Ecologi

Climate Impact

Regionalisation Strategy

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1. Introduction

1.1 Context

Human activities are increasing the atmospheric concentration of greenhouse gases (GHGs), which alters the Earth's radiative balance, in turn increasing global temperatures. These anthropogenic GHG emissions, caused primarily by fossil-fuel burning and land-use / land-cover (LULC) change, come from different sources and locations, leading to a range of impacts such as regional and global changes in temperature, precipitation, water cycles, etc. Globally, GHG emissions continue to rise across all sectors and subsectors, and most rapidly in transport and industry.

In 2019, the energy sector accounted for 34% (20 $GtCO_2e$) of global GHG emissions, followed by industry with 24% (14 $GtCO_2e$), agriculture, forestry and other land use (AFOLU) with 22% (13 $GtCO_2e$), transport with 15% (8.7 $GtCO_2e$), and buildings with 5.6% (3.3 $GtCO_2e$). Historically, developed countries alone contributed to 57% of all cumulative net anthropogenic CO_2 emissions (Figure 1). Despite a peak in consumption-based emissions in 2007, per capita emissions in those countries remain the highest at 9.5 tCO_2e compared to 1.2 tCO_2e in Africa, 4.4 tCO_2e in Asia and developing Pacific, and 2.7 tCO_2e in Latin America and Caribbean (IPCC, 2022a). However, emissions from developing countries grow at a fast pace, mostly driven by population and economic growth, and increased consumption.

Climate change is a multidimensional phenomenon, which is increasingly affecting terrestrial, marine and freshwater ecosystems and their services, food and water security, infrastructure and settlements, and economies. The Intergovernmental Panel on Climate Change (IPCC) clearly shows that extreme weather events and compound hazards have increased in all world regions but some have been more affected than others due to the intensity and lengths of those events and/or their higher vulnerability. For example, droughts induced by the 2015-2016 El Niño phenomena, partially attributable to human influences, led to severe food insecurity in various regions, including in Eastern and Southern Africa as well as Central America (Ewbank et al., 2019).

Overall, 3.3 billion people are living in countries with high human vulnerability to climate change according to the IPCC Sixth Assessment Report (AR6), while 1.8 billion people reside in countries with low vulnerability (IPCC, 2022b). Despite their relatively small contribution to global climate change (Figure 1), the impacts of climate change disproportionately affect developing regions and countries. Due to various geographical and socio-economic factors such as poor access to healthcare, poverty, migration, conflicts, inequity, education, limited financial capabilities, weak institutions, lack of governance capacities and infrastructure, there is a call for a regional response to build climate change adaptation and mitigation strategies. A question of climate and environmental justice is now posed as to raising living standards for developing countries, in part to adapt and mitigate climate, at the expense of reducing global GHG emissions. Research has shown that providing modern energy services universally to support decent living standards and facilitate climate change adaptation and mitigation would only increase global GHG emissions by a few percent (Bruckner et al., 2022). Furthermore, lifting more than one billion people out of poverty would lead to only small relative increases in global carbon emissions of 1.6–2.1% or less (Bruckner et al., 2022). To ensure global progress on poverty alleviation without overshooting climate targets and meeting future energy demands, targeted climate solutions have to be implemented and high-emitting countries need to reduce their emissions substantially.

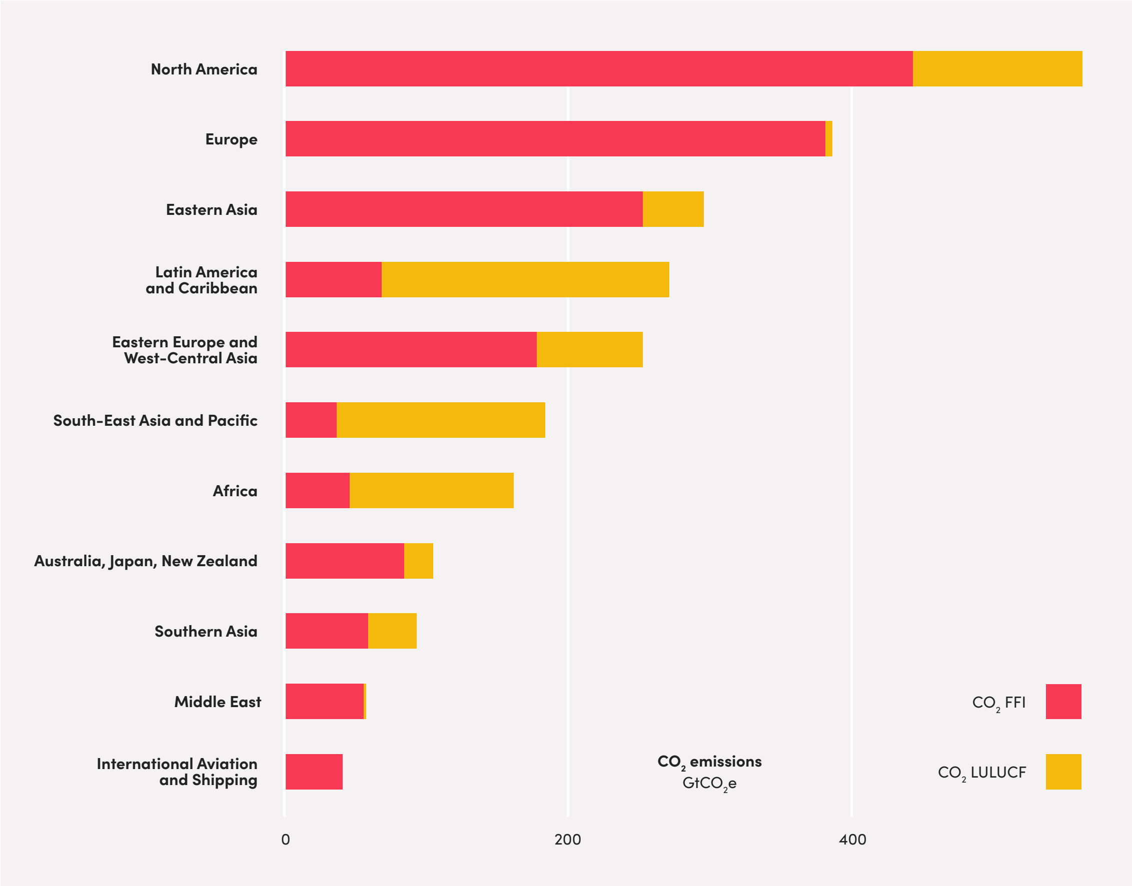


Figure 1. Historical cumulative net anthropogenic CO_2e emissions per region (1850-2019) (adapted from IPCCa, 2022). FFI stands for fossil-fuel industry. LULUCF stands for land use, land-use change and forestry.

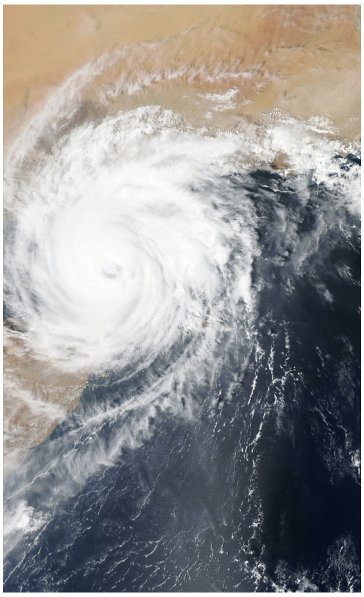
These strategies have to be feasible, integrated and tailored to specific locations, while avoiding conflicts with the UN Sustainable Development Goals (SGDs) and trade-offs with environmental preservation and conservation. Indeed, worldwide trends in biodiversity and ecosystem services continue to be negative with large regional disparities. For example, 75% of the land-based environment and about 66% of the marine environment have been significantly altered by human actions (IPBES, 2019). The Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) argues that the fraction of species at risk of climate-related extinction is 5% at 2°C warming and rises to 16% at 4.3°C warming, based on a synthesis of studies published as part of the Global assessment report. It also evaluates that current negative trends in biodiversity and ecosystems will undermine progress towards 80% (35 out of 44) of the assessed targets of the SDGs, related to poverty, hunger, health, water, cities, climate, oceans and land (SDGs 1, 2, 3, 6, 11, 13, 14 and 15). Loss of biodiversity is therefore shown to be not only an environmental issue, but also an economic, security, social and moral issue as well. On the other hand, nature can also be a large part of the solution to mitigate and attenuate the impacts of climate change. With estimates around 40% of potential climate change mitigation until 2030 to meet the goal of keeping climate warming below 2°C, nature-based solutions (or broader land-based climate change mitigation activities) are crucial to remove and reduce GHG emissions from fossil-fuel use and other industrial and agricultural activities, with likely co-benefits for biodiversity and humans (IPBES, 2019; Soto-Navarro et al., 2020).

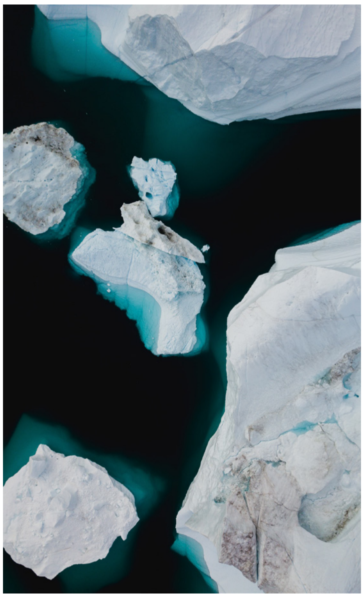
Mitigating the climate and broad environmental impacts of emitting sectors will depend on policies and projects that directly address GHG emissions and mitigation potential. In turn, the efficacy of these policies depend on local-specific factors, which can be either financial and political (e.g. funding, governance, institutions, etc.), or geographical (e.g. size, topography, climate, etc.).

