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Reassessing the need for carbon dioxide removal: moral implications of alternative climate target pathways

Lieske Voget-Kleschin[1], Christian Baatz[1], Clare Heyward[2], Detlef Van Vuuren[3,4] and Nadine Mengis[4,5]

[1]Department of Philosophy, Kiel University, Kiel, Germany; [2]Institute of Philosophy, UiT: The Arctic University of Norway, Tromsø, Norway; [3]PBL Netherlands Environmental Assessment Agency, The Hague, The Netherlands; [4]Utrecht University, Copernicus Institute of Sustainable Development, Utrecht, The Netherlands and [5]Biogeochemical Modelling, GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany

Review Article

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Corresponding author:
Nadine Mengis; Email: nmengis@geomar.de

Abstract

Non-technical summary. Scenarios compatible with the Paris agreement's temperature goal of 1.5 °C involve carbon dioxide removal measures – measures that actively remove CO_2 from the atmosphere – on a massive scale. Such large-scale implementations raise significant ethical problems. Van Vuuren et al. (2018), as well as the current IPCC scenarios, show that reduction in energy and or food demand could reduce the need for such activities. There is some reluctance to discuss such societal changes. However, we argue that policy measures enabling societal changes are not necessarily ethically problematic. Therefore, they should be discussed alongside techno-optimistic approaches in any kind of discussions about how to respond to climate change.

Technical summary. The 1.5 °C goal has given impetus to carbon dioxide removal (CDR) measures, such as bioenergy combined with carbon capture and storage, or afforestation. However, land-based CDR options compete with food production and biodiversity protection. Van Vuuren et al. (2018) looked at alternative pathways including lifestyle changes, low-population projections, or non-CO_2 greenhouse gas mitigation, to reach the 1.5 °C temperature objective. Underlined by the recently published IPCC AR6 WGIII report, they show that demand-side management measures are likely to reduce the need for CDR. Yet, policy measures entailed in these scenarios could be associated with ethical problems themselves. In this paper, we therefore investigate ethical implications of four alternative pathways as proposed by Van Vuuren et al. (2018). We find that emission reduction options such as lifestyle changes and reducing population, which are typically perceived as ethically problematic, might be less so on further inspection. In contrast, options associated with less societal transformation and more techno-optimistic approaches turn out to be in need of further scrutiny. The vast majority of emission reduction options considered are not intrinsically ethically problematic; rather everything rests on the precise implementation. Explicitly addressing ethical considerations when developing, advancing, and using integrated assessment scenarios could reignite debates about previously overlooked topics and thereby support necessary societal discourse.

Social media summary. Policy measures enabling societal changes are not necessarily as ethically problematic as commonly presumed and reduce the need for large-scale CDR.

1. Introduction

Due to the Paris Agreement, much attention and research has gone into the question of how to limit global warming to 1.5 °C (see e.g. IPCC, 2018). In this context, several scenarios were introduced that include carbon dioxide removal (CDR) measures, most prominently the land-based CDR measure bioenergy combined with point source carbon capture and geological storage (BECCS). On average, scenarios that remain within the 1.5 °C temperature limit with no or only a limited (below 0.1 °C) temperature overshoot include 4.5 Gt CO_2 per year of BECCS by 2050, and 12.4 Gt CO_2 per year by 2100 (IPCC, 2018, Table 2.4). The latest IPCC assessment report emphasizes the need for CDR: 'The deployment of CDR to counterbalance hard-to-abate residual emissions is *unavoidable* if *net zero* carbon dioxide or *greenhouse gas emissions are to be achieved*' (IPCC, 2022, C.11, emphasis added).

CDR measures seemingly offer a solution to the shrinking carbon budget that comes with ambitious climate mitigation (Minx et al., 2018). They offer the possibility to (i) support current mitigation efforts by reducing current net emissions, (ii) compensate for future residual emissions to achieve net zero CO_2 or greenhouse gases (GHGs), and (iii) reverse a carbon budget overshoot with net negative emissions. When they first came to prominence, in the early days of the so-called 'geoengineering' debate, CDR technologies were largely regarded as

somewhat benign, but it is now acknowledged that CDR measures raise a host of ethical questions (for an overview see e.g. Heyward, 2019; Minx et al., 2018). One of the first problems raised by commentators was that increasing discussion of CDR measures could distract attention from the essential task of reducing emissions – the objection popularly known as 'moral hazard' (Anderson and Peters, 2016; Fuss et al., 2014). Furthermore, if deployed at the scale specified in the 1.5 °C scenarios, land-based or terrestrial CDR (tCDR) such as BECCs would compete with other demands for land. Given that most of the biomass provided for BECCS in ambitious mitigation scenarios is projected to come from the Global South (Daioglou et al., 2020; Fajardy et al., 2021), biomass-based CDR options have been identified as an agrarian challenge that would be imposed on developing countries (McElwee, 2022) that have contributed little to causing the problem. Therefore, the drive to develop and use tCDR options may provide an excuse for some parties to ride rough-shod over the land rights of indigenous communities, smallholders, or other local communities (Bluwstein & Cavanagh, 2023), as has happened in the past (Neudert & Voget-Kleschin, 2021). Other side-effects associated with land-use demand include stress on water supply and negative effects regarding biodiversity and ecosystems (Boysen et al., 2017; Heck et al., 2018, 2016). Finally, a problem for BECCS approaches is the need for permanent storage of CO_2 in geological formations, given previous controversy in Germany and the Netherlands (Akerboom et al., 2021; *Bürgerinitiative gegen CO2-Endlager e.V*, n.d.; *Mogelpackung CCS*, n.d.). The topic of geological CO_2 storage has since become a deal-breaker within the German political debate (Hahn et al., 2020).

