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What transitions for climate change mitigation? Global transformations, societal dimensions and insights for decision makers

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Abstract: The IPCC Special report on "Global Warming of 1.5 °C" identifies the greenhouse gas emissions trajectories compatible with the global mitigation goal of the Paris Agreement, presents the mitigation actions required to follow these trajectories and analyses the synergies and trade-offs with sustainable development objectives. The assessment highlights the necessity to implement drastic global carbon emissions reductions in the short term, to reach global carbon neutrality between 2050 and 2070 and to implement targeted actions to limit other greenhouse gases. To this aim, rapid and far-reaching transformations are required in energy, industrial, infrastructure and land-use systems. Adopting systemic strategies combining policy packages elaborated according to the specificities of each country context and with a long-term perspective is a requirement for ensuring that these low-emission transformations can be compatible with the achievement of socio-economic and development objectives.

Keywords: IPCC, Attenuation, Greenhouse gas emissions, Transformations, Strategies

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The Paris Climate Agreement sets the goal to "hold the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels". However, at the time this agreement was signed in 2015, little sound scientific knowledge was available on the specifics of a world at +1.5°C, and in particular on the differences compared to a world at +2°C. Countries have therefore asked the Intergovernmental Panel on Climate Change (IPCC) to produce a special report on global warming of 1.5°C that synthesises the scientific literature on this emerging topic for policymakers.

After 2 years of rigorous work mobilising about a hundred authors around the analysis of more than 6,000 scientific studies, the IPCC report on global warming of 1.5°C (SR1.5) was published on 8 October 2018 [IPCC 2018a]. It is the most up-to-date collection of information on climate change knowledge and the most legitimate scientific basis for any decision on climate change.

1. Climate change, a fundamental source of injustice

The SR1.5 report shows that anthropogenic climate change has now reached a global temperature increase of about 1°C compared to the pre-industrial era, and that its effects are already visible, leading to many changes in the functioning of the climate system, and inducing in particular an increase in extreme events (land and marine heat waves, droughts, torrential rains, etc.). These impacts are expected to increase as the global temperature continues to rise by about 0.2°C per decade if the current rate of greenhouse gas emissions continues. Under these conditions, the 1.5°C threshold could be reached between 2030 and 2052.

A world at +1.5°C is a world with more extreme climate events and significant impacts on ecosystems, societies and economies. Accordingly, a climate change of such intensity induces in particular an increase in extreme temperatures, especially in central and eastern North America, Central and Southern Europe, the Mediterranean region, western Asia, Central Asia and southern Africa; frequent extreme heat waves over much of the tropics; intense rainfall in Alaska, Canada, Northern Europe, Northern and Eastern Asia and eastern North America; a likely increase in the intensity of cyclones, and therefore in the intensity of associated rains; a possible doubling of the frequency of extreme El Niño events and therefore of associated impacts on a global scale; an increase in droughts, especially in the Mediterranean region, and an increase in the risks of water shortages in the driest regions (sub-Saharan Africa and South Asia); losses of coastal resources, leading in particular to a decrease in the productivity of fisheries and aquaculture, especially in low latitudes; a decrease in the yields of maize, rice, wheat and other cereals, especially in sub-Saharan Africa, South-East Asia, Central and South America.

All of these climate impacts have a direct impact on people as they affect living conditions and livelihoods. They directly or indirectly lead to an increase in poverty and a widening of inequalities, as it is the poorest who are generally the most exposed to these impacts of climate change. And these most disadvantaged populations are also less able to implement adaptation strategies that could to allow them to partially avoid these impacts.

The analysis of the IPCC report suggests that an additional 0.5°C increase (from 1.5 to 2°C on average globally) has significant consequences for the effects described above, which are intensified as the temperature rise increases. In many cases, the impacts can be more than doubled compared to global warming limited to 1.5°C. Estimates show that up to several hundred million fewer people will be both exposed to climate risks and likely to fall into poverty if the global temperature increase is held at 1.5°C compared to 2°C.

This means that controlling climate change is a fundamental issue of social justice, and that any drift in the global climate can be analysed as a source of increased inequality and poverty. Every tenth of a degree matters in these trends and any shift in global climate action has direct or indirect effects as a vector of injustice.