1.2 Aims and objectives

Whilst climate mitigation and adaptation strategies have to be adopted globally, contextualisation is required to adapt to different geographical, socio-economic, governance and technological settings, and ensure that local needs are addressed in the best possible manner.

The aim of this document is to provide guidance for the regionalisation of climate impact solutions and projects. The study focuses on climate change mitigation to address one of Ecologi's core business activities, carbon offsetting. To gain insights into where climate solutions are most needed, this study first provides an overview of regional climate change impacts on human systems and settlements to better capture regional vulnerabilities, hence the need for targeted climate interventions. We analyse regionalities in light of past and current climate change finance to understand the investment finance gap and the current limitations to climate mitigation. The study will then describe the available climate mitigation strategies globally and by regions, and reflect on the synergies and trade-offs between climate solutions, the SDGs and biodiversity.





1.3 Methodological approach

Research on regional climate change, impact and mitigation covers a wide range of literature which is thoroughly reported in reports from the UN intergovernmental bodies IPCC and IPBES.

This study used the latest IPCC Assessment Report (AR6), including all working groups, and the IPBES Global Assessment Report as the grounding elements of this work. Given the breadth and depth of information needed by decision-makers, the peer-reviewed literature was analysed in detail for two specific purposes. First, assessments reports on climate change put emphasis on regional climate change impact and regional vulnerability but limited attention is given to regional mitigation strategies. To overcome this gap, we scanned the peer-reviewed literature for regionalised and localised information to complement global reports. Second, we acknowledge that research on climate change mitigation is increasing at a fast pace and the need to ensure that the latest scientific data is included in this work. We mainly focused on research since 2019, considered as a cutoff date since three key reports were published that year: IPCC *Special Report on Global Warming of 1.5°C* (SR15), the thematic assessment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) on *Land Degradation and Restoration*, and the IPBES *Global Assessment Report on Biodiversity and Ecosystem Services.* For consistency, we excluded research prior to 2006, the date of publication of 2006 IPCC Guidelines for National Greenhouse Gas Inventories on which the emissions data presented in this study are based.

2. Climate change impact and vulnerability

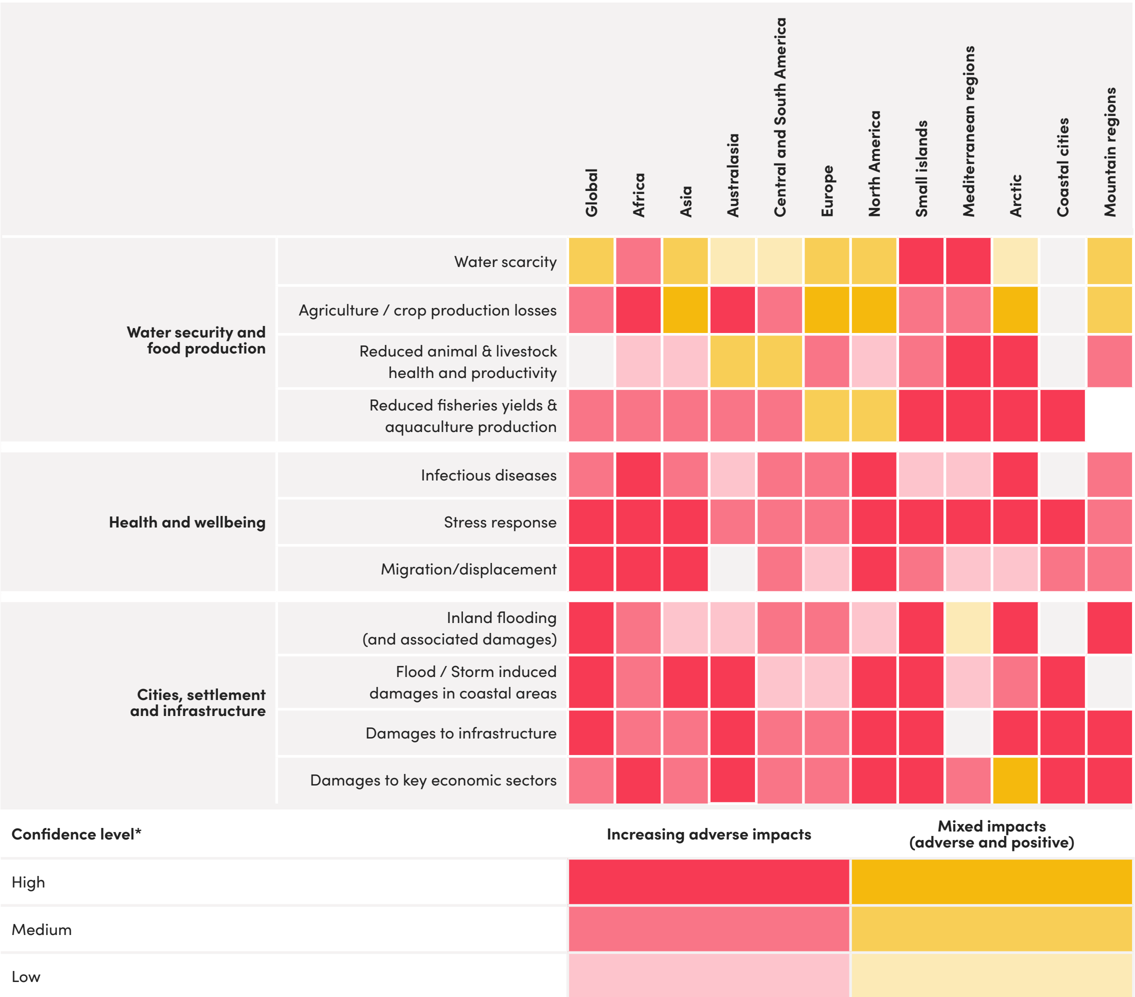
2.1 Global impact and disparities in regional vulnerability

Climate change is a long-term phenomenon whose effects will be most apparent in the second half of the twenty-first century. However, immediate action must be taken to address it. Global CO_2 emissions are currently averaging around 6 tonnes equivalent per year per capita, with wide disparities (Figure 1). Stabilising the climate at a temperature increase of no more than 2°C by 2050 requires a reduction in emissions to around 2 tonnes per year of CO_2 equivalent per capita. Anthropogenic systems should therefore be compatible with a low-CO_2 growth trajectory that will allow this reduction.

Importantly, not all individuals are affected in the same way: physical impacts will differ from region to region. These are mixed with economic impacts depending on the socio-economic vulnerability of individuals and countries. Generally speaking, developing countries are the most vulnerable to the impacts of climate change because of their exposure, sensitivity and lower adaptive capacity (Guivarch and Taconnet, 2020). The difference in vulnerability between rich and poor countries is decreasing but remains considerable: for the period 2007-2016, the mortality rate due to natural disasters was about 4 times higher in poor countries (Formetta and Feyen, 2019). Therefore strong links also exist between sustainable development, vulnerability and climate risks. Limited economic, social and institutional resources often result in low adaptive capacities and high vulnerability, especially in developing countries.

These asymmetric situations are visible in observed global and regional impacts on ecosystems and human systems attributed to climate change including extreme climate variability (Figure 2). For example, the Central and South American region is responsible for about 10% of global emissions and yet is extremely vulnerable to climate change impacts (Figure 1 and 2). Specifically, the agricultural and urban sectors will be among the most affected in the region. Overall, the impacts of climate-related extremes on food security, nutrition, and livelihoods are particularly high and severe for people living in sub-Saharan Africa, Asia, Small Island nations, Central and South America and the Arctic, and small-scale food producers globally. The impact of natural disasters in sub-Saharan Africa is very high due to the heavy dependence on agriculture. The intensification of natural disasters linked to climate change (droughts, floods, rising temperatures) can lead to gradual changes in crop types and a decrease in arable land (desertification, soil degradation), and a drop in yields, which varies from region to region. These developments place a multifaceted constraint on the entire agricultural sector and imply changes in land management and use in both developed and low-income countries.

Table 1. Observed global and regional impacts on ecosystems and human systems attributed to climate change including extreme climate variability (adapted from IPCC, 2022c). *Strength of the impact is defined as low (limited evidence), intermediate (increased diversity of evidence) or high (high evidence).



Most wealthy countries, which are also the least vulnerable to climate change, and a growing list of developing countries, intend to achieve net-zero GHG (or net-zero CO_2e) emissions by mid-century. National economy-wide GHG emissions targets covered 90% of global emissions in 2020 but only 6% of global emissions are covered by targets with an "acceptable" net-zero path according to the Climate Action Tracker (2021). Direct and indirect climate legislation has also steadily increased and this is supported by a growing list of financial investors. Indeed, under the Paris Agreement, each country must establish its contribution to emissions reductions through Nationally Determined Contributions (NDCs). In addition to reducing global emissions, the NDCs would have a collateral effect of contributing to a reduction in per capita emissions inequalities between countries by 2030, with a reduction for the main OECD countries and an increase for emerging and developing countries (Benveniste et al., 2018). However, the resulting emissions in 2030 set by the NDCs are too high to be compatible with the objective of limiting the increase in global average temperature to well below +2°C compared to the pre-industrial era. Currently, they are in the upper range of +2°C. This means that future generations will have to bear the cost of very rapid emission reductions after 2030 and greater impacts of climate change.