Despite these potential difficulties, most scientific articles detailing ambitious mitigation scenarios include large deployment of tCDRs, most usually BECCS; and alternative pathways entailing behavioral change and societal transformation rarely feature (Beck & Mahony, 2018; Bellamy, 2016). It has been observed that in the history of climate change debates, some self-imposed so-called 'taboos' have been present in that certain kinds of response to climate change have been avoided, from adaptation to solar radiation management (Lawrence, 2006; Lawrence & Crutzen, 2017; Rayner et al., 2007). 'Taboo' is perhaps not the most accurate term, but it has been used loosely by these authors to describe collective explicit or implicit reservations about discussing or considering certain options with potentially highly undesirable consequences. Within the broad category of emission reductions, some particular strategies have been similarly tabooed; the most obvious example being the widespread avoidance of discussing limiting population growth (Cripps, 2012, 2016; Heyward, 2012).

To a lesser, but still significant extent, talk about scenarios that more obviously require societal change is largely avoided. It is regularly assumed that such scenarios will be more difficult or costly to implement and/or that it is impermissible to implement policy measures that push people to adopt certain 'green' lifestyles. On a number of accounts, 'telling people how to live', for example, how to dispose of their income, how to spend their time, etc., is morally problematic in itself, being patronizing and disrespectful of the autonomy of adult citizens.

This implicit assumption is connected to the problem of 'moral hazard' referred to above: presumably the chances of anything 'distracting' from emission reductions would be vastly reduced if the latter were easy and cheap to implement and ethically unproblematic. This seems to be behind Pozo et al.'s (2020) claim that an 'international CDR supply chain […] seem [s] to be necessary to meet the long-term Paris goals *and avoid drastic demand side-measures and lifestyle changes*' (Pozo et al., 2020; emphasis added). Relatedly, Healey et al. (2021) state '[for] the majority of high emitting countries, [perceived] fungibility between emissions and CDR sequestration targets provides a *temptation* to delay efforts with the *more lifestyle-challenging or expensive policies of emission reduction*' (emphasis added). Others, for example, Prinzing (2023) have called for a 'reframing' to emphasize the benefits of emission reduction measures and green lifestyles, which makes sense only if the dominant framings claim or imply that such lifestyles are unattractive. (Prinzing notes that much environmentalist discourse has long invoked notions of 'self-sacrifice' and simple, or even austere lifestyles. There has also been considerable use of apocalyptic rhetoric in environmental movements along the lines that [vast sections of] humanity must change its ways in order to avert catastrophe (Heyward & Rayner, 2016). The use of a threat rhetoric implies that those to whom it is directed would be unwilling to make the changes without it.)

The tendency to assume that calling for social change is problematic and thus avoiding it is unhelpful – and perhaps even unnecessary. Achieving emission reductions through requiring or facilitating social transformation might, on closer inspection, not be as morally problematic as sometimes assumed. This study is a first attempt at providing a closer inspection. Van Vuuren et al. (2018) are one of the relatively few who have modeled alternative pathways to 1.5 °C. We here discuss some key moral issues raised by the assumptions of their four alternative transformation pathways involving societal transformations, and their implications. The scenarios are called 'lifestyle change scenario', a 'low non-CO_2 GHGs scenario', an 'agricultural intensification scenario', and a 'low-population scenario' (see info box for more information). All of the scenarios aim to be moderate in their assumptions, for example, reduction rather than abandonment of meat consumption, and decreasing population growth by means of policies aiming at a higher average level of education rather targeting procreation directly. However, as even these moderate scenarios seem vulnerable to ethical objections, it is helpful to examine whether such objections are warranted. This is the task of this article.

We limit discussion to the scenarios in Van Vuuren et al. and the analysis here is intended only as a starting point. We also limit our discussion to ethical permissibility, not political feasibility or any other political concerns. Moral permissibility and political feasibility are linked, but by no means co-extensive. Moral reasons are frequently invoked in political debates and a widespread perception that a policy is unfair, unjust, or morally impermissible will seriously affect public acceptability and therefore (in more democratic countries) political feasibility.

There is of course a risk of a prospective or retrospective political backlash against implementation of any kind of social or technological change motivated by climate concerns. Serious backlashes can even jeopardize overall support for action on climate change and the move toward decarbonization. One possible way of minimizing such backlashes is to take seriously the fact that all climate response measures and initiatives will raise possible moral concerns and to acknowledge and discuss these from the outset. For the vast majority of possible measures – and certainly the pathways discussed in this article – none should be taken as inherently benign nor inherently problematic; their permissibility or lack thereof will depend mostly on context and implementation.

We start by examining four scenarios. Our analysis focuses whether policies assumed in the lifestyle change and in the low-population scenario could qualify as permissible (Section 2.1–2.2). Based on this discussion, and because the low non-CO_2

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and the agricultural intensification scenario seem to assume a significantly smaller extent of societal transformation, our analysis of the latter scenarios centers on more concrete pros and cons (Section 2.3–2.4). Section 3 draws out some implications of each scenario related to both intra and inter-generational justice. Section 4 concludes.

Info box: details on the Van Vuuren et al. (2018) **scenarios**

All scenarios introduced by Van Vuuren et al. (2018) are designed to reach a radiative forcing of 1.9 W/m^2 at the end of the century, which is equivalent to limiting global mean temperature change to 1.5 °C, by implementing a uniform carbon tax. The default scenario includes a rapid transformation of the energy and land-use systems: in the energy system, the uptake of low-carbon energy sources increases rapidly from 15% to about 80% in 2050 worldwide. This is achieved through bioenergy, CCS, and solar, wind, and nuclear power deployments. Nevertheless, the default scenario uses about 750 Gt CO_2 of CDR cumulatively between 2010 and 2100 to offset an overspend carbon budget to then achieve the end-of-the-century radiative forcing limit (Van Vuuren et al., 2018).

