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Prioritizing mitigation pathways in land use and food systems

A systematic framework to assess opportunities

Nathanaël Pingault
Christopher Martius

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Nathanaël Pingault
CIFOR-ICRAF

Christopher Martius
CIFOR-ICRAF

CIFOR-ICRAF

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CIFOR
Jl. CIFOR, Situ Gede
Bogor Barat 16115
Indonesia
T +62 (251) 8622622
F +62 (251) 8622100
E cifor@cifor-icraf.org

ICRAF
United Nations Avenue, Gigiri
PO Box 30677, Nairobi, 00100
Kenya
T +254 (20) 7224000
F +254 (20) 7224001
E worldagroforestry@cifor-icraf.org

cifor-icraf.org

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1 Introduction

1.1 Background

The Intergovernmental Panel on Climate Change (IPCC 2021) has unequivocally demonstrated in its sixth assessment report (AR6) that human activities are the main driver of climate change. At their current level, international commitments under the Paris Agreement, even if fully realized by 2030, would engage the world on a trajectory compatible with +3°C of global warming by the end of the century (Rogelj et al. 2016; Roe et al. 2021; Patt et al. 2022), i.e., far too warm to be safe for human well-being and the environment. The transition towards a sustainable, low-carbon and climate resilient development pathway, in line with the Paris Agreement targets of +1.5°C and 2°C, thus implies to move radically away from current trajectories, and implement unprecedented, rapid, deep and systemic transformations across: (i) energy supply and demand; (ii) industry; (iii) mobility, infrastructure and urban forms; and (iv) land use and food systems (IPCC 2018a; Turnheim and Nykvist 2019; Ara Begum et al. 2022). To enable these four transition pathways, a fifth transformation needs to occur in societal systems, a shift in human values, norms, behaviours and preferences to promote alternative power structures and consumption patterns (Ara Begum et al. 2022; Schipper et al. 2022). The depth, scale and pace of the transformations required across sectors and actors raise critical questions of feasibility (Nielsen et al. 2020).

In 2018, according to the IPCC (Babiker et al. 2022), the global food system emitted 17 $GtCO_2e$ (range: 13–23), that is 31% (range: 23–42%) of total net anthropogenic greenhouse gas (GHG) emissions (54 $GtCO_2e$). These emissions came from agriculture (crop and livestock production: 37% of food system emissions); land use, land-use change and forestry (LULUCF: 24%); energy use (23%); food waste management (10%); and industrial processes in the food industry (5%) (Babiker et al. 2022). While unsustainable practices, production and consumption patterns in the land use sectors (agriculture, forestry and fisheries) and across food systems have historically formed an important part of the problem, land use and food systems can become a critical part of the solution.

Indeed, in recent years, large mitigation potentials have been widely documented in the land use sectors (e.g., Griscom et al. 2017; Roe et al. 2019, 2021; Jia et al. 2019; Nabuurs et al. 2022). For instance, Roe et al. (2019) estimated that land-based mitigation options could possibly contribute about 15 $GtCO_2e$ per year, that is up to 30% of the global mitigation effort needed by 2050 to achieve the Paris Agreement 1.5°C target. This estimation is consistent with the latest findings of IPCC AR6, i.e., a global land-based mitigation in the range of 8–14 $GtCO_2e$ per year over the period 2020–2050 at a carbon price below USD 100 per tCO_2e, of which 30% to 50% could be achieved with a carbon price of only USD 20 per tCO_2e or less (Roe et al. 2021; Nabuurs et al. 2022). Although less documented, mitigation potentials beyond the farm gate, across food value chains, should not be overlooked (Niles et al. 2018; Mbow et al. 2019; Babiker et al. 2022; Pingault and Martius 2023).

However, these vast mitigation potentials are increasingly questioned in the scientific literature in terms of feasibility and desirability (e.g., de Coninck et al. 2018; Jewell and Cherp 2020; Roe et al. 2021; Brutschin et al. 2021; Grubb et al. 2022; Nabuurs et al. 2022; Riahi et al. 2022). Roe et al. (2021) estimated, for instance, that about 80% of the global cost-effective land-based mitigation potential lies in developing and least developed countries, where implementing these measures may generate the greatest feasibility concerns. In the real world, theoretical mitigation potentials are limited by a series of constraints, thus defining a set of decreasing potentials: (i) the *physical potential* is the one limited only by available geophysical or biophysical resources; (ii) the *technical potential* is achievable considering only currently available technologies; (iii) the cost-effective *economic potential* circumscribes the potential available at reasonable cost (for instance, below USD 100 per tCO_2e); (iv) the *sustainable potential* is aligned with sustainable development objectives and societal goals, considers social and environmental safeguards, and thus reflects what is politically or socially desirable; and (v) finally, even if desirable, technically possible, economically viable and sustainable, a mitigation option may not be realizable because of other environmental, sociocultural, political or institutional barriers. What remains is the *feasible potential* (Nabuurs et al. 2022).

Capturing this cascade of limitations therefore becomes crucial to identify the so-called 'low-hanging fruits', i.e., no-regret and viable options that can be most easily implemented in the real word, based on available technologies and knowledge, at reasonable social, environmental and economic costs. To put it differently, these options are viable because they 'pass the test' of the biophysical, financial, social and sustainability barriers, and thus present themselves as viable opportunities that should be given preference.

1.2 Purpose and structure of the paper

Building upon the work of the IPCC, as well as on the ever-growing literature on feasibility, we develop in this paper a simple but systematic framework to assess and compare different mitigation options in land use and food systems according to their level of opportunity, i.e., according to how desirable and feasible they are.