Many developing countries have conditioned their actions on receiving international assistance, particularly from developed countries, with respect to finance, technology development and transfer, and capacity building. The challenge is to find a balance to avoid international cooperation which can impede mitigation efforts, especially because of trade and investment agreements, as well as agreements within the energy sector.

2.2 Climate mitigation finance and needs

Climate finance encompasses all financial flows that enable the implementation of actions with a positive impact on mitigation or adaptation to climate change. Depending on the organisations and definitions, distinctions may exist according to the level of impact and whether it is a co-benefit or a main objective of the action financed.

Achieving the 2°C target requires the mobilisation of significant amounts: several trillion dollars per year by 2030 for all sectors. This mobilisation concerns both the production and use of energy. It is important to emphasise that a scenario based on the continuity of current needs requires investments of the same order of magnitude, whatever the level of climate constraint, i.e. an additional step to be taken. Indeed, the difference between a trend scenario and a low-carbon scenario mainly concerns the distribution of investments. In the latter case, more investments are needed in low-carbon solutions and energy efficiency, but less investments are required in fossil fuel production, for example.

Despite the COVID-19 pandemic, average annual renewable energy investments continued to increase from 2019 to 2020, making up the bulk of climate mitigation investments globally (58%) and around half of global climate investments (Table 2). In 2020, 260 GW of renewables were added globally, with solar PV and onshore wind representing more than 80% of renewable energy investments. It is important to take those numbers with caution, as renewable energy capacity is often added to the existing energy system, and does not always displace fossil-fuel energy. It is interesting to note that the private sector provided a little over ⅔of the investments in renewable energy, but 54% in all mitigation sectors. This is due to the commercial viability and higher competitiveness of some renewable energy technologies, which makes them particularly attractive for private investors, irrespective of public support (Climate Policy Initiative, 2021). Transport is the second most supported, and the fastest growing sector (Table 2). Looking into more details, private road transport (particularly battery electric vehicles and electric vehicle chargers) took the lion's share of low-carbon transport investments while investment levels in the low-carbon rail & public transport sub-sector remains highly insufficient (Climate Policy Initiative, 2021).

A key takeaway from the breakdown of global climate finance by use and sector was the lack of investments in the industry and AFOLU sectors with respectively 7 and 8 billions USD between 2019 and 2020 (Table 2). In many low-carbon scenarios, emissions cuts in the industry sector rely on the emergence and mainstreaming of carbon capture technologies (CCS or CCUS) which are expensive and as yet in a development phase, needing a high level of investment. Despite the latest IPCC report (IPCC, 2022a) arguing for greater intervention in the AFOLU sector, mitigation finance in the AFOLU sector remains very low. Investing in low-carbon solutions for the agricultural sector and the increased use of carbon offsets such as natural carbon sinks have a much greater role to play than what current finance levels suggest.

Climate change being a global, transborder phenomenon, international cooperation is required to address global adaptation and mitigation. At COP15 in Copenhagen in 2009, industrialised countries set a target of mobilising USD 100 billion per year by 2020 to support climate change mitigation and adaptation activities in developing countries. At COP21, they confirmed this commitment until 2025. However, in 2019/2020, 3/4 of tracked climate investments (USD 479 billion) were domestic, highlighting the continuing need to strengthen national policies and domestic regulatory frameworks to ensure the additionality and permanence of these investments. The remaining USD 153 billion flowed internationally to fund projects across borders. The highest share of international finance was observed in the developing regions of Sub-Saharan Africa and South Asia on projects having cross-sectoral impacts, as well as focusing on energy systems, AFOLU and fisheries. These regions are also the ones with the lowest level of climate investments and relying mostly on public finance. In general, non-OECD countries were principally funding their own climate needs, On the contrary, Western Europe, the United States & Canada, and "other Oceania" were primarily funded by private finance and were the largest contributors to international climate finance flows.

Table 2. Breakdown of global climate finance by use and sector in billion US dollars (adapted from Climate Policy Initiative, 2021).

Use/Sector	2019 (USD billions)	2020 (USD billions)	2019/2020 Average (USD billions)
Adaptation	42	49	46
Agriculture, Forestry, Other land uses and Fisheries	5	4	4
Buildings & Infrastructure	1	1	1
Energy Systems	1	0.2	0.6
Industry	0.03	0.01	0.02
Information and Communications Technology	0.25	0.24	0.24
Others & Cross-sectoral	19	25	22
Transport	2	1	1
Waste	0.01	0.02	0.01
Water & Wastewater	15	19	17
Mitigation	566	576	571
Agriculture, Forestry, Other land uses and Fisheries	7	9	8
Buildings & Infrastructure	35	22	28
Energy Systems	321	342	332
Industry	9	5	7
Information and Communications Technology	0.1	0.1	0.1
Others & Cross-sectoral	21	17	19
Transport	169	177	173
Waste	1	3	2
Water & Wastewater	2	1	1
Multiple objectives	15	15	15
Agriculture, Forestry, Other land uses and Fisheries	2	2	2
Energy Systems	2	1	2
Others & Cross-sectoral	9	10	9
Transport	1	0.1	0.4
Water & Wastewater	1	2	2
Total	**623**	**640**	**632**

Perhaps most importantly, climate finance flows are nowhere near estimated needs, conservatively around USD 4.5 – 5 trillion annually (Climate Policy Initiative, 2021), with growing needs from developing nations in Central Asia, the Middle East and North Africa, Sub-Saharan Africa, and to a minor extent Latin America (Table 3). These regions would need current investments to be multiplied by 10 to 20 times on average by 2030 (Table 3). To put this into perspective, fossil fuel investments currently exceed USD 850 billion annually (Climate Policy Initiative, 2021).

Besides policy integration and tailored, local governance for climate mitigation, there is a need to redirect existing financial flows from high- to low-emissions technologies and systems, as well as to provide additional resources to overcome current financial barriers, especially in developing countries. Cross-sectoral considerations are critical for effective mitigation actions, and aligning the different multilateral financing institutions framework and delivery mechanisms is necessary to address the inequities in access to finance. The current mismatch between capital availability in developed countries and the future emissions expected in developing countries could be tackled with increased global cross-border mitigation financing and new business models (e.g. pay as you go) with high support and transparency (IPPC, 2022a). As the extent of the task ahead requires full financial commitment from both the private and public sectors, greater public-private cooperation is needed to encourage the private sector to increase and broaden investments whilst implementing high safeguards and climate standards.

Table 3. Breakdown of global climate finance and need factor by regions in billion US dollars (adapted from Climate Policy Initiative, 2021).

Region	2019 (USD billions)	2020 (USD billions)	2019/2020 Average (USD billions)	Investment needs factor to 2030
Central Asia and Eastern Europe	35	29	32	12-25
East Asia and Pacific	278	305	292	2-4
Latin America & Caribbean	37	33	35	5-10
Middle East and North Africa	16	15	15	12-23
Other Oceania	10	8	0	
South Asia	30	30	0	7-16
Sub-Saharan Africa	19	19	19	7-16
Transregional	11	10	11	
US & Canada	88	79	84	2-4
Western Europe	100	110	105	2-3
Total (USD billions)	**623**	**640**	**632**	**4.3**

2.3 Climate mitigation solutions
costs and benefits

Although essential to reach climate targets, climate mitigation is often associated with high costs and long implementation time tremendously limiting a wide scale adoption, particularly in countries with limited financial and technical capacities. However, the latest IPCC report provided an extensive list of cost-effective and immediately actionable solutions. A quarter of global GHG emissions (based on a 2019 baseline) could be reduced by options with mitigation costs lower than USD 20 tCO_2, available for all sectors.

The cheapest mitigation solutions with the highest climate implications are found in the energy, AFOLU and (to a minor extent) transport sectors. Indeed, the cost of certain solutions is less than zero, meaning that lifetime monetary revenues are higher than lifetime monetary costs (Figure 2). In the case of wind energy, negative cost indicates that the cost is lower than that of fossil-based electricity production, for example. We note that the integration of various renewable energy sources in the mix is expected to be relatively low until 2030. After that, the costs are expected to rise due to alterations and expansion of electricity grids and storage capacities. Besides GHG emissions reduction, the use of carbon dioxide removal (CDR) solutions is critical to achieve net-zero. CDR refers to "anthropogenic activities that remove CO_2 from the atmosphere and store it durably in geological, terrestrial, or ocean reservoirs, or in products" (IPPC, 2022a). The scale and timing of deployment depends on several factors: emission trajectories in each sector, maturity of technology, removal process, storage potential, storage medium, technical capacity, financial capacity, governance, etc. Typically, maturity ranges from lower maturity (e.g., ocean alkalinisation) to higher maturity (e.g., reforestation); removal and storage potential ranges from lower potential (<1 Gt CO_2e yr-1 such as blue carbon management) to higher potential (>3 Gt CO_2e yr-1 such as agroforestry); costs range from lower cost (e.g. USD 45-100/tCO_2e such as soil carbon sequestration) to higher cost (e.g., 100-300 USD/tCO_2e yr-1 such as for Direct Air Carbon Capture and Storage).

Overall, a mix of GHG emission reduction and removal solutions is required. To date, large contributions with costs less than USD 20 tCO_2e come from solar and wind energy, energy efficiency improvements, reduced conversion of natural ecosystems, as well as CH_4 emissions reductions. As shown in the next section, the mitigation potentials and associated costs of individual technologies vary between regions and contexts. We also note the relatively small contribution of high-cost (well over USD 50 tCO_2e) carbon capture and storage across sectors to the overall GHG emission reduction potential (Figure 2).

