate change impacts may lead to involuntary migration by making certain areas uninhabitable, such as through sea level rise and inundation of small islands. Conflicts, also resulting in forced migration, are one of the key reasons for current increases in the number of food insecure people in the world. There is a need to coordinate migration processes and policies in both sending and receiving countries, so that migration strengthens individual and system resilience to climatic and other shocks.

A science agenda for resilient food systems

There have been tremendous advances in a better understanding of the interactions between climate change and food systems in recent decades (IPCC, 2019; Wheeler and von Braun, 2013). Investments in research and science need to be expanded into the future to better understand diverse risks to adaptation, particularly in the food systems (Magnan et al., 2022). The UN Food Systems Scientific Group recommends the following seven priority action areas for science and research for the transformation and resilience of food systems (von Braun et al., 2021):

1. Context-specific policy and institutional innovations to end hunger and increase availability and affordability of healthy diets and nutritious foods
2. De-risking food systems and strengthening resilience, in particular for climate-neutral, climate-positive, and climate-resilient food systems
3. Innovations for efficient and fair land, credit, and labor arrangements
4. Bioscience innovations for peoples' health, systems productivity, and ecological wellbeing
5. Technology-based and policy innovations for productive soils, land and water, and to protect the agricultural genetic base and biodiversity
6. Innovations for sustainable fisheries, aquaculture, and protection of coastal areas and oceans
7. Digital innovations for efficiency and inclusiveness of food systems and rural communities.

Rigorous *implementation research* on these themes is needed to strengthen the fit-to-context design and delivery of policies and programs to strengthen the resilience of food systems, especially for chronically vulnerable communities. Improved qualitative and quantitative data collection on resilience to climate change and the efficacies of adaptation interventions needs to become part of priority actions.

Conclusions

Climate change is projected to pose serious challenges to the resilience of food systems both globally and locally, by also amplifying other non-climatic risks to food systems resilience. Numerous practices, technologies, knowledge, and social capital already exist for strengthening food systems resilience, such as sustainable land management, safeguarding biodiversity, social protection, early warning mechanisms, traditional and local knowledge, agricultural services and extensions, diversification and insurance, food waste and loss reduction, and many others. These actions boosting food system resilience are often also synergic with other climate-resilient development goals. However, many of these actions are presently being applied selectively at the local scale, but need to be scaled up where they are already known, and scaled out to new areas worldwide. Some of these actions require further research and development investments. Especially because climate change will also increasingly result in unprecedented impacts, with cascading and compounding factors playing together for which there is little past knowledge enabling us to deal with them in a business-as-usual way. A widescale proactive application of these resilience-building measures in food systems would create sustainable development benefits well beyond them.

Designing relevant, cost-effective policies for strengthening food systems resilience requires significantly more research on more sustainable food systems technologies, socio-economic research on risks and uncertainty faced by food systems, as well as on synergies and tradeoffs between numerous resilience-building measures and technological solutions. Unprecedented climate change impacts and associated uncertainties in combination with strong economic interests make independent and trustworthy science an essential requisite for achieving resilient food systems.

Science provides options and solutions, but science alone, without strong political support and integration of the food systems resilience agenda into related international processes, will not be sufficient. It is critical that considerations for food systems resilience are made an integral and institutionalized part of global efforts to mitigate and adapt to climate change under the UN Climate Change Convention, land degradation neutrality and land restoration under the UN Convention to Combat Desertification, and global and national biodiversity frameworks under the UN Convention on Biological Diversity.

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Agroforestry for Climate Change Adaptation and Resilience of People and Ecosystems

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Summary

- Our wellbeing, the wellbeing of our planet and the forces that are driving climate change are interconnected. Integrated approaches to land and natural resource management are needed to adapt, restore biodiversity, and to enhance resilience of people and ecosystems.
- Already, at 1.1°C warming, tree mortality and severity of forest fires and pests are increasing. Yet, at a possible warming of 2°C by 2040, some trees might still have a better chance of survival than annual crops.
- Agroforestry, with its multifunctional properties, provides a sound framework for optimizing synergies to reduce climate risks, adaptation and greenhouse gas emissions mitigation and, at the same time, enhancing biodiversity at the interface of agriculture and forestry. It also addresses the issues of food insecurity, malnutrition, energy insecurity, livelihoods, inequity and social injustice.
- The COVID-19 pandemic, and the increasing conflicts and costs, are paradoxically giving us a unique opportunity to reflect, drive real change, restore our mindsets and inspire and harness the enthusiasm of the public, including the youth, to transform our way of life. We should strive to seize this moment to ensure that societies better recognize the value of trees and urban agroforestry in building resilient green economies.
- There is no single 'silver bullet' agroforestry solution, but a synergy of the right mix including: an integrated landscape approach, co-producing context-specific knowledge and management options with people at the centre, enabling government policies, effective partnerships, direct funding support and long-term commitments and stability.
- If synergized, simultaneous pursuit of agroforestry, restoring degraded lands, halting deforestation, and sustainably utilizing forests, can help address the crises facing people and the planet.

Introduction

Climate change is one of the biggest threats to nature and humanity today. The landscape of risk is already changing and is expected to change significantly in the coming decades. Risks are especially high where climate and non-climate drivers jointly cause food insecurity, poverty, social conflicts, land and water degradation, pandemics and biodiversity loss. There is widespread agreement that Africa is facing significant challenges from increasing climate variability. This is despite the fact that it contributes only 4% of global carbon emissions. Many livelihoods, economic activities and energy sources in Sub-Saharan Africa are largely dependent on climate-sensitive natural resources. Scarcity of fuel wood in many rural areas compels farm households to burn manure and crop residues for energy, thus reducing soil fertility. According to the Food and Agricultural Organization (FAO 2022), over 30% of new diseases reported since 1960 are attributed to land-use change and deforestation, which has also been associated with an increase in infectious diseases such as dengue fever and malaria.

Continued land degradation compounded with climate change and a subsequent increase in frequency and intensity of extreme climatic events will have a negative effect on the vitality, productivity, and quality of ecosystems. Loss of ecosystems and their services will have a long-term impact on communities (IPCC AR6). Despite the global goal of achieving zero hunger by 2030, malnutrition remains prevalent and is especially acute in vulnerable regions of the world (Queiroz et al. 2021). According to a recent IPCC report, 3.3-3.6 billion people live in areas that are highly vulnerable to climate change.

The impact of climate change on trees and their ecosystem services

Although it is often difficult to disentangle climate change from other stresses, evidence shows that climate change is contributing to decreased tree growth in the tropics (Zuidema et al. 2022), trees die back from heat and drought stress, and there has been an increase in the number of forest fires, pest and disease outbreaks (Hammond et al. 2022). We found high cocoa tree mortality related to heat and drought stress, plus fungal attacks in Côte d'Ivoire.

A rise in CO_2 concentrations is also causing an increase in intrinsic water use efficiency of trees globally (Rahman et al. 2020). The tipping point of this trend, and its repercussions on the hydrological cycle is yet to be fully understood. According to IPCC AR6 (2022), at global warming levels of 1.5°C, about 3-14% of species assessed in terrestrial ecosystems will likely face a high risk of extinction. On the other hand, near term actions that limit global warming to close to 1.5°C would substantially reduce projected losses and will further determine the magnitude and rate of climate change and associated risks beyond 2040. To ensure progress towards attaining the Sustainable Development Goals (SDGs), it is crucial that the negative impacts of climate change on trees and forests, and forest-dependent communities be addressed. Hence, the aim of this paper is to describe the principles, challenges and opportunities of agroforestry in climate change adaptation and its contribution in building the resilience of people and ecosystems.

Agroforestry as a climate resilient development path

In most parts of Africa, Asia and tropical America, agroforestry is not new. There are traditional agroforestry practices spanning centuries. Examples include the parkland systems of the Sahel, the Moringa-based

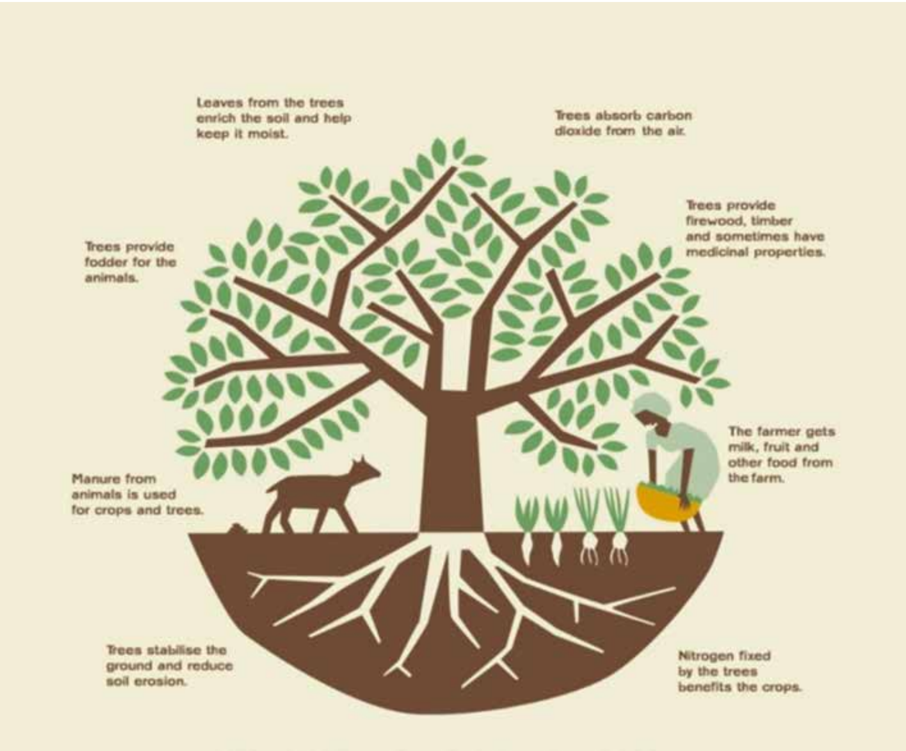

Figure 1. Multifunctional properties of Agroforestry. Source: World Agroforestry (ICRAF)

agroforestry system in Ethiopia, the Gedo home garden cultural landscapes in Ethiopia, coffee agroforestry systems, *Faidherbia albida*-based cropping system in Malawi, multistory home gardens in Mt. Kilimanjaro, cocoa systems in Cameroon, rotational woodlots in Kenya, and farmer-managed natural regeneration in the Sahel. Agroforestry is also gaining ground in the global North. For instance, in southern France, where ripening time is now 2-3 weeks earlier than just 50 years ago, some growers are adapting by keeping their traditional varieties from ripening too soon by simply growing trees – "vines among the pines" (Hoffner 2020).

As a result of their diversity, agroforestry systems are more resilient to environmental shocks and the effects of climate change than conventional agriculture (van Noordwijk et al. 2021). Trees serve as safety nets in times of emergency such as natural disasters (e.g., floods and droughts). Trees substantially cool cities. Agroforestry provides a range of other benefits – food and nutrition security, improved health and wellbeing, and livelihoods (Garrity et al. 2010). In addition, homestead agroforestry empowers women and youth. Agroforestry connects habitats and provides corridors for vulnerable species. Depending on the system and local conditions, agroforestry can achieve 50-80% of the biodiversity of natural forests (FAO 2022). By restoring wildlife habitats, it guarantees the balance of ecosystems.

Despite its multiple benefits, adoption of agroforestry has not been widespread in many parts of Africa. Research is required to better understand the challenges and opportunities at local level. Some general principles, from lessons learned so far, are discussed below.

Important lessons learned for transformative climate change adaptation. Building resilience at landscape level

Land degradation and deforestation usually occur due to lack of alternative sustainable livelihoods. Ecosystem degradation, biodiversity loss and poverty are linked; this means that environmental rehabilitation and poverty reduction must be tackled together (Hagazi et al. 2020). The interconnectedness of these factors underlines the value of working across sectors and addressing environmental, social and economic issues in an integrated manner. Landscape includes the physical and biological features of an area, as well as the institutions and people who influence it. In most areas, forests and trees are embedded within a broader landscape influenced by a range of biophysical, social and institutional forces. Working at the landscape level will promote building of resilience of land-use systems, natural resources and people's livelihoods in a cohesive way, and is more likely to optimize their contributions to the stability and vitality of ecosystems, harness biodiversity and their ability to support societal needs in a sustainable manner (Hagazi et al. 2020; Mbow et al. 2014).

People at the centre

Effective climate adaptation through agroforestry and land restoration is achievable if: decisions are made based on shared visions; implementations are framed with clear action-oriented purposes; and local communities are enabled to articulate their values in ways that can be included in decisions from benefit-sharing to monitoring and evaluation. It is important to identify leaders and key agents who can promote deep social changes. Understanding the dynamics between the different elements (biophysical, social, economic and institutional power dynamics) and engaging local stakeholders in decision-making will help in the development of strategies and actions.

"No silver bullet" agroforestry practice

Agroforestry is not new in most parts of Africa, Asia and America. While important lessons can be learnt from existing traditional practices, scaling up agroforestry will require one to co-produce context-specific data and management options based on traditional, local and scientific knowledge. Selected options should ideally enhance household resilience to shocks. Common desirable traits for climate adaptation in agroforestry include diversification of varieties or species; integrating fertilizer, fodder, fruit, fuel wood and timber tree production with food crops; cultivar improvements (heat- and drought-tolerant species); planting techniques and post-planting care; diversification of on-farm activities; plus, use of clime information and seasonal climate forecasting. It also includes conservation of water resources; enhancement of agrobiodiversity (including bees and pollinators); adapted livestock and pasture management; improved management of pests, diseases and weeds; and promotion of energy efficiency (solar and biofuels) (Hagazi et al. 2020).

Restore the mindset first

By 2050, urban areas could be home to two-thirds of the world's population. Cities provide a global opportunity to advance adaptation and mitigation. Diversifying where and how we grow our food helps reduce the risk of disruption to supplies and cut emissions. It is an opportunity to introduce agroforestry into the fabric of urban life and could bring

Figure 2. Examples of agroforestry systems in Ethiopia a) UNESCO World Heritage Konso Cultural Landscape: dry stone terraces and Moringa-based agroforestry system; b) Homestead agroforestry in Lemo; c) *Faidherbia albida*-based cropping system in Tigray and d) Gedo cultural agroforestry landscapes. Source: Photos by author.

greenery and sustainable lifestyles closer to home. Opportunities in rural areas for agroforestry range from the homestead to the landscape. Similarly, opportunities for urban farming extend beyond backyards: rooftops, walls, under solar panels (agrivoltaics), informal and refugee settlements. We can draw lessons from traditional agroforestry practices to design urban agroforestry. Of course, urban agroforestry sites can be challenging due to limited space, but we can draw from the option-by-context approach to create agroecosystems that appeal to urban settings.

In addition to the climate crisis, this will address the One Health concept as set out in the WHO Manifesto for a healthy and green recovery from COVID-19.

Science capacity

Although the African continent faces significant challenges from climate variability and change, it has limited scientific capacity to manage their adverse effects (IPCC 2022). Not all smallholder farmers have the capacity neither technically nor economically, to adapt their trees and ecosystems to climate change. There is also lack of basic information on how climate and ecological processes operated in the past, which tree species will be resilient to climate change and how sustainable their future ecosystems will be. In view of these crucial issues, there is need to generate data, knowledge and predictive systems. Evidence-based approaches to matching the right trees and management practices to production systems, ecosystems and microsite conditions are required. There is a need to link indigenous knowledge to modern agroecological knowledge.

Valuing ecosystem services

The way we assign value to nature and environment is misleading. They are usually economically undervalued. For instance, Cuni-Sanchez et al. (2021) found that forests in Africa store around 150 tons of carbon per hectare, but existing guidelines for African mountain forests set the figure at 89 tons. Another aspect which is completely ignored in the global climate change discourse is the role of trees in the hydrological cycle. The Abraha We Atsbeha community in Tigray described the ecosystem benefits of landscape restoration in an interesting way: "Water bank – we spend our time and labour restoring degraded lands upstream, and our ATM machine is downstream through ground water recharge". This was because the number of shallow wells increased significantly as a result of the rising water table and landscape-level infiltration during the rainy season. As a result, farmers could easily develop hand-dug wells and check dams for growing vegetables and fruit trees through small-scale irrigation practices, which enabled them to cultivate twice during the off-season. The role of trees in modifying micro- and meso-climates and in the hydrological cycle needs to be valued. Instrumental values that judge nature by the human benefits it could generate should be balanced with 'relational' values, that go beyond 'utility' and express respect and stewardship.

Monitoring and evaluation

This is key to managing tradeoffs and synergies between adaptation and mitigation, ecosystem services, and benefits to avoid maladaptation. Adaptation should not be evaluated only by the number of trees planted, hectares restored or the amount of carbon sequestered. It must be assessed by looking through the community's eyes, in relation to their expectations, envisioned adaptation pathways and whether it allows them to benefit and protect their land in the long term. New business models in agroforestry in rural and urban settings should reward communities for promoting the resilience and adaptive capacity of their trees, forests and ecosystem services. The system should focus on resilience and adaptive capacity as key indicators (FAO 2022).

Incentives, institutions and governance mechanisms to support resilience

On average, agroforestry realizes profitable returns after 3-8 years. Therefore, offering secure, long-term rights to land, trees and tree products, in exchange for the adoption of good management practices, incentives and strategic investments are required. Empowering and incentivizing local actors, including women, youth and indigenous communities, to play a leading role is also crucial. Long-term political commitment and follow-through across all levels of government, promotion of participatory and innovative approaches, plus collaboration among multiple stakeholders can help in the attainment of consensus for system-wide actions.

Conclusion

We reached 1.1°C of warming in 2021. The goal is to restrict global warming to 1.5°C by 2100, thus ignoring adaptation is not an option. Abandoning adaptation means deserting those most vulnerable to and least responsible for global warming. The IPCC recommends agroforestry as a sustainable solution to addressing the challenge of climate change. Beyond the climate crisis, agroforestry can address the issues of food insecurity, malnutrition and biodiversity loss. Agroforestry in both rural and urban settings is a powerful concept with popular appeal, inspiring diverse people to imagine urban food systems on a wider scale – from homesteads to landscapes, from residential lots to vacant lots to public green spaces. According to FAO (2022), of the 2.2 billion ha of degraded land identified as potentially available for restoration worldwide, 1.5 billion ha may be best suited for mosaic restoration, combining forests and trees with agriculture.

However, to improve the adoption rates of agroforestry, and adaptation objectives, incentives and strategic investments will be required for 3-8 years. Effective adaptation requires more science, better data and bold policies across multiple sectors, plus effective partnerships. Most importantly there is a need for action on the ground. Meaningful action calls for mobilization of finances. It is worth noting that adaptation does not replace mitigation by any means, and vice-versa. Expanding agroforestry and restoring degraded lands must be complemented with halting deforestation and maintaining forests. Otherwise, as warming proceeds, both adaptation and mitigation become more expensive and less effective. Thus, wealthy nations must fund adaptation in the global South. The time for bold climate action is now.

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VI. BUILDING INSTITUTIONS

Debriding Adaptation Action in African Drylands

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Abstract

Climate change affects faster and deeper the drylands in Africa than other systems with severe vulnerabilities to people and ecosystems. In addition to the impacts of climate change, the drylands are highly disrupted by conflicts of various kinds, some of which related to land resource competitions. However, African drylands possess a lot of remarkable resources and opportunities that are poorly tapped. Resilience, under these conditions, will necessitate stronger deliberate processes that lead to unleashing these potentials to sustain a rapidly growing population under severe climate impacts. Among the outcomes that lead to optimizing resources opportunities, are the knowledge and action to support both traditional and innovative options for current and future livelihoods. While the African drylands face many of the same climate challenges as other parts of Africa, there are typical features of drylands that suggest specific approaches (processes) to building their adaptive capacity and resilience (knowledge). These include tailored empowerment for locally-led adaptation (policy) that take into account the resources available (assets and outcome), the best practices and asset endowment such as rural infrastructures, promotion of neglected natural resources; and reduction of human capital outflows from these to create jobs for youth and women in the face of climate change.

Introduction

Nearly a third of global drylands occur in Africa, where they cover around 19.6m km2. These two-thirds of Africa's land area are home to the most vulnerable communities, ecosystems and livelihoods (GCA, 2021, Chapter "Dryland"). Biophysically, the drylands are diverse and refer to ecosystems such as the Sahel, the miombos and other open vegetation types, some Mediterranean ecosystems and desert lands. This diversity leads to various agricultural, pastoral and sylvopastoral livelihoods (Mbow, 2015). Africa's drylands are generally perceived as marginal lands with a strong negative rhetoric because of recurrent droughts, famine and desperation (Stavi et al., 2021).

The disconnection of drylands limits their inclusion to core governance and due care mechanisms leading to high exposure to conflicts that exacerbate the vulnerability and the fragility of current local livelihood (GCA, 2021). After decades of rainfall decline, poverty, food insecurity and undernourishment are on the rise with more than one-third (282 million) undernourished people living in Africa, according to FAO (2021). The impacts of climate change include reduced water availability, increased occurrence of vector and water-borne diseases and damage to transportation infrastructure and buildings (Spear, 2015).