2. Methods of analysis of mitigation strategies in the SR1.5 Report

Three levels of assessment underpin SR1.5's analyses of mitigation pathways.

First, global greenhouse gas (GHG) emission pathways are presented as they emerge from integrated analyses of how global society can transform into a low-carbon future. These results are mainly derived from integrated assessment modelling exercises, supplemented to a limited extent by sectoral and bottom-up studies [Rogelj et al. 2018]. Many scenarios from the scientific literature, which differ in how GHG emissions and concentrations are reduced over time, shed light on this issue. These scenarios differ specifically according to the magnitude of short-term CO_2 emission reductions and the scale of deployment of solutions to remove carbon dioxide from the atmosphere, or 'negative emission' solutions. The portfolio of solutions considered in these analyses is broad but not exhaustive. For example, among negative emission solutions, only afforestation, reforestation (AR) and bioenergy with CO_2 capture and storage (BECCS) are generally considered. In addition, depending on model characteristics and specific scenario assumptions, mitigation pathways and associated solutions may vary in their technological content, for example, in their dependence on nuclear energy, CO_2 capture and storage, and behaviour change strategies.

Second, the report assesses the multidimensional feasibility of mitigation pathways, identifying the available solutions, the specifics of the context deciding this availability, and the changes needed to remove barriers and provide a broader context conducive to the deployment on the scale needed to achieve the emission reduction targets [by Coninck et al. 2018]. In particular, SR1.5 assessed 28 mitigation options in six dimensions — economic, technological, institutional, socio-cultural, environmental and geophysical. Each of these dimensions is characterised, with the help of scientific literature, through three to five indicators, such as political acceptability, legal and administrative feasibility, institutional capacity, transparency and accountability under the institutional dimension; or social co-benefits (e.g. for health, education), public acceptance, social and regional inclusion, intergenerational equity and human capacities.

Finally, SR1.5 expands the analysis by discussing in detail the interactions between different mitigation options and other goals and objectives that society pursues, including sustainable development [Roy et al. 2018]. This allows to take into consideration dimensions related to societal and environmental goals other than climate change. The assessment was carried out by assessing the strength of synergies and the risks of trade-offs with the Sustainable Development Goals (SDGs), using an interaction dashboard [McCollum et al. 2018]. The analysis provides concrete information for policymakers to understand how to align mitigation options with the sustainable development goals and thereby improve public support and social acceptability of actions, encourage faster and more effective action and support the design of equitable mitigation.

These three levels of assessment provide further information on the global mitigation pathways towards the 1.5°C target. Global modelling can provide a quantitative and internally consistent picture based on techno-economic optimisation, which needs to be complemented by a more practical perspective and grounded in field assessment to evaluate the conditions for these transformations to actually materialise. It is about taking into account the importance of contextual factors at the regional, national and sub-national levels. It is also about reflecting all the institutional and socio-cultural dimensions, as well as certain technological, economic, geophysical and environmental indicators which are usually not fully captured by modelling studies, such as risk assessment, distributional aspects or technical developments. Finally, it is about discussing broader conditions that allow for system transitions such as policy instruments, finance and investment, behavioural change, technological innovation, multi-level governance and institutional capacity. The previous two perspectives are complemented by the third level of analysis, which adds an explicit and detailed examination of a number of key sustainable development goals for the assessment of an alternative portfolio of mitigation options. This last component allows to discuss the interactions of different mitigation solutions with broader social, economic and environmental issues, and to highlight the impact of different policy packages and measures on the nature and extent of synergies and risks of trade-offs between the mitigation goal and the broader goals of the transition.

3. Emissions pathways

The analysis of scenarios consistent with the goal of holding the increase in the global temperature below 1.5°C leads to the identification of the corresponding greenhouse gas emission pathways

3.1. *Global carbon dioxide pathways*

The report analyses in detail the challenges posed by carbon dioxide emissions, which is the main determinant of long-term climate change due to its long lifetime in the atmosphere. These emissions are mainly caused by the combustion of fossil fuels (oil, gas, coal), especially for energy uses, by changes in land uses such as deforestation and by certain industrial processes such as those involving cement production.