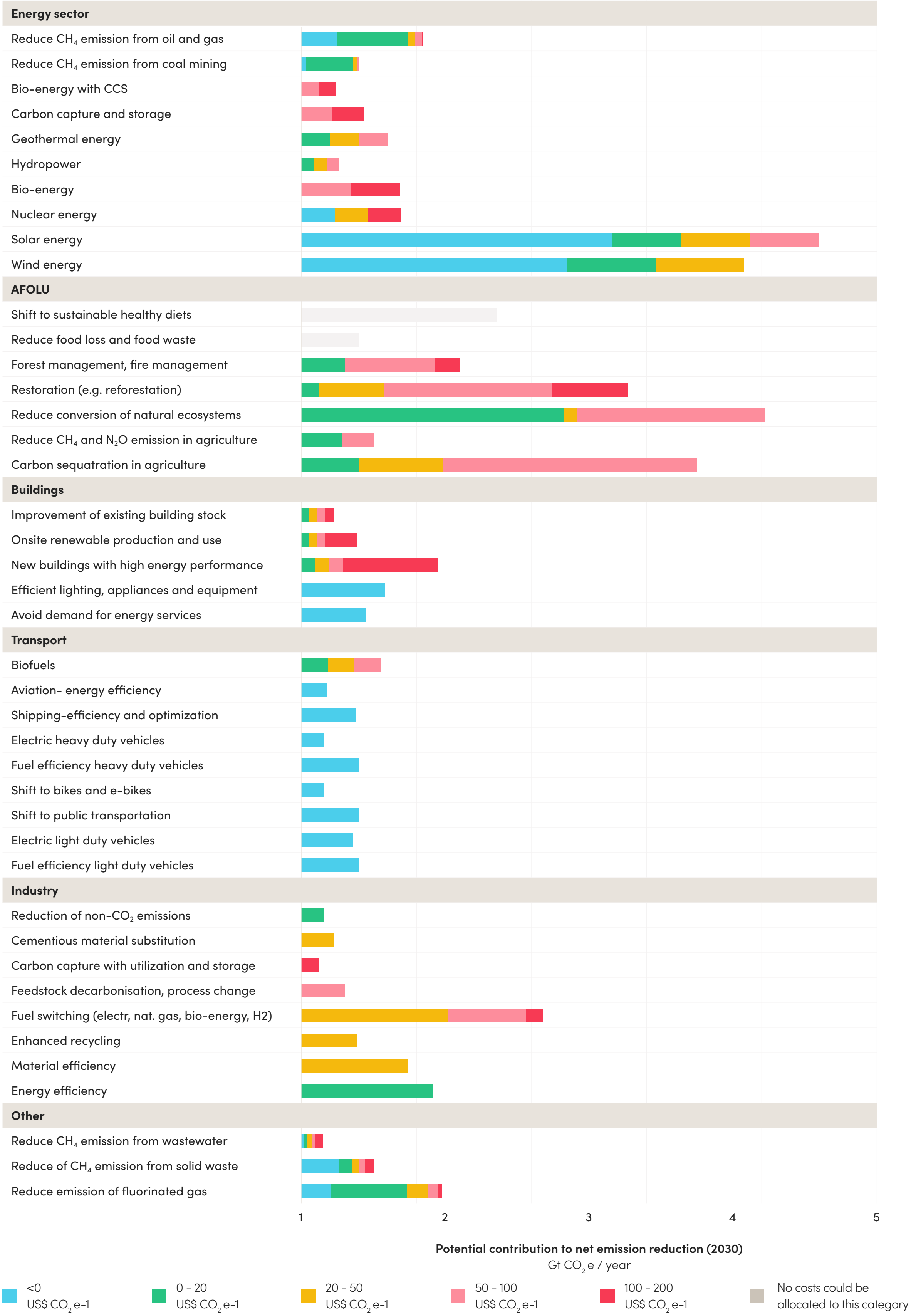


Figure 2. Emission mitigation options by sector including their costs and potential contribution to net emission reductions by 2030 (adapted from IPCC, 2022a). Note that mitigation options relate to specified emission baselines that reflect "current policies" in the period 2015-2019. Mitigation options may overlap or interact and cannot simply be summed together. If costs are less than zero, lifetime monetary revenues are higher than lifetime monetary costs.

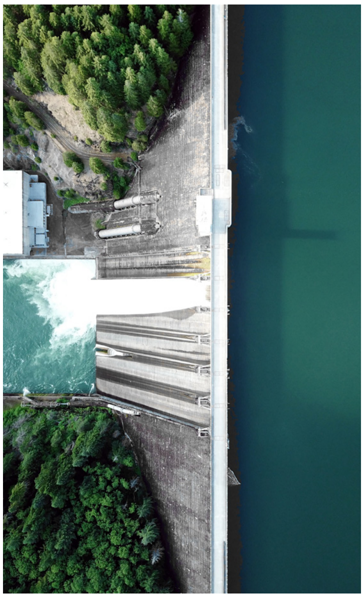
3. Regional mitigation strategies and financing

3.1 Mitigation strategies: disparities between regions

3.1.1 Renewable energy

To have a chance to reach climate targets, the electricity sector will have to go through extensive decarbonisation by 2050, exploiting the full potential of the range of options available to us. In 2019, worldwide electricity generation was more than 26,900 TWh, of which renewables accounted for 26.4% (mostly hydro, at around 17%), with fossil fuels at 63.2% and nuclear at 10.4%. Overall, solar PV and wind will need to lead the transformation as renewable energy will need to supply more than 40% and 60% of final energy consumption (65% and more than 90% of electricity) in 2030 and 2050, respectively, compared to a little over 15% today. To be on the 1.5°C pathway, the installed generation capacity of renewable power will need to expand to 10,770 GW in 2030 and close to 27,800 GW by 2050 globally, a four-fold and ten-fold increase by 2030 and 2050, respectively, over the 2020 level. A sharp decrease in fossil-fuel electricity generation is needed - coal-fired electricity generation needs to drop from 39% today to 11% in 2030 before being phased out in 2050. Natural gas needs to drop from 24% in 2019 to 16% in 2030 (IRENA, 2022).

Nevertheless the scale and extent of renewable energy deployment varies greatly between regions (Figure 3). The proposed mix solution is also to be considered. Elements such as the nature of the proposed solution (e.g. utility scale, distributed, off-grid), the level of development of the sector, the power system's organisational structure, and broader policy objectives are critical to ensure the deployment and scalability of the solution. Although wind and solar PV will dominate the growth of renewables in the global electricity sector, due to the availability of resources, cost-competitive markets, and the low cost of energy supply, it will do so particularly in developing regions such as Sub-saharan Africa and Latin America, which require primarily solar PV and onshore wind. These are also the two energy sources for which the increase needed compared to 2017 level is the highest, with multiplication by a factor of 16x (solar PV) and 12x (wind) in Sub-saharan Africa, and, respectively, 22x and 4x in Latin America. We note that besides solar PV, investments in "other renewables" (such as bioenergy, geothermal, solar thermal and ocean power) are needed in Southeast Asia, and in G20 countries along with offshore wind.