This comprehensive framework considers not only the size of GHG emissions and the corresponding physical mitigation potential, but also all dimensions of feasibility, including costs, as well as technical, political and institutional constraints. Indeed, smaller sources of emissions along food value chains might be easier, cheaper or quicker to mitigate, offering some quick or early wins while continuing to work on emission sources that are larger but much more complex to mitigate, such as reducing methane emissions from agriculture – e.g., from enteric fermentation, manure management and rice cultivation (Reisinger et al. 2021; Lecocq et al. 2022; Pingault and Martius 2023). In other words, this framework aims to encompass the political economy behind mitigation strategies, and assess all the barriers and enabling conditions that prevent or support the implementation of a sustainable, low-emission and climate resilient development pathway in the real world. In a world of limited resources, this systematic opportunity assessment framework could support decision making and help optimize resource allocation by enabling the identification of priority areas for mitigation action in different contexts, at different spatial and temporal scales.

The next section illustrates and articulates the three notions of opportunity, feasibility and desirability. Based on these three notions, the third section then develops a systematic framework, as well as the corresponding indicators and metrics, to assess and rank alternative mitigation options in land use and food systems according to their level of opportunity. Finally, the last section discusses briefly the strengths and weaknesses of this framework and opens some perspectives for further work.

2 Concepts and definitions

Nielsen et al. (2020) defined a mitigation opportunity as “a pathway toward achieving mitigation of climate change”, i.e., a possible option or solution to combat climate change. However, for a mitigation *opportunity* to become reality, it needs to be both *feasible* and *desirable*, at least for some change agents (Gilabert and Lawford-Smith 2012). This section develops these two concepts of *feasibility* and *desirability*, and discusses their articulation.

2.1 Feasibility

For social scientists and political philosophers (e.g., Majone 1975a, 1975b; Gilabert and Lawford-Smith 2012; Jewell and Cherp 2020), an outcome is *feasible* if an agent or a group of agents have the acting capacity to make this outcome happen in a specific context (i.e., in a given place at a given time). *Feasibility* is basically about *agents, actions, outcomes* and *contexts*. This links to the three central questions that feasibility assessments need to answer: ‘feasible for whom?’; ‘feasibility of what?’; and ‘feasible when and where?’ (Gilabert and Lawford-Smith 2012; Jewell and Cherp 2020). The first question refers to the agents of change, which can be individuals, like consumers, citizens, civil society organizations, social movements, lobbies, political parties, private companies or public agencies. The second question refers to the desired outcome (e.g., a 1.5°C climate target) and to the set of actions required to make it happen. And the third question refers to the spatial and temporal context that constrains or enables action.

The literature distinguishes *hard* and *soft* constraints to feasibility. Hard constraints can make an outcome impossible to reach, considering for instance available geophysical resources and existing technologies. Soft constraints, for instance the economic or institutional environment, can make an outcome less easy to reach, without completely ruling out its realization (Gilabert and Lawford-Smith 2012; Jewell and Cherp 2020). However, the concept of feasibility is eminently dynamic, blurring this distinction between hard and soft constraints. The feasibility frontier, beyond which implementation challenges prevent mitigation action, is susceptible to rapid and sometimes unexpected changes as new technologies and norms emerge, and as new political coalitions are formed (Turnheim and Nykvist 2019; Jewell and Cherp 2020; Singh 2020; Brutschin et al. 2021; Riahi et al. 2022). What is feasible somewhere or for one group of agents may be practically impossible elsewhere or for disadvantaged groups with more limited human or financial capacities. Over time, what seems infeasible now can become feasible in the future, for instance thanks to the emergence of new technology. In conclusion, even what tends to be considered a hard constraint here and today, and impossible to overcome, may become a soft constraint, and possible to overcome, elsewhere or in the future. By contrast, climate change may affect current ecosystems and the services they provide, threatening food and water security, livelihoods and health, and potentially limiting future land-based mitigation potentials (de Coninck et al. 2018). As a result, currently feasible mitigation options could become harder or even impossible to implement in the future. As highlighted in IPCC AR6 (Pathak et al. 2022; Clarke et al. 2022; Riahi et al. 2022; IPCC 2022), the feasibility of mitigation options is place-, time-, scale- and goal-dependent. Indeed, it depends on the context (in a given place, country or region); on the speed of implementation (e.g., 2030 versus 2050); on the scale of implementation (local, national or global); and on the stringency of long-term climate goals (e.g., 1.5°C versus 2°C).

Hence, a comprehensive and systematic feasibility assessment framework must go far beyond a binary (yes/no) evaluation (Allen et al. 2018), and try to identify the extent to which different barriers and enablers prevent, limit or encourage the implementation of alternative mitigation options (Roe et al.

2021; IPCC 2022). Beyond a mere assessment of the physical mitigation potential, such a framework must embrace all dimensions of feasibility, their interactions, as well as their variations across space and time. In doing so, such a framework could help identify and prioritize the "low hanging fruits", i.e., those actions that have both the highest potential for transformative impacts and the capacity to be implemented faster and more easily, at a lower cost and/or at a greater scale. Such actions should satisfy the three characteristics identified by Atmadja et al. (2021a, 2021b), that are expected for a change to become transformational: depth, speed and scale. However, shifting away from the dominant paradigm to implement a deep, radical and systemic change will likely face many challenges and resistances, and may not happen quickly at a large-scale. As a result, simultaneously achieving depth, speed and scale seems virtually impossible. Considering these trade-offs and accepting the need to focus first on one or two objectives, even at the expense of the third, may open more feasible and realistic pathways towards the needed transformation, which then must be considered as the final objective (Termeer et al. 2017; Atmadja et al. 2021b).