These known challenges hide the other dimension of drylands that are home to exceptional natural resources such as water, energy, land for food production, natural products of high nutritional value etc. (Mbow, 2020). The African Union and UNCCD support the opportunity to craft a new African narrative away from the image of desperation to an image of hope that embraces and is inspired by the multiplicity of natural resources available and accessible to shape a vibrant development pathway that drives its own resilience.

In this paper we intend to deconstruct the common conviction that there is little that can be done in the drylands of Africa. In the analysis we offer process-based outcomes for local adaptation that are supported by a number of recommendations on how adaptation can be achieved using local opportunities.

Unshackling local barriers for the adaptation of Africa's drylands

A common feature of the recent programs on resilience is that they are ill-framed because of fuzzy interventions and priorities targets to favor improved lives and livelihood of vulnerable people. Recent developments with new global support to adaptation through the GEF (Global Environment Facility), GCF (Green Climate Fund) and AF (Adaptation Fund) show that adaptation is intrinsically a local issue and therefore requires locally-led processes and interventions to improve resilience. Local interventions include encompassing actions such as support for land restoration, water resources management, sustainable energy systems, health, organizational aspects and transparent governance for inclusive growth. Most of these local solutions are not difficult to implement, do not involve expensive modern machinery, and strongly depend on local knowledge (Mbow et al., 2021) (Figure 1).

Why then do we struggle to have massive impact of these interventions on adaptation? A major challenge in resilience is the lack of articulation between various levels of government and community-level responses. This entails limited coordination of local organizations with central agencies that leads to a limited use of human capital to help connect and harmonize multiple initiatives. Examples from regional initiatives such the Great Green Wall, NAP (National Adaptation Plans), and NDC (Nationally Determined Contributions) processes indicate the dominance of top-down approaches rather than bottom-up action by local stakeholders. Participatory and deliberative engagement of local decision-makers, and multi-institutional partnerships are necessary to optimize capacity mobilization through participatory approaches (Mapfumo et al., 2017). Local and inclusive adaptation pathways are bound to the imperative of addressing local barriers to adaptation such as land rights, transparent governance and benefit-sharing mechanisms, proper social inclusion, and empowerment of women and youth.

It is important to address local barriers through the enablers that help lift them. One set of barriers is structural, for drylands are often dependent on uncertain rainfall. Rainfall variability (through irrigation and improved water management) results in low productivity of land, but through agro-

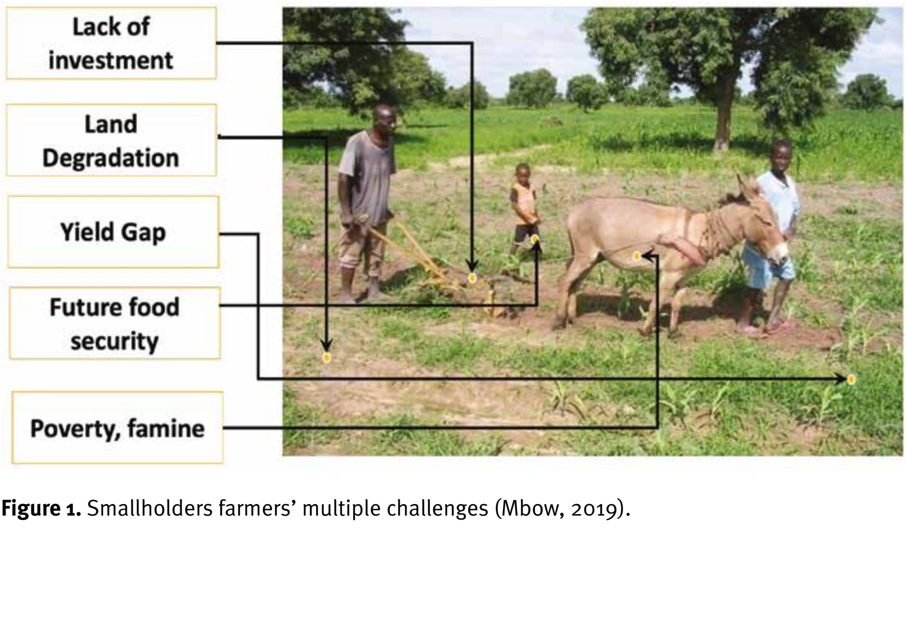

Figure 1. Smallholders farmers' multiple challenges (Mbow, 2019).

forestry and sustainable farming practices, improved yield can be attained (Mbow et al., 2020). The other barrier to address is the one related to rural infrastructures and support to market connection, in order to accelerate the transformation and use of local products. Many enablers are there to create transformation towards higher production and improved livelihoods, that leads to safety net and social protection. These are: 1) the support of local social dynamics (distant voices, promotion and use of local knowledge); 2) addressing (armed) conflicts, prevention and resolution (multi-level governance, empowering local stakeholders within broader positive vision, ensuring local benefit from large projects) and; 3) development of new financial mechanisms to bring investments directly to local level. None of these can be achieved without building a new rhetoric that deconstructs old perceptions of drylands.

Changing rhetoric on dryland resilience

For a long time, drylands were pictured through a general perception of endemic low fertility, recurrent droughts resulting in desperate poverty and vulnerability and, ultimately, in hopeless social-ecological systems. In particular, when policies and interventions are driven by mental models arising from a pessimistic mindset, less positive actions can be promoted. We suggest here an evolving recognition towards a constructive rhetoric that opens the door to a radically more positive narrative about the African drylands.

African drylands are well-endowed with resources, biodiversity and space, sustained by secular cultures and practices. Dryland ecosystem services in Africa are among the most reliable sources of living but they face several impediments such as competition for land, climate change, poor governance and conflict, among others. But these should not inhibit a vision for the possibility to encourage a deep and rapid transformation at scale to inform realistic programs which have the potential to trigger a virtuous cycle that can stabilize and improve the security, wellbeing and prosperity of dryland inhabitants (Mbow, 2020).

Land restoration policies are not new in drylands. But, for many years, land restoration has been driven top-down, with government technical services playing an end-to-end role in tree plantation, soil restoration, water harvesting, etc. These centralized policy approaches have failed to deliver community expectations (Mbow, 2017), as almost 50 years of centralized approaches to massive tree plantations have proven ineffective (Ribot et al., 2002; Diouf et al., 2002), and have undermined local equity and stewardship outcomes in places where local people have sustained the resources

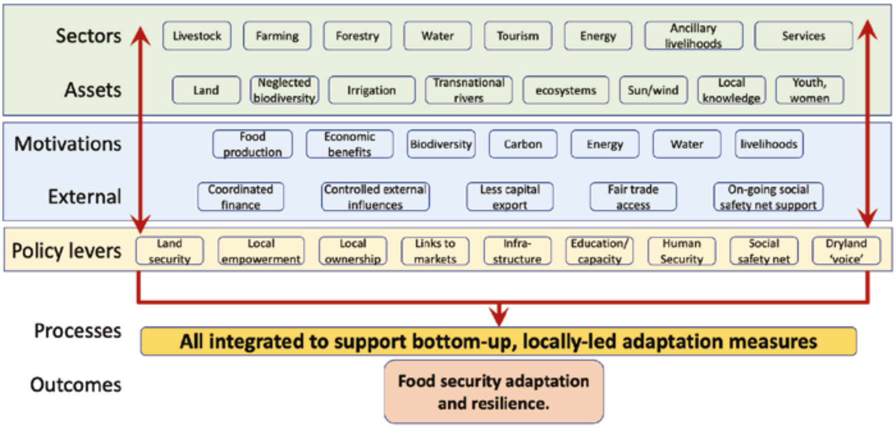

Figure 2. Process-based outcomes for adaptation in drylands Africa (Source: The authors).

for centuries. However, many African drylands have moved a long way towards adopting decentralization and devolution of environmental actions to local communities since the 1990s. In this move, land restoration by communities has mostly proven to be effective and sustainable despite the scarcity of financial resources and equipment. Communities develop (or re-instate) restoration practices that are context specific to soil, biodiversity or productivity related issues. These responses are often more appropriate to the local system (whether for ecological or social and economic reasons) than imported solutions that often fail by not being adapted to local conditions (Duponnois et al. (Eds), 2011). When seen through local eyes, restoration can look quite different from the perspective of international development (Figure 2).

Several interventions to build resilience have been tested with success in the Sahel and they all require clarity about what process to put in place to achieve them. A collection of winning interventions is listed below:

1. Improving soil structure and water retention to improve crop productivity (sectors)
2. Trees planted to buffer climate extremes and protect soil against soil erosion, reduce run-off and support biological pumping of water and fertilizers (assets)
3. Land reclamation through mechanical approaches has given excellent results in the Sahel and includes: zai, stones lines/stripes, half-

moons, small dams, slow infiltration to combat salinization etc. Salted land reclamation, soil acidity control, manure as local fertilizers, crop by-products for soil fertilization (assets and motivation)

4. Water harvesting and management of small water bodies, micro-dams and small irrigation, underground dams, small rivers dykes (asset)
5. Managing multifunctional landscape, agrobiodiversity, diversification and agroforestry (assets, motivation)
6. Herd mobility and shifting agriculture, managing pastoral corridors and managing conflicts, fodder banks and management of fires to improve pastures, small waters bodies management (assets, motivation and policies)
7. Nature-based solution for erosion control, sand encroachment, protection of farming land including green fencing (policies, external)
8. Crop variety selection, germplasm support, domestication, agrobiodiversity, biomass management (sectors, assets)
9. Trade, high value products transformation, new market opportunities, entrepreneurship for youth and women (sector, asset, motivation and external)
10. Organizational, institutional readiness dimensions of adaptation sustain all of the above to support local empowerment of vulnerable communities (policies).

Where to start? The "Big Levies" for adaptation

Water resources

Africa's drylands do not generally lack water, but do lack the investments in sustainable water use to support agriculture, human consumption and land restoration with appropriate access and equity. There are multiple large transboundary regional watersheds in the drylands, including the Niger, Senegal, Gambia, Nile, and Limpopo rivers, as well as the Lake Chad network, and the Orange River; groundwater is also extensive (Figure 2), albeit at times deep. For example, currently 11 billion m3 y1 of renewable water resources are withdrawn in West Africa (excluding Cameroon and Chad) from 1,300 billion m3 available, less than 1%; of this, agriculture uses 75%, domestic consumption 17%, and industry 7% (GWP-WATAC, 2000). Dams are often used to reduce variability and generate hydro power, though such centralized infrastructure often accounts poorly for impacts on local communities and smallholder farmers. If governed well,

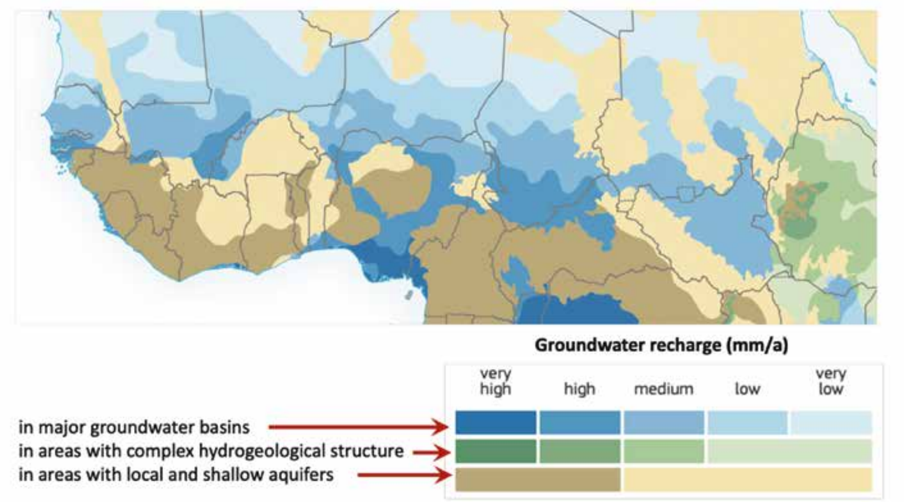

Figure 3. Groundwater in Africa (from Cherlet et al., 2018, p. 92).

these resources offer major opportunities. A fully adaptative response relies also on small water bodies management for local uses to support small gardening efforts, particularly during the dry season. An ambitious program is also needed to access the deep water table that shows exceptional potential across the Sahel (Figure 3).

Neglected and underutilized plant species

Modern agricultural systems are based on very few crop species and have neglected many indigenous crops, despite growing evidence of their potential to improve food and nutrition security, particularly for resource-poor households in Africa (Baldermann et al., 2016, Chivenge et al., 2015). Many other underutilized crops are cultivated, traded, and consumed locally, and are adaptable to poor soils, severe climates, and low-input agricultural systems (Mbow et al., 2020). Food based on some of these, like cassava bread in West Africa (Pereira, 2017), teff in Ethiopian cuisine (Cheng et al 2017), and many fruits are being sold both into African and often international markets.

On the agricultural side, adaptation of dryland farming to cope with warming, possibly dryer and more variable climates will include changing cropping systems and patterns, switching from cereal-based systems to cereal-legumes, and diversifying production systems for higher value and greater water use efficiency (Thomas, 2008). These shifts cannot be achieved without paying more attention to neglected plants, mainstreaming them into national programs and policies and re-vitalizing their use in local food systems, with benefits to food and nutritional security, as well as biodiversity and local economies in drylands. Research is needed in agronomy, breeding, post-harvest handling and value addition, and linking farmers to markets (Sinclair et al., (2019); Chivenge et al., 2015) as well as guidelines to assist countries in making the best use of biodiversity for food and agriculture in their nutrition programs (FAO, 2016). Policies must also consider a more equal distribution of land to enable scaling up of neglected plants (Lipton and Saghai, 2017).

Under-rated services

African drylands offer a variety of services that have been poorly leveraged for livelihoods in the past, but offer significant opportunities in the future. In many cases these opportunities have been under-rated and underutilized. This feature raises dryland-specific challenges of monitoring, aggregating and assuring important benefits. Three examples, among many, are:

- *Nature-based solutions*: nature, as biodiversity or ecosystem functions, can support many services essential to adaptation in drylands, including recycling nutrients, pollination, protecting shorelines, formation of soils, reducing heat extremes, and cycling of water and nutrients. Through these effects, nature-based solutions can contribute to food security, human health, building materials, water security and energy supply. A focus on nature-based solutions can achieve multiple benefits that are particularly important in drylands where climate change and desertification are projected to cause reductions in crop and livestock productivity (UNEP, 2021, p.113).
- *Biodiversity*: whilst the significant biodiversity of drylands clearly contributes towards nature-based solutions, biodiversity is also recognized for its more general values; whether through tourism, or targeted financial mechanisms for biodiversity conservation, the evolving concept of biodiversity can be designed to support livelihoods at the same time (Porras and Steele, 2020).
- *Solar energy and green energy*: High levels of energy imports in Africa widely are a huge opportunity for solar especially in drylands, albeit tempered by transmission distances. But there is also local potential for irrigation, dryland towns, and possible surpluses for value-adding ore processing where appropriate.

– *Carbon sequestration*: the vast areas of drylands play a significant role in the global carbon cycle, partly due to the previously-unrecognized levels of tree cover (Brandt et al., 2020), and shown by their effect on inter-annual variability in CO_2 uptake (Ahlström et al., 2015; Mbow et al., 2020). 'Greening' Africa's drylands as a result of land restoration, for example through the AFR100 process (https://afr100.org/), has a substantial co-benefit in carbon sequestration, justifying improved monitoring of biomass of trees outside forests (Skole et al., 2021).

Where to act now? Conclusion

This paper shows that process matters as much as the type of intervention used for adaptation. A set of interlinked processes for resilience can be summarized into a small set of major directions for *adaptation programs to support as an integrated intervention* in Africa's drylands:

– *New business opportunities through trade* between Sahel's countries if we drastically improve transparency standards, transport systems, conservation of goods, and abate child labor, and gender and equity issues; establish new business models for inclusive economies and align them to consumer power, particularly in growing urban centers, to drive sustainable value chains; create Green Enterprises (social enterprises) who become employers; link land resources with tourism, handicrafts, and services.
– *High-level political commitment* to land restoration and tenure security for local benefits: Climate-proofed economic growth model. Mostly policies are on production not responsive to CC. This includes the importance of multi-institutional and multi-level partnerships.
– *Stronger coordination of local initiatives*; e.g., optimizing the use of fertile lands such as around small freshwater bodies, wetlands, and riparian ecosystems along rivers that can sustain sustainable intensification production systems. Large areas of land are seen as productive but require combined effort for clean energy and water that exist underground to boost production and transformation.
– *New financial mechanisms* tied to local ownership and decision making. Funding local adaptation action through new mechanisms of direct access of resources by local communities.
– *Promotion and scaling up the enhanced direct access modality* introduced by financial mechanisms such as AF or GCF. This allows local communities to build their capacity to develop adaptation programs and implement adaptation actions

– *Social inclusion* to incorporate the needs and perspectives of the most marginalized users, including indigenous people, women, youth and pastoralists.

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Finance for Resilience of People and Planet. Reflecting on 50 years after the Stockholm Conference in 1972

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Summary

Fifty years might not seem long in the history of planet Earth, but the last 50 years have had profound implications for the climate system, natural systems and all life on Earth. The year 2022 marks the 50th Anniversaries of the historic 1972 United Nations Conference on the Human Environment, and the beginning of multilateral collaboration on environmental and sustainability challenges. Financial pledges to support developing countries in their efforts to achieve climate and sustainability ambitions, and the importance of economic indicators have always been at the center of international sustainability debates. This anniversary invites us all to reflect on the successes and failures of multilateral attempts to define economic and sustainability indicators, and the ambitions to accelerate funding flows in ways that support a transition towards sustainability. This article reflects on these ambitions, and concludes that the world has made limited progress on these issues in the last decades. The gap between funding needs and actual allocation is widening, and worsened recently due to the economic repercussions of the COVID-19 pandemic and the war on Ukraine. Wealthy countries have still do fulfill their promises to mobilize US$100 billion per year to support developing countries, at the same time as estimates show that the impacts of climate change could cost developing countries between $290 to $580 billion in 2030, and exceed $1 trillion by 2050. We propose a number of principles that will be needed both in the near (next 25 years) and long term (beyond 2050) to build resilience of both vulnerable groups and communities, as well as of important ecosystems, biomes and the climate system. These principles are based on the latest insights about the features of transformations include: a) defining a

new direction, b) creating enabling conditions, c) support phasing out of damaging activities, d) drive accelerated investor action for resilience, e) act with urgency and speed.

1. Introduction

"International co-operation is also needed in order to raise resources to support the developing countries in carrying out their responsibilities in this field". This sentence from the Stockholm Declaration from 1972 summarizes one of the most important and contentious issues of international collaboration on climate change: the lack of access to finance for mitigation and adaptation measures. Such lack of economic resources has stifled the ability of governments, local communities and individuals in climate-vulnerable countries to mitigate and build resilience to a rapidly changing climate.

The world has changed drastically in the last five decades since Stockholm 1972. Humanity and societies have truly become a global force of planetary change. The way economies are organized, and the way the financial sector acts plays a fundamental role in this context. Economic decisions by businesses, financial institutions, central banks, governments and many others have climatic and ecological impacts that, in turn, impact society and economies, threatening livelihoods, food security, and the resilience of vital ecosystems. A climate resilient and just future is not possible without the engagement of the financial sector, nor without economies that operate in ways that counteract social inequalities and contribute to the stewardship of global commons and the biosphere.

This brief overview summarizes what we view as major current challenges facing current international ambitions to allocate and redirect funding flows to support climate and sustainability ambitions. The overview is organized around five major topics. These are: a) a new and unequal planetary reality, b) failed promises of financial support, c) shocks and lock-ins, d) rethinking economic and financial indicators, and e) a new agenda for resilience of people and planet.[1]

2. A new and unequal planetary reality

We live in a different planetary reality compared to in 1972. The growth of the world's economies has brought substantial benefits to many in the

[1] This summary builds on our report prepared for and presented at the international meeting Stockholm+50 on June 2nd-3rd, 2022. For details, see Galaz, V. and D. Collste (2022). Online: https://financetransformation.earth/

last decades (however in highly unequal ways), enabled by substantial consumption of resources from the planet's oceans, rivers, forests, grasslands, coastal plains and other landscapes. Changes in the climate system and the biosphere, previously assumed to unfold in a distant future and affect only future generations, are happening now and with increasing speed and force as confirmed by the latest assessment made by the Intergovernmental Panel on Climate Change (2022).