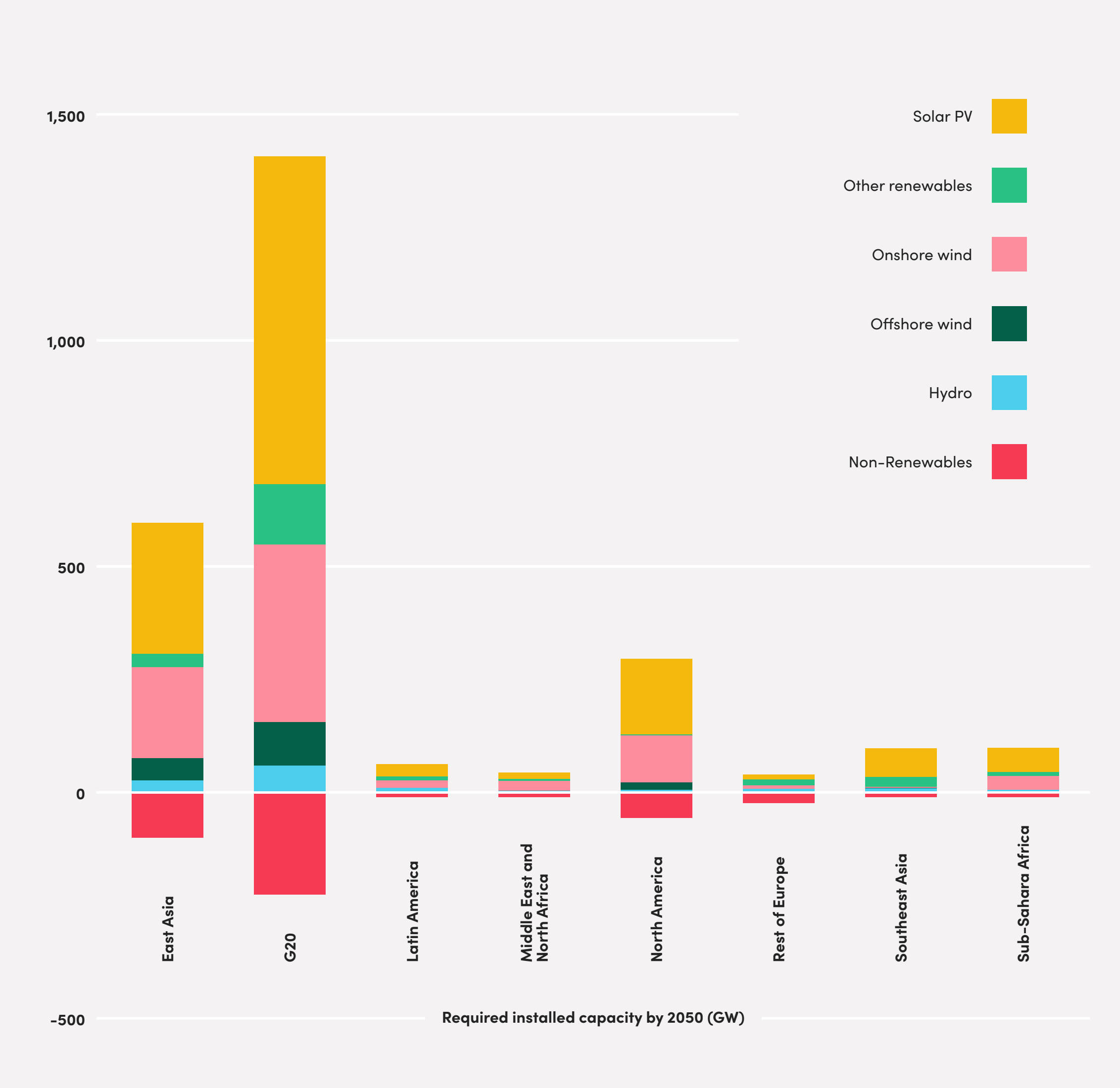


Figure 3. Renewable energy capacity to be installed by 2050 according to the Transforming Energy Scenario (adapted from IRENA, 2022).
The "Transforming Energy Scenario (TES)" describes an ambitious, yet realistic, energy transformation pathway based largely on renewable energy sources and steadily improved energy efficiency (though not limited exclusively to these technologies). This would set the energy system on the path needed to keep the rise in global temperatures to well below 2 degree Celsius (°C) and towards 1.5°C during this century.

Despite the fact that Asia, North America, and Europe will account for more than 80% of new capacity installation by 2030 and 2050, it is the Middle East and Africa that the increase factor in installed capacity is the greatest. For example, the Middle East and North Africa need to multiply their installed capacity of solar PV and onshore wind by 36 and 45 times, respectively (IRENA, 2022). In that respect, there is an opportunity for Europe and North Africa to work jointly to ramping-up solar PV electricity generation capacity and establish a mechanism of energy trading. Several challenges such as limitations in grid connection and flexibility, a lack of skilled workers, and unfavourable policy frameworks could be addressed by inter-regional cooperation. They could also be addressed by tailored, innovative market designs such as peer-to-peer electricity trading, community-ownership, or time-of-use tariffs (IRENA, 2022). We note the limited impact of other renewable energy sources such as bioenergy, geothermal, concentrated solar power (CSP), and ocean energy, except in specific regions like the Middle East and North Africa, North America, and Asia for CSP. In general these less-mature technologies need to be promoted in this decade to gather (and to understand) their full potential as well as lowering their cost. We also note that the little input from hydropower is dominated by increased capacity in China, India, and the Russian Federation, and to a limited extent North America.

Although the International Renewable Energy Agency (IRENA) decided to withdraw their support to nuclear energy in 2009, it is still a significant contributor to global electricity generation. At 10% globally, and 18% in advanced economies where it is the largest low-carbon source of electricity, the implications of nuclear fade-out could be extensive on supply security, global climate change mitigation (cumulative CO_2 emissions could rise by 4 billion tonnes by 2040), and energy transition costs. The International Energy Agency (IEA) estimates that without additional nuclear power, the clean energy transition becomes more difficult and more expensive – requiring USD 1.6 trillion of additional investment in advanced economies over the next twenty years. In addition to addressing some of the technical challenges linked to integrating renewables and lowering the cost of transforming the electricity system, nuclear power provides flexibility to electricity systems in conjunction with intermittent renewable energy sources (IEA, 2019). Although the largest share of efforts should be towards renewable energy sources, ruling out nuclear power should not be the priority in the short or medium term, and have the possibility to fall back on this technology should be left open in certain contexts (e.g. pre-installed capacity, know-how, regulatory framework in place, etc.).

1. Advanced economies consist of Australia, Canada, Chile, the 28 members of the European Union, Iceland, Israel, Japan, South Korea, Mexico, New Zealand, Norway, Switzerland, Turkey and the United States.

3.1.2 Nature-based solutions vs carbon capture and storage

The role of nature in climate change mitigation has long been recognised: around 30% of anthropogenic CO_2 emissions were estimated to be re-absorbed annually into the land surface (12.5 ± 3.3 $GtCO_2e$ year−1) between 2010 and 2019 through forest growth and regrowth. A further 25% is absorbed by the ocean. However, those natural sinks are not able to follow the increase in anthropogenic emissions. Implementing natural climate solutions makes sense to take advantage of the systemic links between the climate system, the land, the oceans and nature in general. Griscom et al. (2017) argued that natural climate solutions (NCS) can reduce and reverse AFOLU sector emissions, and provide about a third of the climate mitigation needed by 2030 and 20% by 2050 to meet the goals of the Paris Agreement - keeping warming below 2°C with a 67% probability. Here we refer to NCS and Nature-based solutions (NBS) interchangeably, although the latter is generally a broader term referring to climate adaptation, water and food security, etc. NCS are defined as "a suite of protection, restoration and improved land management pathways that generate climate change mitigation outcomes" (Griscom et al., 2020). Studies have found that holding warming below 2°C across all sectors and reaching the cost threshold below which the cost of climate change to society is greater than the cost of mitigation, a maximum marginal cost of less than USD 100 / tCO_2e is needed.

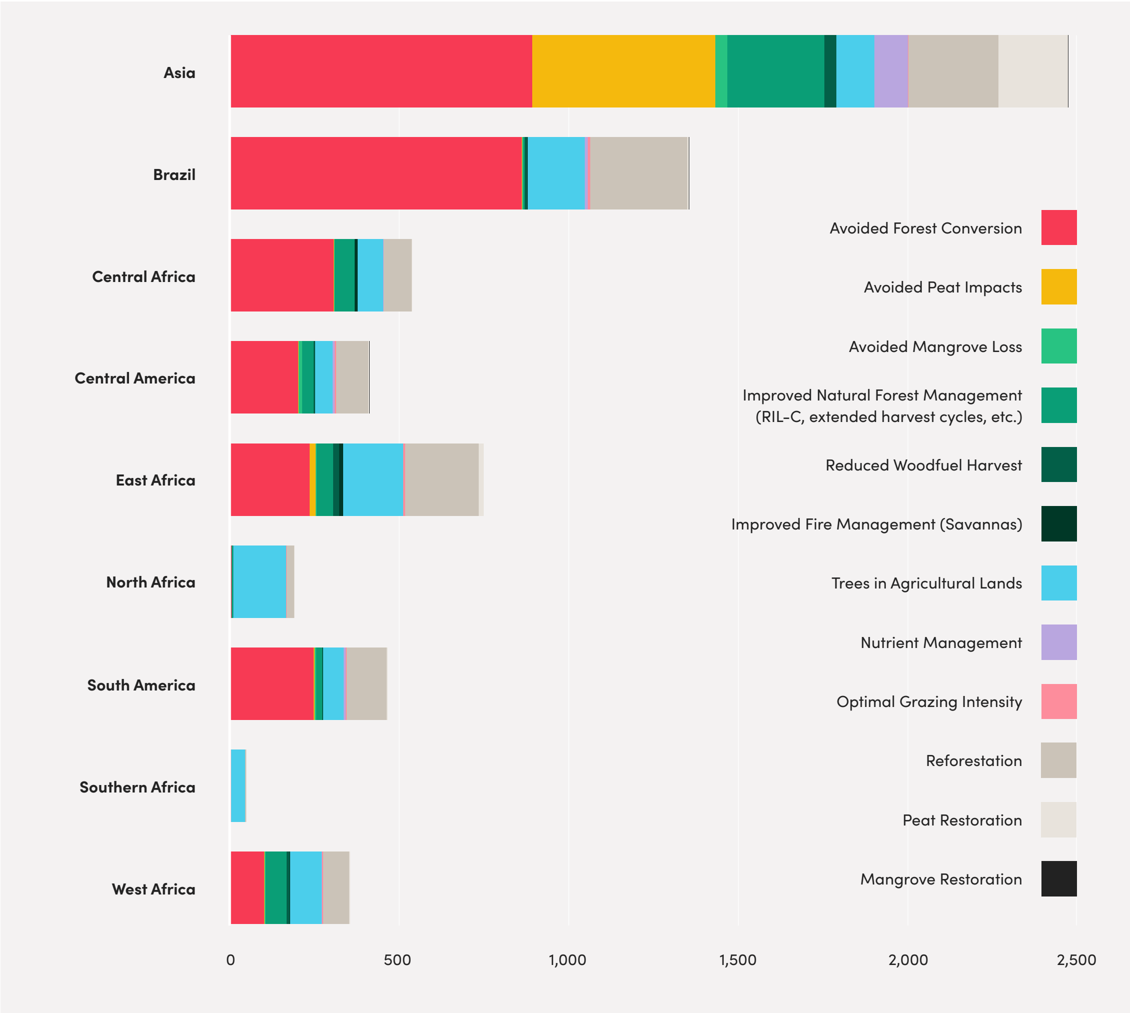


Figure 4. Mitigation potential of twelve cost-effective natural-climate solutions by regions (adapted from Griscom et al., 2020). Note that "Cost-effective" levels (<100 USD $MgCO_2e$). Units are mean annual million metric tonnes of CO_2 equivalents during the period 2030-2050 ($TgCO_2e$ yr-1)

The twelve NCS presented in Figure 4 represent the largest share of NCS potential (86%) and all have the capacity to provide ecosystem services and address some SDGs (Griscom et al., 2017). It focuses on tropical countries which have the highest global NCS potential (61%), the highest rates of forest cover change, and the highest gross carbon fluxes, compared with temperate and boreal latitudes (Feng et al., 2022: Li et al., 2022). We aggregated the results by regions to match the purpose of this study but left Brazil standing alone to show the high potential in this country alone. National figures used to construct Figure 4 are available if needed. Estimates of the mitigation potential for nature-based mitigation (equivalent to NCS) in other world regions are found in Table 4.