The IPCC and the international scientific community increasingly rely on climate models, in particular integrated assessment models, to provide insights into future climate trends and into the feasibility of mitigation options and mitigation pathways that are compatible with long-term goals (Riahi et al. 2022). Modelled pathways offer "stylized journeys towards long-term destinations" (Turnheim and Nykvist 2019), but they generally fail to fully account for real world complexities (Checkland 1985; IPCC 2017; Turnheim and Nykvist 2019). Models tend to focus more on the geophysical, technical and economic dimensions of feasibility, and to overlook its sociocultural, political and institutional dimensions (Riahi et al. 2015, 2022; Turnheim and Nykvist 2019; Jewell and Cherp 2020; Brutschin et al. 2021). As a result, solutions considered technically feasible and economically viable by the models may remain out of reach in the real world, for instance because of past choices and existing lock-ins, political and social inertia, vested interest of powerful actors, lack of political and public support, or other constraints not appropriately considered in the models (Riahi et al. 2015; Brutschin et al. 2021; Bosetti 2021; Blanco et al. 2022; Denton et al. 2022). By contrast, some solutions may appear in the real world that have not been anticipated by the models; for instance thanks to the emergence of disruptive technologies and new coalitions of actors leading to the establishment of new norms, or to more radical changes in political regimes. In recent years, progress in the deployment of small-scale technologies in renewable energies (such as solar panels, wind turbines and batteries for electric vehicles) has been much faster than anticipated by experts in previous mitigation scenarios, because of rapid innovation and decrease in costs (Dhakal et al. 2022). To address this gap between models and the real world, Turnheim and Nykvist (2019) highlight the need to bridge between different forms of knowledge, enrich the modelling work with new insights from social sciences, and develop multidimensional and transdisciplinary assessments. For them, models must be considered 'learning machines' rather than 'truth machines' as they provide only partial insights on the current situation and possible futures.

2.2 Desirability

In the literature, the two notions of *feasibility* and *desirability* have often been confounded. For instance, according to Patterson et al. (2018), "*political feasibility refers to the collective belief within a domestic political system about the scale and speed of decarbonization that is seen to be desirable and plausible within that society*". Similarly, the IPCC and subsequent studies have defined feasibility as 'the degree to which climate goals and response options are considered *possible* and/or *desirable*' (IPCC 2018b; Singh et al. 2020).

In reaction, other authors (e.g., Gilabert and Lawford-Smith 2012; Turnheim and Nykvist 2019; Jewel and Cherp 2020; Brutschin et al. 2021; Riahi et al. 2022), call for a clear distinction between these two notions, between what is *possible* or *plausible* (feasibility) and what is *appealing* or *desirable* (desirability). *Desirability* can then be defined as "*a normative assessment of the compatibility with societal goals (i.e., SDGs)*", while *feasibility* evaluates "*the plausibility of what can be attained given the* *prevailing context of transformation*" (Riahi et al. 2022). While *feasibility* deals with costs, constraints and capacities, *desirability* focuses on benefits, motivations and norms (Jewell and Cherp 2020). While *desirability* looks at the end-point, the final goal; *feasibility* studies the pathway, the next steps required to reach this goal. *Desirability* is concerned about the end, while *feasibility* deals with the means. In other words, *desirability* answers the 'Where? Where do we want to go?' when *feasibility* focuses on the 'How? From here, how can we get there?'. Moving from *desirability* to *feasibility* is moving from the problem statement to a more solution-oriented approach, concerned about the practical implications of the needed systemic changes (Turnheim and Nykvist 2019).

2.3 Tension and interlinkages between feasibility and desirability

Overall, the tension between *desirability* and *feasibility* is one between our ideal and the real world; between what we should do and what we can do. This tension is what John Rawls (2001) has called 'realistic utopia'. Social justice, moral and ethical considerations suggest a vision of what is morally desirable, which might turn out to be utopian. Hence, some compromises may be needed; more realistically feasible, 'second-best' or intermediate objectives may need to be defined. This tension between what should be and what, ultimately, can be is also reflected in the collective social learning cycle developed by Brown and Lambert (2015) and illustrated in Figure 1.

However, even if conceptually independent, these two concepts closely interact and may not be easy to distinguish in practice. On one side, desirability impacts feasibility. For instance, if a mitigation option provides multiple co-benefits for, say, climate action, food security and nutrition and poverty alleviation, it may appear as extremely desirable and may thus get wider political and public support. This, in turn, will create an enabling environment and facilitate implementation, also making the option more feasible. Long-term goals need to be translated in a sequence of short-term actions (temporal ordering), and moral and equity considerations always contribute to determining the success or failure of any process of policy reform (Gilabert and Lawford-Smith 2012; Turnheim and Nykvist 2019). On the other side, feasibility also affects desirability. For instance, if an option is considered hard or impossible to reach by the majority of agents (low feasibility), it will likely get less buy-in and appear less desirable. As Gilabert and Lawford-Smith (2012) note: "*We generally choose to stay away from uphill battles if we have another choice*".