The additional six scenarios include the same assumptions but then employ additional measures attempting to reduce the need of CDR: (1) energy efficiency (Eff), (2) renewable electricity (RenElec), (3) agricultural intensification (AGInt), (4) low non-CO_2 emissions (LoNCO2), (5) lifestyle changes (LiStCh), (6) low-population growth (LowPop).

Van Vuuren et al. (2018) found that at the end of the century, all scenarios have a similar amount of gross positive carbon emissions of about 1,000 Gt CO_2 (see black bars of Figure 1). The main difference between the scenarios is the amount of gross negative emissions implemented (i.e. blue and green bars of Figure 1) and accordingly the net amount of net cumulative emissions (yellow dots of Figure 1). The most effective scenarios for reducing the need for tCDR are the low non-CO_2 GHG, the lifestyle change, and the agricultural intensification scenarios (Van Vuuren et al., 2018). Cumulative BECCS emissions between 2010 and 2100 were reduced to about 200 Gt CO_2 for the low non-CO_2 scenario, compared to about 750 Gt CO_2 in the default scenario. Van Vuuren et al. (2018) conclude that the amount of BECCS can be limited if societal and technological factors are changed, and even entirely avoided if all six efforts are combined (see total scenario in Van Vuuren et al., 2018).

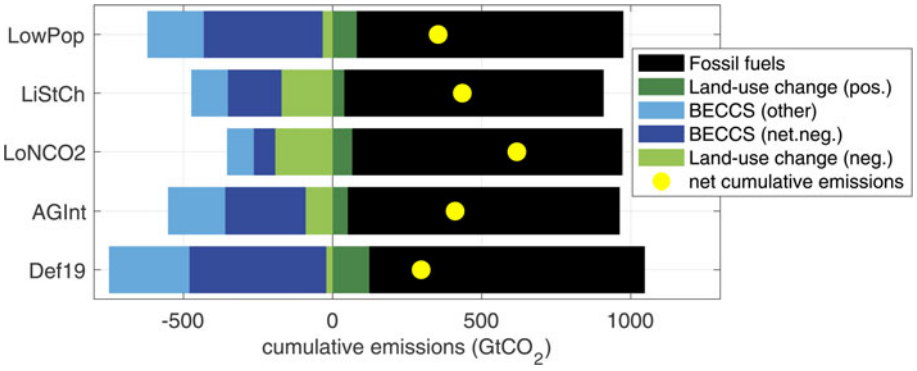

Figure 1. CO_2 emissions for the 1.9 W/m2 mitigation scenarios. The plot shows cumulative emissions for the 2010-2100 period partitioned into positive fossil fuel emissions (black), negative emissions from BECCS (dark blue for net negative emissions, light blue for other BECCS) and land-use change emissions (dark green for positive emissions, light green for negative emissions). The yellow marker represents the net emissions. Source: Fig. 2c in Van Vuuren et al., 2018

2. Moral analysis of the scenarios

Before we begin our analysis, a note on the terminology and set up might be helpful. The 'lifestyle change scenario' is not about lifestyle changes per se. After all, any response to climate change, like climate change itself, will cause changes in at least some of the ways that at least some people live their lives. Instead, this scenario is limited to consumer habits connected to everyday economic consumption. (In particular, those consumption patterns associated with a relatively affluent [Western] lifestyle.) In this scenario, consumers reduce meat consumption and food waste. They also adopt less CO_2-intensive transport modes, reduce ownership and use of domestic appliances, and less intensive use of heating and cooling systems in their homes. The second scenario, 'low population', is different in that it is not about individual consumer choices. Whilst having children clearly affects household consumption, it is not normally classified as a consumer choice. This is arguably for good reason: the decision to have a child is qualitatively and morally different from engaging in high-emission economic consumption and the two should not be treated as morally equivalent (e.g. Heyward, 2012). The third scenario, 'low non-CO_2', turns from the realm of household choices to the production of goods. In this scenario, the focus is on reducing non-CO_2 GHG emissions, in particular, the CH_4 emissions associated with livestock farming and meat production. A key part of such reduction is the move from traditional livestock rearing for meat production to cultured meat and animal products. This scenario would not only lead to reduced emissions, but also increase animal welfare without opposition from people that do not want to switch to vegetarian or vegan diets. Finally, the fourth scenario 'agricultural intensification' retains the focus on meat production but does not envisage the replacement of traditional meat and animal-based food products.

2.1 Lifestyle changes

As noted above, Van Vuuren et al.'s 'lifestyle change scenario' assumes that consumers change their consumption habits: namely dietary changes, the use of less CO_2-intensive transport, heating, and cooling, and an outright reduction of the use of domestic appliances. In many countries, there is already increasing vegetarianism and veganism, which has not been directly policy-induced. However, it is unreasonable to expect that sufficient numbers of consumers will make such changes without significant policy initiatives and incentivization. Therefore, to ensure sufficient change at scale, policy measures should aim at designing so-called 'consumption environments' that enable, support, and – in certain situations – demand climate-friendly consumption (WBAE, 2020).

However, such a substantial incentivization of low-GHG lifestyles and accompanying discouragement of high-GHG lifestyles are criticized in public debates as interfering with people's

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ability to freely choose how to live. According to such critique, the state ought to not tell people how to live fulfilling lives, as that is up to its citizens to decide for themselves (Food and Soft Drinks: Nanny State Index in the European Union [EU-28] 2021, 2021; Harrabin, 2018; Schmidt and Engelen, 2020; Sugden, 2009; Tapsfield, 2021).