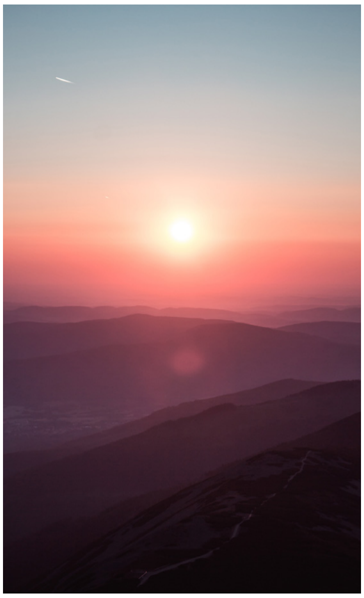
Overall, the twelve solutions could deliver 6.56 $GtCO_2e$ yr−1 across 79 tropical countries and territories between 2030 and 2050 at 'cost-effective' levels. A key finding is that more than half of this contribution comes from the protection of natural ecosystems such as the avoided conversion of non-wetland forests (43%) and avoided impacts to peatlands and mangroves (10%). One fifth of the contribution comes from the restoration of native forest and wetland cover (Figure 4). However, putting in perspective the large differences between the potential contribution of forest protection vs reforestation, and the land area needed for reforestation to generate the same climate mitigation outcome as avoided forest conversion, restoration activities need to be targeted to specific regions, for example with low opportunity cost and high conservation value from a biodiversity perspective (see section 3.2). We also note the little contribution of mangrove restoration globally, due to the scale of intervention (coastal mangrove ecosystems restoration can only be applied in a small proportion of the world), which in line with other work showing that mangrove regeneration may help restore carbon stocks back to pre-disturbed levels over decadal to century time scales only (Sasmito et al., 2019). However, mangrove restoration can play a disproportionate role in national climate mitigation in island nations and territories, as well as coastal regions.

Across most of Central and South America and Southeast Asia, forest and peat protection (especially for the latter in Indonesia and Papua New Guinea) is the most effective pathway, although the reforestation potential is not negligible. Restoration and improved management of agricultural lands are major opportunities in the north and south of the Congo Basin. Most countries where restoration (primarily reforestation) is the major NCS opportunity are situated in Africa (Figure 4 and Table 4), although the largest mitigation potential in absolute terms is in Central and South America. Even if not directly visible on Figure 4, it is important to note that over half of the NCS mitigation potential in the tropics stands in four countries - Indonesia, Brazil, Democratic Republic of the Congo and India. Interestingly, these countries (except DRC) have high governance indicators and strong to intermediate financial capacity to implement the solutions, providing a strong base for implementing nature-based mitigation at scale (Griscom et al., 2020).

It is very interesting to couple NCS with CH_4 mitigation strategies as both groups show little interaction, and their potential climate mitigation can be summed up, which is not the case with bioenergy with carbon capture and storage (BECCS) (Hayman et al., 2021). Afforestation, reforestation, reduced deforestation, and CH_4 mitigation can be co-beneficial mitigation approaches. BECCS could be realised through either minimising the loss of carbon from farm to final storage or maximising the productivity of the bioenergy crop. We can see its broader impact when setting the BECCS carbon sequestration at 3 to 5 times its original value (k=3 in Table 4) by considering additional bioenergy harvest and/or the reduced carbon losses from farm to storage, which leads to a notable increase of the global Anthropogenic Fossil Fuel Emission Budgets (AFFEB). Harper et al. (2018) argued that using BECCS "in regions where bioenergy crops replace ecosystems with high carbon contents could easily result in negative carbon balance". The contribution of BECCS to overall land-based mitigation, if optimised, could be the greatest in North America and Russia (and to a minor extent India) but would lead to a decrease in the carbon uptake from natural ecosystems due to the loss of forests to BECCS (Table 4). Interestingly, we note the relatively lower, positive, natural-based mitigation, with a high increase to overall contribution from BECCS in Brazil, the rest of South America, Mexico, East Africa, and Southern Africa (excluding South Africa). Here both bioenergy crops and forest expand at the expense of agricultural land. In West Africa, Central America and Indonesia, nature-based solutions are favourable across the board. Overall, avoided deforestation is preferable in boreal regions, while both afforestation/reforestation and avoided deforestation make sense in the tropics. Hayman et al. (2021) argues that "growing bioenergy crops for BECCS is only preferable where it replaces existing agricultural land" which occurs in regions highlighted in light green in Table 4. Finally, CH_4 mitigation makes the largest contribution in high emitting regions, especially when it targets emissions from fossil fuel production, distribution and use for energy in India, Southern Africa, the USA, China, and Australasia. We note that estimates provided in Table 4 do not account for fire regimes and the nitrogen cycle which could have an impact on emissions in significant areas of fire-dominated vegetation cover and agriculture emissions, respectively.

Other forms of carbon capture and storage have been at the centre of attention recently (IPCC, 2022a; Kim et al., 2020; Terlouw et al., 2022). The latest IPCC report estimates that the potential for mitigation coming from Direct Air Capture with Carbon Storage (DACCS) (5–40 $GtCO_2e$ yr-1) is limited mainly by requirements for low-carbon energy and by cost (Figure 2). It is also at a medium technology readiness level which makes it a complex, poorly scalable mitigation solution, except in specific contexts in developed countries.

Terlouw et al. (2021) conducted the life cycle assessment of DACCS with low-carbon energy sources of five different configurations with the specific supply of heat and electricity in eight countries. Although, one of the findings was that for all cases the climate change impact is smaller than the amount of CO_2 removed and stored - meaning that negative emissions were observed across the board - the best climate impact were achieved by system layouts using waste heat, and in countries with low CO_2 intensities in the national electricity grid (Norway, Iceland, Switzerland). These are also the countries and the solution with the lowest overall environmental burdens from DACCS compared to other configurations relying on a fossil-fuel oriented electricity mix. Besides the competition for clean electricity sources and the environmental burden, other limitations make DACCS' mitigation potential context-sensitive. These include: potential battery storage limitation in semi-arid and arid countries, the land-use impact of autonomous system designs with DAC units, and the provision of waste heat and the availability of geological storage capacity. To add up on the land-use challenges, the authors note that removing 1 $GtCO_2$ year−1 with an efficiency of 79% (representing worst-case Autonomous HTHP + PV for Mexico) will have a land footprint of 59'000 km2, which is about 1.5 times the surface area of Switzerland.



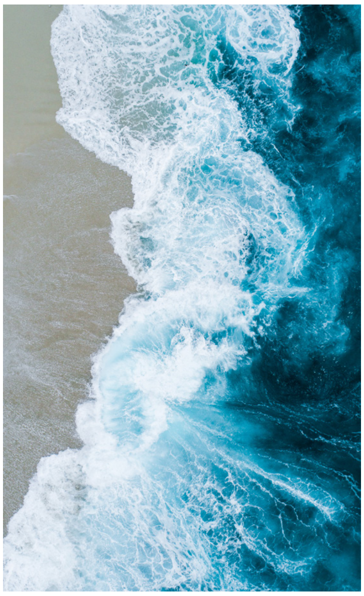


Table 4. Contribution of different mitigation options to the increase in allowable Anthropogenic Fossil Fuel Emission Budgets (AFFEB) to meet a 2°C of warming. (adapted from Hayman et al., 2021).

Methane-based mitigation corresponds to a series of measures such as a) maximising CH_4 recovery from underground mining of hard coal; (b) control of fugitive emissions from equipment and pipeline leaks and from venting during maintenance and repair; (c) change in animal diet and the use of more productive animal types; (d) capture and use of the CH_4 emissions in anaerobic digesters; (e) changes to the water management regime and to the soils to reduce methanogenesis; (f) reducing the amount of organic material deposited and by capture of any CH_4 released; and (g) using more wastewater treatment plants and also recovery of the CH_4 from such plants and through more aerobic wastewater treatment. Natural mitigation corresponds to afforestation/reforestation. BECCS mitigation to Biomass energy with carbon capture and storage. LULUC mitigation is the sum of natural-based and BECCS mitigation.