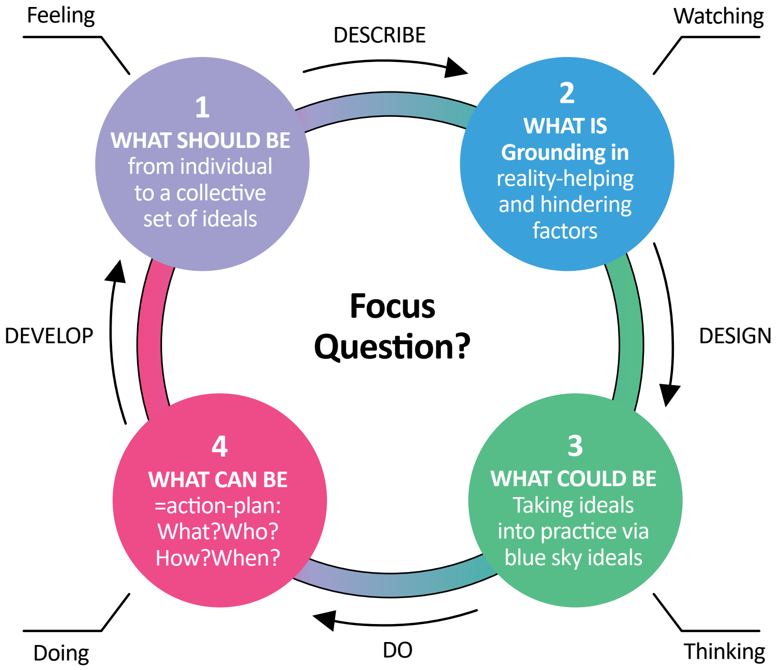

Figure 1. The four stages of the collective social learning cycle

Source: Atmadja et al. (2021), modified after Brown and Lambert (2015)

3 A comprehensive opportunity assessment framework

This section presents a comprehensive framework building upon the two interlinked notions of feasibility and desirability to assess the opportunity of mitigation options. Such a framework can help decision makers to rank alternative mitigation options and prioritize those that are both highly feasible and desirable.

3.1 Dimensions, indicators and metrics

Assessing and comparing the feasibility[1] of alternative mitigation options, all the more in a world of incomplete information, uncertainty and rapid changes, ultimately relies on subjective interpretation and a value judgement, based on one's own interests, views, perspectives, priorities and needs. However, frameworks, indicators and metrics can help assess and rank mitigation options, thus illuminating our choices and supporting decision making (Loftus et al. 2015).

Building upon previous political philosophy literature (e.g., Majone 1975a, 1975b; Gilabert and Lawford-Smith 2012), the IPCC special report on global warming of 1.5°C (SR1.5) introduced a multidimensional framework to assess the feasibility of adaptation and mitigation options, also used, with small adjustments, in IPCC AR6 (IPCC 2017; Allen et al. 2018; de Coninck et al. 2018; Grubb et al. 2022; IPCC 2022). This IPCC framework is already widely used by the scientific community (e.g., Singh et al. 2020; Brutschin et al. 2021; Roe et al. 2021; Tirado et al. 2022) and will likely become a reference for future studies. This IPCC framework covers six dimensions of feasibility that block (hard constraints), constrain (soft constraints) or enable (enabling conditions) the implementation of a mitigation option. These six dimensions are: the geophysical; environmental-ecological; technological; economic; sociocultural; and institutional dimensions.

The *geophysical* dimension assesses the physical potential of a given mitigation option and the available natural resource base, i.e., the capacity of a geophysical system to carry the option. The *environmental-ecological* dimension reviews the impacts of the option on the environment and its various components (e.g., biodiversity, soil, air and water). The *technological* dimension examines the simplicity, readiness and scalability of the required technology, as well as the corresponding risks. The *economic* dimension considers costs and impacts on employment and economic growth. The *sociocultural* dimension deals with human behaviours, sociocultural norms and beliefs. It assesses public support, distributional effects and impacts on human health and well-being. Finally, the *institutional* dimension analyses political support, participation, institutional capacity and governance mechanisms, and the legal and regulatory framework (de Coninck et al. 2018; Grubb et al. 2022).

As highlighted in the previous section, feasibility in these six dimensions is highly dynamic and context-specific. It varies across space, time, scale and according to the temperature goal (Roe et al. 2021; IPCC 2022; Pathak et al. 2022). Synergies and trade-offs can occur across space and time, between alternative mitigation and/or adaptation options, among development objectives (mitigation, adaptation and other SDGs), and across feasibility dimensions (Allen et al. 2018; de Coninck et al. 2018; Singh et al 2020; IPCC 2022). Therefore, adopting an integrated perspective, which aligns climate action and sustainable development, and privileges mitigation options that provide multiple co-benefits and advance various SDGs simultaneously, could likely improve resource-use efficiency and reduce the social costs, thus increasing stakeholder buy-in,

1 The same can be said about desirability and, finally, opportunity.

social acceptability and political support and, finally, strengthening the political feasibility of such integrated mitigation options (Denton et al. 2022; Lecocq et al. 2022; Pathak et al. 2022). The IPCC (2022) has suggested a set of 18 indicators to document these six feasibility dimensions, as illustrated in Table 1.