The political philosophy in which such arguments are rooted claims that the state ought to be neutral regarding questions of the good life. This is regarded by some as a key component in liberal democracies. According to John Rawls, state neutrality is achieved if the 'aims of the basic institutions and public policy […] can be said to be neutral with respect to […] conceptions of the good' (Rawls, 2001, p. 153). Such conceptions give meaning to one's life and entail ideas about, for example, whether and how to believe in a deity; whether, with whom and how to form a family and what occupation and hobbies are rewarding.

However, the argument that the state ought not to promote low-GHG lifestyles because this would violate the principle of state neutrality must overcome several difficult challenges. To begin with, note that the argument against incentivizing low-GHG lifestyles can only get off the ground if the principle of neutrality is accepted. So-called perfectionist theories in philosophy reject this principle (Hurka, 1993; Wall, 1998). Rather than being neutral, the state should advance the good life of its citizens based on an objective account of what is a valuable human life. The most prominent examples of perfectionism in politics are theocratic states, but other forms of perfectionism in politics are possible, including 'liberal perfectionism'. (For a seminal critique of the neutrality principle and defense of liberal perfectionism, see Raz [1986].)

Putting this aside, we can note that low/high-GHG lifestyles as such do not seem to be 'conceptions of the good' at least as understood by Rawls. Such conceptions are 'an ordered family of final ends and aims which specifies a person's conception of what is of value in human life […]. The elements of such a conception are normally set within, and interpreted by, certain comprehensive religious, philosophical, or moral doctrines in the light of which the various ends and aims are ordered and understood' (Rawls, 2001, p. 19). Thus understood, low/high-GHG lifestyles are not themselves conceptions of the good but rather (partial) expressions or simply results of such conceptions. That is, these lifestyles may be rooted in more fundamental and comprehensive ideas of, say, autonomy, seeking pleasure, or how own relates to nature. Think of a person akin to Walter Faber in Max Frisch's novel *Homo Faber*: to such a person, living well may mean to distance oneself from the natural world via technology and he may cherish travelling in cars and planes, spend time in energy-intensive built environments, and use many electric appliances. Still, his conception of the good is *not* to emit lots of GHGs. The emissions rather are an unintended side-effect of how he chooses to live, not a constitutive element of it. (We are grateful to an anonymous reviewer who pressed us on this point.)

Take the examples of vegetarian days in canteens (De Keyzer et al., 2012) or speed limits on auto-routes (Madireddy et al., 2011). These policies do not restrict or disincentivize conceptions of the good such as living autonomous lives or seeking pleasure as there are many different ways of achieving these aims. By contrast, a policy that aims at incentivizing the adoption of certain religious (or atheist) practices would violate the principle of state neutrality. As current policy proposals for encouraging the adoption of low-GHG lifestyles do not touch upon the level of basic and comprehensive values, they do not favor conceptions of the good in the sense that concerns proponents of state neutrality. Hence, the objection from state neutrality fails, at least in the case of the policies discussed in the lifestyle change scenario.

Moreover, a key principle, in Rawls' theory and most contemporary accounts, is that each person possesses a set of basic rights compatible with the same set of rights for all (see Rawls, 2001, p. 42) and that a state may intervene to prevent transgressions of these rights, even if these interventions conflict with some conceptions of the good. It has long been acknowledged that climate change undermines key human rights for millions if not billions of present and future people (for an overview see Bell, 2013). Thus, even if one assumes if emitting large quantities of GHGs is a constituent element of a conception of the good, it would nevertheless be permissible for the state to restrict them on the grounds that high-GHG lifestyles collectively undermine basic human rights. Correspondingly, at the political level, those who generally support state neutrality accept that policy measures can enable, support, and sometimes direct certain lifestyle changes, if current lifestyle choices harm others, or put others at considerable risk. For example, measures taken across EU countries to reduce smoking in public places are now largely accepted. (Such policies can draw on different legal resources. For instance, smoke-free legislation built on labor laws and might have been more difficult to advocate based on public health reasons.) Hence, the state may take action which compromises citizens' abilities to pursue their conceptions of the good provided that the reason is to avoid or reduce the violation of established principles of basic justice (e.g. regarding basic rights). Given that states are to protect their (and other) citizens from climate-related harms, they must severely limit GHG emissions, support adaptation, and more (Gardiner, 2010).

To summarize, anyone who wishes to claim that policies to promote low-GHG lifestyles violate the requirement that states ought to be neutral between the conceptions of the good has to show that consuming high amounts of GHGs can count as a conception of the good in the relevant sense. Furthermore, they have to claim also that climate change will not involve transgressions of human rights. We consider the first challenge to be very hard and the second virtually impossible to overcome. Therefore, the neutrality objection is unconvincing.

There is also a positive argument to promote low-GHG lifestyles. As a general rule, we maintain that climate mitigation measures should not be viewed in isolation from other goals, such as promoting human rights, sustainable development, or protecting biodiversity (Heyward, 2019; following Caney, 2013; IPCC, 2022). Some policies have greater potential for bringing about *multiple benefits* (including the benefits of GHG emission reduction) than others. For example, the substitution of meat by pulses and/or oil crops offers leeway to implement more extensive animal husbandry systems which will allow for improvements in animal welfare and biodiversity conservation, respectively. Against this backdrop, and as long as no other convincing critique is brought forward, we consider these 'lifestyle change' – or rather – 'consumption change' pathways in countries of the Global North as an important (and in our view compelling) alternative pathway to the 1.5 °C target. It therefore should be explicitly considered in both scientific and policy debates, including discussions about the need for CDR measures.