AFFEB 2015-2100 (GtC)	Canada	USA	Mexico	Central America	Brazil	Rest of South America	Western Africa	Eastern Africa	South Africa	Western Europe	Russia region	India	Southeastern Asia	Indonesia region	Rest of South Asia	Rest of Southern Africa
at BECCS k=1																
Methane-based	2.98	15.51	2.01	1.06	7.85	9.9	8.24	4.34	12.79	8.71	11.16	28.02	9.22	4.97	5.48	1.83
Natural	0.13	1.42	1.13	0.3	6.68	4.65	20.31	2.13	-0.13	-0.25	0.84	0.21	1.71	0.9	0.13	6.11
BECCS	0.02	0.82	0.4	0.05	1.71	1.3	0.01	0.12	0	0.37	0.18	0	0.85	0	0	0.76
LULUC mitigation	0.15	2.14	1.54	0.36	8.47	6.04	20.33	2.28	-0.13	0.11	1.03	0.22	2.5	0.9	0.13	6.89
Linear mitigation	3.12	17.68	3.54	1.43	16.41	15.95	28.66	6.62	12.67	8.84	12.27	28.3	11.74	5.87	5.62	8.73
at BECCS k=3																
Methane-based	2.98	15.51	2.01	1.06	7.85	9.9	8.24	4.34	12.79	8.71	11.16	28.02	9.22	4.97	5.48	1.83
Natural	-3.09	-0.5	0.85	0.3	5.49	4	20.29	1.54	-0.15	-2.32	-4.79	-0.02	1.59	0.9	0.13	3.89
BECCS	4.91	5.71	1.91	0.17	7.95	5.46	0.09	1.17	0.04	5.4	9.45	0.4	2.7	0	0	7.26
LULUC mitigation	1.57	5.13	2.77	0.47	13.53	9.52	20.38	2.78	-0.11	3.1	4.5	0.35	4.21	0.9	0.13	11.17
Linear mitigation	4.57	20.7	4.77	1.54	21.35	19.36	28.71	7.11	12.69	11.82	15.73	28.45	13.45	5.87	5.62	13.03

High negative contribution from natural scenario and high positive contribution from BECCS

Nature scenario is prefered with little BECCS

BECCS scenario is preferred. Natural mitigation contribution is negative

Lower, positive, natural mitigation, with high increase to overall contribution from BECCS

Table 5. Projected water demand for irrigation and other anthropogenic activities, including BECCS, and the additional water required for BECCs as percentage of total water demand. (adapted from Hayman et al., 2021). In dark red, the regions where demand exceeds the available water. In light red, regions where BECCs demand is greater than other water demands (irrigation and others).

	Canada	USA	Mexico	Central America	Brazil	Rest of South America	Western Africa	Eastern Africa	South Africa	Western Europe	Russia region	China region	Southeastern Asia	Oceania	Rest of Southern Africa
2100 Total water demand % of available water	25.5	27.7	154.1	12.8	31.9	9.9	15.4	42.8	3563.3	38.3	53.5	61.8	16.2	136.5	97.9
2100 BECCS demand % total demand	73.8	16.5	9.9	2.8	56.0	18.7	0.2	9.9	2.1	18.5	41.0	13.4	9.9	160.0	42.5

3.2 Arbitration and the introduction of biodiversity co-benefits and trade-offs

3.2.1 Planetary boundaries

In 2009, Rockström et al. published the planetary boundaries framework, outlining nine key processes which threaten the stability of the Earth System. The stability of these processes are essential to maintaining systemic balance and avoiding large-scale abrupt or irreversible environmental changes. Out of these nine boundaries, six have been transgressed to date and only one of them is climate change. Five others - namely biosphere integrity (functional and genetic), land-system change, freshwater change, biogeochemical flows (nitrogen and phosphorus), and release of novel entities (chemicals) - were transgressed, including freshwater and novel entities in 2022 (Persson et al., 2022; Wang-Erlandsson et al., 2022). Besides meaning that the life crisis goes well beyond the climate issue, it is an opportunity to find solutions which jointly address several of these planetary boundaries.

With the freshwater planetary boundary transgressed this year, global water requirements for different negative emission technologies, including BECCS, should be factored in the choice of suitable mitigation solutions. Assuming that bioenergy crops are grown sustainably and are rain-fed, Table 5 provides the projected water demand for irrigation and other anthropogenic activities, including BECCS, as well as the additional water required for BECCS as percentage of total water demand. The former is expected to be (far) greater than the total available water in Mexico, Southern Africa (including South Africa) and Oceania. When looking only at the additional water required for BECCs, it is expected to be more than 50% of the total water demand in Canada, Brazil and Oceania. In other words, additional demand for BECCS is greater than the total water withdrawals from anthropogenic activities in those regions (Hayman et al., 2021). BECCS mitigation is then only preferable in specific regions like Southeast Asia and Western Europe.

This shows that the high risk of trade-offs brought out by the deployment of some CDR should be taken into consideration. On the contrary, nature-based CDR such as reforestation, improved forest management, soil carbon sequestration or peatland restoration are more likely to bring out co-benefits. For example, they are very likely to enhance biodiversity and ecosystem functions, employment and local livelihoods. In contrast, afforestation or production of biomass crops for BECCS or biochar, when poorly implemented, can have adverse socio-economic and environmental impacts, including on biodiversity, food and water security, local livelihoods and on the rights of indigenous communities, especially if implemented at large scales and where land tenure is insecure.

3.2.2 Biodiversity

Future land use changes will drive trade-offs between anthropogenic activities and nature. For example, sub-Saharan Africa is expected to experience the most extreme land-use change across all regions with an expansion of agricultural areas, especially those occurring in the edges of the Congo basin. Doelman et al. (2018) argued that agricultural demand cannot be fulfilled in the region regardless of land-use scenarios, and that price will increase across the board through land competition, especially with high reforestation and land-use regulations. Key drivers of change are population growth, changes in food consumption depending on per capita GDP, and agricultural efficiency. Large yield gaps exist in sub-Saharan Africa with potential for increased production so major benefits can be gained from an increase in efficiency and shift in production mix (e.g. grazing land vs cropland). The authors warn about potential tradeoffs between land-based mitigation and some of the SDGs such as NO POVERTY, ZERO HUNGER, and LIFE ON LAND, as well as biodiversity loss. Therefore large-scale deployment of land-based solutions have to be concomitant with actions to avoid these trade-offs. These include forest conservation (e.g mix of land sharing and land sparing), incentives for ecosystem services and secure tenure, crop and livelihood insurance, agriculture extension services, agricultural production subsidies, etc. (Van Vuuren et al. 2018; O'Neill et al. 2017).

Soto-Navarro et al. (2019) mapped co-benefits for carbon storage and biodiversity and identified areas where conservation actions can have both biodiversity and climate change mitigation benefits. These are mainly located in Napo and Solimões-Japurá moist forests and Iquitos várzea (northwest of South America), Afrotropics (particularly montane forests, swamps of the Congo basin, and Madagascar), Indomalayan and Australasia. A high match between carbon and biodiversity hotspots was also found in boreal and tundra ecosystems. As for restoration, the authors found that the huge opportunities were present throughout the tropics, particularly in lowland tropical rainforest landscapes. It is also where restoration is likely to provide the greatest potential benefits and cost-effective outcomes, in accordance with the study of Griscom et al. (2020). In general, it is crucial to restore and conserve unprotected, degraded ecosystems, particularly in the Neotropics and Indomalaya, and retain the remaining areas of intactness. It also confirms that preservation / conservation has an equally important role as restoration to mitigate climate change.

3.2.3 Health and social co-benefits: the example of clean cooking

Globally, over 3 billion people rely on solid fuel sources and biomass for cooking which further emits GHGs, depletes natural resources along being a major public health concern (Johnson et al., 2019). Traditional woodfuels, which include both firewood and charcoal used for cooking and heating, represented approximately 55% of global wood harvest and 9% of primary energy supply in 2013 (Bailis et al., 2015). CO_2 is emitted because a large fraction of the wood is harvested unsustainably, while CH_4, black carbon and other short-lived climate forcers (SLCFs) are emitted because of incomplete combustion. Beyond climate and environmental impacts, burning these fuels has significant health impacts releasing plumes of smoke and soot, and causing close to 4 millions premature deaths, mostly among women and the world's poorest and most marginalised people.

Many cleaner cooking solutions exist including improved cookstoves (ICS) and clean cookstoves, either reducing biomass fuel consumption by increasing thermal efficiency or ventilation, or using other fuel sources such as solar energy. Replacing a traditional cookstove is a suitable step to mitigate the effects of emissions linked to cooking while introducing other positive benefits.

Recent work by the Project Drawdown estimated that globally between 31.38 to 76.34 $GtCO_2e$ could be reduced between 2020-2050 with clean cooking (Project Drawdown, 2021). Bailis et al. (2015) built a spatially explicit assessment of pan-tropical woodfuel supply and demand combined with the rates of non-renewable biomass utilisation (i.e. the wood harvested exceeds the incremental growth rate) and the burden of disease from household air pollution exposure. While they estimated the potential climate impact to be around one tenth of the Project Drawdown's estimate due to varying methodologies, it still remains substantial and provides the opportunity to focus mitigation efforts in regions where both climate and health impacts are the greatest (Figure 5). These include countries in West and East Africa (Togo, Somalia, Ethiopia, Kenya, Uganda, Mozambique or Burundi for example), as well as Southern and Southeast Asia (e.g. Bhutan, Myanmar, Nepal, Laos). While countries in Latin America host the lowest traditional woodfuel consumption and some of the lowest burden of disease from household air pollution exposure, many countries have high non-renewable biomass utilisation so remain a suitable target following the countries listed above.

Figure 5. Selected countries with highest per capita woodfuel demand, highest expected non-renewable biomass use, and highest burden of disease from household air pollution exposure (Bailis et al., 2015).