Figure 1 presents an overview of the CO_2 emission pathways consistent with the 1.5°C target, distinguishing between pathways that remain below this threshold without (or with a slight) temporary overshoot of the 1.5°C threshold before returning to that level, identified in blue, and pathways that imply a high temporary overshoot in grey.

Beyond the variabilities depending on specific assumptions about the context or mitigation solutions, common characteristics can be identified.

In all cases, meeting the 1.5°C threshold requires a very steep CO_2 emissions reduction in the short term. The analysis shows a necessary reduction in the range of 40 to 60% in 2030 compared to 2010 emissions, with an average value around 45%. Even a target of "only" +2°C requires deep deviations from current trends to achieve a 20 to 25% decrease from 2010 emissions. This is a significantly higher reduction ambition than what states have committed to do so far and significantly higher than what is set in the nationally determined contributions (NDCs) submitted by countries ahead of the Paris Agreement.

As a necessary condition, meeting the 1.5°C threshold requires achieving carbon neutrality — not emitting more emissions than what human activities can store — around 2050. Even a goal of "only" +2°C requires reaching this carbon neutrality target with only a possible delay until around 2070. In any case, the goal of "carbon neutrality" therefore appears as the primary fundamental goal of climate action, as it is the necessary condition to ensure that anthropogenic activities stop causing the accumulation of greenhouse gases in the atmosphere. This point is explicitly recognised in Article 4.1 of the Paris Agreement. Carbon neutrality is therefore the scientifically legitimate compass that must guide the evaluation of policies and measures implemented to control climate change [Rankovic et al. 2018].

3.2. *Four models of mitigation scenarios*

SR1.5 highlights four illustrative types of mitigation pathways, all of which achieve the 1.5°C stabilisation target but with different unerpinnings corresponding to four different transition narratives, associated with contrasting types of CO_2 emission pathways (Figure 2) for the main sources, namely fossil fuel combustion (coal, oil, gas) for energy supply (in grey), reforestation/afforestation (in brown), and negative emission technologies such as BECCS (in yellow). Scenario P1 is a scenario in which social, commercial and technological innovations lead to a decrease in energy demand before 2050, while living standards rise, especially in the countries of the South. The reduction in the size of the energy system allows a rapid decarbonisation of energy supply. Afforestation is the only negative emission option considered; neither fossil fuels with CCS nor BECCS are used.

The P2 scenario has a strong focus on sustainability, especially on energy efficiency, human development, economic convergence and international cooperation, as well as the shift towards sustainable and healthy consumption patterns, low-carbon technological innovation and well-managed land tenure systems, with limited societal acceptability for the BECCS.

Scenario P3 is an intermediate scenario in which societal and technological developments follow historical trends. Emission reductions are mainly achieved by changing the way energy and goods are produced, with a lesser role for demand reduction.