The remaining part of this paper presents and discusses an improved framework developed by the authors for the assessment and ranking of alternative mitigation options according to their level of opportunity. This opportunity assessment framework (OAF), illustrated in the table in the Annex, is largely inspired by the IPCC (2022) framework, with some significant differences and specific developments. This OAF differs from the IPCC framework in three important ways:

First, the OAF covers the six dimensions of feasibility defined by the IPCC and considers the 18 IPCC indicators listed in Table 1. But it also includes additional indicators and metrics, shedding more light on some topics of particular importance for land use and food systems, which were covered under broader indicators in the IPCC framework, but deserve to be considered separately or more explicitly. These additional (or expanded) topics include: dependence on fossil energy; soil organic carbon (SOC) stock and soil health; poverty; food security and nutrition; and absence of technological risk.[2] Regarding the economic dimension, the OAF, unlike the IPCC framework, considers not only mitigation costs, but also the economic mitigation potential and the expected benefits of the mitigation option.

Table 1. Feasibility assessment of mitigation options: The IPCC framework (dimensions and indicators)

Dimension	Indicators
Geophysical	Physical potential: physical constraints to implementation
	Geophysical resource availability (including geological storage capacity): availability of resources needed for implementation
	Land use: claims on land when option would be implemented
Environmental-ecological	Air pollution: increase or decrease in air pollutants, such as NH_3, CH_4 and fine dust
	Toxic waste, mining, ecotoxicity and eutrophication
	Water quantity and quality: changes in amount of water available for other uses, including groundwater
	Biodiversity: changes in conserved primary forest or grassland that affect biodiversity, and management to conserve and maintain land carbon stocks
Technological	Simplicity: is the option technically simple to operate, maintain and integrate
	Technology scalability: can the option be scaled up, quickly
	Maturity and technology readiness: R&D and time needed to implement the option
Economic	Costs now, in 2030 and in the long term, including investment costs, costs in USD tCO_2e^{-1}, and hidden costs
	Employment effects and economic growth
Sociocultural	Public acceptance: extent to which the public supports the option and changes behaviour accordingly
	Effects on health and well-being
	Distributional effects: equity and justice across groups, regions and generations, including security of energy, water, food and poverty
Institutional	Political acceptance: extent to which politicians and governments support the option
	Institutional capacity and governance, cross-sectoral coordination: capability of institutions to implement and handle the option, and to coordinate it with other sectors, stakeholders and civil society
	Legal and administrative capacity: extent to which supportive legal and administrative changes can be achieved

Source: IPCC (2022)

2 This last indicator on risk, originally present in the 2018 version of the IPCC framework, was not included in the 2022 version.

Second, the OAF adds a new layer of precision to the previous IPCC framework by suggesting, for each indicator, specific metrics – either quantitative or qualitative – that are relevant for mitigation actions in land use and food systems. Even the metrics initially designed as quantitative can be transformed into a qualitative scale when and where the required quantitative data are missing. The OAF includes 39 different metrics, of which 21 are quantitative and 18 qualitative, serving to illustrate and document each indicator more precisely and more explicitly, thus better guiding expert judgement and evaluation. This list of metrics can be adjusted based on local needs and priorities, data availability and context specificities. This gives flexibility to the general framework (in terms of its dimensions and indicators) so it can be easily adapted and applied in a variety of situations. The current list of indicators and metrics that make up the OAF is open to discussion and adaptation, based on emerging evidence. Its relevance, sensitivity and robustness still need to be tested in a diversity of situations on the ground, and to receive feedback from various stakeholder groups to improve it.

Third, the OAF makes a clearer conceptual distinction between *feasibility* (F) versus *desirability* (D), linking each specific metric with one of these two notions. Metrics illustrating expected impacts and benefits or assessing the alignment between climate action and other development objectives (e.g., food security and nutrition, poverty reduction) are preferably linked to *desirability.* By contrast, those metrics illustrating constraints, costs or capacities (such as timeline for readiness or upfront investments) are preferably linked to *feasibility.* In the current version of the framework, out of the 39 metrics, 23 are linked to *feasibility* and 16 to *desirability.* Of course, this classification is also open to discussion and adjustments, since, as demonstrated in Section 2, the distinction between these two notions is not always clear-cut. When aggregating the results obtained across indicators and metrics, this classification allows the calculation of two sub-scores to separately assess the overall feasibility and desirability of a given mitigation option.[3]

3.2 Scoring and aggregation method

The IPCC (de Coninck et al. 2018; IPCC 2022; Pathak et al. 2022) suggested methods for scoring and aggregating that allow an averaging of results obtained within and across feasibility dimensions, or at different points in time. This supports assessment of the overall feasibility and desirability of a mitigation option in a given (spatial and temporal) context. Such integrated aggregation methods also allow for the identification of potential trade-offs among feasibility dimensions, and an assessment of the timing, scale and disruptiveness of the required transformations.

Following up on and improving the IPCC work, for a given mitigation option in a given (spatial and temporal) context, each metric in the OAF, whether quantitative or qualitative, can be assessed qualitatively according to the following list:

- NA (not applicable): the metric is not relevant to the given mitigation option in the given context
- NE (no evidence): the opportunity assessment cannot be grounded on available evidence
- LE (limited evidence: there is limited available evidence on which to ground the opportunity assessment[4]
- HC (hard constraint): the metric is likely to block the feasibility of the given option in the given context
- SC (soft constraint): the metric is likely to limit the feasibility of the given option in the given context (soft constraint), or to impact negatively on its desirability
- ±: Mixed evidence: the metric has mixed positive and negative, or uncertain impacts on the feasibility or desirability of the given option in the given context
- N: Neutral: the metric does not affect the feasibility or desirability of the given option in the given context
- + (enabler): the metric is likely to strengthen the feasibility or desirability of the given option in the given context.

3 See the next section for the scoring and aggregation method.

4 For the IPCC (de Coninck et al. 2018), evidence is considered limited if less than two papers can be used as a basis for the assessment, or more than two papers but where the topic is covered as a side-issue and not as the core focus of the paper.