By now, the human alterations of the planet (into cropland monocultures, forest plantations, filled wetlands, and fish farms) have changed the properties of the entire biosphere, and also led to the transgression of "planetary boundaries" (Folke et al., 2020; Steffen et al., 2018). Human

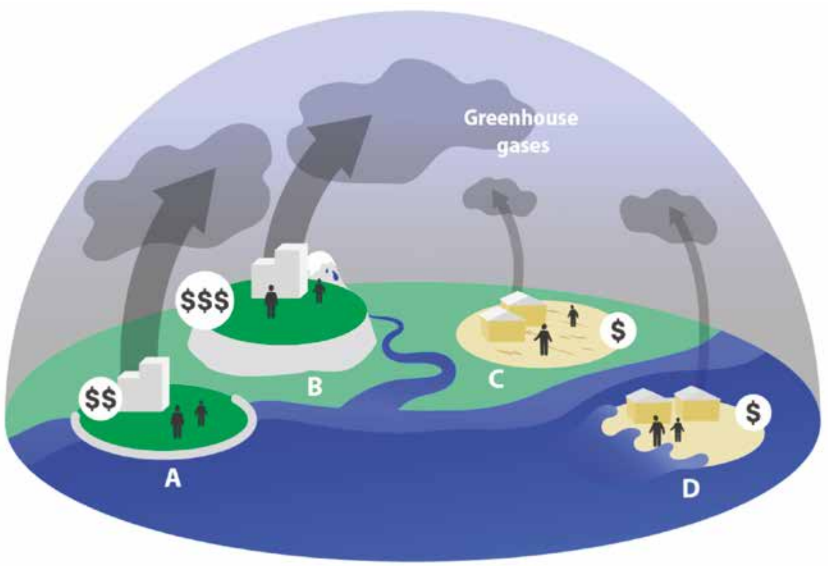

Figure 1. Planetary change, responsibilities, and exacerbated inequalities. While many high-income countries (A and C) carry a historical responsibility for high emissions that are causing global warming and sea level rises (Hickel et al. 2022), some of them, such as the Netherlands (A), also need to significantly adapt to these consequences and have the ability to do so. Other high-income countries such as Switzerland (C) are less vulnerable to the direct consequences of global warming and therefore might need to spend less to mitigate its consequences. At the same time, lower- and lower-middle-income countries, such as Bangladesh and Mali (B and D), have limited historical responsibility for ecological breakdown, but are hurt at least as seriously by its consequences (including sea level rises, floods, and droughts) but with much less ability to cope with these. This exacerbates the inequality between countries and will have complicated consequences in our globalized society. Note, however, that this simplification hides that the wealthy, also in lower- and middle-income countries, heavily contribute to the excess resource use. Source: (Galaz and Collste, 2022).

societies are also more connected than in 1972. There is considerable evidence that cross-continental connections are part of our new planetary reality through information flows, global norms and policies, tourism, migration, trade, and foreign direct investments. Shocks – such as disease outbreaks, droughts, energy supply disturbances, and food price spikes – that previously occurred locally within one sector, risk becoming globally contagious (Keys et al., 2019).

This is our new planetary reality. Human societies are more connected than ever before; abrupt and sometimes irreversible changes occur; the climate system is destabilized; and the biosphere that supports humanity grows ever more fragile and depleted.

But there is another aspect of this new planetary reality that undermines our ambitions to build a sustainable future for all – the continued increases in social inequality. As the world strives to accelerate action towards sustainability, inequality prevents sustainable solutions. Inequality is persistent and associated with multiple social and health problems (Pickett and Wilkinson, 2015). High levels of inequality undermine the resilience of individuals, communities and countries, as illustrated by the COVID-19 pandemic (Sidik, 2022). The drivers of climate and planetary change are, in addition, the result of unequal societies. The wealthiest of the world's population contribute the most to increasing pressures on the planet with high-income countries responsible for 74% of excess resource use (Hickel et al., 2022), while the poorest will suffer the most from the climate crisis and biosphere degradation. Without effective actions, our rapidly changing climate system will further amplify inequalities over the 21st century (Hamann et al., 2018). This is illustrated in Figure 1.

3. Failed promises of financial support

Mitigation of planetary pressures and adapting to a changing planetary reality will require considerable investments to promote the resilience of both people and the planet, both in the short- and long-term. Such investments could for example include; nature-based infrastructure that protect coastal cities from increased floods; support to replace fossil-fuel powered with clean energy sources; and investments in more resilient health systems. With a more human and environmental well-being focused economic incentive architecture, such financing needs can be delivered through private capital toward commercially viable projects. However, many will require public finance support, especially in low-income countries (Voegele and Puliti, 2022).

Climate-related financial investment has steadily increased over the last decade, reaching USD 632 billion in 2019/2020 (Global Landscape of Climate Finance, 2021). Environmental, Social and Governance (ESG) debt issuance reached USD $1.6 trillion in 2021 (+116% compared to 2020, from IMF, 2022). This growth is likely to continue as countries and financial institutions such as the Glasgow Financial Alliance for Net Zero (GFANZ) and multilateral development banks follow up on their commitments after COP26 and the Glasgow Climate Pact (Robins and Muller, 2021).

These positive trends obscure the fact that current increases in climate finance are far from enough to help achieve the Paris Agreement target of limiting global warming to 1.5°C above pre-industrial levels (Global Landscape of Climate Finance, 2021), and the ambitions of the Sustainable Development Goals (OECD, 2021). Reaching 'net zero' emissions by 2050 and limit warming to 1.5°C have been estimated to require investments of around $7 trillion during 2020–24, but have failed to materialize despite promises to "build back better" after the COVID-19 pandemic (Nahm et al., 2022). Securing financing to increase the resilience of communities and important ecosystems has also proven particularly challenging in many parts of the world since such investments require a longer-term time horizon (i.e., decades) than investors normally operate on (Kreibiehl et al., 2022).

Data from the Climate Policy Initiative (2022) in addition show that climate finance flows in 2019/20 reached $653 billion on average, and estimates for 2021 suggest that climate finance flows amount to $850 –$940 billion. However, finance towards renewable energy made the most progress, whereas adaptation and resilience finance lags significantly. Investments in resilience hence need to consider not only total volumes of investments, however, but also to which sectors these investments are directed. Recent assessments by the Intergovernmental Panel on Climate Change (IPCC) show that the yearly total investments need to increase by 10 to 29 times in sectors like agriculture, forestry, and other land use by the year 2030 to be able to achieve the climate mitigation goals of the Paris Agreement (Kreibiehl et al., 2022).[2]

Estimates show that adaptation finance reached about $20 billion in 2021, creating a growing funding gap over time as developing countries

[2] Note that the mentioned IPCC assessment was unable to provide a synthesis for investments needed to protect the world's oceans (70 percent of Earth's surface) that sustain life and support the well-being of billions of people worldwide (see Sumaila et al., 2020).

need around $70 billion per year, with increasing costs to about $140 to $300 billion by 2030. (By comparison, in 2021, the world spent $423 billion in fossil fuel subsidies, from Stuart-Watt, 2022). Estimates also show that loss and damages associated with climate change (i.e., those impacts that are difficult or impossible to adapt to) also could cost developing countries between $290 to $580 billion in 2030, and exceed $1 trillion by 2050 (Markandya and Gonzáles-Eguino, 2019).

The financial sector has for a long time centered its work on sustainability on the reporting of carbon emissions and capture. As a result, financial risks are consistently viewed to evolve from climate change alone, rather than from the wider suite of changes in ecosystems and the Earth system (Crona et al., 2021).

High-income nations made a commitment in 2009 to mobilize US$100 billion per year by 2020 to support low- and middle-income countries in tackling climate change. These promises have yet to materialize, with funding estimates for 2018 ranging widely between US$19-80 billion. These are also likely to be stalled further owing to the COVID-19 pandemic, raising concerns that these commitments will never be fulfilled (Timperley, 2021). The COVID-19 pandemic and the war on Ukraine are widening the already existing economic gap between rich and poor countries even further. Many developing countries have been forced to cut budgets for education, infrastructure and other capital spending during the pandemic, with sovereign debt often growing as a result. The war on Ukraine has escalated these pressures with prices for energy, food and other commodities rising, and increased inflation and accompanying volatility in financial markets.

The need to build stronger multilateral mechanisms that fulfill the promises of finance mobilization, that increase both the volume of investments to sectors that build resilience for both people and planet, and that are able to help fragile countries navigate an increasingly turbulent global context, has become increasingly urgent.

4. Shocks and lock-ins

The COVID-19 pandemic has exposed the systemic weaknesses of health systems and global supply chains, yet led to an unprecedented mobilization by the scientific community and governments to produce new vaccines at record-speed. However, the past two years have also exposed the vast fragilities and lock-ins that characterize our world, and the brittle abilities of governments and multilateral institutions to direct much need-

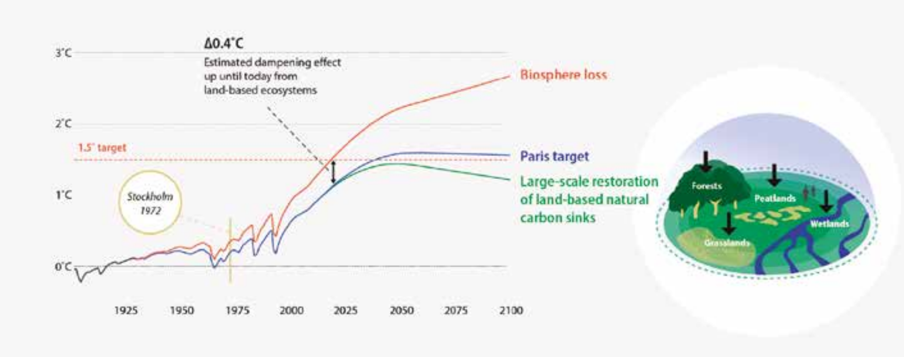

Figure 2. The importance of the biosphere for the Paris target. The world would already have breached the Paris target without the carbon sinks provided by a resilient biosphere. Source: from (Galaz and Collste, 2022), original source (Rockström et al., 2021).

ed structural changes (Galaz, 2022). Despite the rhetoric about the need to "build back better" through fiscal stimulus packages in support of economic recovery in the wake of the pandemic, it is evident that the opposite has occurred. Since the beginning of the pandemic, G20 countries have directed around $300 billion towards fossil fuel activities. Of the $3.38 trillion of proposed longer-term post-COVID recovery investments, only 15% is currently "green" with a focus on cutting greenhouse gas emissions or air pollution, with just 3% directed towards contributing to a more resilient biosphere (Rockström et al., 2021).

This underinvestment is notable considering that a stable climate future depends on the resilience of the biosphere. Recent analyses show that the world would have breached the Paris Accord 1.5°C target already today without the capacity of the living planet – our oceans and land-based ecosystems – to absorb human carbon emissions (Figure 1). However, this capacity cannot be taken for granted with continued greenhouse gas emissions, and the loss of resilience of the biosphere (Steffen et al., 2018).

5. Rethinking economic and financial indicators

The choice of economic and financial performance indicators shapes the trajectories of economies, businesses and policy decision-making. Our new planetary reality requires a rethinking of indicators for macroeconomic performance. GDP has mistakenly been used as a measure of human well-being. At the Stockholm+50 meeting, UN Secretary-General António Guterres highlighted the need to "shift to a circular and regenerative economy" (Guterres, 2022) and to move beyond GDP. Complimentary macroeconomic measures for national accounting include the Inclusive Wealth Index (IWI). IWI measures stocks of natural capital, reflecting prerequisite conditions of a functioning biosphere to achieve human well-being. According to estimates, natural capital in IWI decreased by 0.7 per cent per annum, and per person values nearly halved, between 1990 and 2014. This reflects a degradation of Earth's life-support systems (Managi and Kumar, 2018).

Financial institutions have been accounting for sustainability through environmental, social, and governance (ESG) criteria. Current ESG data and criteria, however, fail in precision as there is limited consistency across ESG raters. What is more worrisome, however, is that they also lack accuracy. As an example, ESG ratings do not reflect what companies do to minimize deforestation in their supply chains. There is a need for open disclosure of ESG data and criteria, and for active engagements by regulators to delineate how they can prevent and reverse significant harm (Crona et al., 2021).

6. An agenda for resilience of people and planet

This summary has until now focused on the limitations and challenges facing the world as countries strive to allocate enough public and private funds needed to build resilience to a more turbulent climate future, both in the long and short term. However, lock-in processes are not insurmountable. Connectivity is not only a source of fragility, but also offers opportunities to unlock such rigidities, and support transformations.

Transformative capacities are a central feature of resilience as some forms of adaptation could result in increasing fragility and risks for people and nature, unless actors find ways to initiate a transformation (Folke et al., 2010). Such a transformation entails the ability to initiate fundamental shifts in the way authority, power, and resources are structured and flow in a particular social system. As has become increasingly clear, investments in climate adaptation can end up making people more, rather than less, vulnerable to climate change without a proper understanding of the drivers of vulnerability (e.g., gender inequity, marginalization of certain ethnic groups and other power inequalities) and local realities (Schipper, 2022).

As we elaborate in detail in (Galaz and Collste, 2022), the financial sector and governments need to focus less on tracking and stimulating growing volumes of "sustainable investments", and more on complementing their work with interventions that use indicators and investments in ways that build transformative capacities (Figure 4).

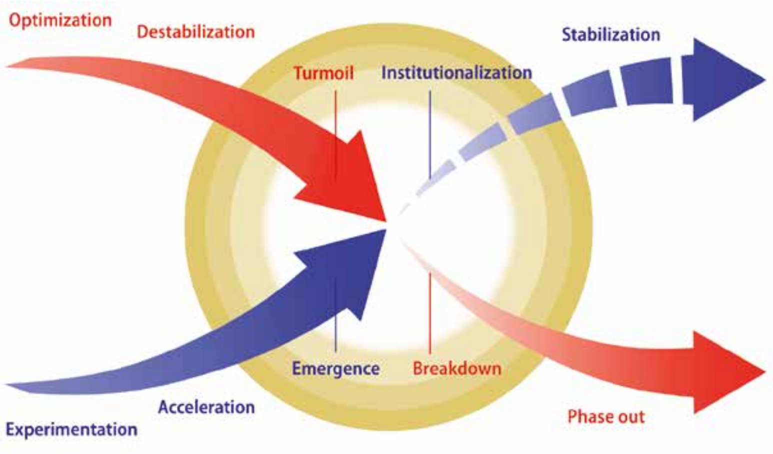

Figure 3. The X-curve of transformative change. The X-curve portrays the parallel processes of build-up and breakdown. Often, deeper system changes unfold following crises that temporarily dislodge vested interests and conventional ways of looking at the world. These disruptions sometimes allow innovative ideas and practices to be seeds for a new direction, but require the mobilization of strategic alliances (often between state and non-state actors), and the parallel dismantling of older and malfunctioning institutions, infrastructure and practices. Source: (Galaz and Collste, 2022).

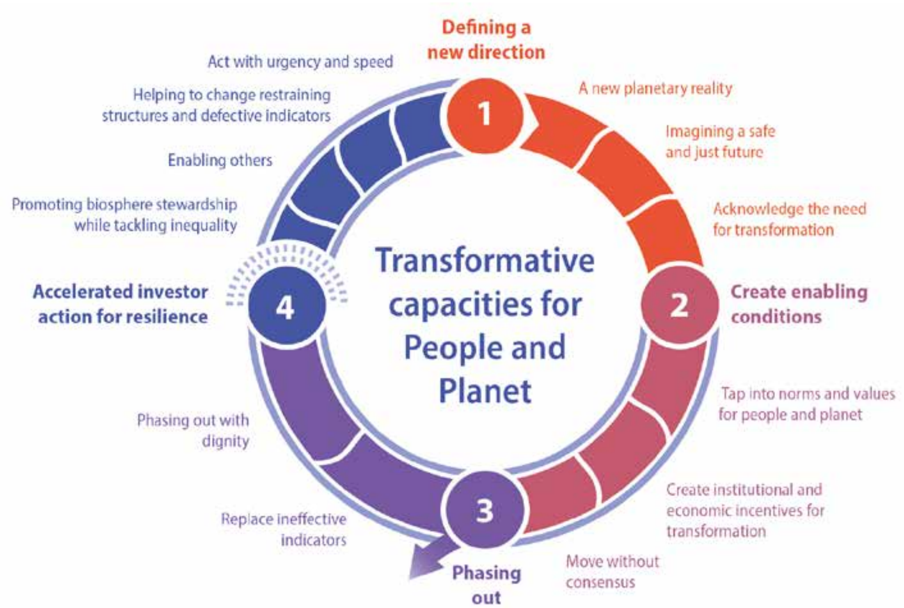

Figure 4. Building transformative capacities for people and planet. Visual summary of recommended principles to mobilize the financial sector, economic indicators and policy-actions towards resilience for people and planet. From (Galaz and Collste, 2022).

This includes the following:

1. Defining a new direction

A safe and just future is possible. The financial sector has, until now, been unable to properly direct their engagements and investments in ways that build resilience in the short and long term. Ample examples of initiatives that support resilience for both people and planet exist, and these create multiple social-ecological synergies – including a safe and just ocean economy and a transformed food system. The financial sector can, and should, align with such science-based visions and opportunities.

2. Creating enabling conditions

Existing institutions, political interests and economic incentives can all hinder the emergence of sustainable alternatives. Therefore, creating conditions that enable transformations is important. Three key actions contribute to creating such conditions:

a) Tapping into norms and values that support the change towards sustainability, using policies to guide the formation of new norms and behaviors.
b) Creating institutional and economic incentives for transformation – existing economic policy instruments can help accelerate transformations, but these policies require careful consideration during and after a transformation.
c) Daring to move without consensus. Change often causes disagreements about ends and means, resulting in impasse and halting the process. To help accelerate transformation, identify co-benefits and find innovative ways to collaborate across ideological differences.

3. Phasing out

Transformative change is as much about letting go as it is about promoting innovation. Older defective structures that reproduce inequities and unsustainability – such as investments in fossil fuels, subsidies to deforestation risk industries, and activities that lead to overfishing – should be phased out. Policy-makers, financial institutions and others can support the destabilization and phaseout of unsustainable systems, and can ensure that people are not left behind during such a change.

4. Accelerated investor action for resilience

Phasing out must be matched by growing investments in biosphere-based sustainability. Increased investments for resilience should be directed towards activities that help both people, ecosystems and the biosphere as a whole to cope with the changing planetary reality. Accelerated investments in resilience also need to 1) integrate biosphere stewardship with equity, 2) act in ways that enable people to be part of the transformation, and 3) help reform malfunctioning economic and financial structures.

5. Act with urgency and speed

Our planet has changed profoundly in the last 50 years. Today the prospects for a just and safe future for all look bleaker in many ways. But the science, innovation and action-based experience developed through efforts to tackle these challenges, have improved in astounding ways as well. The science is overwhelmingly clear: we must act with urgency and speed to secure a safe and just future for all on a thriving planet. This is both our opportunity, and our responsibility.

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New Economic Lessons on Resilience Learned from COVID

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Abstract

Our society relies on increasingly complex and interconnected systems. It is vulnerable to stress events anticipated by current capabilities. The Global Financial Crisis of 2008 already showed how our society has been exposed to systemic disruption and how policymakers were challenged by threats of recession and socio-political crisis. COVID-19 demonstrated how damage to a natural system, such as biodiversity loss, can heavily deteriorate socio-economic conditions. Current risk management theories are often based on maintaining the leanest possible operations for efficiency purposes, reducing redundancy to zero. However, without redundancy, greater vulnerability is at risk. Due to increasing interconnectedness, there is a strong need to adopt a systemic approach to resilience that focuses on the resilience of complex systems in response to a shock event. Aiming for system resiliency will enable rapid and effective protection of socio-economic conditions than tools currently available to most governments.

Introduction

The COVID-19 pandemic represented a shock to our society and a moment of reflection to move forward with better ways to rethink resilience, risk management, and recovery. This paper will discuss how a resilience approach can support systems to address uncertainty and complexity and overcome disruptions. The economic system is interlinked through financial markets, global supply chains, social networks, and ecological foundation. Complex interactions at the individual level could raise unstable properties at the macro level, such as shocks that may emerge from various sources, including pandemics, financial crises, natural disasters, geopolitical conflicts, and cyber-attacks (Hynes et al., 2020). Resilience offers a topic of increasing interest not only for academia but for international organizations, national and local governments. As both a governing philosophy and a tool for system assessment, resilience represents the capacity to understand the ability to recover and adapt to unpredictable circumstances.

Lessons from the financial crisis

Before the financial crisis, most economists provided a favorable view of financial globalization's effects on resilience. The majority thought that the growth of the financial sector would allow economic agents and countries to diversify risk through financial instruments. The expectation was that cross-border financial integration would lead to more risk-sharing. However, former IMF Chief Economist Raghuram Rajan (2005) warned that "even though there are far more participants who can absorb risk today, the financial risks that are being created by the system are indeed greater. [...] They may also create a greater probability of a catastrophic meltdown". In fact, between 2007 and 2008, issues related to the national home loans market escalated into a financial crisis that heavily impacted the global banking system. As a result, the 2008-09 recovery was fragile. Employment, private investment, and productivity growth rate remained below pre-crisis levels in multiple countries, while public debt continued to increase. During these years, countries suffered from various economic shocks, sovereign debt crises, and volatility in the world economy, further causing social unrest (Caldera-Sánchez et al., 2017). The financial crisis demonstrated that economic fragility could develop under the appearance of stable macroeconomic conditions, putting into question rethinking tools to predict economic risks and the urgency of strengthening the resilience of our societies to adverse shocks (Caldera Sánchez et al., 2015). The crisis showed us that the search for efficiency and eliminating redundancy negatively impacted the global financial system of the mid-2000s, exposing society to systemic disruption and showing that focusing on hardening core governance and finance systems may not adequately protect against future shocks (Hynes et al., 2020).