4. Conclusion and targeted recommendations

Global warming is the increase in average global surface temperatures. The increase in the amount of greenhouse gases (GHGs) increases the amount of infrared radiation reflected in the atmosphere, causing a change in global surface temperatures. This results in changes in the temperature of the various compartments of the earth, both land surfaces and oceans. As stated by the IPCC reports, it is imperative to keep the rise in global temperatures below 1.5°C by the end of the century, even if the current trend is well above 2°C.

To achieve this, GHG emissions must be reduced now and actions put in place to sequester more of them. Although impacts of climate-related extreme events on food security, nutrition, and livelihoods will be particularly high and severe for people living in sub-Saharan Africa, Asia, Small Islands, Central and South America, all countries, including developed nations, will encounter very severe and adverse consequences on their cities, settlements and infrastructure. However, not all countries have the same responsibility for climate change, the requirements to mitigate it. Developed countries have industrialised from the large-scale exploitation and use of fossil fuels. They also have more financial resources than developing countries, partly because they have a historical lead, and partly because the prosperity of developed nations is based on the exploitation of resources in the least developed countries. These countries, which are also seeking to develop, must be able to follow a different, climate-friendly development process. Among other things, they must invest in renewable energies, protect and restore natural ecosystems and give up certain fossil resources. Contextualised and appropriate solutions must be put in place according to the resources available locally.

Annual renewable energy makes up the bulk of climate mitigation investments globally (58%) and around half of global climate investments. On average, current climate investments need to be multiplied by 10 to 20 times by 2030 in Central Asia, the Middle East and North Africa, Sub-Saharan Africa, and to a minor extent Latin America. It is noted that a quarter of global GHG emissions (comperated to 2019) could be reduced by options with mitigation costs lower than USD 20 tCO_2, available for all sectors, including the energy sector. Wind and solar PV will dominate the growth of renewables in the global electricity sector, due to the availability of resources, cost-competitive markets, and the low cost of energy supply, it will do so particularly in developing regions such as Sub-saharan Africa and Latin America, which require primarily in solar PV and onshore wind. It is also where the two energy sources where the increase needed compared to 2017 level is the highest with respectively multiplication by a factor a 16 and 12 in Sub-saharan Africa, and 22 and 4 in Latin America. Over the input from hydropower is dominated by increased capacity in China, India, and the Russian Federation, and to a limited extent North America.

On the contrary, there is the lack of investments in the industry and AFOLU sectors. Investing in low-carbon solutions for the agricultural sector and the increased use of carbon offsets such as natural carbon sinks have a much greater role to play than what current finance levels suggest. Natural climate solutions (NCS) can reduce and reverse AFOLU sector emissions, and provide about a third of the climate mitigation needed by 2030 and 20% by 2050. We note the relatively small contribution of high-cost (well over USD 50 $tCOCO_2e$) carbon capture and storage across sectors to the overall GHG emission reduction potential.

Overall, half of this contribution comes from the protection of natural ecosystems such as the avoided conversion of non-wetland forests (43%) and avoided impacts to peatlands and mangroves (10%). One fifth of the contribution comes from the restoration of native forest and wetland cover. Restoration activities need to be targeted to specific regions, for example with low opportunity cost and high conservation value from a biodiversity perspective. This is the case in the north and south of the Congo Basin, Central and South America (in absolute values, especially Brazil). In those regions, except in West Africa, nature-based mitigation as shown before could be associated with a high increase to overall contribution from BECCS. These are namely Brazil, the rest of South America, Mexico, East Africa, and Southern Africa. BECCS mitigation only is preferable in specific regions like Southeast Asia and Western Europe. A balance between avoiding deforestation and BECCS should be found in North America and Russia. If a balance cannot be found within land-based mitigation solutions (afforestation, reforestation and avoided deforestation VS BECCS), we recommend focusing on CH_4 mitigation solutions along with renewable energy in high emitting regions, such as India, southern Africa, the USA, China, and Australasia. Other forms of carbon capture and storage are suitable in countries with high waste heat production and low CO_2 intensities of the national electricity grid such as Norway, Iceland, Switzerland. DACCS are not recommended in developing countries, (semi)arid regions, and countries with a fossil-fuel oriented electricity mix.

By integrating the planetary boundaries, we realise that the life crisis goes well beyond the climate issue, it is an opportunity to find solutions which jointly address several of these planetary boundaries. For example, when accounting for the additional water required for BECCS, it becomes an unrealistic solution in Mexico, Southern Africa (including South Africa), Oceania, Canada and Brazil. Similarly, when accounting for biodiversity co-benefits, conservation efforts should focus in northwest South America, the Afrotropics (particularly montane forests, swamps of the Congo basin, and Madagascar), Indomalayan and Australasia. A high match between carbon and biodiversity hotspots was also found in boreal and tundra ecosystems. Finally, the example of improved cookstoves shows how the integration of social co-benefits such as health can prioritise one region or country over another. As for restoration, efforts should focus in regions throughout the tropics, particularly in the lowland tropical rainforest landscape. A summary of the funding recommendations is provided in Table 6.

Table 6. Summary of recommendations for funding by main regions. The decision for funding accounts for both the potential regional climate impact and the possible co-benefits. An explainer for CH_4 is provided in Annex 1.

Offset type	Solution category	Solution type	Canada	USA	Mexico	Central America	Brazil	Rest of South America	North Africa and ME	Western Africa	Eastern Africa	South Africa	Western Europe	Rest of Europe	Russia region	China region	Southeastern Asia	Oceania	Rest of Southern Africa
Removal	Land-based	Reforestation / Afforestation	Y	G	G	G	G	G	G	G	G	Y	Y	Y	Y	Y	G	Y	G
		Peatland/coastal wetland restoration	Y	Y	Y	Y	Y	Y	Y	Y	G	Y	Y	Y	Y	Y	G	Y	Y
		BECCS	R	Y	R	Y	R	Y	R	R	Y	R	Y	Y	Y	Y	G	R	R
	Chemical	DACCS	Y	Y	Y	R	Y	Y	R	R	R	R	Y	Y	R	R	R	Y	R
Reduction	CH_4 mitigation	CH_4 mitigation	G	G	G	G	G	G	G	Y	G	G	G	G	G	G	G	G	G
	Conservation	Avoided forest conversion	G	G	G	G	G	G	Y	G	G	Y	G	G	G	G	G	G	Y
		Preservation of peatlands/wetlands	G	G	G	G	G	G	Y	G	G	G	G	G	G	G	G	G	G
	Renewable energy	Solar	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
		Onshore wind	G	G	G	G	G	G	G	G	G	G	G	Y	G	G	Y	G	G
		Offshore wind	Y	Y	Y	Y	Y	Y	R	R	R	R	G	R	G	G	R	R	R
		Hydro	R	R	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	R	Y
		Others	R	R	Y	Y	Y	Y	Y	Y	Y	Y	Y	G	Y	Y	G	Y	Y
	Buildings	Clean cooking	R	R	Y	Y	Y	Y	Y	G	G	Y	R	R	R	R	G	R	G

(G) Ecologi should fund (Y) Ecologi can fund on a case-by-case basis (R) Ecologi should avoid funding

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Annex One

Methane mitigation explainer

Methane (CH_4) is the second most important anthropogenic greenhouse gas, after carbon dioxide, and a precursor of ozone (O3) which is also a greenhouse gas. In 2019, CO_2 emissions were 45±5.5 $GtCO_2$ and methane (CH_4) 11±3.2 $GtCO_2e$. Most CH_4 emissions come from three sectors: energy (35%), agriculture (40%) and waste (20%).

CH_4's characteristics make it a very attractive target for reducing global warming. With a high global warming potential (100-year GWP around 27) and an average lifetime in the troposphere of 9-10 years, successfully removing CH_4 can have great effectiveness in mitigation of climate change. The IPCC argues that reducing non-CO_2 emissions, especially those of methane, would greatly affect the level of peak warming. In both 1.5°C and 2°C pathways, CH_4 emissions have to drop by 50% by 2050 but deeper cuts would put us closer to reaching this goal. In addition, reducing CH_4 emissions became most critical when research showed with climate models that methane continues to contribute to global warming, even when CO_2 emissions may be stabilising. In other words, if we do not curb our CH_4 emissions, it will be impossible to meet global climate targets (Nisbet et al., 2020).

At COP26 in 2021, the Global Methane Pledge was announced. Since then, over 100 countries have signed the Pledge, to reduce CH_4 emissions globally by 30% by 2030 (from 2020 levels). Solutions are at hand to address the methane issue. Shindell et al. (2017) considered that as much as a cut of 0.11 $GtCH_4$ per year was possible by scaling up existing technology and industrial best practice and policy options representing a little less than a third of current global CH_4 emissions at 0.37 $GtCH_4$ per year on average between 2010 and 2019. Some key CH_4 mitigation measures are:

- Maximising CH_4 recovery from underground mining of hard coal
- Controlling fugitive emissions from equipment and pipeline leaks and from venting during maintenance and repair
- Changes in animal diet and the use of more productive animal types
- Improved agricultural production practices — specifically focused on improving efficiency
- Reducing the production volume of the animal husbandry sector and improving management of rice cultivation and manure
- Capturing landfill gas and generating energy
- Capture and use of the CH_4 emissions in anaerobic digesters
- Changes to the water management regime and to the soils to reduce methanogenesis
- Reducing food loss and waste and by capture of any CH_4 released
- Using more wastewater treatment plants and also recovery of the CH_4 from such plants and through more aerobic wastewater treatment.

Thank you for reading

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