Table 2. Attributing a quantitative score to the qualitative assessments

Qualitative assessments*	Quantitative score
NA; NE; LE	-
HC	0
SC	0.5
N; ±	1
+	2

Note: *Acronyms in this column are defined above in the main text.

Source: Authors, based on the IPCC (de Coninck et al. 2018; IPCC 2022).

These qualitative assessments can then be associated with a quantitative score, as shown in Table 2.

As a final step, scores obtained for each metric can then be aggregated within and across each indicator, feasibility dimension and category (feasibility versus desirability) to assess the overall opportunity of the given mitigation option in the given context. No score is attributed when the metric is not relevant or the evidence base is lacking, and such metrics are excluded from aggregation exercises. Following the IPCC (Pathak et al. 2022), we use the geometric mean for aggregation, so that one hard constraint identified on one metric (associated with a score of 0) is enough to block the overall feasibility of a mitigation option.

4 Discussion and conclusion

The opportunity assessment framework (OAF) introduced in this paper is designed to facilitate the assessment and ranking of alternative mitigation options in land use and food systems, based on their desirability and feasibility. As mentioned above, desirability and feasibility depend heavily on the local context, the speed and scale of implementation, and the stringency of the climate target (IPCC 2022; Pathak et al. 2022). The OAF covers the six dimensions of feasibility defined by the IPCC, namely the geophysical, environmental-ecological, technological, economic, sociocultural and institutional constraints.

Given that the global food system accounts for about one third (range: 23–42%) of total global net anthropogenic GHG emissions, an integrated framework can be very helpful for policymakers to identify the “low-hanging fruits” among all possible mitigation measures, i.e., those that have the highest transformative potential; can be most easily implemented; and are most adapted to the local conditions, priorities and needs. This OAF could thus help countries raise the ambition of their NDCs by prioritizing and implementing highly viable mitigation options immediately, to rapidly achieve a maximum drawdown of emissions. While climate action pathways that rely on a large variety of mitigation options are generally seen as more robust and resilient (Pathak et al. 2022), spreading limited financial and political resources across too many options could reduce efficiency and thus the chances of success for them all (Jewell and Cherp 2020). By identifying priority mitigation options, the OAF can help address this trade-off, optimize resource allocation, and support effective decision making, thus leading to faster and more sustainable results, because obstacles are identified at an early stage. This will likely lead to lower frustration levels and lower risk of reversals following policy swings. Yet, the successful implementation of mitigation options still depends heavily on the following enabling conditions: stakeholder engagement and participation; multi-level governance; public acceptance and political support; institutional capacity and resource mobilization; changing lifestyles and behaviours; technological innovation; and knowledge and technology transfer (de Coninck et al. 2018).

One of the strengths of the OAF is its comprehensive and integrated nature, covering a wide range of feasibility dimensions. This integrated OAF will facilitate the identification of synergies and trade-offs across feasibility dimensions, mitigation options and development objectives. It will also help align mitigation action with broader development goals (such as food security, poverty reduction and sustainable development) on the one hand, and with local conditions, priorities and needs on the other. This better alignment will likely foster political support and public acceptance for the proposed options, thus increasing their political feasibility and desirability. Such an integrated approach will facilitate the design and implementation of robust, sustainable and climate-resilient development pathways through stakeholder engagement and collaborative governance at multiple levels (Schipper et al. 2022). It will support a holistic evaluation of mitigation options, balancing quick wins with long-term goals. Finally, the inclusion of 23 indicators, extending beyond the 18 original IPCC indicators, ensures that critical aspects specific to land use and food systems, such as soil health and food security, are adequately addressed. Additional indicators on economic mitigation potential, production enhancement potential and impact on poverty in the OAF also reinforce the economic dimension that has been somewhat neglected in the original IPCC framework.

Because of its relative conciseness and simplicity, some blind spots remain in this short set of 23 indicators. The current version of the OAF is quite static, providing a comprehensive picture of a given mitigation option at a given time in a given place. Enriching the framework with dynamic indicators (such as rate of technology development or rate of decarbonization) would allow relevant stakeholders to also consider the spatial and temporal interactions and dynamics at stake, critical in the development of any climate scenario (Gambhir et al. 2017). While it considers different mitigation potentials, the current version of the framework does not explicitly address the three issues of additionality, permanence and leakage that critically impact the effectiveness of any mitigation option (see for instance Nabuurs et al. 2022 for a more detailed discussion on these issues). Filling these gaps is another key area for further work.

However, the more is added, the more complex and expensive the framework becomes. This could potentially make it less viable for any practical application without significant deployment of efforts and resources. Data collection and, more generally, effective climate action can prove to be even more complex in the agrifood domain given its inherent heterogeneity and fragmentation, characterized by the multiplicity of actors, farming systems, products and value chains (Turnheim and Nykvist 2019; Nabuurs et al. 2022). In such a fragmented landscape, large stakeholder engagement and coalitions will be critical to enable transformational changes (Atmadja et al. 2021b). The framework's reliance on both quantitative and qualitative metrics can also introduce subjectivity and variability in assessments, particularly where data availability is limited, and where different users apply the qualitative parameters in different ways. On the other hand, qualitative indicators can contribute to filling the knowledge gap when quantitative information is missing. The lack of data can be remedied by more direct data collection, in line with a new emphasis given to local data also in the UNFCCC context. The lack of consistency in assessment can be overcome by the development of rigorous protocols for (qualitative) data collection and training provided to applicants of this approach. Therefore, a key area for further development is enhancing the framework's precision and robustness without compromising its viability. This might involve streamlining indicators, improving data collection methods, and fostering collaborations with local stakeholders to ensure the OAF is appropriately tailored to their specific contexts, priorities and needs.