COVID-19 crisis

After the financial crisis, the world economy experienced another shock: the COVID-19 pandemic. The virus has killed over six million people so far (WHO, 2022), causing unprecedented pressure on healthcare systems (Nicola et al., 2020) and severely deteriorated socio-economic conditions worldwide. Restrictions in mobility caused severe effects on the labor market and poverty rates (Delardas et al., 2022). Global poverty increased for the first time in a generation, and income losses dramatically increased inequality across countries (World Bank, 2022). The World Bank (2021) estimated that the pandemic pushed between 119 and 124 million people into extreme poverty around the globe in 2020. According to the

IMF (2022), the cost of COVID-19 is predicted to reach $12.5 trillion by 2024 and the amount the world is losing due to this crisis is costing as much as 500 years' worth of investment in preparedness for global health crises (Global Preparedness Monitoring Board, 2020). The Wellcome Global Monitor Report (2020) found that the pandemic disproportionately impacted low-income countries and people with low incomes across all countries. Forty-five percent of workers in low and lower-middle-income countries lost their jobs or businesses due to the crisis, compared to just 10 percent in high-income countries. In addition, the costs of school closure negatively impacted students' mental health and learning, also underlining how a less skilled workforce implies lower national economic growth rates (Hanushek and Woessman, 2020).

Furthermore, the COVID-19 crisis has reinforced the economic links between households, companies, the financial sector, and the government. The pandemic exacerbated financial fragilities, such as a dramatic increase in private and public sector debt which currently represents a serious threat to a solid long-term recovery (World Bank, 2022).

COVID-19 resulted in multi-system challenges. In 2020 it was possible to observe a substantial loss of functionality in the system as the pandemic released multiple system vulnerabilities. The pandemic presented critical issues such as the lack of ventilators or PPE, which had an impact on infrastructure failure, business disruption, and further deteriorated human health (Trump et al., 2020). COVID-19 demonstrated how society is vulnerable to systemic shocks and disruption if it relies excessively on prioritizing system efficiency over resilience. Efficiency emphasizes performance at maximum capacity with minimal use of resources. However, in order to meet the rising demands of society, efficiency-based approaches often depend on increasingly complex and interconnected systems. In this case, when an interdependent society encounters stressors beyond its capabilities, highly efficient systems risk catastrophic failure that can prevent recovery (Hynes et al., 2020). COVID-19 further showed how subjective factors such as trust in institutions can influence how a disaster unfolds. For example, at the beginning of the COVID-19 pandemic, the adoption of social-distancing measures was associated with trust in government, and the mistrust in COVID-19 vaccine recommendations represented a clear threat to recovery (Seale et al., 2020). However, a positive consideration of the pandemic resulted in how crises offer opportunities to expand social protection and health measures against future health threats.

Moreover, the pandemic highlighted the need for well-resourced data systems to understand and mitigate social and economic consequences and design short-term responses. For instance, the OECD developed the "Weekly Tracker of GDP" using machine learning and Google Trends data to track countries' economies during COVID-19 (Woloszko, 2020). The Tracker suggested that the immediate impact on GDP of the global pandemic was heterogeneous across advanced economies and that the economic recovery was much more gradual than following the initial impositions. COVID-19 also demonstrated that damage to a natural system, such as biodiversity loss, will create serious socio-economic consequences (OECD, 2020). The cost of recent losses of ecosystem has been estimated at USD 4 trillion–USD 20 trillion per year. While land degradation is estimated to cost USD 6 trillion–USD 11 trillion per year and oceanic degradation to USD 200 billion per year (Kapnick, 2022). Land-use change influenced by agricultural expansion and infrastructure development is considered to be the most common driver of infectious diseases, accounting for around one-third of all emerging disease urgencies (Loh et al., 2015). According to the OECD (2020), pressures on biodiversity are expected to increase, exposing future risks of facing another pandemic. Investing in biodiversity as part of the COVID-19 response and recovery remains key in mitigating these risks. Scientists have further called for the strengthening of wildlife trade regulations to close loopholes in current governance to reduce the risk of zoonosis and spillover emergence, and consider the need to balance biodiversity conservation with the protection of food security and livelihoods of communities dependent on this trade (e.g., Booth et al., 2021; Borzée et al., 2020; Roe et al., 2020). Finally, it is worth noting that stresses such as the climate emergency are nonlinear as the system seems to continue to function normally or to degrade slowly. However, it can then reach a tipping point and rapidly collapse.

Systemic resilience

The economy can be defined as a system of interconnected institutions and markets that is continuously correcting itself. However, it inevitably reaches a critical state that may lead to cascade effects and a broader type of instability that does not correctly allow capital flows (Bak et al., 1993). Guzman and Stiglitz (2020) introduced a "dynamic disequilibrium" macro framework based on the premise that "a better way to understand deep downturns is to think of the economy experiencing a constant evolution, marked by uncertainty, in which there is continual learning about the economic system." This means that the system is seen as an adaptive behavior that is both exogenously and endogenously produced by intervention and design. Furthermore, in the ecological modeling literature, natural systems tend to evolve towards higher resilience, defining a balance between efficiency and redundancy (Ulanowicz, 2009). Trade theories also describe trade systems following a highly efficient network. For example, the economic globalization of the past decades has made trade networks vulnerable to cascading economic shocks (Fagiolo et al., 2010), with the decreasing of vital systems characteristics such as redundancy, diversity, and modularity, which enable resilience. It is also crucial to analyze the relationship between redundancy and modularity and measures of resilience to understand their contribution to resilience preparedness (Fath et al., 2015). Conventional risk management is mainly based on preventing a threat from happening or mitigating consequences if prevention does not represent a possible option. However, in an interconnected world, cascading effects are inevitable. This type of risk management is not able to adequately protect economic and social conditions, and prevention seems to be expensive to implement to assure policymakers of adequate protection (Michel-Kerjan, 2012; Linkov et al., 2019). Also, risk management often focuses on keeping the leanest possible operations, aiming for efficiency and reducing redundancy to zero. However, it is more likely to have more vulnerability and less ability to absorb shocks without redundancy, which can quickly turn shock events into failures.

Under the context of disaster risk, UNDRR (2017) defined resilience as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including the preservation and restoration of its essential basic structures and functions through risk management." According to the OECD (2020), resilience refers to the ability to absorb and recover from shocks while adapting and transforming their structures for operating during long-term stresses or uncertainty. Another consideration of resilience is how it accepts the uncertain and unpredictable nature of systemic threats and addresses them through building system resilience. Instead of relying on the ability of system operators to prevent, avoid, withstand, and absorb threats, resilience highlights the importance of recovery and adaptation in case of disruption. Furthermore, resilience considers that critical disruptions can occur in the future. Therefore, current systems must develop the capacity to recover and adapt to ensure survival. This approach can contribute to developing a better strategy against multiple uncertain and complex threats, such as climate change or economic and financial challenges, by emphasizing the capacity of these systems to recover from disruption and better adapt to future disruptions efficiently. Moreover, resilience can be applied to stress-test networks and system complexities to evaluate corrective policies to prevent the failure of critical operations (Hynes et al., 2022). Linkov, Trump, and Hynes (2019) recommend the following guidelines to implement resilience:

1. Design systems, including infrastructure, supply chains, economic, financial, and public health systems, to be resilient, i.e., recoverable and adaptable.
2. Develop methods for quantifying resilience to make explicit trade-offs between a system's efficiency and resilience, and guide investments.
3. Control system complexity to minimize cascading failures resulting from unexpected disruption by decoupling unnecessary connections across infrastructure and making necessary connections controllable and visible.
4. Manage system topology by designing appropriate connections and communications across the interconnected infrastructure.
5. Add resources and redundancies in system-crucial components to ensure functionality.
6. Develop real-time decision-support tools integrating data and automating the selection of management alternatives based on explicit policy trade-offs in real-time.

It is also suggested that four main domains need to be identified in a resilience approach: physical (sensors, system states, and capabilities); information (creation, manipulation, and storage of data); cognitive (understanding, mental models); and social (interaction and collaboration). Moreover, integrating existing modeling tools from different fields and linking environmental models with economic growth and trade models remains crucial to systemic resilience (Hynes et al., 2021).

The International Risk Governance Centre's Guidelines for the Governance of Systemic Risks (2018) need to be further considered in the discussion as those highlight a procedure that analyses systemic risks with multi-system viewpoints regarding possible threats. This procedure supports stakeholders to either prevent the shift of the system under undesirable circumstances or facilitate the transition of the respective system to a preferable regime. The IRGC's guidelines state:

1. Explore the system, and define its boundaries and dynamics.
2. Develop scenarios considering possible ongoing and future transitions.

3. Determine goals and the level of tolerability for risk and uncertainty.
4. Co-develop management strategies dealing with each scenario.
5. Address unanticipated barriers and sudden critical shifts.
6. Decide, test, and implement strategies.
7. Monitor, learn from, review, and adapt.

Accepting that resilience acknowledges that disruptions can happen, core systems must guarantee the capacity for recovery and adaptation. Therefore, resilience needs to focus on "the ability of a system to anticipate, absorb, recover from, and adapt to a wide array of systemic threats" in order to bounce forward (Linkov et al., 2019). As previously described, efficiency exposes the systems we rely on at risk of sudden disruption. System resilience will allow more receptive protections of economic prosperity and well-being. Uncertainty of events linked with complex systems requires a systemic response.

Resilience and policymaking

COVID-19 demonstrated how government capacity is critical in shaping effective crisis responses (Fukuyama, 2020). Given the complexity of shocks and their multiple consequences, governments must adapt quickly and ensure appropriate capacity for coordination. Identifying systemic threats and reviewing the analytical and governance approaches to manage threats and build resilience to contain their impacts is also crucial. This will allow policymakers to create safeguards of resilience toward economic, social, and environmental shocks. According to Guzman and Stiglitz (2020), societies need to develop institutions to deal with the macro inconsistencies inherent in the functioning of market economies and support adaptable institutions. Usually, the "Centres of Government" take care of the action of crisis and management of government operations. The CoGs have been defined as a "group of bodies that provide direct support and advice to Heads of Government or the Council of Ministers" (OECD, 2018). The structure of the Centres of Government can vary depending on the political system, contextual and historical factors. Thanks to the Survey on the Organisation and Functions of the Centre of Government, the OECD (2017) found that 83 percent of CoGs took responsibility for risk management. However, only around 10 percent of the Centres of Government listed risk management as a vital responsibility. The OECD (2020) mentioned that most countries established ad hoc entities to manage the pandemic and categorized these institutional groups into precise arrangements and structures provided by crisis-management policies. It remains critical for policymakers to prioritize the implementation of resilience methods. Policies must enable governments to tackle various problems simultaneously, such as supporting recovery, easing multiple stressors, and introducing resilience to mitigate threats (OECD, 2020). Finally, reforms are essential in building resilience to future shocks, both within and across countries, and in avoiding negative externalities on a global level.

Conclusion

COVID-19 represented one of the main unpredictable shocks to multiple interconnected systems, where recovery is required in various sectors. This paper describes how it is critical to shift from risk-based to resilience-based approaches to managing shocks properly. Systemic resilience shows that crises are part of complex systems, such as public health, financial or labor markets, and how resilience needs to be prioritized in system management to contain future disruptions. Policymakers need to acknowledge that all systems may fail. Therefore, they must be prepared for tentative failures, even when redundancy does not seem to be effective. This will result in allowing a more robust recovery and "bouncing forward" to a more reliable system.

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The Freedom to Move in Response to Uninhabitability: Enabling Climate Migration by a Nansen-Type Passport

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Introduction

Globally, the 1.5-2°C limit was accepted as the mitigation target to which all countries have to adhere. For adaptation to unavoidable climate change, however, the targets are dispersed, highly contextual and sometimes even contradictory. We need to set specific goals for global adaptation or else risk failure. Our proposal for such a minimum adaptation target: Legitimizing managed migration out of all areas that will become too dangerous to live in.

Climate change is already inducing species migration, and rising emissions will accelerate the speed and scale of this process (Pecl et al. 2017). Due to changing ecosystems and shifting climatic zones, many species populations may no longer find sufficient means to survive *in situ*, resulting in terrestrial movement towards the poles and to higher altitudes (Pecl et al. 2017). Governments have taken action to support animals in migrating across different landscapes and obstacles by building wildlife bridges and corridors (Glista, DeVault, and DeWoody 2009; Samways and Pryke 2016). In contrast, human migration is often deterred, and not infrequently punished, through the construction of physical obstacles, such as walls or fences, the unlawful detention of migrants and the separation of their families (McLeman 2019; García Hernández 2017; Hagan, Eschbach, and Rodriguez 2008; Brabeck, Lykes, and Hunter 2014; Godenau and López-Sala 2016). However, taking into account the growing body of evidence on the compounding risks inherent to climate change (IPCC 2022), one of the few feasible global adaptation strategies available to many humans will be to move out of exposed areas. Contrary to the idea that climate migration is a "myth" (Boas et al. 2019), recent research points to the fact that without emissions reductions or migration, a large part of the global population will be located outside the "human climate niche" (Xu et al. 2020).

Existing international institutions or instruments support migrants' rights, dignity and wellbeing at best partially, rendering migration an often-ineffective strategy, one that ensures survival but that also frequently perpetuates inequalities and deepens impoverishment (Betts 2013). Therefore, migration flows connected to emerging climate impacts will ultimately require institutional innovation and improved governance approaches. New legal instruments will be necessary to manage possibly larger and more abrupt forms of survival migration or to provide legal pathways to migrate in anticipation of uninhabitability (Biermann and Boas 2008; WBGU 2018).

We suggest as one measure the introduction of a legal document that would permit citizens of territories that are at high risk of becoming uninhabitable due to climate change impacts to live, work and eventually gain full political rights in other countries, including those that have substantially contributed to global emissions. The idea has already found some traction, with initial discussion by Heyward and Ödalen (Heyward and Ödalen 2013) and the German Advisory Council on Global Change (WBGU) (WBGU 2018). It follows and commemorates the humanitarian leadership of Nobel Peace Laureate and Polar explorer Fridtjof Nansen who, in the aftermath of World War I, facilitated the establishment of the so-called "Nansen Passport" system for the protection of stateless persons. We suggest that a document akin to the Nansen Passport ought to be part of the deliberations and drive towards solutions within institutions and processes already with a mandate to respond to climate-linked human mobility. We are thinking, in particular, of the Taskforce on Displacement, incorporated under the Executive Committee of the Warsaw International Mechanism for Loss and Damage (UNFCCC), the Santiago network, the Platform on Disaster Displacement, those involved in implementing the *Global Compact for Safe, Orderly and Regular Migration*, as well as relevant other parties – nation states, international organisations, etc. With the right support, the model could gain momentum even if only a limited group of states would accept the document as part of fulfilling their obligations under the UNFCCC and in solidarity with countries severely affected by transboundary damages. In this paper, we consider climate change-linked passport-type schemes already proposed but situate these within the concept of uninhabitability in an effort to stimulate further discussion about the scientific, legal and ethical grounds for a climate passport-type instrument.

Responding to Migration

Large- and small-scale human migration has occurred throughout history for various reasons, including political upheaval, conflict, natural and man-made disasters, livelihoods loss and economic recessions (Haas, Castles, and Miller 2019). Broadly speaking, human mobility occurs on a spectrum ranging from forced displacement to voluntary migration, and for reasons of sudden or slow drivers, as well as across and within national boundaries. In the climate change context three types of mobility have garnered a lot of attention: migration, displacement and planned relocation (UNFCCC 2011). The line between what is voluntary, forced or planned is, in reality, often rather blurred, however. In light of the conceptual obscurity inherent to the topic, we use migration as the umbrella term for the various forms of human mobility in this paper. Where formal migration management is concerned, three strategies strike us as having been historically predominant: 1) ordering/planning relocation in often top-down manner, 2) rejecting or deterring human mobility, not least where crossing borders is concerned, as well as 3) enabling the movement of people, including through the international legalization of transboundary movement.

The first strategy, top-down planned relocations of communities, has predominantly been used by governments to effect development projects: dams, mines, slum-upgrades or other objectives often connected to the resource sector. In the past, planned relocation frequently did not lead to positive outcomes for the communities involved. On the contrary, with commonly little community involvement throughout the process, relocations have led to social fragmentation, loss of livelihoods or alienation at points of destination (Viratkapan and Perera 2006; Cernea 2000; Fullilove 1996). Comparatively, large-scale relocations of communities for coal and other mining projects, in particular, have frequently failed to consider local realities and have led to detrimental consequences for people (Owen and Kemp 2016; Ess 2019). Moreover, human rights violations during mining-related relocations have been reported from different regions of the world, particularly, but not solely, under authoritarian forms of governance (Spohr 2016). This dark history is one to avoid in the community relocations driven by climate change impacts now already underway in some locations around the world (Tabe 2019).

Entrapment in precarity is the issue in the second strategy we wish to highlight. Restrictive border policies have repeatedly led to humanitarian disasters where access to safe migration corridors is cut off. Infamously, the

Evian conference in 1938, which aimed for a multilateral agreement to give asylum to Jewish refugees, failed – leaving millions of persecuted Jews without an escape route from Nazism (Thies 2017; Wyman 1992). In the Great Lakes Refugee Crisis following the Rwandan Genocide, more than 50,000 migrants died due to lack of food and disease outbreaks in refugee camps that provided no way out (Wagner 2009; Wilkinson 1997). Between 2014 and early 2019, more than 15,000 migrants drowned in the Mediterranean (IOM 2019; Last and Spijkerboer 2014), an ongoing situation and one linked to Europe's restrictive border policies. In recent times, groups of migrants fleeing from Central America to the United States because of gang violence, economic depression and not least severe drought (OCHA 2018; UN 2018) have also been stopped at the US-Mexican border following a zero-tolerance approach of the US government. The Trump Administration prosecuted all individuals who illegally crossed the border, regardless of whether they were applying for asylum or were accompanied by children (Congressional Research Service 2019). The resulting detentions led to the separation of families – more than 2,600 children were removed from their parents and placed in shelters under unsanitary conditions or with sponsors, some of whom could not be tracked down and went missing (Nixon 2018). This situation has only partially been rectified by the Biden Administration. These notorious examples illustrate that hindering people from crossing international borders in the face of danger results in great human suffering. Large-scale humanitarian disasters could increasingly occur in the context of rising climate impacts if relief efforts fail and safe migration is prevented. Such developments could not only limit human development, but also contribute to rising insecurity in climate vulnerable countries.

On the other end of the spectrum, the inter-war Nansen Passport scheme is illustrative of the third migration management strategy we have noted, legal measures supportive of migration, especially in times of crisis. After the end of World War I, the first High Commissioner for Refugees of the League of Nations, Fridtjof Nansen, hosted the Intergovernmental Conference on Identity Certificates for Russian Refugees in July of 1922, which was attended by representatives of 16 nations (White 2017). Mandated in particular with the repatriation of stateless Russian refugees and overseeing a negligible budget, Nansen effectively utilized the conference to get participating states to agree on a scheme by which each would recognize identity papers issued to eligible persons without naturalizing them. The so-called Nansen Passport was born. It was effective between 1922 and 1942 and its protection eventually extended to other persecuted and stateless groups, including Armenians and Jewish people and was accepted by 52 countries (Hieromyni 2003). It was issued for one year with the possibility of extension in the countries that acknowledged the document and later by the League of Nations itself. Despite the popular designation it attracted, the document was not actually a passport nor did it confer rights or obligations inherent to citizenship, although it enabled people to travel and obtain legal residence (Meyer 2009). Importantly, it not only offered individual protection but also had greater positive societal effects. For example, it enabled its recipients to integrate into labor markets instead of being forced to take up informal work or suffer unemployment. However, not legally equal to citizenship, it rightfully received criticism for creating second-class citizens, since holders lacked essential civil and political rights, such as the right to vote. Among the 450,000 recipients of the Nansen Passport were ballet dancer Anna Pawlowa, photographer Robert Capa, modernist painter Marc Chagall, novelist Vladimir Nabokov, and the composer Igor Stravinsky (Huntford 2001; Wolff 2017). Creating legal pathways for migration out of crisis regions is a pillar of protection for refugees or similar persons. Other examples of granting protection in times of crises exist. For example, when Ukrainian refugees left the country fleeing Russia's war of aggression in 2022, the European Temporary Protection Directive was evoked (2001/55/EC), in order to grant temporary protection in European countries without lengthy bureaucratic asylum procedures. Also, the 2023 earthquake in Turkey and Syria has raised demands by the diaspora to provide quick responses and humanitarian visas. However, despite these positive examples, the relevant norms, which largely emerged after the two World Wars, have not been further developed to meet the challenges of a world in transition, something we argue for here.