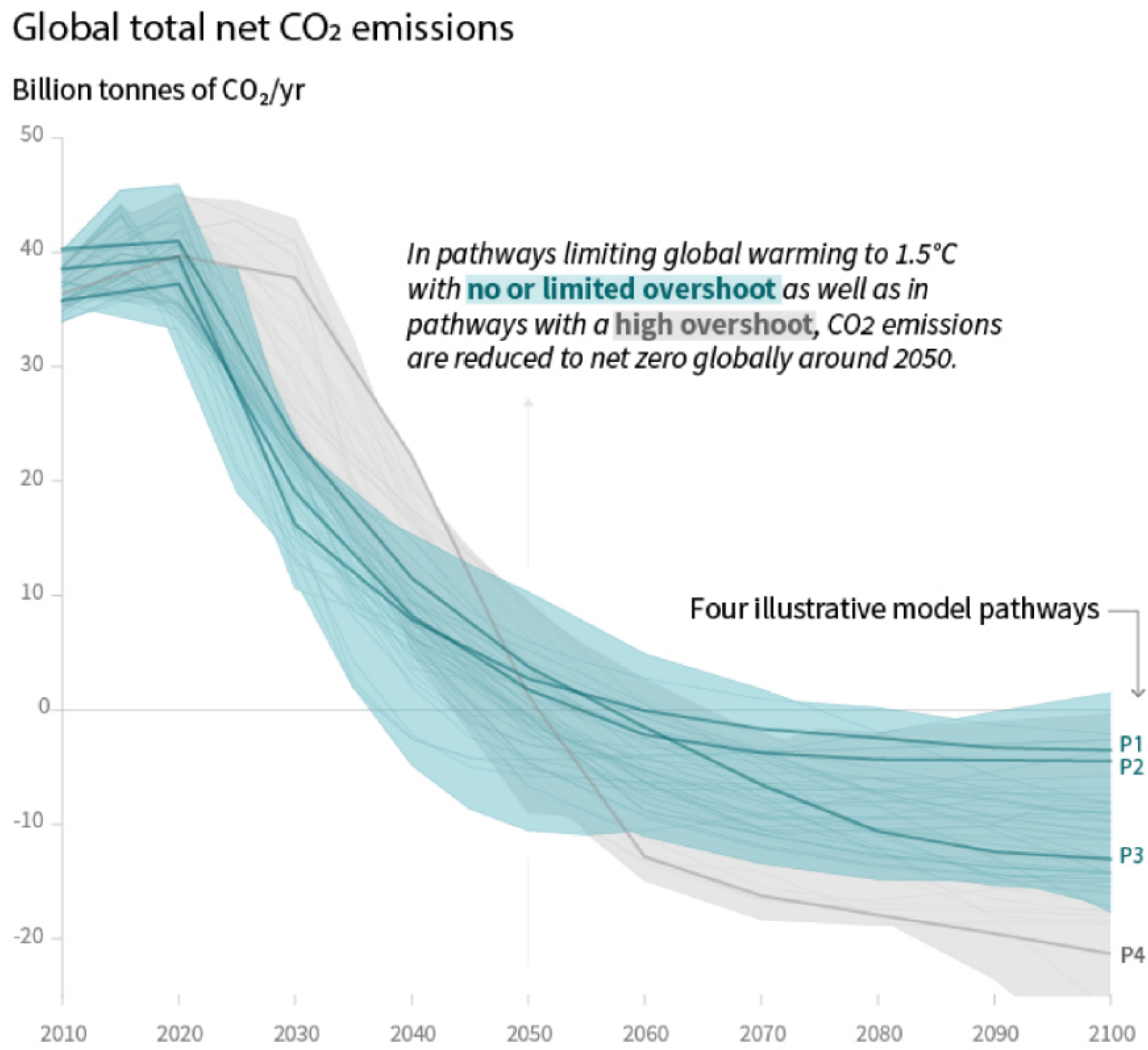

Figure 1. Global CO_2 pathways in scenarios consistent with limiting global warming to 1.5°C. (Source: Figure SPM.3a in [IPCC 2018b])

Scenario P4 is a resource- and energy-intensive scenario, in which economic growth and globalisation lead to the adoption of greenhouse gas-intensive lifestyles, including high fuel demand for transport and food products. Emission reductions are mainly achieved through technology, with in particular a very high deployment of negative emission technologies, notably BECCS. This model of scenarios achieves the stabilisation target of 1.5°C, with a "high" temporary overshoot.

For each of these families of scenario, illustrative scenarios are chosen for which detailed technological configurations are provided [2018b, figure SPM3.b]. However, it should be noted that these illustrative pathways correspond to an arbitrary choice in the full database of scenarios and do not cover all possible dimensions of variation. A thorough review of the complete database of scenarios underlying the assessment [Huppmann et al. 2018] is necessary to understand the full extent of the technological trends supporting each of these

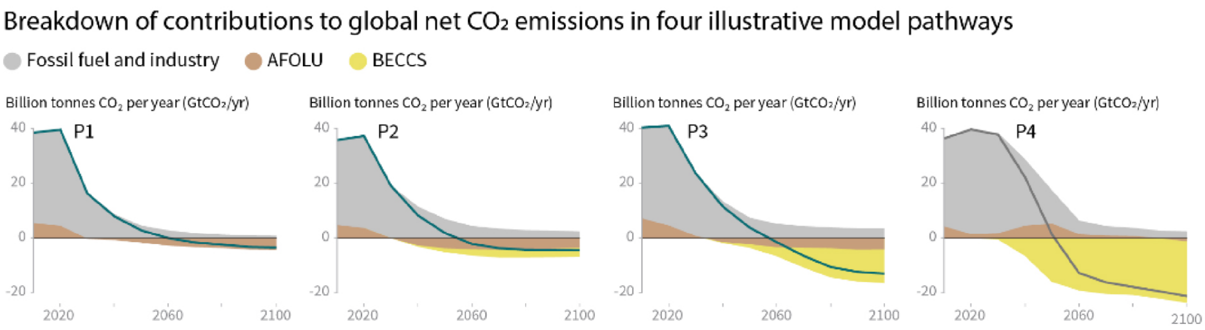

Figure 2. Breakdown of CO_2 emissions in the four illustrative models. (Source: Figure SPM.3b in [IPCC 2018b])