2.2 Low population

Calls for population-focused policies to reduce GHG emissions are perhaps the most controversial kind of mitigation measure.

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Early discussions of population and climate change referred to the topic as 'the elephant in the room' (Cripps, 2012), and pointed to the misanthropic veneer of policy discussions in the past as well as flawed framings in the philosophical discourse (Heyward, 2012). Coercive measures such as China's infamous 'one child policy' are unacceptable from the point of view of most normative frameworks. From a human rights perspective, they violate basic human rights such as women's right to decide freely and responsibly on the number and spacing of their children (see Final Act of the International Conference on Human Rights, 1968, p. XVIII, 3). Moreover, as population increase is highest in lower-income countries, advocating population reduction measures can be interpreted as shifting the focus from the Global North's responsibility to act to the Global South. (However, there is also some scholarly debate on lowering population in the Global North, given the higher per-capita emissions rates [Hedberg, 2019; Rieder, 2016].)

However, there are indirect ways that can have the effect of reducing global population or rather the rate of population increase, particularly education of women, along with greater protection of women's rights and work opportunities for women outside the home (Sen, 1997). Thus, the shared socioeconomic pathway 1 (SSP1) as chosen in the low-population scenario by Van Vuuren et al. (2018) assumes a different trajectory of education in general by adding one further year of schooling, especially in the Global South (Samir & Lutz, 2017). This was projected to result in an earlier peak in global population and lower population, respectively, compared to the default SSP2 scenario in the Van Vuuren study. By 2100, the global population in SSP1 is 6.9 billion people, compared to a projected 9.0 billion in SSP2. One key driver for this development is increased female education attainment (Samir & Lutz, 2017). (Whether seven billion people can live sustainably on earth is disputed [see e.g. Dasgupta, 2019], but this strongly depends on consumption and production patterns.)

Moreover, increasing educational attainment for women in particular is also linked to reduced risk of domestic abuse, reduced child mortality (Balaj et al., 2021), increased child educational performance (Mak Arvin & Summers, 1999), and improved economic performance (Klasen, 2018). Realizing a higher average level of education among women thus contributing to realizing human rights and the sustainable development goals (SDGs) relating to both education and gender equality. In addition to improving education for women, other strategies, that is, those that target realizing the human right to reproductive choice, reduction of childhood mortality, human rights to an adequate standard of living, and human rights to equal employment opportunities can simultaneously contribute to the realization of human rights, SDGs, and GHG emission reductions (Caney, 2020; Heyward, 2012; Sen, 1996, 1997). (Counteracting racial, ethnic, or religious tension could also reduce the temptation for some group leaders to adopt 'pro-natalist' polices, in order to gain a demographic advantage over their rivals [see e.g. Morland, 2014].)

Two further points should be noted here. The first is that education for men and boys is also important as female empowerment cannot happen without the support of men. Males with higher levels of education are typically more willing to endorse gender equality policies and practices (Barker et al., 2012; Fulu et al., 2013; Marcus, 2014; UNESCO, 2022). (We thank an anonymous reviewer for raising this point.) The second is that realizing higher average level of education is desirable regardless of its impact on population. (The importance of education for human quality of life is the reason why education features as one of three dimensions in the United Nations Human Development Index [also see Anand & Sen, 1997].) This is all the more true regarding the Global South which on average features a comparatively low level of education and a high level of illiteracy, linked to limited opportunities for employment and income generation and higher chances of poor health (see Cree et al., 2012; Maddox, 2008).

To summarize, a lower total world population correlates with significantly lower GHG emissions, especially in the long term. Furthermore, [a] 'stabilising or even declining global population after 2050 (as often projected) could reduce the pressure from competing land claims, allowing for more bioenergy production or reforestation' (Van Vuuren et al., 2018). While direct population policies potentially violate human rights, there exist a bundle of measures that contribute to realizing human rights and SDGs, respectively, and in addition result in lower total world population. Due to their multiple socio-economic and human rights benefits in addition to emission reduction, it is arguable that, rather than being tabooed, such strategies are preferable to CDR and any other measures that target only climate mitigation.

2.3 Low non-CO_2

The low non-CO_2 scenario assumes the implementation of the best available technologies for reducing GHG emissions other than CO_2, like methane (CH_4) and nitrous oxide (N_2O), and a wide-spread adoption of cultured meat in 2050. Van Vuuren et al. (2018, supplement) assume that 80% of meat-like products (including eggs) are replaced by cultivated meat and that dairy products are produced by the remaining 20% of animals still used for meat (product) production. In this section, we focus on the replacement of traditional meat products by cultured meat.

Animal husbandry is associated with CO_2, CH_4 (especially ruminants), and N_2O emissions. Cultured or in-vitro meat is produced using stem-cell technology and inputs of energy and (plant) protein. And while the adoption of cultured meat is dependent on further research and requires the development of market-ready products, this option could become competitive in the long run (at least as a niche product with a premium price) (Garrison et al., 2022; Post, 2012). The fact that an increase in vegetarianism and veganism in some countries has caused a demand-driven uptake of such products by existing food companies as well as start-ups shows that the free market can already play a significant role in this development (see e.g. https://cellbasedtech.com/lab-grown-meat-companies). However, while some consumer-uptake is to be expected, the degree of uptake as envisioned by Van Vuuren et al. would require overcoming some continuing concerns by means of policy measures that support or even demand uptake. Such concerns include unnaturalness, safety, healthiness, anticipating inferior taste, texture, and/or appearance of cultured meat, expectation of high prices in comparison to conventional meat and societal concerns regarding the effects on traditional animal agriculture, distrust in companies producing cultured meat, and concerns regarding the energy required for production (see e.g. Bryant and Barnett, 2018; Siegrist and Hartmann, 2020).