Population Shifts under Climate Change

Failures and successes of past migration management provide valuable insights for preventative measures that could shape the international migration regime to enable effective governance of human mobility in a changing climate. Contrary to the perspective that climate migration is a myth (Boas et al. 2019), climate change impacts are already materializing in the livelihoods of subsistence farmers, fishermen and nomadic pastoralists, or are indirectly contributing to other social, political or economic pressures, which in turn can influence migration (McLeman 2019; Vinke 2019; IPCC 2022). For example, conflicts in two of the three largest source countries of refugees in 2017, South Sudan and Syria, were at least indirectly linked to climate-related environmental change, aggravating tensions in the region (Kelley et al. 2015; UNHCR 2018; Maystadt, Calderone, and You 2015). While observed climate change impacts are contributing to migration decisions, it is not yet clear how exactly climate change will shape global migration patterns. Moreover, the ability to migrate is heavily constrained by the vulnerabilities that are amplified by the effects of climate change on the household in the first place. Viviane Clement et al. (2021) lay out three scenarios for climate-induced internal migration in Latin America, South Asia and Sub-Saharan Africa until 2050, ranging from 216 million in a pessimistic high emissions and unequal development (RCP 8.5 and SSP4) scenario to 44 to 113 million who will have to move in a lower-emissions (RCP 2.6, SSP4) scenario (Viviane Clement et al. 2021). Many of those displaced will come from traditional small-scale agriculture or fisheries, with few skills to match urban labour markets. Providing training and education opportunities to diversify incomes will be crucial, but is a tall order, given the scale of potentially affected persons. While these scenarios were considering internal displacement, which is anticipated to make up a larger share of climate-related movements (also IPCC 2022), it is unlikely that in densely populated and poor countries all population redistributions will successfully take place within national boundaries. In some regions, such as low-lying small island states or around some parts of the densely populated tropical zones around the equator international migration could become the only viable form of adaptation if emissions do not swiftly decrease (Storlazzi et al. 2018). Even if global mean temperature rise is limited to between 1.5 and 2°C, the multilaterally-established warming limit defined in the Paris Agreement, some areas, such as deltaic regions or low-lying islands may be subjected to severe climate change risks (IPCC 2021). Managing such a scenario proactively, we argue, is more desirable than putting lives at risk in regions highly exposed to climate hazards.

The Protection Gap for Climate Displaced Persons

There are persistent legal and protection gaps for different categories of migrants who are, or who will be, moving for reasons connected of climate change. These gaps apply to internal and cross-border migration, long- or short-term migration, and at all levels of jurisdiction –domestic, regional, global, etc. Efforts to address them have been partial and limited in scope. More than two decades after the launch of the Guiding Principles on Internal Displacement, there is still a protection gap for (climate-) displaced persons, as in many regions where internal displacement is a pressing challenge, such as in the Middle East, Oceania and Asia, national implementing legislation and applicable policies are lacking (Nicolau and Pagot 2018). Even where legislation exists, enforcement is often weak (McAdam 2018). An effort to revitalize the internal migration system globally is underway with the UN-Secretary General's High-Level Panel on Internal Displacement, which has produced a draft agenda, in which climate change is prominent. In the meantime, the mismanagement of internal migration can prompt displaced persons to migrate internationally or have cascading effects by triggering movements of other population groups. However, people moving across borders because of climate change are under an even lower level of protection. Some may move as labourers, where this option is available. But the international asylum regime defines refugees through the element of persecution on only five grounds, which arguably do not apply to climate-displaced persons (UNHCR 2010; McAdam 2011b). By now, there have been several attempts to succeed in a refugee-type claim on the grounds of climate change effects, in particular in the Australian and New Zealand protection systems. Although some claimants have been permitted to stay in the relevant host nation, this has been on grounds unrelated to climate change (e.g., family ties) (AD (Tuvalu), 2014). Some regional asylum regimes hold some promise in the climate change displacement context (e.g., Kampala Convention), and there are also already many states which individually do not return migrants on their territory to places where enjoyment of fundamental human rights cannot be guaranteed, including as a result of the effects of natural disasters. However, a binding, comprehensive regime for the protection of those affected by the impacts of climate change remains sorely lacking (Thornton 2018).

Top-Down or Bottom-Up? Planned Relocation vs. the Freedom of Movement

It is imperative to close the existing protection gap amongst growing concerns related to climate change. Several organizations have begun to raise awareness, as well as document and provide advice on climate migration. The Nansen Initiative (more recently continuing as the Platform on Disaster Displacement) identified "*enhancing the use of humanitarian protection measures for cross-border disaster-displaced persons, including mechanisms for lasting solutions*" as a priority area for future activities (The Nansen Initiative 2015). The Global Compact for Safe, Orderly and Regular Migration, which was endorsed by the UN General Assembly in December 2018, highlighted the importance of developing mechanisms that would address climate migration (International Organization for Migration 2018). Leaning on recommendations outlined in the Compact and by the Nansen Initiative, respectively its successor organization the Platform on Disaster Displacement, we explore what concepts could guide migratory movements out of exposed areas.

A Climate Change-Linked Passport

The idea of providing Nansen-type passports to nationals of small island states that could lose their territory has already been introduced by Heyward and Ödalen (2013) and WBGU (2018) (Heyward and Ödalen 2013; WBGU 2018). We suggest that any changes in the migration regime should be robust and linked to temperature changes beyond 1.5 to 2°C. The climate change impacts that stem from this may be life-threatening beyond small island states, which the WBGU proposal[1] already noted focuses on, and hence affect regions across the world. We therefore suggest the development of indicators for uninhabitability in general, not only for small island states. Heyward and Ödalen find that individuals should be able to determine where they could live, rather than depend on immigration quotas of specific states. In contrast to their demand for all countries to accept the Nansen Passport, we urge a particular group of states to recognize it: those that have a moral debt to a country in which a territory may become uninhabitable. These can be countries that have substantially contributed to global greenhouse gas emissions (WBGU 2018) or countries which have other ethical obligations to assist, for example historical debts due to colonization.

Since adoption of the Paris agreement, global emissions have not started to decrease and thereby threaten the internationally agreed Paris guardrail of 1.5-2°C. In Article 7.1. of the Paris Agreement parties agree to ensure "*an adequate adaptation response in the context of the temperature goal referred to in Article 2*". Given this, we argue to prepare an assessment for the immediate issuance of Nansen Passport-type documents for the benefit of citizens of all particularly exposed places once the 1.5°C threshold has passed and where uninhabitability thresholds as outlined above are passed. The 1,5°C warming level is approaching fast. Xu et al. (2018) analyze that there is a fifty-fifty chance that the limit could be crossed by 2030.[2] This

[1] Several authors are also authors of the present paper.

[2] https://pubmed.ncbi.nlm.nih.gov/30518902/

analysis has been further supported by work of the World Meteorological Organization which projects that 1,5°C warming could be reached within the next 5 years, also with a 50% probability.[3]

The Right to Stay and the Freedom to Go

Individuals and communities often prefer to stay and pursue in-situ adaptation strategies, even if this means continued exposure to risk (Laurice Jamero et al. 2017; Patel 2006). Confronted with a multiplicity of climate impacts across regions, a variety of measures will have to be taken to ensure effective adaptation in very different local contexts. A Nansen Passport-type document is a necessary, but not sufficient, condition to manage the negative impacts of climate change and would not be a replacement for expenditure on in-situ adaptation. It should be designed to complement such measures where and when they reach a limit. Ideally, migration with a 'Nansen Climate Passport' would be assisted by pre-departure trainings for labor market integration, language skills and financial assistance. Climate impacts on land and livelihoods can undermine social or cultural rights (UN General Assembly 1966), as the traditional way of living may in some regions no longer be possible because of land degradation or disappearance. Having to migrate can in itself mean significant challenges of transition and non-economic losses. The Nansen Climate Passport would hence give people a degree of agency to determine their future despite the fact that they had to experience extensive damage or harm.

Evidently, the current tendencies of criminalizing immigration (García Hernández 2017) and forceful migration deterrence policies (McLeman 2019) stand in contrast to the approach of the Nansen Climate Passport. The rejection of the Global Compact for Migration by five countries, including the US, signifies the rejection of international human rights norms on which the compact is based. Likewise, the criminalization of migrants and refugees in public discourses provides for this deterioration of international norms. But ultimately, the exclusionary policies towards those who, for various reasons, can no longer find refuge in their home country, will undermine the objectives of the Sustainable Development Goals to which the international community has committed itself. Markedly, climate change is affecting vulnerable countries the most and will widen existing inequalities in the future. In the face of this grave global injustice,

[3] https://public.wmo.int/en/media/press-release/wmo-update-5050-chance-of-global-temperature-temporarily-reaching-15%C2%B0c-threshold

enabling transboundary migration is one of the few feasible adaptation strategies. Our paper has outlined a concrete pathway by which this could be achieved, one with roots in historical instances of mass displacement to which states responded practically but compassionately. The freedom of movement of many a species in case of environmental change is a necessity that few people would deny. This inevitably raises the question, why we have not yet adopted a legal framework that would give this freedom to our own kind, too.

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Nature: Hope for Climate Resilience, Biodiversity, and Equity

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Summary

Nature makes Earth habitable and meaningful. The rich biodiversity in our ocean, in freshwater, and on land sustains us, delivering the oxygen we breathe and the food we eat, regulating climate, underpinning economies, and providing inspiration, knowledge, solace, and cultural identities. Even as people strive to advance and prosper, we have opportunities – and responsibilities – to create a future that is respectful of and enabled by nature. Doing so aligns with the moral call to action from people of faith and others to be responsible stewards of nature – our common home and heritage. However, humanity faces three major, interacting crises: biodiversity loss, climate change, and inequity. Biodiversity is disappearing at rates three to four orders of magnitude higher than natural extinction due primarily to habitat degradation, unsustainable exploitation, pollution, and climate change. Impacts of climate change and biodiversity loss also exacerbate existing inequities because the consequences fall disproportionately on the disadvantaged and underserved. An equitable, resilient future is possible, but only with integrated actions that address all three crises together. Restoring and maintaining biodiversity can provide powerful solutions for climate mitigation and adaptation and for advancing equity. Natural, scalable solutions already exist, but they are not deployed at the pace or scale needed for success. Leadership grounded in ethics and morality is needed to help realize the actions required to achieve a vibrant, just, diverse, and resilient future.

Introduction: Three megacrises, one big holistic opportunity

Society faces multiple, intersecting challenges whose resolution will determine the resilience of people and the ecosystems on which they depend (Fig. 1). Chief among these are three interrelated crises: biodiversity loss, climate change, and inequity. Here we focus on biodiversity and argue that neither of the other two challenges can be fully and successfully addressed without it. Further, tackling the three together produces more efficient and successful outcomes due to synergies and co-benefits.

Biodiversity refers to the rich diversity of life on Earth, including all animals, plants, and other groups of species – the genes they contain, the ecosystems they create and inhabit, and the functions and processes they support. Due to impacts of human activities, biodiversity is in rapid decline. Species extinction is occurring at a rate that is three to four orders of magnitude higher than would be expected without human influence (IPBES, 2019). For example, continued conversion of habitats to other uses results in the loss of forests, grasslands, and coastal ecosystems. This releases greenhouse gasses that escalate climate change (primarily driven by fossil fuel emissions) which in turn intensifies biodiversity loss. Entire ecosystems, like coral reefs, are expected to completely disappear from Earth if the climate is not rapidly stabilized (IPCC, 2018). Their loss creates cascading harms. For example, coral reefs and other coastal ecosystems protect people and property from storm damage and sea level rise by reducing flooding – one of many hidden benefits nature provides to people. In the United States alone, the disappearance of coral reefs would result in an additional annual loss of 18,000 lives and USD1.8 billion in storm damages (Storlazzi et al., 2019). In this paper, we consider the term 'nature' as inclusive of all biodiversity and the benefits it delivers to humankind.

As nature loss and climate change advance, they worsen existing inequities and create new ones. The largest climate-change-driven decreases in ocean animal biomass are expected at low to middle latitudes, where many nations are highly dependent on seafood and fisheries (Lotze et al., 2019). On land, both climate change and biodiversity loss hamper agricultural yields, pests, and food supplies and prices (IPBES, 2019; IPCC, 2018). Continuation of these trends is projected to create major impediments to many Sustainable Development Goals including overcoming inequality and poverty (Ebi and Hess, 2020; Fig. 2). Nature also provides substantial mental health benefits (Bratman et al., 2019), but access to natural spaces is inequitably distributed (Sun et al., 2022).

Given this tangle of challenges, piecemeal approaches will fail. Actions that appear to make progress towards a single goal often have repercussions for other goals that in turn undermine the original intent. For example, non-native pine plantations established for climate benefit in

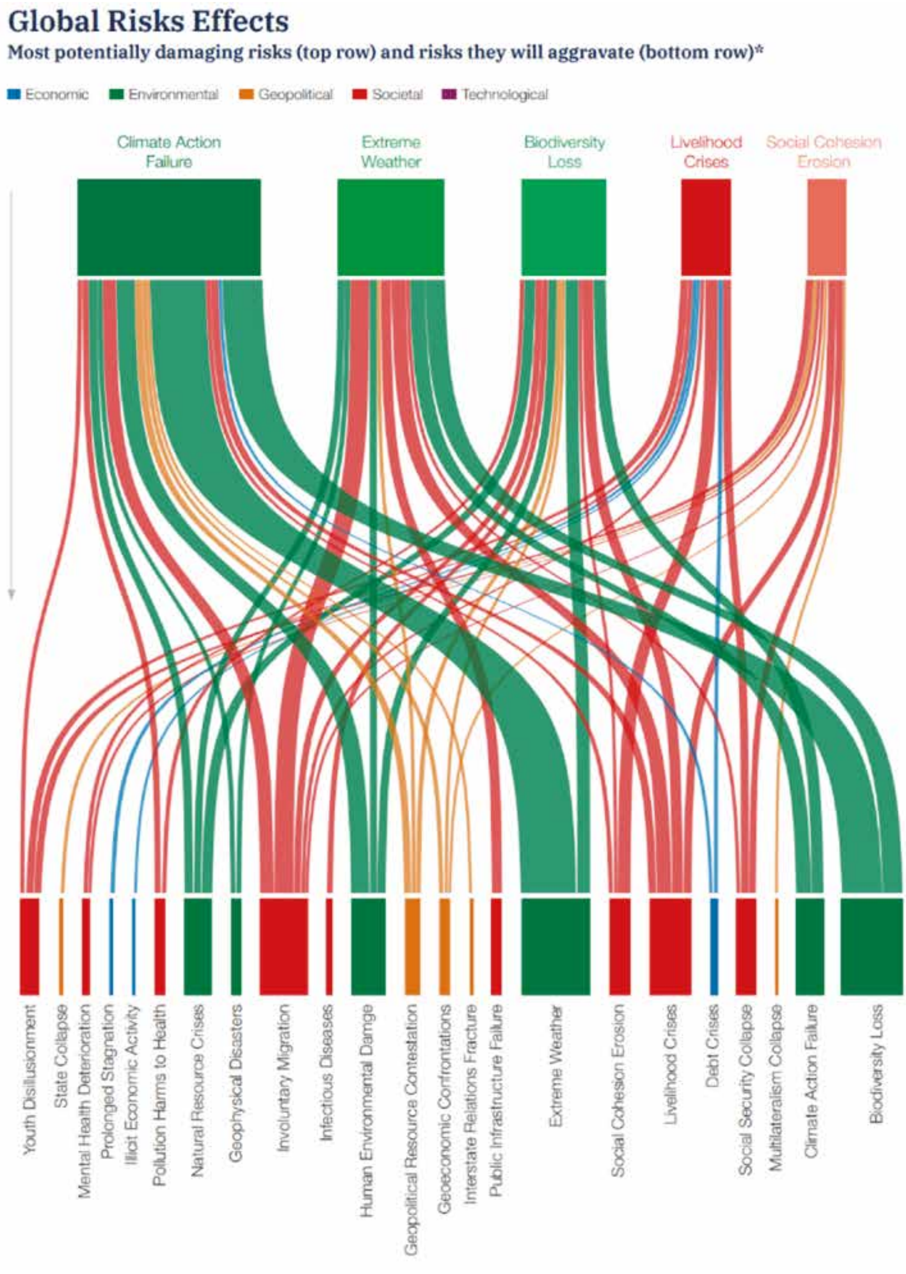

Figure 1. Global business leader perception of greatest risks, reproduced from The World Economic Forum Global Risk Report (World Economic Forum, 2022). Line thickness is scaled according to number of links.

Ecuador's páramo region reportedly had negative consequences because they displaced and harmed local species, reduced water supplies (including for the city of Quito), failed to deliver promised benefits to Indigenous groups (https://www.wrm.org.uy/bulletin-articles/josefina-and-the-water-springs-against-pine-plantations-in-ecuadors-paramos), and eliminated the substantial carbon storage provided by the natural grassland they displaced (Quiroz Dahik et al., 2021). Similarly, business-as-usual methods of economic development, food production, energy production, and urban growth often harm biodiversity and contribute to climate change, but could be adjusted to avoid strongly negative tradeoffs and realize co-benefits (Tallis et al., 2018).

Nature: A wealth of powerful solutions

Nature provides powerful and durable options for addressing climate change mitigation, adaptation (Fig. 3; Seddon et al., 2019), and inequities. Healthy biodiversity can contribute significantly to achieving each of the 17 Sustainable Development Goals (Fig. 2). For example, climate mitigation goals require a focus on biodiversity because transitioning to clean energy must be coupled with drawdown of existing emissions and enhanced carbon sequestration, for example through forest restoration (e.g., http://www.drawdown.org). Retaining and recovering nature is a proven, ready option that can achieve up to 30% of the climate mitigation needed to avoid the worst impacts from climate change (Griscom et al., 2017).

Coastal protection by mangrove ecosystems also provides nature-based climate mitigation and adaptation, biodiversity, and equity benefits. Like other structural coastal habitats such as salt marshes, dunes, reefs, and mangroves can provide durable and flexible protection for coastal communities against flooding and storm damage. Mangroves protect communities by stabilizing shorelines and slowing coastal erosion, acting as 'speed bumps' for hurricanes, and protecting inland areas from storm surge. Their value was demonstrated in Sumatra where significantly less tsunami damage occurred in areas with mangroves compared to areas without (Danielsen et al., 2005). Further, as sea levels rise and storms intensify with climate change, gray infrastructure such as sea walls becomes inundated, whereas nature-based solutions like mangrove habitats can migrate if given room. Green infrastructure provides lower-cost, more sustainable options for coastal protection for vulnerable communities (Silver et al., 2019). Further, mangroves actively sequester carbon – up to 10x as much per unit area as land forests (Hoegh-Guldberg et al., 2019); provide nursery habitat for economically

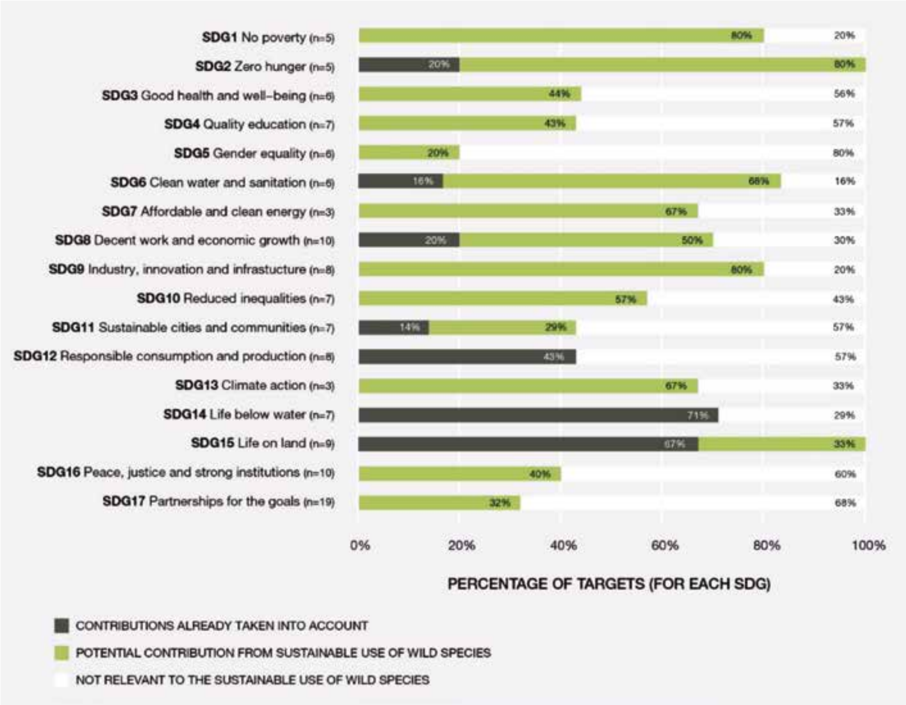

Figure 2. From (IPBES, 2022). "Sustainable use of wild species has unacknowledged potential to contribute to the achievement of many targets of the Sustainable Development Goals (SDG). This figure shows the untapped potential to include sustainable use of wild species in strategies to achieve the Sustainable Development Goals. The potential contribution of the sustainable use of wild species to achieve a Sustainable Development Goal was assessed based on the wording of the 'outcome targets' (n = x) under each Sustainable Development Goal and the evidence documented in the IPBES Assessment of the Sustainable Use of Wild Species. The percentages showed in the figure refer to the number of targets related to the sustainable use of wild species that: are 'already taken into account' (grey bar), has 'potential relevance' (green bar), or has 'no relevance' (white bar) to achieve each Sustainable Development Goal. Supporting information and detail on assessments for each Sustainable Development Goals are available in Chapter 1 {1.6}. A data management report for this figure is available at: 10.5281/zenodo.6036274".

and culturally important fisheries; produce valuable timber, fuelwood, and charcoal; trap sediment; and detoxify pollutants. Through these benefits, mangroves provide jobs and livelihoods, supporting valuable fisheries and tourism. Nevertheless, they are among the world's most threatened habitats.