The development of the OAF is an ongoing process, requiring testing, feedback and refinement to ensure it is robust, relevant, practical and effective in real-world contexts and applications. Developing case studies and examples of successful implementation can provide valuable insights and demonstrate the framework's utility. Future implementations could focus on specific countries or regions to identify priority pathways and validate the framework's relevance and robustness. Finally, financial support and collaboration with stakeholders will be two crucial enabling conditions to operationalizing the framework and achieving the necessary systemic transformations to meet the global climate targets of the Paris Agreement and advance the broader sustainable development goals of the 2030 Agenda.

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Annex

Annex. Opportunity assessment framework (OAF) to rank mitigation options based on their desirability and feasibility

Dimensions	Indicators	Metrics	Feasibility vs. desirability	Quantitative vs. qualitative	Unit or list of possible answers
Geophysical	Physical mitigation potential	Expected quantity of GHG saved or removed through the considered option	D	Quant.	tCO_2e
	Resource availability (land, water, energy): Is the option constrained by geophysical resource availability?	Quantity of land required or saved	F	Quant.	ha tCO_2e^{-1}
		Quantity of water required or saved	F	Quant.	m^3 tCO_2e^{-1}
		Quantity of non-renewable (fossil) energy required or saved	F	Quant.	GJ tCO_2e^{-1} or MWh tCO_2e^{-1}
Environmental-ecological	Soil Organic Carbon (SOC) stock	Expected increase or decrease in SOC stock (down to 1 m depth)	D	Quant.	tC ha^{-1} $year^{-1}$ (or % annual variation)
	Soil health and land degradation	What is the expected impact (of the option) on soil health and soil degradation processes (e.g., erosion, compaction and sealing, acidification, salinization and sodification)?	D	Qual.	Negative, Neutral, Positive
	Water quality	Expected impact on water quality (e.g., eutrophication)	D	Qual.	Negative, Neutral, Positive
	Biodiversity	Expected impact on biodiversity and ecosystems	D	Qual.	Negative, Neutral, Positive
	Air quality	Expected impact on air quality (e.g., by releasing air pollutants such as NH_3, CH_4, fine dust)	D	Qual.	Negative, Neutral, Positive
	Pollution	Risk of diffuse pollution for air, soil and water	F	Qual.	Absent, Low, Medium, High
		Risk of point-source pollution for air, soil and water	F	Qual.	Absent, Low, Medium, High

Continued on next page

Annex. Continued

Dimensions	Indicators	Metrics	Feasibility vs. desirability	Quantitative vs. qualitative	Unit or list of possible answers
Technological	Maturity and technology readiness	In which phase of the IPCC innovation cycle does the option presently lie?	F	Qual.	Emergence, Early adoption, Diffusion, Stabilization
		Expected timeline for readiness	F	Qual.	Now, Before 2030, 2030–2050, After 2050
	Simplicity and scalability: What are the barriers to implementation and scaling up?	Required upfront investments	F	Quant.	USD tCO_2e^{-1}
		Required human capacities and skills	F	Qual.	Absent, Insufficient, Available
		Required physical infrastructure	F	Qual.	Absent, Insufficient, Available
	Absence of risk related to the technology	Description and qualification of the risk(s)	F	Qual.	Absent, Low, Medium, High
Economic	Economic mitigation potential	Break-even carbon price	F	Quant.	USD tCO_2e^{-1}
		Economic mitigation potential at a carbon price of USD 20 t^{-1} or USD 100 t^{-1}	F	Quant.	tCO_2e
	Production enhancement potential	Expected benefits	D	Quant.	USD tCO_2e^{-1}
	Costs	Marginal costs	F	Quant.	USD tCO_2e^{-1}
		Stranded assets (in case of phasing out of a technology)	F	Quant.	USD tCO_2e^{-1}
		Evolution of cost-benefit ratio over the project lifetime	F	Quant.	No unit (%)
	Impact on poverty	Prevalence of poverty among involved or affected population	D	Quant.	%
	Impact on employment	Number of jobs created or destroyed	D	Quant.	Number tCO_2e^{-1}
		Number of skilled jobs created or destroyed	D	Quant.	Number tCO_2e^{-1}

Continued on next page

Annex. Continued

Dimensions	Indicators	Metrics	Feasibility vs. desirability	Quantitative vs. qualitative	Unit or list of possible answers
Sociocultural	Distributional effects and equity	Ratio winners / losers among involved or affected population	D	Quant.	No unit
		Expected impact on the different vulnerable groups (women, young, elderly, Indigenous Peoples, rural communities)?	D	Qual.	Negative, Neutral, Positive
		Expected impact on power structures and power asymmetry	D	Qual.	Negative, Neutral, Positive
	Public support	% of support among the involved or affected population	F	Quant.	%
	Food security and nutrition	Prevalence of undernourishment among involved or affected population	D	Quant.	%
		Prevalence of obesity and overweightness among involved or affected population	D	Quant.	%
	Effects on health and well-being	Expected impact on human health and well-being	D	Quant.	Negative, Neutral, Positive
Institutional	Political support	Governmental support for the option	F	Qual.	Absent, Low, Medium, High
		Political consensus around the option (among political parties and elected representatives at different scales)	F	Qual.	Absent, Low, Medium, High
	Institutional capacity	Multilevel and cross-sectoral governance mechanisms	F	Qual.	Absent, Insufficient, Available
		Inclusive stakeholder consultation and participation	F	Quant.	%
		Capacity building, extension services	F	Qual.	Absent, Insufficient, Available
	Legal, regulatory and administrative capacity	Need for policy reform to enable implementation	F	Qual.	Yes, No