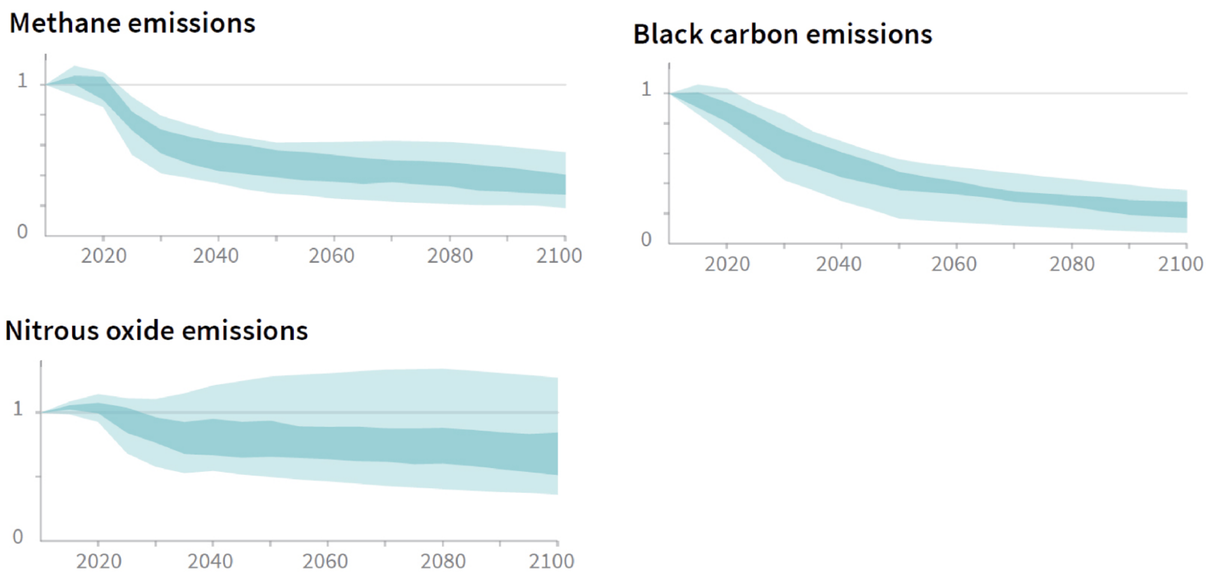

Figure 3. Global pathways of methane, black carbon and nitrous oxide in scenarios consistent with limiting global warming to 1.5°C, with a slight overshoot. (Source: Figure SPM.3a in [IPCC 2018b])

pathways.

3.3. *Global pathways of other greenhouse gases*

The report also analyses in detail some of the shorter-lived gases that significantly influence the short and medium term temperature pathways, notably methane (CH_4), black carbon and nitrous oxide (N_20). Methane emissions are linked to specific agricultural processes (enteric fermentation linked to meat production, rice production), fossil energy production and waste management. Black carbon emissions are particles emitted by diesel engines used in transportation and industry, wood and coal used for residential uses, forest and savannah fires, and some industrial processes. Nitrous oxide emissions are linked to specific agricultural processes (in particular the use of fertilisers), energy combustion and some industrial processes.

These emissions contribute significantly to the maximum level of warming in the transition period. Mitigation scenarios consistent with the 1.5°C target with a low overshoot predict a significant decrease in methane emissions as well as black carbon emissions and stabilisation of nitrous oxide emissions (Figure 3). In most cases, these reductions are comparable to the levels to be targeted for stabilisation at "only" 2°C. A significant proportion of these gases are emitted alongside carbon dioxide emissions, so that reduction strategies can go hand in hand with those to be considered for reducing carbon dioxide emissions. However, for some sources, specific complementary strategies will have to be adopted in addition to those adopted anyway for CO_2, in particular for actions targeting methane and nitrous oxide linked to agricultural activities. It should also be noted that some strategies related to the deployment of bioenergy are associated with potential significant increases in some of these non-CO_2 climate forcers, so that scenarios that consider a very high deployment of these solutions create a risk for these greenhouse gases, which will require appropriate strategies.