In addition to this coastal nature-based pathway for greenhouse gas emissions reductions, other ocean-based climate solutions might come from decarbonizing shipping, renewable ocean energy, or protection of vast carbon

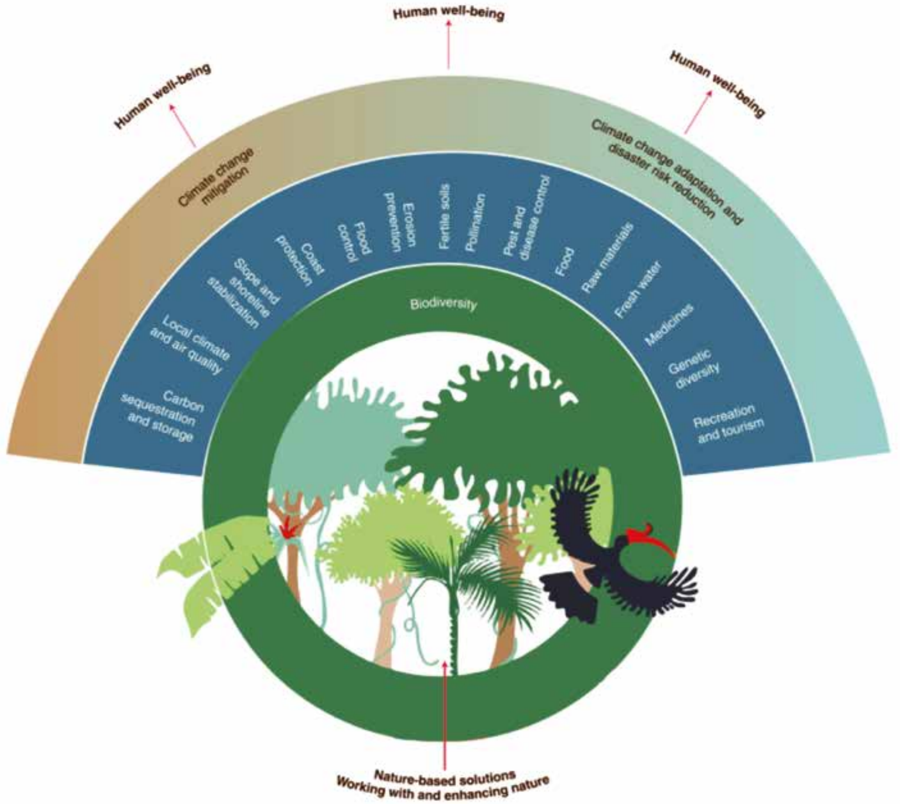

Figure 3. Nature-Based Solutions, from (Seddon et al., 2019). Solutions centered around biodiversity can provide diverse benefits for climate resilience and human well-being. Other benefits exist that are not listed here, ranging from mitigation of the effects of ocean acidification to enhancing national security to supporting physical, emotional, and spiritual health. Some feedbacks between biodiversity, its benefits, and human well-being are not represented here, but crucial; for example, equity, as a component of human well-being, is central to achieving climate resilience and stemming biodiversity loss, and these in turn broadly support human well-being.

stores on the seabed through fully protected marine protected areas (MPAs) (ibid; Sala et al., 2021). Together, these ocean-based activities might provide up to one fifth of the greenhouse gas emission reductions needed to achieve the 1.5°C Paris target by 2050 (Hoegh-Guldberg et al., 2019).

Beyond climate mitigation, fully and highly protected MPAs hold strong potential for climate adaptation, biodiversity protection, and contributions to equity (Grorud-Colvert et al., 2021). By reducing or eliminating extractive and destructive activities, they restore healthy, functioning, diverse ecosystems with both species- and genetic-level diversity, allow nature to recover and increase resilience to climate change (ibid). However, MPAs are vastly underutilized. Currently, only 2.4% of the global ocean is robustly protected (http://MPAtlas.org).

As with all protected areas, attention to the enabling conditions that promote long-term and equitable success is critical (ibid). Some MPAs have created or worsened inequities by excluding disadvantaged communities from fishing, imposing high management costs, or creating unequal distribution of MPA benefits, e.g., from tourism or fishery revenues. Yet others like Papahānaumokuākea Marine National Monument provide positive models demonstrating how simultaneous attention to biodiversity, equity, and climate can produce win-win-win outcomes (Office of Hawaiian Affairs et al., 2021). Native Hawaiians championed its establishment and now co-manage the MPA along with state and federal agencies. Rich biodiversity is protected within this very large area. And a climate vulnerability assessment, guided by Native Hawaiian perspectives, has been produced.

Nature-based solutions grounded in community leadership offer additional promise. Community-based fisheries management guided by Indigenous knowledge and local communities can help address food insecurity by recovering fish stocks and strengthening food supplies. For example, seafood provides an important source of protein and key nutrients for over 3.3 billion people (FAO, 2020). Yet inequities persist. Women are often excluded from fishery decisions despite representing approximately 40% of small-scale fisheries workers (Galappaththi et al., 2022). Community-based fisheries management can help reduce gender inequity by advancing women's leadership. Where women help shape decisions on who, where, and how to use ocean resources, sustainability and equity in small-scale fisheries is improved (ibid). Some community-based programs further address gender and health inequities through population, health and environment approaches. For example, the Tuungane program in Tanzania aims to empower communities and provide access to reproductive health services by addressing issues related to the environment, food security, and livelihoods (https://www.pathfinder.org/projects/tuungane/).

Wildfire risk in the United States is another complex challenge requiring integrated, nature-based solutions. As climate change increases the frequency and severity of wildfires, it threatens biodiversity and releases carbon, accelerating climate change. Communities of color are disproportionately likely to live in fire-vulnerable areas (Davies et al., 2018), and more likely to suffer respiratory diseases – including COVID-19 – that can be exacerbated by wildfire smoke (Dey and Dominici, 2020). Forest management that imitates historical fire patterns can reduce undergrowth and high-density vegetation and restore healthy, diverse forests that are less vulnerable to widespread, destructive fire. Indigenous knowledge foregrounds these forest management strategies; in the U.S., many Native American cultures have used fire as a tool to live with diverse landscapes for thousands of years. California's 2022 "Strategic Plan for Expanding the Use of Beneficial Fire" aims to address climate, wildfire, and biodiversity risks by revitalizing cultural burning practices through the leadership of local Tribes (https://www.gov.ca.gov/2022/03/30/governors-task-force-launches-strategic-plan-to-ramp-up-wildfire-mitigation-with-prescribed-fire-efforts/).

Health, well-being, and spirituality are also influenced by nature, which becomes increasingly important as individuals and communities are impacted by the inequitable effects of biodiversity loss and climate change. Contact with nature has multiple health benefits including better sleep, reduced depression and anxiety, lower blood pressure, and increased social connectedness (Frumkin et al., 2017). An appreciation and reverence for nature is reflected in many spiritual and faith traditions, which can in turn lead to greater care for nature. For example, Indigenous knowledge systems include a deep connection between humanity and the environment (Tu'itahi et al., 2021). Sacred writings across numerous faith-based traditions express a responsibility for stewardship of nature, for example Pope Francis' Encyclical *Laudato si'*.

Recommendations for nature-based solutions with climate, biodiversity, and equity benefits

Multiple opportunities exist for leadership and integrated action that build up on the above findings. We offer four actionable recommendations for durable, integrated solutions to the coupled biodiversity, climate, and equity crises.

1. Embed nature in climate, equity and other decisions. Despite the clear importance of considering nature, it is often ignored in favor of technology. At this critical moment, all viable, responsible solutions should be considered. Sufficient methods and data now exist to move beyond a myopic techno-centric view and embed nature and its downstream effects on climate and equity in all decisions taken by nations, programs, companies, and communities. For example, nature can and should be accounted for in major economic accounting systems and the powerful

decisions they inform. Nations are increasingly adopting natural capital accounts that place nature on national balance sheets, with methods akin to those used to generate gross domestic product (GDP). The G7 and other countries have committed to this approach (www.wavespartnership.org), including the United States (https://www.whitehouse.gov/ostp/news-updates/2022/04/24/accounting-for-nature-on-earth-day-2022/), but uptake by more countries is needed.

Governments, companies, and communities frequently make decisions using benefit/cost analysis or impact assessments without considering nature. Technology to mitigate and adapt to climate change should be considered in tandem with nature-based solutions, and evaluated for co-benefits to biodiversity and equity. Guidance and precedent exist for collectively addressing energy, food or water security, health, livelihoods, and beyond. Calls for this approach are increasing (https://www.federalregister.gov/documents/2022/04/27/2022-09138/strengthening-the-nations-forests-communities-and-local-economies), and adoption should be rapidly streamlined across sectors.

2. Elevate Indigenous Peoples, other historically excluded groups, and local communities in decision-making. Indigenous Peoples have customs and practices for living in balance with nature that have been refined over hundreds of generations and are growing in international recognition, for example in the UN Secretary General's call for an alignment of Indigenous worldviews and strategies with global efforts to make peace with nature. Dialogue across Indigenous Peoples and non-Indigenous peoples through trust-based relationships is necessary to inform existing management structures and future decision-making and improve both equity and effectiveness. Co-management such as that being developed for the Northern Bering Sea Climate Resilience Area (https://www.whitehouse.gov/wp-content/uploads/2022/06/06-2022-Readout-of-the-NBSCRA-JOINT-BFTF-BITAC-Meeting.pdf), is a promising option.

3. Protect and sustainably manage the whole Earth. Nearly 200 countries are actively negotiating a global conservation framework through the Convention on Biological Diversity that will guide conservation action for the next decade. The framework is centered in the recognition that climate, equity, and biodiversity challenges are intertwined, and that addressing them will take a 100% approach. This includes a commitment to protect one third of the Earth or more ('protect at least 30% by 2030') in

well-managed, effective, connected networks of refuges that represent the spectrum of diversity around the globe (A new global framework for managing nature through 2030: First detailed draft agreement debuts | Convention on Biological Diversity (cbd.int)). This ambition for protection is gaining support from many nations, organizations, and leaders including Pope Francis, as in his message for the World Day of Prayer for the Care of Creation (https://www.youtube.com/watch?v=xHnSdWDXf2M).

However, despite the urgent need for more and more effective protection of nature and ecosystems, protection alone is insufficient. Unsustainable resource use, pollution, climate change, invasive species, and other threats ignore protected area boundaries and threaten nature and people (Fig. 4). All sectors need to adopt sustainable actions.

Progress towards 100% sustainable management has begun but more comprehensive actions are needed to make progress toward a truly sustainable Earth. The sixteen Ocean Panel countries – representing nearly half of the planet's national ocean waters – committed to sustainable management of 100% of their ocean jurisdictions (https://oceanpanel.org/). Other countries are setting comprehensive restoration goals, like the European Union's recent Nature Restoration Law that commits EU countries to restore 20% of degraded lands and waters by 2030, and all ecosystems in need of restoration by 2050. Corporate leaders are also contributing, recognizing the influential impacts of supply-chain decisions on ecosystems around the globe [e.g., Seafood Business for Ocean Stewardship (https://seabos.org/) and the Capitals Coalition (https://capitalscoalition.org/)].

4. Align incentives to nature. A wide range of factors – from family or religious values to company advertisements to school curricula to government policies, funding, and subsidies – influence our options and choices. These mechanisms can create friction and impede change, or they can catalyze new hope and bold action.

In all parts of life, the incorporation of effective incentives that recognize and reward inclusion of nature should be routine and disincentives should be eliminated. Preliminary efforts are underway. The World Trade Organization recently agreed to prohibit harmful fishery subsidies that undermine long-term harvests and biodiversity and put food sources at risk. The G7 countries recognized the harmful environmental and social effects of some subsidies and have committed to deliver nature-positive outcomes (https://www.gov.uk/government/publications/g7-climate-and-environment-ministers-meeting-may-2021-communique/g7-climate-and-environ-

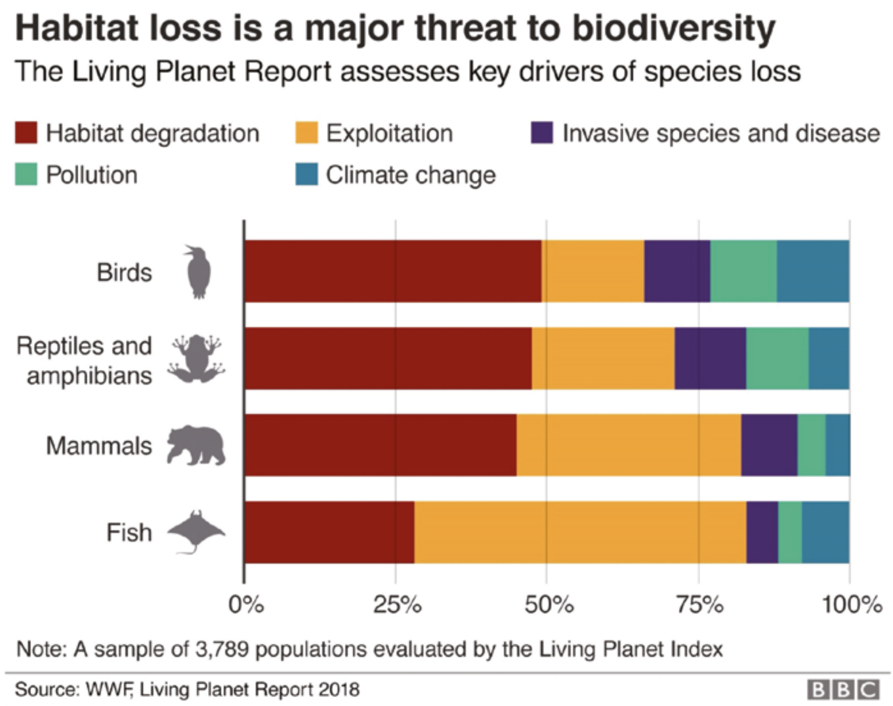

Figure 4. Key drivers of species loss by taxonomic group. Figure reproduced from https://www.bbc.com/news/science-environment-48104037

ment-ministers-communique-london-21-may-2021). President Biden called for increased adoption of nature-based solutions across the US Federal government. Pathways under consideration include changing workforce training and professional development; increasing nature-based solutions to protect Federal facilities and resources; changing policies and guidance to make it easier to consider, and when appropriate, prioritize nature-based solutions; and other avenues to make nature the go-to option for achieving climate resilience, equity, and prosperity. Spiritual and faith-based incentives also exist, for example through the Catholic Church's liturgical Season of Creation, which includes a focus on global to community-level service and volunteerism. These actions are encouraging but a quantum leap in effective actions is needed to realign incentives with nature-positive outcomes.

Conclusion

The urgency of each problem – climate change, biodiversity loss, and inequity – often drives a myopic focus on just that threat. Yet, successful solutions to each will require a unified approach that integrates all three. Such holistic solutions exist, but are not being adopted at the pace or scale that is required in part because the three communities are often siloed and focused on solving just one problem without recognizing the interconnected nature of all three. In addition, each community has biases; for example, the climate community is heavily weighted toward a focus on mitigation and on technology. A focus on resilient ecosystems and people provides the opportunity to broaden the horizons of each community and consider integrated, holistic solutions. In short, a resilient future depends on bold leadership to champion these integrated approaches.

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Declaration and Recommended Actions

The Climate Challenge: **A Grave Danger.** The continued emissions of heat trapping gases at record levels have transformed climate change into climate disruption. Poor and vulnerable populations (about 4 billion) are at the receiving end of the devastation despite their low emissions (only 15%). World food and water security is seriously threatened, partly due to climate disruption. The northern hemisphere has witnessed a six-fold increase in large heatwaves since the 1980s, and such weather extremes have adversely impacted 4 billion people since the 1990s, posing grave threats to ecosystem health and public health, including mental health. In about ten years, the heating of the planet's surface is projected to amplify by about 50% to 1.5°C, followed by more heating beyond. The proportional intensification of climate extremes along with the crossing of natural and social tipping points will strike rich and poor. Mass displacements and migrations of people could pose political instabilities. Since such changes are irreversible for centuries, generations unborn will suffer. A full-blown climate crisis is likely by early 2030s.

Climate Resilience: **A New Approach.** The Pontifical Academy of Sciences, prompted by grave concerns about the climate crisis in the Anthropocene, convened a meeting during July 13-14, 2022 to recommend steps to forestall the crisis. The attendees viewed human-nature interactions through a triplet of interlinked crises: Climate, Biodiversity, and Inequality. The consensus was: *it is too late to rely just on mitigation. Adaptation to climate risks is overdue and must become a central theme of climate actions. A global effort to build climate resilience is needed, and the following recommendations placed on the agenda of COP27 and beyond.*

Recommendations: *Resilience building must rest on three pillars:* **Mitigation, Adaptation & Transformation.**

Mitigation: *Reduce climate risks.*

1) *Bending the warming curve down*: Bend and flatten the warming curve below 2°C before 2050 and bend it further below to 1.5°C before 2100, through deep cuts in emissions of CO_2 and other heat-trapping pollutants; and extraction of at least a third of the 1.2 trillion tons of CO_2 from the atmosphere. The wealthy billion must drastically reduce their emissions and provide financial/technological assistance to the

vulnerable 4 billion people to enhance their adaptive capacity and to build their resilience.

2) *Nature-based solutions*: Include nature-based climate solutions for emission reductions, that bring in oceans, mangroves, agroforestry, working farmlands and forests. These solutions also provide adaptation benefits and offer powerful options for addressing biodiversity and inequality with huge co-benefits for health of people and ecosystem.

Adaptation: *Reduce exposure and vulnerability to unavoidable climate risks.*

Exposure & vulnerability reduction has three faces: Reductions in sensitivity to climate change; Reductions in risk exposure; & enhancement of adaptative capacity. There are limits to adaptation and hence adaptation has to be integrated with mitigation actions to avoid crossing the limits. Furthermore, isolated adaptation actions might inadvertently result in maladaptation, which can be avoided by an integrated resilience approach and choosing those actions with co-benefits to biodiversity.

3) *Inequality*: Initiate a major effort to help the poor and vulnerable four billion to adapt to climate risks now. Affordable access to clean energy, water, health care, sustainable farming and resilient infrastructures must be part of the milestones. It is, moreover, critical to develop novel legal instruments for the protection of people displaced by anthropogenic global warming. One important step forward would be the introduction of a "Climate Passport" to enable self-determined and dignified survival migration of individuals in response to severe climate impacts. This instrument could be modeled after the legendary "Nansen Passport", which was eventually accepted by more than fifty states. It guaranteed legal residence for displaced persons in the aftermath of World War I and allowed them to work in their host countries.

4) *Governance*: Solutions should be locally and nationally determined actions. Coordinate the available resources at various levels of government with the local actions.

5) *Food & water security*: Worldwide scaling up of the following are required: sustainable land and soil management, forest protection and agroforestry, advanced plant breeding, social protection with nutrition components, water use efficiency in farming, and access to clean drinking water and sanitation. Water security, already threatened perceptibly

by global warming and related weather extremes, needs to become a visible element of climate change negotiations. A concerted effort is required to reduce food waste and excessive meat consumption.

6) *Construction and housing:* Transform settlements into carbon banks by prioritizing organic building materials in support of sustainable bio-economy and circularity through multiple material reuse, including such homes which transform todays' slum areas.

7) *Regional hotspots*: Special attention must be given to regional hotpots for climate stress: Amazon, Small Island nations, Drylands of Africa, Southern Africa, Mediterranean, Middle East, South Asia, NE China and South-West USA.

Transformation: *Change of lifestyle, transformation of society and ecosystems, to mitigate, adapt and bounce back.* This transformation is akin to an ecological conversion (Pope Francis' statement) and must integrate actions on the triplet of crises: climate, biodiversity, and inequality.

8) Transformation of economic systems and societies by moving swiftly to renewable energy systems, applying incentives such as carbon pricing and regulations for reducing demand for emission-intensive goods, including policies that account for the values of nature and take us on a path of stewardship and restoration of Nature. We must also recognize the obligations of wealthy societies providing technological and financial assistance to the less wealthy, and of all societies to pursue scientifically and environmentally informed economic development.

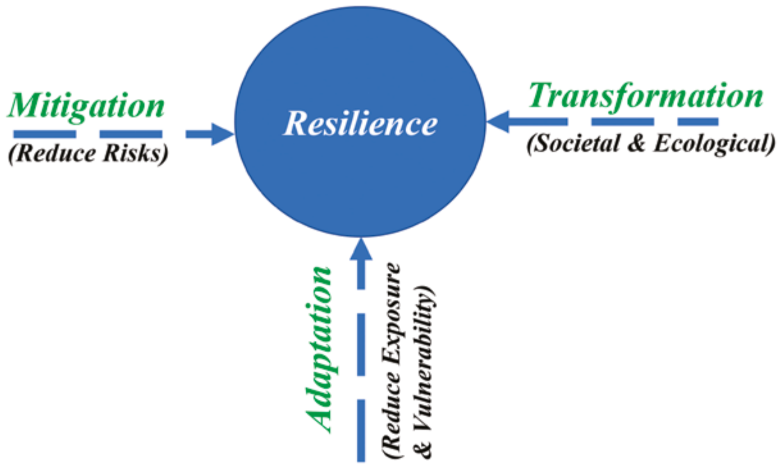
9) Behavioral change of people, communities, and business is needed to achieve the transformation. A major new global initiative is required for mass education of everyone, from children to senior citizens, in ecological citizenship (*Laudato Si'*, para 211) and on sustainable living. Public, civil society and faith-based communities of all world religions can productively engage in this moral task.