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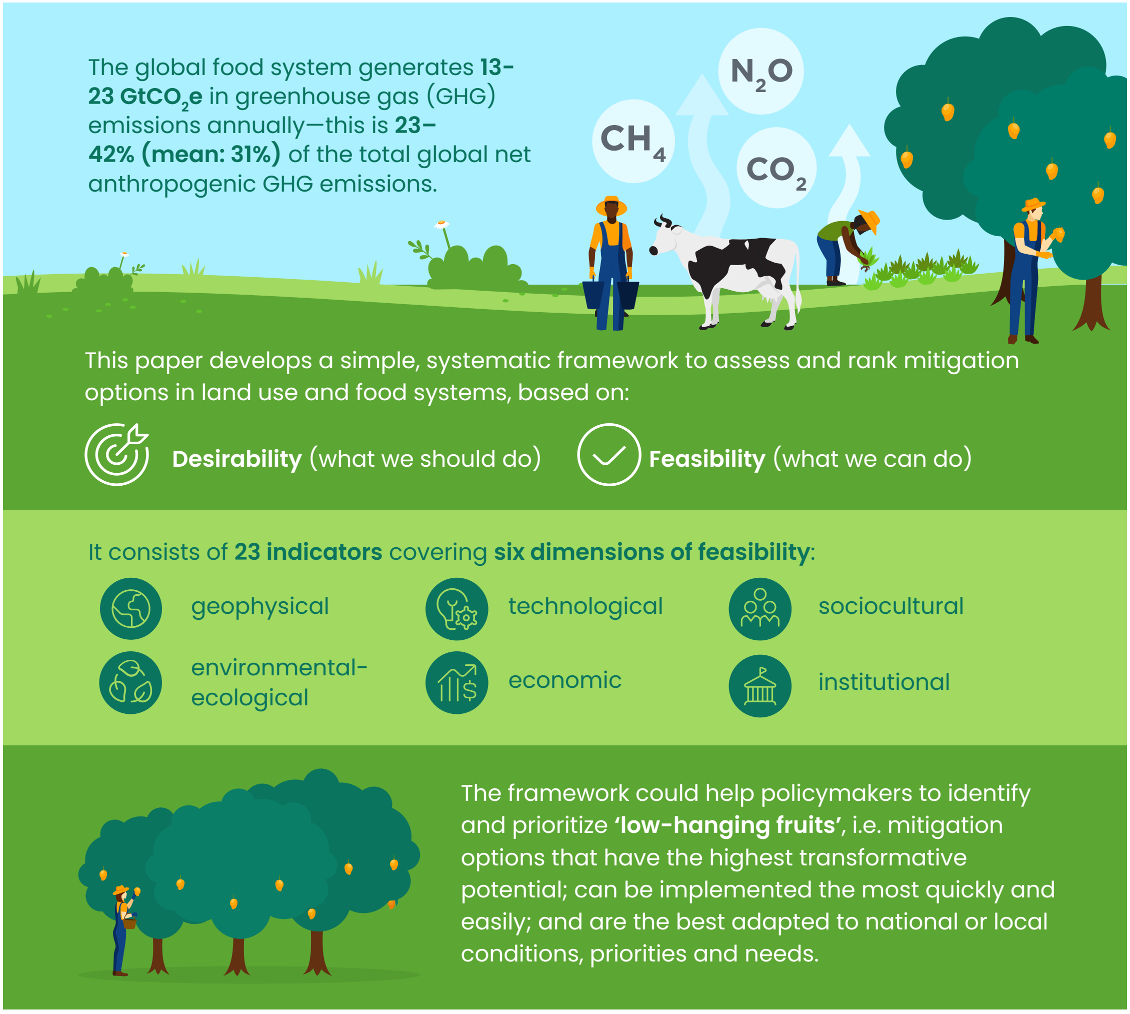
***CIFOR-ICRAF Working Papers* contain preliminary or advanced research results on important tropical forest issues that need to be published in a timely manner to inform and promote discussion. This content has been internally reviewed but has not undergone external peer review.**

The global food system generates substantial greenhouse gas (GHG) emissions, amounting to 13–23 $GtCO_2e$ annually, or 23–42% (average: 31%) of the total global net anthropogenic GHG emissions. Yet, despite its importance, the food system is still rarely considered holistically in climate policies, strategies and plans. To help fill this gap, this paper develops a simple but systematic, comprehensive and integrated framework to assess and rank alternative mitigation options in land use and food systems, based on their desirability (what we should do) and feasibility (what we can do). This framework consists of 23 indicators covering the six dimensions of feasibility defined by the Intergovernmental Panel on Climate Change (IPCC), namely: the geophysical, environmental-ecological, technological, economic, sociocultural and institutional dimensions. Such a framework could help policymakers to raise the ambition of their Nationally Determined Contributions (NDCs) and climate policies by identifying and prioritizing 'low-hanging fruits', i.e., mitigation options that have the highest transformative potential; can be implemented the most quickly and easily; and are the best adapted to national or local conditions, priorities and needs.



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