4. Systemic Transformations

The analysis of the report shows that achieving these emission targets requires major and rapid transformations in all areas (energy, land use, spatial planning, urban planning, infrastructure, industry, etc.). There is no single, universal solution to induce the greenhouse gas emission reductions presented in Part 3. Such reductions imply instead large-scale economic, technological [Waisman, De Coninck, Rogelj 2019a], social, organisational and institutional transformations in all systems: energy system, industrial system, infrastructure and transport system and land use system. These transformations in turn require the use of a wide range of mitigation measures, including massive investments, appropriate policy instruments, accelerated innovation and behavioural change.

The report provides detailed information on the scale and characteristics of the transformations to be targeted on a global scale, which can serve as a guide to assess the consistency of the actions undertaken with the stated climate goal. It identifies inevitable changes such as the massive deployment of renewable energies, the phasing out of unabated fossil fuels for electricity generation by 2050, the large-scale deployment of new technologies in industry and construction, the rapid renewal of the vehicle stock to quickly move way from internal combustion engine, changes in spatial organisation in cities and in the use of agricultural land.

In all cases, the reduction in emissions is ensured, among other things, by a massive decarbonisation of the energy sector and a massive use of decarbonised energy to meet final demand, in particular through the electrification of uses, where possible. The use of coal is almost completely abandoned by 2050. Gas and oil could continue to be present in the global energy mix but, in any case, with significant reductions compared to their current role and under certain conditions. For example, gas would only account for 8% of the world's electricity generation, on average in the scenarios, and only if coupled with carbon capture and storage technologies. Demand should therefore be met, mainly through renewable energies, by continuing and expanding recent substantial advances notably in wind, solar and energy storage technologies. Depending on the scenario considered, between 1 and 7 million km^2 would have to be devoted to crops for biofuels, with issues and constraints between energy and food security.

In the industrial sector, emissions need to be reduced by 65 to 90% by 2050 compared to 2010 levels. These reductions cannot only be achieved through energy efficiency measures and also require mobilising a combination of existing technologies and practices and innovative solutions, such as electrification, hydrogen, the use of sustainable natural raw materials, product substitution and the use of carbon capture, storage and use technologies. All these solutions have been demonstrated, but their deployment on the required scale requires overcoming the economic and financial constraints of human capacity and institutions in certain contexts and the specific characteristics of certain large-scale facilities.

The transition of the urban system and infrastructure consistent with the stabilisation target of 1.5°C implies, including changes in urban development styles and associated land use patterns in cities; substantial emission reductions are also required in the transport and buildings sector. The technical measures include various actions to induce energy efficiency and a significant increase in electrical use reaching for example 55 to 75% of the energy consumption in the buildings sector. The role of low-carbon energy is increasing very significantly in transport, from a very minor role today to a majority share by 2050. The dissemination of these solutions requires to take into account the possible economic, institutional and socio-cultural barriers as well as the specificities of national, regional and local contexts, the capabilities and constraints related to the availability of capital.

Mitigation strategies consistent with the goal of stabilising at 1.5°C imply significant changes in land uses which raise important challenges in terms of competition between land uses for agriculture, energy production and negative emissions. The extent and nature of these competitions will depend heavily on the overall strategies adopted. The evolution of agricultural practices, the preservation of ecosystems and changes in food demand are fundamental aspects to consider in order to align climate goals with food production and biodiversity conservation issues. They pose many challenges for the sustainable management of different land uses (socio-economic, institutional, technological, financial, environmental). The search for solutions that maximise synergies between emission reduction and risk reduction is key to a just and fair transition, especially in agricultural systems, which requires anchoring in local specificities and experience and requires a dynamic and adaptive approach, in a context of uncertainty.