Apart from consumer acceptability, there are a number of objections that could be raised against the large-scale replacement of traditional meat products by cultured meat. One objection points out that grasslands are important habitats for many animal and plant species and are therefore rich in terms of biodiversity. The habitat for these plant and animal communities depends

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on grazing, which means keeping ruminants for meat or dairy. However, Van Vuuren et al. assume that 20% of today's number of farm animals remain, mostly for the production of dairy. These could (theoretically) be raised in extensive, grass-based systems and thereby ensure the preservation of valuable highly biodiverse grasslands.

Another objection points to a loss of employment in animal husbandry. However, if we assume that the reason for cultured meat replacing conventionally produced meat is to reduce GHG emissions so as to protect individuals' basic rights in the face of climate change (see Section 2.1), employment in conventional meat production/animal husbandry is not as such deserving of protection. But like the phasing out of other unsustainable branches, such a transition should be accompanied by measures supporting affected people and regions. Does that mean that the adoption of cultured meat as assumed by Van Vuuren et al. constitutes a promising alternative to the 1.5 °C target compared to relying heavily on CDR measures? Here, we want to highlight two issues. First, as an alternative pathway to the 1.5 °C target, increasing production and consumption of cultured meat is only desirable if it results in fewer GHG emissions. However, producing cultured meat is energy intensive, and accordingly only reduce GHG emissions if energy generation is decarbonized (Lynch & Pierrehumbert, 2019) and a decarbonized energy sector leaves enough energy for surplus demand to produce cultured meat. Second, in the low non-CO_2 scenario, the GHG reductions ultimately result from the decrease of conventional meat production. The reductions are achieved by substituting conventional with cultured meat, which only describes one pathway to reduced conventional meat production. Alternatively, consumers could simply choose to demand less meat, conventional or cultured, by switching to already available plant-based products. The non-CO_2 scenario thus entails the additional assumption that consumer demand for meat of whatever form will not change.

We have argued above (Section 2.1) that policies such as those aiming to motivate consumers to adopt low-GHG lifestyles are permissible, if not even imperative. Policies to encourage consumers to limit or forego consumption of conventional meat are part of this. If, however, both dietary changes and the increase of consumer demand for cultured meat require policy measures, one can ask which kind of behavioral change is preferable: a change toward less consumption of both conventional and cultured meat products or a replacement of conventional meat by cultured meat. With regard to this, studies show that the environmental impact (including GHG emissions) of cultured meat is better than some (e.g. beef) and comparable to other (e.g. pork, chicken) traditional meats but worse than that of plant-based meat alternatives (see Jetzke et al., 2020; Van der Weele et al., 2019; Vural Gursel et al., 2022). Given that some kinds of measures to discourage meat consumption overall are permissible (see Section 2.1), it seems that policies to incentivize this should be preferred to encouraging replacement of conventional by cultured meat.

The possibility to reduce GHG emissions via an increase in production and consumption of cultured meat as an alternative to conventional meat thus could be another promising alternative to a corresponding increase in CDR, since the measures would have benefits for animal welfare, as well as human and animal health. However, it only is an alternative if the energy sector is decarbonized and leaves enough energy for surplus demand to produce cultured meat. Moreover, we regard the possibility to reduce GHG emissions via an increase in production and consumption of cultured meat as inferior to doing so via dietary changes to a more plant-based diet.

2.4 Agricultural intensification

The agricultural intensification scenario assumes increasing livestock efficiency and increasing yields to the most efficient levels globally. Increasing livestock efficiency allows reducing cattle stock, which plays an important role for reducing non-CO_2 GHGs (Van Vuuren et al., 2018).

The potential for agricultural intensification is highest where the 'yield gap' is highest. The yield gap designates the gap between what is actually produced and what could be produced under intensive animal husbandry systems and given agro-climatic conditions. (The concept of yield gap is widely used in production ecology and can also be applied to livestock science [see Van de Ven et al., 2003; Van der Linden et al., 2015].) Globally, crop yield gaps are highest in Sub-Saharan Africa, followed by South-East Asia and South America. Quantifying the yield gap in livestock is more difficult (see Gerber, 2016) but generally, the productivity of livestock in the Global South is low (Herrero et al., 2016). Accordingly, agricultural intensification primarily involves increasing livestock efficiency and yields in the Global South.

The potential ethical problem for this scenario is that given the above, this may lead to 'rescaling of the land rush' (Bluwstein & Cavanagh, 2023, p. 288). Starting with the financial crisis in 2008, countries in the Global South, especially Sub-Saharan Africa experienced a stark increase in (large-scale) land acquisitions (LSLAs) by domestic and foreign investors that aim at rapidly increasing (crop) productivity through high inputs of capital, new technologies, and agrochemicals (Behrman et al., 2014). (To our knowledge, the majority of the literature focuses on LSLA that aims to produce crops, but the evidence shows that there are also LSLA aiming at producing livestock [e.g. Borras et al., 2011; Schneider, 2014, see also https://landmatrix.org, *Land Matrix*, n.d.].) Whilst this was legitimized as 'much-needed investment', Borras and Franco conclude that the land rush largely favored the landed classes and elite actors (2018, p. 7).