10) The above recommendations require a major engagement of science. Science must assist in prioritization of evidence-based actions without losing focus on equity issues. The analyses of solutions must include the modeling of two-way natural/social systems interactions to achieve a transformational improvement in the predictive power of climate trajectories.

Faith and science can form trans-disciplinary alliances to deliver the requisite mobilization of public support for climate actions. Such alliances are feasible because protection of all of creation is the stated goal of all faiths. The Pontifical Academy of Sciences has been nurturing such alliances through series of meetings on climate change and sustainability for over two decades.

It is within our reach to become better stewards of the planet and make people and ecosystem bounce back from the multiple environmental crises to a safer, healthier, and sustainable world.

Extended Declaration with Problem Statement



Statement of the Problems

1. Climate change has become a central problem of world society. It is disrupting industrial and agricultural systems, adversely impacting the health of billions and water security, and most importantly imposing unprecedented harms on the poor and on those who are climate vulnerable, numbering over 3.3 billion people. It is also contributing significantly to loss of biodiversity and to the worsening of inequality within – as well as across – nations. These climate change-related consequences contribute directly and significantly to reduction of resilience.[1] This has become the age of humans: we have ushered in the Anthropocene.

2. We are now facing three interrelated challenges. The first is to bend the emissions curve as soon as possible to reduce climate risks. The second challenge is to reduce the pressure on nature and loss of biodiversity, as

[1] Resilience is understood as *the capacity of social, economic and ecosystems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure as well as biodiversity in case of ecosystems while also maintaining the capacity for adaptation, learning and transformation* (IPCC-WGII Report, 2022).

much as possible. And the third challenge is to enable and help people, especially the vulnerable 4 billion people, adapt to unavoidable climate changes.

3. The Pontifical Academy of Sciences has raised its deep concern about Climate Change and lack of action to address its root causes during the past three decades.[2] We refer to Pope Francis' seminal Encyclical *Laudato Si'*, that highlighted key issues of climate change, inequality and destruction of nature. With this conference and statement, we draw attention to the accelerated risks resulting from climate change for people and planet, and particularly we focus on the urgent need to strengthen resilience with accelerated multilateral collaboration, improved policies, investments, social action, and behavioral change.
4. The planet crossed a major warming threshold (1°C) during the 2010 to 2020 decade, a warming not seen in the last 2000 years. It has reached about 1.2°C and is very likely to cross the 1.5°C warming threshold by early 2030s... that is, about 10 years from now. The 1.5°C warming is the threshold for dangerous warming. Everyone on the planet will be adversely affected, either directly or indirectly. The climate crisis is upon us, and it could get lot worse in about 10 years from now. With unchecked emissions, it is likely to cross the 2°C threshold before 2050 and the catastrophic warming threshold of 3°C to 4°C by end of this century.
5. Because the warming is associated with intensification of weather ex-

[2] Examples include:
- Reconstructing the Future for People and Planet https://www.pas.va/en/events/2022/reconstructing_the_future.html
- Dreaming of a Better Restart https://www.pas.va/en/events/2021/dreaming_restart.html
- Faith and Science: Towards COP26 https://www.wiltonpark.org.uk/faith-and-science-towards-cop26/ https://www.pas.va/en/news/2021/2021_cop26.html
- Health of People, Health of Planet and Our Responsibility Climate Change, Air Pollution and Health *Scripta Varia 139*. https://www.pas.va/en/publications/scripta-varia/sv139_springer.html
- *Laudato si'* and the Path to COP22 *Scripta Varia 128* https://www.pas.va/en/publications/scripta-varia/sv128pas.html
- Fate of Mountain Glaciers in the Anthropocene *Scripta Varia 118* https://www.pas.va/en/publications/scripta-varia/sv118pas.html
- Geosphere-Biosphere Interactions and Climate https://www.pas.va/en/publications/scripta-varia/sv96pas.html

tremes such as heatwaves, extreme rainfall and floods, tropical storms such as hurricanes and cyclones, mega droughts and fires, climate change is adversely affecting the health of people, ecosystems, and biodiversity. The number of weather/climate/water-related disasters increased five-fold during the last 50-year period. Climate change is a global health crisis as well as an environmental crisis. A further increase in the warming beyond 1.5°C to 2°C can trigger natural and social tipping points which can cascade into a domino effect, many of which are irreversible on time scales of at least few centuries.

6. The food and water security of the world is threatened by climate risks. The world food system is significantly contributing to climate change with about 30% of greenhouse gas emissions. At the same time, the food system is exposed to major risks from climate change, leading to reduced productivity and growing hunger. Climate change interacts with other sources of risks to the resilience of the food systems, in particular loss of biodiversity, and risks such as conflicts, global pandemics such as COVID-19, social inequality and marginalization.

7. Thus far, the poorest three billion people have been at the receiving end of the adverse effects of climate change and loss of the benefits provided by intact natural systems. Global warming has significantly decreased the income of the poorest. The contribution of the poorest three billion to climate pollution is less than 10%, while the wealthiest one billion are responsible for at least 50% or more of the emissions.

8. We emphasize the three combined and interrelated planetary crises: climate change, biodiversity, and inequality. Climate change amplifies also the other two crises, with implications for survival of humans and many species. Climate change has become a multiplier of the underlying socio-economic forces that are responsible for inequality between the wealthiest and the poorest nations, as well as the inequality between the wealthiest and the poorest people within each nation. The inordinate delays in enforcing deep cuts to climate warming emissions has turned the climate crises into a moral problem.

9. The Climate crisis is being compounded by other crises. The COVID-19 pandemic has compounded the problems arising from climate change and inequality. We are now also faced with many wars being waged in the world, such as Russia's invasion of Ukraine, the Tigray war in Ethiopia, Yemen, and others, which have grave negative influ-

ences on human survival, inequality, health and wellbeing, migration, food security and climate pollution.

10. Given the intersecting nature of the three crises [Climate, Biodiversity, and Inequality], the design approach of climate solutions must broaden the current focus and include nature-based climate solutions that bring in oceans, mangroves, farm lands and forests, which will contribute to addressing the biodiversity and inequality crises, along with technological and institutional innovations. Nature-based solutions should also be the basis for the built environment transformation. The Amazon is one of the most important biomes on Earth in delivering ecosystem services that are essential to increase resilience of global systems to climate change. But the Amazon is also suffering from a pronounced loss of Resilience. A particular case for just land and natural resource management can be made for Congo basin and the African drylands. Nearly a third of global drylands occur in Africa, where they cover around 19.6 km2. These two-thirds of Africa's land area are home to the most vulnerable communities, ecosystems, and livelihoods. Energy poverty must be eliminated for climate adaptation plans to succeed. Over 2.5 billion currently rely on firewood, dung, and solid coal for meeting basic energy needs such as cooking and heating, with very little energy and financial resources to cope with heat stress, floods, and droughts. And nearly one billion lack access to electricity. Universal access to affordable clean energy sources must become one of the major milestones for achieving climate resilience.
11. Progress on adaptation is uneven and there are increasing gaps between action taken and what is needed to deal with the increasing risks. Adaptation is intrinsically a national or local issue and therefore requires national or locally-led processes and interventions to improve resilience. Adaptation is cost-effective but vastly under-funded, which reduces implementation. Financial pledges to support developing countries in their efforts to achieve climate and sustainability ambitions, and the importance of economic indicators have always been at the center of international sustainability debates, but the world has made limited progress on these issues in the last decades.
12. Time is now short to scale up climate mitigation actions and prevent crossing the 2°C or warmer thresholds before 2050. Deep decarbonization by itself, while essential, is not sufficient to limit the warming below 2°C. Additional measures such as deep cuts in emissions of non-

CO_2 warming pollutants, extraction of CO_2 that is already up there in the atmosphere, and nature-based solutions must be integrated with deep decarbonization measures.

13. Yet, any approach to resilience building must recognize the fact that it could take three to five decades to bend the global warming curve below 1.5°C. We can no longer take comfort in just relying on climate mitigation. Adaptation to current weather extremes and related climate risk are upon us and should be considered as a central theme in climate policy actions. We need enhanced focus on adaptation challenges, which are confronting the entire world, but particularly the poorer segments of countries and societies.
14. We note that these multiple crises are a challenge for policy actions. Science can and must assist in identifying options for priorities, and actions that are evidence based. In doing so, science-based recommendations must pay close attention to implications for equity. This is a major new rationale for focusing science and policy on resilience.

RECOMMENDATIONS: THREE PILLARS OF THE RESILIENCE PATHWAYS

Photo: Fareed Khan, The Associated Press.

Efforts to build climate resilience must rest on **three pillars**:

Mitigation – Bending the warming curve: Reducing climate hazards through mitigation actions such as deep cuts in emissions is an imperative.

First, the wealthy one billion, who are contributing over 50% of the pollution, must reduce their own emissions and provide financial as well as technological assistance for the rest of the world to follow their example.

Adaptation – Addressing inequalities Governance & Access to finance: The second pillar of resilience requires society to start a major effort to help people, especially the poor and the middle class, to adapt to the impacts of climate change now. Special attention must be given for access to energy, water and food for the vulnerable populations, numbering over 3 billion.

Transformation – The Role of Science: The third pillar of resilience is transformation of society, and integrating actions on the climate crisis with actions on the biodiversity crisis. This includes economic systems and policies to be more informed by capturing, tracking and accounting for the values of nature in economic models and sustainable access to natural resources, minimize GHG emissions from all sectors. All this calls for a major engagement of science.

First Pillar: Mitigation – Bending the warming curve below 2C before 2050

1) *Bending the warming curve down: Bend and flatten the warming curve below 2°C before 2050 and bend it further below to 1.5°C before 2100, through deep cuts in emissions of CO_2 and other heat trapping pollutants; and extraction of at least a third of the 1.2 trillion tons of CO_2 from the atmosphere. The wealthy billion must drastically reduce their emissions and provide financial and technological assistance to the poor and vulnerable 4 billion people to enhance their adaptive capacity and to build their resilience.*

1.1) Short-lived climate pollutants (methane, HFCs, surface and lower atmosphere ozone & Black Carbon soot) – With available technologies and current air-pollution governance mechanisms, we can cut the emissions of these pollutants by 40% to 100% within 25 years and cut the rate of warming by about a third to half before 2050.

1.2) Deep Decarbonization – We must bring down the fossil fuel related emissions of CO_2 close to zero before 2050; This is the most important step for keeping the warming below 2°C for the rest of the century and beyond. Carbon mitigation actions that have co-benefits for biodiversity and inequality should be prioritized.

1.3) Atmospheric Carbon Extraction (ACE) – The blanket of carbon dioxide is already too heavy. It now weighs 1.1 trillion tons, and we are emitting about 40 billion tons every year. From now to 2050 we may have to extract as much as 300 billion tons of CO_2 from the air to thin the heat-trapping blanket sufficiently.

2) *Nature-Based Solutions: These include nature-based climate solutions for emission reductions that bring in oceans, mangroves, agroforestry, farmlands, forests and degraded landscapes. These solutions also provide adaptation benefits and offer powerful options for addressing biodiversity and inequality with huge co-benefits for health of people and ecosystem.*

2.1) Nature-based climate solutions, especially those delivered by people-centered approaches, can be more efficient in producing outcomes that are simultaneously relevant for climate, biodiversity and inequality crises. There is an opportunity to scale up people-centered approaches to reduce deforestation, protect biodiversity and reduce inequality in the Amazon, Africa and Asia. New and bold finance mechanism are needed, given the threats or a tipping point on Amazon ecosystem.

2.2) People-centered approaches, embedded with nature-based solution, should use a systemic approach and include goals to improve public health; food and nutrition security; water and energy security, among others. People-based solutions can reduce migration to urban areas which are overcrowded throughout the developing world, with high levels of extreme poverty and violence. Investment in rural resilience can have indirect effects for urban resilience.

2.3) Hybrid interaction of biological processes and technology should become a model for climate-resilient development for the built environment. Buildings adaptation to the ambient conditions resembles biological models, in which such factors as body temperature, humidity, gas and fluid exchange, shape and color modification, allow organisms to adjust to the environment without harmful effects nor resource over-consumption. Natural models enable active metabolism, including air and water quality improvement, pollutant filtration, energy and waste management, and circularity. At the building and city scales, this enables carbon sequestration, natural cooling, humidification, and air purification.

Second Pillar: Adaptation – Addressing Inequalities, Governance & Adapting Systems

Addressing Inequalities

3) *Inequality: Initiate a major effort to help the poor and vulnerable four billion, to adapt to climate risks now. Affordable access to clean energy, water, health care, sustainable farming; and resilient infrastructures must be part of the milestones. It is necessary to consider novel legal instruments to manage climate-forced displacements and survival migration for climate refugees.*

3.1) Social protection and inclusion: Incorporation of the needs and perspectives of the most marginalized users, including indigenous, women, youth, and pastoralists must be a core element of adaptation governance. Social protection and health insurance mechanisms must be expanded. On the social side, behavioral changes for reducing consumption (by the 50% of the population who contribute more than 2/3 of the emissions) and working for the common good are going to be essential attributes for climate risk reductions.

3.2) Eliminating Energy Poverty: The poorest three billion, who now rely on primitive energy technologies, should be given clean energy access that is also affordable. Specifically, eliminating Energy Poverty requires: Governments to develop structured programs when pursuing universal electricity access following the core principles set out in the Integrated Distribution Framework (IDF) adopted by the Global Commission to End Energy Poverty, including a focus on economic impact. In partnership with international experts and institutions, governments should use modern geospatially-referenced tools to plan resilient and affordable energy infrastructure to enable universal access and drive equitable economic growth. To enable this agenda, the international community must be far more generous in supporting access programs with greatly expanded concessional lending and grant-making to poor countries.

3.3) Considering the growing body of evidence on intensifying climate impacts, it is necessary to consider novel legal instruments to manage climate-linked forms of survival migration or to provide legal pathways to move elsewhere in anticipation of uninhabitability. We propose the introduction of a legal document, a Climate Refugee Passport, that would permit citizens of territories that are at high risk of becoming uninhabitable due to climate change impacts to live, work and eventually gain full political rights in other countries, including those that have substantially contributed to global emissions.

Governance

4) *Governance: Solutions should be locally and nationally determined actions. Coordinate the available resources at various levels of government with the local actions.*

4.1) Adaptation solutions should be regionally and locally-led processes and interventions to improve resilience. Implementation of adaptation solutions must have a governance structure that coordinates the available resources at various levels of government with the community level responses. In countries there is limited coordination and connectivity of local organization with central agencies that leads to sub-optimal use of the limited human capital to help network multiple initiatives.

4.2) Taking Africa as a major example for adaptation urgency, an integrated intervention in Africa's drylands should include the following actions and governance structure: Establish new business models for inclusive economies, particularly in growing urban centers to drive sustainable value chains. Create Green Enterprises (social enterprises) who become employers. Establish high-level political commitment to land restoration and tenure security for local benefits. Facilitate strong coordination of local initiatives, e.g., optimize the use of fertile lands such as around small freshwater bodies, wetlands, and riparian ecosystems along rivers that can sustain sustainable intensification production systems.

4.3 New financial mechanisms tied to local ownership and decision-making for indigenous and vulnerable populations. Funding local adaptation action through new mechanisms of direct access to resources by local communities. This allows local communities to build their capacity to develop adaptation programs and implementing adaptation actions.

Adapting Systems

5) *Food & Water Security*: *Worldwide scaling up of the following are required: sustainable land and soil management, forest protection and agroforestry, advanced plant breeding, social protection with nutrition components, water use efficiency in farming, and access to clean drinking water and sanitation. Water security, already threatened perceptibly by global warming and related weather extremes, needs to become a visible element of climate change negotiations. A concerted effort is required to reduce food waste and excessive meat consumption.*

Photo: Anne Wangalachi CIMMYT Tanzanian farmer with drought-affected maize (license free).

5.1) The world food system is in an acute crisis that is, to a significant extent, prompted by climate change and related indirect and ripple effects.[3] Numerous practices, technologies, knowledge, and social capital already exist for strengthening food systems resilience, such as sustainable land management, social protection, early warning mechanisms, traditional and local knowledge, agricultural services and extensions, diversification and insurance, and many others. These actions, applied selectively at local scales, need to be scaled up to new areas worldwide. Agro-biodiversity needs more protection as it is a basis for modern plant breeding which is essential for resilient food systems under climate stress. Considerations for food systems resilience should be made an integral and institutionalized part of global efforts to mitigate and adapt to climate change, land degradation neutrality and land restoration under the UN Convention to Combat Desertification, and global and national biodiversity frameworks under the UN Convention on Biological Diversity.

[3] Science and Innovations for a Sustainable Food System Preparing for the UN Food Systems Summit 2021 https://www.pas.va/en/events/2021/food_systems.html

5.2) Agroforestry for resilient and productive landscapes: with its multi-functional properties, agroforestry should be scaled up in rural and urban settings to provide a sound framework for optimizing synergies to reduce climate risks – adaptation and greenhouse gas emissions-mitigation and, at the same time, enhance biodiversity at the interface of agriculture and forestry. Agroforestry solutions should have a mix of the following: an integrated landscape approach with people at the center, co-producing context-specific knowledge, and management options with people at the center, enabling government policies, effective partnerships, direct funding support and long-term commitments. Expanding agroforestry and restoring degraded lands must be complemented with halting deforestation and maintaining forests.

6) *Construction and housing: Transform settlements into carbon banks by prioritizing organic building materials in support of sustainable bio-economy and circularity through multiple material reuse, including such homes which transform today's slum areas.*

6.1) Transforming the built environment is a crucial factor in the climate equation: Buildings and infrastructures are directly responsible for up to 40% of the global greenhouse gas emissions. Novel options for "building better" are becoming available now, such as timber-based high-rise construction, AI-assisted design, serial pre-fabrication of components, smart recycling technology, multi-functional land use, community-based urban development, and so on.

6.2) The resulting bioeconomy must capitalize on both advanced bio-sciences and neglected traditional and indigenous knowledge.

7) *Regional hotspots: Special attention must be given to regional hotpots for climate stress: Amazon, Small Island Nations, Drylands of Africa, Southern and Eastern Africa, Mediterranean, Middle East, South Asia, NE China and South-West USA.*

Third Pillar: Transformation

Transformation: *Change of lifestyle, transformation of society and ecosystems to mitigate, adapt and bounce back. This transformation is akin to an ecological conversion (Pope Francis' statement) and must integrate actions on the triplet of crises: climate, biodiversity, and inequality.*

8) Transformation of economic systems and societies by moving swiftly to renewable energy systems, applying incentives such as carbon pricing and regulations for reducing demand for emission-intensive goods, including

policies that account for the values of nature and take us on a path of stewardship and restoration of Nature. We must also recognize the obligations of wealthy societies providing technological and financial assistance to the less wealthy, and of all societies to pursue scientifically- and environmentally-informed economic development.

8.1) Transformation must be a central feature of resilience and entails the ability to initiate fundamental shifts in behavior and socioeconomic systems including governance, and consumption.

8.2) Integrated solutions and multi-stakeholder cooperation are required, to lead us toward global and local governance to be more responsive to sustainable development.

8.3) The current spending on harmful subsidies for fossil fuels or unsustainable agriculture should be redirected to support universal health coverage, public transport, affordable healthy food choices and other policies that improve health, reduce GHG emissions and promote equity. This reform could also be key for achieving public and political support for climate change action.

8.4) Transformative mitigation aims for energy consumption becoming decoupled from economic growth, by increasing energy efficiency, reducing energy waste, and reducing the carbon intensity of energy consumption.

8.5) The financial sector and governments need to do more on complementing their work with interventions that use indicators and investments in ways that build adaptive capacities. Financial pledges to support developing countries in their efforts to achieve climate and sustainability ambitions should be fulfilled as soon as possible to secure the resilience of vulnerable communities and nature.

8.6) Resilience-building must take center stage of climate summits and protect people and ecosystem from unavoidable climate extremes in the coming decades, fostering justice and the crucial good that is peace.

9) Behavioral change of people, communities, and business is needed to achieve the transformation. A major new global initiative is required for mass education of everyone, from children to senior citizens, in ecological citizenship (*Laudato Si'*, para 211) and on sustainable living. Public, civil society and faith-based communities of all world religions can productively engage in this moral task.

Role of Scientific Institutions, Scientists and Educators

10) All of the 9 recommendations above require a major engagement of science. Science must assist in prioritization of evidence-based actions without losing focus on equity issues. The analyses of solutions must include the modeling of two-way natural/social systems interactions to achieve a transformational improvement in the predictive power of climate trajectories.