5. Consistency with the Sustainable Development Goals

A fundamental issue for the assessment of climate action is its consistency with the priority goals of society, in particular the eradication of poverty and the reduction of inequalities in all their forms.

The report analyses the synergies and possible trade-offs between the measures adopted to reduce greenhouse gas emissions and the sustainable development goals. This analysis is key for judging the measures taken to control climate change, since measures that would limit emissions at the cost of significant negative effects on development would simply shift the problem of social justice without addressing it.

The report shows that many options, if properly implemented, have important synergies with sustainable development goals: improving air quality, food security and water resources, maintaining ecosystem services, reducing disaster risk, reducing poverty and inequality, etc. However, poorly designed or implemented projects can have negative effects. For example, a large-scale deployment of biofuel crops and afforestation may compete with food production, but also with the preservation of biodiversity. Another example concerns the rapid shift away from fossil fuels can pose a significant transition risk for regions that rely heavily on fossil fuels for income and jobs.

Overall, the analysis shows that synergies outweigh the risks of trade-offs and that a choice of appropriate measures can maximise the positive effects of climate action. The report identifies a number of key conditions to foster these synergies and thus enable the alignment of climate protection with social and environmental objectives. State action will therefore have to be assessed in terms of consistency with these structural conditions, beyond the details of the choices made by each one.

First of all, putting in place urgent measures to ensure a rapid inflection of emissions opens the range of choices in the future and limits the risk of painful arbitration between different goals. Secondly, society as a whole must be involved — national and subnational authorities, civil society, the private sector and local communities — because a harmonious transition requires coordinated action that mobilises all the levers that are in the hands of these different actors. Moreover, the combinations of measures chosen to induce transformations must be integrated into articulated and well-designed strategies according to the specifics of the context, as each country is responsible for defining its own path towards carbon neutrality. Finally, international cooperation is crucial to ensure the effectiveness and equity of the transition, both to build on the benefits of collaboration to bring about lower-cost solutions and to ensure universal access to finance, technology and capacity-building.

6. Conclusion

The IPCC report on global warming of 1.5°C highlights the magnitude of the changes needed to implement mitigation strategies that can stabilise the climate. It provides guidance and identifies specific challenges that will need to be addressed. This report does not provide a specific assessment of required actions by each country, as it would be outside the mandate of the IPCC to be relevant to the decision without being prescriptive. Moreover, the global goals do not allow for a direct and simple recommendation of the goals that would be the responsibility of each country. The only sound scientific basis for judging whether a State's action is in line with the global goal is to assess whether the transformations implemented are consistent with the transformation requirements as described in detail in the report, taking into account the specific national circumstances.

Such an exercise is at the heart of the processes at the international level under the Paris Agreement, which invites countries to submit their Nationally Determined Contributions describing their ambitions and actions and to revise them regularly in the light of progress in scientific knowledge. The report states clearly that current commitments are insufficient to achieve the global goal set out in the Paris Agreement and that future revisions will be crucial to foster this alignment through more ambitious national strategies. The definition of such strategies by countries requires the adoption of an analytical approach adapted to these challenges of integration between global scale and local anchoring, between long-term issues and short-term action, between profound sectoral transformations and global systemic approach [Waisman et al. 2019b].

The IPCC report on global warming of 1.5°C thus provides guidance on the directions to be followed, but does not provide straightforward solutions to achieve them. Indeed, the practical implementation and translation into concrete measures applicable to the different scales cannot respond to a systematic and generic logic, but, on the contrary, require a variation of these broad directions according to the specifics of each context. Policy implementation presents significant challenges in practice because it depends on all stakeholders taking ownership of the issues and choices to be made, on the establishment of innovative governance processes to enable the involvement in the decision-making process of all these stakeholders and on the development of packages of policies and measures to respond in the short term to long-term challenges in a context of high uncertainty that challenges the decision-making process. Significant progress has been made on these different dimensions in recent years, with an acceleration since the Paris Agreement, but it is clear that the movement is not yet up to the challenge and that time is running out if we want to keep the window of opportunity open for truly ambitious climate action. The way in which the transformation requirements identified in the IPCC report will be taken into account in the design of the measures taken in response to the COVID-19 crisis will, in this respect, reveal the effective centrality of climate issues in decision-making in different contexts, beyond federating discourses.

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