In contrast to intensification based on high inputs of capital, new technologies, and agrochemicals, pro-poor, low-input, and sustainable intensification focuses on improved management of existing inputs rather than drawing on higher external inputs such as mineral fertilizer or agrochemicals. Sustainable intensification 'is defined as a process or system where agricultural yields are increased without adverse environmental impact and without the conversion of additional non-agricultural land' (Pretty & Bharucha, 2014, p. 1578). It causes less perturbation of the nitrogen and the phosphorus cycles than intensive agriculture and is more aligned to the needs and possibilities of the poor.

Part of the negative consequences of high-input agricultural intensification results from background injustice. That is, investments in land take place in the context of strong and rigid intra- and intercommunal inequities that systematically privilege certain actors (Kleemann et al., 2013; Nolte & Voget-Kleschin, 2014). This is one reason why successful pro-poor and/or sustainable intensification requires 'a holistic cross-sectoral harmonization of policies – i.e. in agricultural, land, and urban industrial policies, as well as public investments in physical infrastructure, health, education, family planning, etc.' (Jayne et al., 2014, p. 12). While such cross-sectoral governance changes that aim at alleviating injustice are desirable, they are also complex and

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will take time. In other words, they require substantial societal transformations promoting social justice and sustainable development. As such, pro-poor intensification can be understood as a building block of an encompassing sustainable development strategy. This also means that it is desirable not only for its effects regarding emission reductions but its multiple benefits, that is, its contributions to reaching the SDGs (FAO, 2018).

To summarize, increasing livestock efficiency and increasing yields to the most efficient levels primarily requires implementing corresponding measures in the Global South. To avoid negative social consequences requires that this be done in a pro-poor way. This presupposes substantial societal transformations, that is, addressing the encompassing institutional background against which agricultural development takes place. Therefore, it represents a long-term strategy for sustainability.

2.5 Overarching reflections on social transformation and state neutrality

The upshot of the above discussion is that while state neutrality is an important principle, it should not mislead us into foregoing the discussion of any scenarios requiring societal transformation. Nor should it lead to the unquestioned assumption that scenarios that (allegedly) require less societal transformation such as agricultural intensification or CDR are generally preferable to those that quite obviously involve societal transformation such as the lifestyle change and low-population scenarios.

Moreover, as our discussion of agricultural intensification has demonstrated, pathways that seem to primarily build on technical approaches may well involve societal transformations. Interestingly, some of the issues raised here, for example, negative social

Table 1. Outline of the main arguments of Section 2

Section/ scenario	Assumptions by Van Vuuren et al. (2018)	Implementation	Main arguments/issues	Promising alternative pathway to large-scale CDR?
2.1 Lifestyle changes	Consumers change their habits toward a lifestyle leading to lower GHG emissions	Policy instruments including incentives, disincentives, and the restriction and elimination of choice	The key argument against such policies, that interfering with people's ability to freely choose a particular way of life is illegitimate, is not convincing. Many low-GHG lifestyle choices feature important co-benefits.	Yes
2.2 Low population	Lower global population	Higher average level of education especially in the Global South being accompanied by lower fertility levels	Realizing a higher average level of education is desirable in its own right, independent of its effects regarding population growth and emission reductions respectively.	Yes
2.3 Low non-CO_2	80% of meat-like products (including eggs) are replaced by cultivated meat	Policy instruments including incentives, disincentives, and the restriction and elimination of choice that target the uptake of cultured meat	As cultured meat is energy intensive, it will only result in GHG emission reductions if energy production is decarbonized. Features co-benefits regarding animal welfare and public health. Van Vuuren et al. assume that 20% of today's animals remain for the production of meat and dairy. Their production could ensure the preservation of high-biodiversity-value grassland. If complemented by policy measures that support a transition of the agricultural sector, loss of jobs in livestock production seems acceptable. Substitution of animal products by plant-based alternatives would feature higher co-benefits than substitution by cultured meat.	Only in so far as energy generation is decarbonized and if a decarbonized energy sector leaves enough energy for surplus demand to produce cultured meat
2.4 Agricultural intensification	Primarily involves increasing livestock efficiency and yields in developing countries	Capital-intensive large-scale land acquisition (-like) intensification OR Pro-poor/sustainable intensification	Large-scale land acquisition (-like) intensification results in extensive negative social effects for smallholders in the Global South, and negative environmental and animal welfare effects. Pro-poor/sustainable intensification is a long-term strategy requiring cross-sectoral policy approaches. The required societal transformation exceeds that assumed in lifestyle change and low-population scenarios.	Only in so far as it avoids negative social and environmental consequences and is compatible with some level of animal welfare

Please note that the table only serves as guidance to the reader. Without the context provided in the above sections, it is not meaningful and should thus not be used in isolation.

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consequences of agricultural intensification or the assumption of a decarbonized energy sector for increasing production and consumption of cultured meat, are also raised in the context of large-scale CDR. Our study highlights the need to look closely at the ways different pathways could be implemented and the need for reflection on what kinds of societal transformations are compatible with taking state neutrality seriously (also see Fragnière, 2014).

3. Some remarks on burden sharing

As mentioned above, the topic of burden sharing has been extensively discussed and it is not our intention to contribute to that debate here. However, different mitigation pathways and policies will inevitably have implications on the distribution of economic and non-economic costs. We would like to make a few remarks in this regard because a burden-sharing perspective sheds further light on the moral permissibility of the scenarios and related policies.

Economic and non-economic costs of climate policies will be distributed within states, across states (matters of global justice), and across generations (matters of intergenerational justice). With regard to global justice, the prevailing view is that the lion's share of costs and burdens of dealing with climate change should be shouldered by states in the Global North (see e.g. Hayward, 2012), or the global elite regardless of where they live (Caney, 2005, 2013; Chakravarty & Ramana, 2012).