10.1) Scientists must act as citizens and consider the question of the earthly future of humanity and of planet Earth and, as responsible persons, help to prepare for it, preserve it and eliminate the risks, in a resilient way, especially in the current situation of anthropic climate stress, wars, poverty, famine and threats of nuclear catastrophes. The climate policy agenda and choices raise large ethical issues. Addressing these would benefit from systematic interaction between science and faith.[4]

Photo: Matt Palmer (license free).

[4] *Faith and Science: Towards COP26* https://www.wiltonpark.org.uk/faith-and-science-towards-cop26/ https://www.pas.va/en/news/2021/2021_cop26.html

10.2) The science communities focused on mitigation, adaptation and resilience must move forward together, as the two can no longer be treated separately, if they ever could. Policy analyses on options addressing mitigation and adaptation need to be tackled in an integrated way, including in climate modelling and scenarios. The design focus and scientific analyses of solutions must consider the two-way coupling between natural systems and social systems. Current models of climate mitigation are too limited in their ability to treat such two-way couplings and feedbacks and, as a result, their predictive capability of future climate trajectories is potentially subject to large and unknown uncertainties.

10.3) Science based establishment of policy options: Unprecedented climate change impacts and associated uncertainties in combination with strong economic interests make independent and trustworthy science an essential requisite for achieving climate resilience. It is imperative that every effort to build resilience is rooted in appropriate science and data-driven decision making. The IPCC plays an appropriate role, as do academies of sciences and universities.

10.4) The institutional and organizational set up of science and knowledge generation at national and global levels also require transformational thinking in the areas of interdisciplinary and transdisciplinary science to help guide the transformations needed. Serious considerations must be given for establishing national and regional Climate Adaptation Science Centers with partnerships with universities to integrate climate adaptation and resilience science into research and education for preparing future generations of sustainability champions and leaders in resilience science and actions.

Background Data

1. Climate/Weather (CW) Statistics

CW-1: 1995-2015: Weather-related disasters claimed 606,000 lives and affected 4.1 billion people with injuries, homelessness and emergencies. Deaths occurred primarily in low-income countries. The number of disasters peaked in China, India and USA; recorded losses totaled $1.9 trillion.

The United Nations Office for Disaster Risk Reduction (UNISDR), 2016. *The Human Cost of Weather-Related Disasters 1995-2015.* https://www.unisdr.org/files/46796_cop21weatherdisastersreport2015.pdf

CW-2: 1970-2019: Weather/climate/water-related disasters led to 2.06 million deaths and economic losses of $3.64 trillion; numbers increased by a factor of five from 1970s to the current decade and the economic costs increased 7-fold from $175.4 billion during 1970-1979 to *$1.3 trillion during current decade.*

World Meteorological Organization (WM) Report, 2021. *WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970-2019)*, WMO-No. 1267. https://library.wmo.int/index.php?lvl=notice_display&id=21930#.Yq9RTC-B2kE

CW-3: 1979 to 2019: Concurrent heatwaves across the Northern Hemisphere mid & high latitudes witnessed about sixfold frequency increase.

Rogers et al., 2022, Sixfold Increase in Historical Northern Hemisphere Concurrent Large Heatwaves Driven by Warming and Changing Atmospheric Circulations. *J Climate*, Feb 2022; American Met. Society. https://doi.org/10.1175/JCLI-D-21-0200.1

CW-4: 1850/1900 to 2020: Hot temperature extremes frequency increased 180% (10-year event) to 380% (50-year event); Heavy precipitation frequency increased 30% (10-year event); Agriculture and ecological droughts in drying regions increased 70%.

Intergovernmental Panel on Climate Change (IPCC-WGI), Report, 2022. *Climate Change 2021: Physical Science Basis.* https://www.ipcc.ch/report/ar6/wg1/

CW-5: 1850/1900 to 2020: The planet warmed by 1.2°C.

World Meteorological Organization (WMO): *WMO State of the Climate 2020.* https://library.wmo.int/doc_num.php?explnum_id=10618

CW-6: 1850.1900 to 2021: The planet warmed by 1.1°C. *WMO State of the Climate 2021.* https://public.wmo.int/en/media/press-release/four-key-climate-change-indicators-break-records-2021

2. Inequality (IE) Statistics

IE-1: Current Period: The poorest 40% of the population, about 3 billion, live on less than $10/day. The middle 45% or about 4 billion, earn between $10/day to $30/day. The combined wealth of the poorest 3 billion is about 2%; and that of the top one billion is 76%. Out of the total global inequality, between countries is 2/3 and 1/3 is within country.

Chancel, L, T Piketty, E Saez, G Zucman (2022). *World Inequality Report 2022*. https://wir2022.wid.world

IE-2: Current Period: 50% of the world population are subject to severe water shortages and 3.3 billion people live in countries with high climate vulnerability.

Intergovernmental Panel on Climate Change (IPCC), 2022. *Climate Change 2022: Impacts, Adaptation and Vulnerability.* Publishers: WMO and UNEP: https://www.ipcc.ch/working-group/wg2/

IE-3: Current Period: Of the total GHGs emissions, top 10% produce close to 50% of emissions while the bottom 50% of population (3.8 billion) produce only 12%. The poorest 50% of population in wealthy countries is already at 2030 emission targets. Reference is same as in IE-1.

IE-4: Current Period: An increase of one percentage point in climate vulnerability leads to an increase of 1.5 percent in income inequality. While climate vulnerability has no effect on the distribution of income in advanced economies, the coefficient on climate vulnerability is seven times greater and statistically highly significant in developing countries, which tend to have weaker capacity to adapt to and mitigate the consequences of climate change. Serhan Cevik and João Tovar Jalles, 2022: *For Whom the Bell Tolls: Climate Change and Income Inequality*. International Monetary Fund; WP/22/103.

IE-5: Current Period: Per capita gross domestic product (GDP) has been reduced 17-31% at the poorest four deciles of the country-level per capita GDP distribution, yielding a ratio between the top and bottom deciles that is 25% larger than in a world without global warming. In addition to not sharing equally in the direct benefits of fossil fuel use, many poor countries have been significantly harmed by the warming arising from wealthy countries' energy consumption. Noah S. Diffenbaugh & Marshall Burke, 2019. Global warming has increased global economic inequality. PNAS 116 (20) 9808-9813. https://doi.org/10.1073/pnas.1816020116

3. Resilience (RE) Statistics

RE-1: Current Period: Climate change is the single biggest health threat to people. Global heating of even 1.5°C is not considered safe.

RE-1.1 WHO-2021: COP-26 *Special report on climate change and health*. Published by WHO.

RE-1.2 PAS-PASS-2017: *Health of People, Health of Planet, Our Responsibility*. Proceedings of workshop. Editors: V. Ramanathan, P. Dasgupta and M. Sánchez Sorondo.

RE-2: Health shocks and stresses already currently push around 100 million people into poverty every year, with the impacts of climate change worsening this trend.

RE-2.1 Same reference as in RE-1.1.

RE-3: 2010-Now: 15-fold more people died from floods, droughts and storms in very vulnerable regions, including parts of Africa, South Asia and Central and South America, than in other parts of the world. Climate change is exacerbating mental health issues, including stress and trauma related to extreme weather events and the loss of livelihoods and cultures. Healthy diets are unaffordable to about 3 billion people.

RE-3.1 IAP-2022: *Health in the climate emergency: a global perspective*. Inter Academy Partnership (IAP).

RE-4: 2012: Air pollution from fossil fuels kill 10.5 million people per year.

RE-4.1 K. Vohra, *et al.*, Global mortality from outdoor fine particle pollution generated by fossil fuel combustion, 2021. *Environ. Res.*

RE-5: 1961-2020: Climate change decreased global agriculture productivity by 21%. Air pollution has even larger impacts; in India, air pollution decreased wheat yield by a third.

RE-5.1. Ortiz-Bobea Ariel et al., 2021. Anthropogenic climate change has slowed global agricultural productivity growth. *Nature Climate Change*, 11, 306-312.

RE-5.2. Burney, J., and V. Ramanathan (2014) Recent climate and air pollution impacts on Indian agriculture, *Proc. Natl. Acad. Sci.*

RE-6: Current: Hundreds of millions of the world's poorest people directly depend on smallholder farming systems. These people now face a changing climate and associated societal responses. 84% of the world's more than 570 million farms are small and family-run (less than 2 ha). They operate about 12% of the world's agricultural land. Smallholders present a greenhouse gas (GHG) mitigation paradox. They emit a small amount of CO_2 per capita and are poor, but they produce GHG intensive food and emit disproportionate quantities of black carbon through traditional biomass energy.

RE-6.1: Sarah K. Lowder et al., 2017: The Number, Size, and Distribution of Farms, Smallholder Farms, and Family Farms Worldwide. *Annu. Rev. Environ. Resour.* 2017. 42:347-75 https://doi.org/10.1146/annurev-environ102016-060946.

RE-6.2: Avery S. Cohn et al., 2017. Smallholder Agriculture and Climate Change. *Annu. Rev. Environ. Resour.* 42:347-75 https://doi.org/10.1146/annurev-environ102016-060946

RE-7: Now until 2100: Future projections by the Agricultural Model Intercomparison and Improvement Project (AgMIP) (RE7.1) suggest that end-of-century maize productivity losses can be as low as -23% under high vulnerability-high warming scenario (RE7.2). Under the same scenario, about one third of the currently suitable area for major crops and livestock production would become unsuitable by the end of the century (RE7.3).

RE-7.1: Rosenzweig, C., F., Tubiello, D., Sandalow, Benoit, P., Hayek, M., 2021. Finding and Fixing Food System Emissions: The Double Helix of Science and Policy. *Environ. Res. Lett.*

RE-7.2; Jägermeyr, J., et al., 2021. Climate impacts on global agriculture emerge earlier in new generation of climate and crop models. *Nat. Food* 2, 873-885. https://doi.org/10.1038/s43016-021-00400-y

RE-7.3: Kummu, M., Heino, M., Taka, M., Varis, O., Viviroli, D., 2021. Climate change risks pushing one-third of global food production outside the safe climatic space. *One Earth* 4, 720-729. https://doi.org/https://doi.org/10.1016/j.oneear.2021.04.017

RE-8: Current: Globally, agriculture accounts for 72 percent of all surface and groundwater withdrawals, mainly for irrigation. Rainfed farming produces 60 percent of the world's food on 80 percent of the cultivated land. Irrigated farming produces 40 percent on 20 percent of the land. Agriculture is a significant contributor to water stress in countries with high levels of water stress. Rainfed and irrigated agriculture are operating at the limit of sustainability. 98 percent of global calorie production is derived from land and there is little room for expansion. Complex feedback loops between climate and land present agriculture with amplified levels of risk. Of the 2.2 billion ha of degraded land identified as potentially (biophysically) available for restoration worldwide, 1.5 billion ha may be best suited for mosaic restoration combining forests and trees with agriculture. A further 1 billion ha of croplands on previous forestlands affected by land-use change would benefit from strategic additions of trees to increase agricultural productivity and the provision of ecosystem services. Agroforestry systems tend to be more resilient than conventional agriculture to environmental shocks and the effects of climate change. Depending on the system and local conditions, agroforestry can achieve 50-80 percent of the biodiversity of natural forests; increase food security and nutrition by serving as a safety net; and increase crop productivity.

RE-8.1: FAO-2022. The State of the World's Land and Water Resources for Food and Agriculture: Systems at Breaking Point, *FAO Synthesis Report 2021.* https://www.fao.org/land-water/solaw2021/en/

RE-9: Water security is threatened by the intensification of the hydrological cycle caused by global warming and related weather extremes. Currently, roughly half of worlds ~8 billion people are estimated to experience severe water scarcity for at least some part of the year due to climatic and non-climatic factors (medium confidence). Since the 1970s, 44% of all disaster events have been flood-related. Not surprisingly, a large share of adaptation interventions (~60%) are forged in response to water-related hazards. In 2017, approximately 2.2 billion people lacked access to safe drinking water, and roughly 4.2 billion people could not access safe sanitation. At a global warming of about 2°C, between 0.9 and 3.9 billion people are projected to be at increased exposure to water stress, depending on regional patterns of climate change and the socio-economic scenarios considered.

RE-9.1: Caretta, M.J, A. Mukherji et al., 2022: Water. Chapter 4 of *Climate Change 2022: Impacts, Adaptation and Vulnerability.* Working Group II, Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 551-712, doi:10.1017/9781009325844.006.

RE-10: 2000 to Now: Pronounced loss of Amazon Forest Resilience since the early 2000s, may be approaching tipping point.

RE-10.1: Boulton, C.A, Lenton, T.M, Niklas Boers; 2022: Pronounced loss of Amazon rainforest resilience since the early 2000s. *Nature Climate Change*, 12.

RE-11: Current and Future: Mass coral bleaching is underway. 99% of coral reefs are projected to be lost when warming exceeds 2°C.

RE-11.1: IPCC, 2018: Summary for Policymakers. In: *Global warming of 1.5°C.* https://www.ipcc.ch/sr15/chapter/spm/

RE-12: Current: Amundsen Sea embayment of West Antarctica might have passed a tipping point; When this sector collapses, it could destabilize the West Antarctic ice sheet. Part of the East Antarctic ice sheet – the Wilkes Basin – and the Greenland ice sheet which is melting at an accelerated rate might be similarly unstable. Sea ice is shrinking rapidly in the Arctic and at 2°C warming, the region has a 10-35% chance of becoming largely ice-free in summer.

RE12.1: IPCC-2019. *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.* https://www.ipcc.ch/srocc/; RE12.2: Lenton, T., et al., 2019. Climate tipping points – too risky to bet against. *Nature*, 575.

4. Biodiversity (BD) Statistics

BD-1: Current: Biodiversity is the rich variety of living things that, woven together, support and sustain life on Earth. The continued health of all life on the planet, including human life, depends on making choices that will protect biodiversity.

BD-1.1: National Academy of Sciences Report, 2022. *Biodiversity at Risk.* NAS Press. https://www.nationalacademies.org/news/2022/01/biodiversity-at-risk-new-booklet

BD-2: Current: The loss of species is 10 to 100 times faster than in pre-human times. At least 1 million species are currently threatened with extinction.

BD-2.1: Same as BD-1.1

BD-3: Coming Decades: Climate change is projected to be the biggest single threat to biodiversity in the coming years.

BD-3: Same as BD-1.1

BD-4: Current: Nature and its vital contributions to people, which together embody biodiversity and ecosystem functions and services, are deteriorating worldwide. Biodiversity – the diversity within species, between species and of ecosystems – is declining faster than at any time in human history.

BD-4.1: IPBES, 2019: *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.* E.S. Brondizio, J. Settele, S. Díaz, and H.T. Ngo (editors). IPBES Secretariat, Bonn, Germany. 1148 pages. https://doi.org/10.5281/zenodo.3831673

BD-5: Current: More than 75% of global food crop types, including fruits and vegetables and some of the most important cash crops, such as coffee, cocoa and almonds, rely on animal pollination.

BD-5.1: Same as BD-4.1.

BD-6: Current: 75% of the land surface is significantly altered, 66% of the ocean area is experiencing increasing cumulative impacts and over 85% of wetlands area has been lost. Across much of the highly biodiverse tropics, 32 million hectares of primary or recovering forest were lost between 2010 and 2015.

BD-6.1: Same as BD-4.1.

BD-7: The direct drivers of change in nature with the largest global impact have been (starting with those with most impact): changes in land and sea use; direct exploitation of organisms; climate change; pollution; and invasion of alien species. Climate change is a direct driver that is increasingly exacerbating the impact of other drivers on nature and human well-being. Increase in extreme weather and sea level rise have contributed to widespread impacts in many aspects of biodiversity, including species distribution, phenology, population dynamics, community structure and ecosystem function.

BD-7.1: Same as BD-4.1.

BD-8: Limiting global warming to ensure a habitable climate and protecting biodiversity are mutually supporting goals, and their achievement is essential for sustainably and equitably providing benefits to people. The adaptive capacity of most ecosystems and social-ecological systems will be exceeded by unabated anthropogenic climate change, and significant adaptive capacity will be required to cope with residual climate change even under ambitious emissions reduction. Tropical coral reefs, savannas, tropical forests, high latitude and altitude ecosystems and Mediterranean-climate ecosystems, and coastal ecosystems are already highly impacted, and require robust intervention.

BD-8.1: *IPBES-IPCC Workshop Report*, 2021. IPBES-IPCC Co-Sponsored Workshop Report on Biodiversity and Climate Change. https://ipbes.net/events/ipbes-ipcc-co-sponsored-workshop-report-biodiversity-and-climate-change

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Program

DAY 1

WEDNESDAY 13 JULY 2022

Opening Session

8:30 *Opening Remarks*
President Joachim von Braun
& Chancellor H.Em. Card. Peter K.A. Turkson

I. Setting the Scene

(Chair: Joachim von Braun)

8:45 *Climate Resilience: Why, When and How?*
Veerabhadran Ramanathan
(PAS; University of California, San Diego & Cornell University, USA) by Zoom

9:10 *The Limits to Regional & Global Resilience*
Hans Joachim Schellnhuber (PAS; PIK- Potsdam, Germany)

9:35 Open Discussion

10:00 Coffee Break

II. Global Context and Priorities for Resilience

(Chair: Chancellor, Cardinal Peter Turkson)

10:30 *Practical Options for Mitigation*
Susan Solomon (PAS; MIT, USA)

10:55 *Economic Options for Transformation & Resilience*
Stefano Zamagni (PASS; University of Bologna, Italy)

11:20 Harmony Between Economy, Environment & Society
Mohan Munasinghe (Munasinghe Institute for Development, Sri Lanka) by Zoom

11:45 *Resilience as Development of the Real Potential of Nature and Scientific Discovery*
H.E. Msgr. Marcelo Sánchez Sorondo (Vatican)

12:10 Open Discussion

12:50 Lunch

III. Cry of the Poor and the Youth

(Chair: Stefano Zamagni)

14:05 *Ethical Moral Dimensions of Resilience*
Joshtrom I. Kureethadam (Salesian Pontifical University, Rome, Italy)

14:30 *Youth Perspectives*
Gabriela May Lagunes (Graduate Student, Master of Information and Data Science, School of Information, University of California, Berkeley, USA) by Zoom

14:55 *Adaptation Science for Least Developed Countries*
Joyce Kimutai (IPCC & African climate Development Initiative, South Africa)

15:20 Open Discussion

15:50 Coffee Break

IV. Regional to Local Resilience Building

(Chair: Susan Solomon)

16:10 *Climate Change Adaptation Policies and Strategies in Africa*
Mohamed H.A. Hassan (PAS; Sudanese National Academy of Sciences, Sudan)

16:35 *Ecological Environment Management in China*
Weijian Zhou (Chinese Academy of Sciences, China) by Zoom

17:00 *Ending Energy Poverty*
Robert Stoner (MIT, USA)

17:25 *People-Based Solutions for Resilience to Climate Change in the Amazo*n
Virgilio M. Viana (PASS; Amazonas Sustainability Foundation, Brazil)

17:50 *Climate Action to Protect and Promote Health: Sharing Knowledge Among Regions for Adaptation Solutions*
Robin Fears (Inter Academy Partnership, UK)

18:15 Open Discussion

18:45 Dinner

DAY 2
THURSDAY 14 JULY 2022

V. Building Adaptive Capacity for Humanity

(Chair: Joyce Kimutai)

8:30 *Nature-Based Solutions for the Built Environment*
Barbara Widera (Wrocław University of Science and Technology, Poland)

8:55 *Resilient Food Systems*
Joachim von Braun (PAS; Bonn University, Germany)
and Alisher Mirzabaev (Bonn University, Germany)

9:20 *Resilient Water Access*
Aditi Mukherji (Intl Water Management Inst; India; IPCC AR6)

9:45 *Agroforestry for Resilience of People and Ecosystems*
Aster Gebrekirstos Afwork (World Agroforestry, Kenya)

10:10 Open Discussion

10:40 Coffee Break

VI. Building Institutions
(Chair: Jane Lubchenco)

11:10 *Adaptation in Drylands Africa*
Cheikh Mbow (Centre de Suivi Ecologique, Dakar, Senegal)

11:35 *Economic & Financial Institutions for a Just Future: Stockholm-50*
Victor Galaz (SRC, Stockholm University, Sweden)

12:00 *New Economic Lessons on Resilience Learned from COVID*
Clara Latini (Sustainable Development Solutions Network Youth, Paris, France)

12:25 *Climate Migration in Dignity*
Kira Vinke (GDAP, Germany) by Zoom

12:50 Open Discussion

13:10 Lunch

VII. Closing Session: Way Forward
(Chair: Veerabhadran Ramanathan)

14:30 *Triple Challenges of Bio-diversity, Climate and Inequality*
Jane Lubchenco (PAS; Oregon State University; and White House Office of Science and Technology Policy, USA) by Zoom

14:55 *Bringing it together on action agendas serving people and ecology. The science agenda for climate resilience; Key elements of a statement (with some focus on COP27 and beyond)*

15:45-15:55 **Closing Remarks**
Joachim von Braun (PAS President)