In the lifestyle change scenario, consumption rates converge globally, meaning that the burden of change falls on current high consumers, both in the Global North and South. In the low non-CO_2 scenario, persons in all countries are asked to take up cultured meat. However, as global elites tend to consume more meat, the main burden falls upon them. By contrast, in both the population scenario and the agricultural intensification scenario, changes predominantly affect the Global South. Accordingly, mitigation scenarios requiring social transformation in the Global South are only acceptable if they primarily aim at improving the quality of life for non-elite individuals in the Global South. From a global justice perspective, the lifestyle change and the low-population scenarios as well as agricultural intensification via pro-poor growth strategies are clearly preferable to the low non-CO_2 and agricultural intensification scenarios.

With respect to the distribution of costs over generations, there is no strong prevailing view equivalent to that found in the context of global justice. However, it is widely agreed that impacts of climate change will be more severe over time and thus disproportionately burden future generations. From the perspective of intergenerational justice, pathways that take seriously the problem of cumulative CO_2 emissions and avoid putting even greater climate burdens on future generations are more attractive.

Cumulative CO_2 emissions determine long-term warming (Rogelj et al., 2019) since their impact on atmospheric warming is occurring on much longer time scales compared to shorter lived GHGs or climate forcers (see Arias et al., 2021, Fig. TS.20). Of particular relevance here is CH_4, which is the second most important GHG contributor to climate change, but which has a much shorter lifespan than CO_2.

The low non-CO_2 and agricultural intensification pathways reduce non-CO_2 GHG emissions. This would also be the case if meat consumption overall were reduced, as in the lifestyle change scenario. The consequent atmospheric cooling effectively reduces the need for CDR to meet end of the century warming goals (Van Vuuren et al., 2018). By reducing non-CO_2 GHG emissions from CH_4, the radiative forcing of the non-CO_2 GHGs is reduced, which allows for more warming by CO_2. As a result, the cumulative CO_2 emissions by the end of the century in these scenarios are higher (see Figure 1). This is especially evident for the low non-CO_2 scenario, in which cumulative emissions until 2100 are about 50 Gt CO_2 higher than in the energy and material efficiency or the renewable energy scenario (Van Vuuren et al., 2018). (In this paper, we do not discuss these additional scenarios of Van Vuuren et al. because they are less controversial.)

The long-term warming in scenarios with higher cumulative CO_2 emissions will accordingly be higher, putting additional pressure on future generations that are already burdened substantially with climate risks, impacts, and realizing net zero emissions. Therefore, with a view to burden-sharing across generations, the low non-CO_2 and agricultural intensification scenario are ethically less problematic if they are pursued in addition to reducing net CO_2 emissions, rather than as a substitute for short-term CO_2 reductions as assumed in the scenarios discussed here.

4. Conclusion

We have discussed the moral implications of four scenarios that would reduce GHG emissions and hence the need for large-scale tCDR in ambitious mitigation scenarios (for a summary see Table 1). Two of them, the lifestyle changes and the low-population scenarios, are very clearly linked to societal transformations and the need for different lifestyles at the individual level. This has led to them being met with substantial skepticism and largely tabooed in political debates (cf. Section 1). By contrast, the other two scenarios, the low non-CO_2 and the agricultural intensification scenarios, are commonly perceived as less challenging, possibly because at first glance they seem to encompass less need for societal transformation.

We show that the latter two scenarios are in fact the ones that turn out to be in need of further scrutiny. In the Global South, where potential for agricultural intensification is highest, an intensification based on high inputs of capital, new technologies, and agrochemicals is associated with considerable negative social consequences. A low-input, pro-poor agricultural intensification is far more ambitions in terms of societal transformations (especially regarding land governance and equity issues) than those implied in the lifestyle change and low-population scenario. By contrast, the switch from conventional meat production to cultured meat as a measure within the low non-CO_2 scenario is not so challenging and goes along with co-benefits for animal welfare, human and animal health. But we argued that reducing GHG emissions via an increase in production and consumption of cultured meat is inferior to doing so via dietary changes toward a more plant-based diet.

Regarding the lifestyle changes and low-population growth scenario, we find that these pathways do indeed constitute permissible, perhaps even preferable, alternative options for contributing to the 1.5 °C goal. Our discussion shows that the key argument against the promotion of less GHG-intensive lifestyles, that is, that it violates the key principle of state neutrality, fails. Furthermore, we have pointed out that the lifestyle changes assumed by Van Vuuren et al. (2018) go along with significant co-benefits. To argue for CDR to be on par or preferable to such lifestyle changes therefore requires presenting *other* arguments against measures that enable, support, or demand lifestyle changes and/or showing that large-scale CDR measures can bring about a similar extent of co-benefits than those associated with less GHG-intensive lifestyles. Similarly, low-population growth

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scenarios that result from increasing the average level of education as assumed by Van Vuuren et al. (2018) constitute a multiple-benefit strategy in that increasing the average level of education brings about several positive effects, of which reduced emissions stemming from lower population growth is only one. If these pathways are indeed ethically preferable, we should discuss how to increase their political and societal feasibility, rather than simply assuming that they are unviable.

An open-ended discussion of different alternative pathways that does not rule out certain options from the outset on account of their involving societal transformations broadens the horizon to include much-needed multiple-benefit strategies. Against this backdrop, we reject the assumption that in comparison to large-scale tCDR, the alternative pathways modeled by Van Vuuren et al. are ethically problematic. Rather, we encourage a broader critical discourse on the role the state should play and on the implicit assumptions made by scientists and policy-makers regarding the ethical permissibility of certain policy pathways, including those that have been seemingly 'tabooed'.

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