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Moral Conflicts of several "Green" terrestrial Negative Emission Technologies regarding the Human Right to Adequate Food – A Review

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Abstract. Several terrestrial Negative Emission Technologies (tNETs), like Bioenergy with Carbon Capture and Storage (BECCS), Afforestation/Reforestation (AR) and Enhanced Weathering (EW), rely on natural processes and could therefore be designated as "green" forms of geoengineering. However, even those "green" tNETs may lead to undesirable side effects and thereby provoke moral concerns and conflicts. In this paper, I investigated whether BECCS, AR and EW would cause moral conflicts regarding the human right to adequate food if implemented on a scale sufficient to limit global warming "to well below 2 °C". Reviewing recent publications concerning BECCS, AR and EW, I found that EW would not conflict with the human right to adequate food but would likely even promote agricultural food production due to a higher nutrient provision. However, EW does not provide a feasible solution to limit global warming "to well below 2 °C", since a large-scale deployment of EW would require large investments and considerable amounts of energy to grind suitable rock-material. In regard of BECCS and AR, I found that even under the optimistic Representative Concentration Pathway 2.6 (RCP2.6), as assessed by the Intergovernmental Panel on Climate Change (IPCC) in its latest assessment report from 2013, a large-scale deployment of BECCS and/or AR would cause moral conflicts regarding the human right to adequate food for present and future generations. Due to this, I advocate for more and stronger mitigation efforts in line with efficient land management actions concerning, e.g. peats and soils, designated as "natural climate solutions" (NCS) and a deployment of multiple tNETs in near future.

1 Introduction

Since the beginning of the industrial revolution at the end of the 18th century, manifold anthropogenic activities have altered various ecological systems (ecosystems) of the Earth, including inter alia, biodiversity loss (IPBES, 2019) and climate change (IPCC, 2014, 2018), as well as related ocean acidification and ocean warming (Böhm and Ott, 2019). Even though the impacts of these alterations have been known for decades (United Nations, 1992a, b; IPCC, 1992), current efforts to mitigate them are mostly insufficient (IPBES, 2019, UNEP, 2018). On 12 December 2015, the members of the 21st Conference of the Parties (COP21) under the United Nation Framework Convention on Climate Change (UNFCCC) adopted the Paris Agreement (UNFCCC, 2015a). Ipso facto, 195 nations of the world agreed to "[h]olding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change" (UNFCCC, 2015a: Art. 2). They also agreed to foster sustainable development, thus to improve climate resilience and lower greenhouse gas (GHG) emissions, while thereby not threatening food production (UNFCCC, 2017). The Paris Agreement is based on the Nationally Determined Contributions (NDCs), which were submitted by the members of the UNFCCC until COP21 (Rogelj et al., 2016). The NDCs are national pledges that should expound how climate change should be addressed on the national level. They encompass several strategies how to avoid, to adapt to or to cope with climate change. Recent findings, however, suggest that current pledges made by the parties of the Paris Agreement would result in a global average warm-

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ing of about 3 °C by the end of the 21st century (UNEP, 2018; UNFCCC, 2015b). Such a warming would threaten many ecosystems (IPBES, 2019; IPCC, 2018) and agricultural food production (FAO, 2018). In its latest assessment report from 2013, the Intergovernmental Panel on Climate Change (IPCC) has considered roughly 300 baseline scenarios and 900 mitigation scenarios from about 30 integrated assessment models (IAMs) (Anderson and Peters, 2016). From all scenarios assessed by the IPCC, 116 scenarios were consistent with the representative concentration pathway 2.6 (RCP2.6) according to which global average warming could be limited with a more than 66 % chance to 2 °C above pre-industrial levels by 2100. Besides RCP2.6, two intermediate scenarios (RCP4.5, RCP6.0) and a 'business-as-usual" scenario (RCP8.5) exist. 101 scenarios of those that are consistent with RCP2.6 rely upon the large-scale deployment of terrestrial negative emissions technologies (tNETs) from the second half of the 21st century (Fuss et al., 2014). Sanderson et al. (2016: 7137) argue that because since 2005, the world has moved along "an unmitigated emission pathway closely approximating RCP8.5 [...] the exact trajectory described in RCP2.6 is now impossible." Given the degree of mitigation assumed in RCP2.6 and starting those actions in 2015 or even later, reduces the probability of limiting global warming to 2 °C by the end of the 21st century to less than 66 % (Sanderson et al., 2016). Thus, to reach the 2 °C target notwithstanding, substantially greater net negative emissions in the second half of the 21st century are indispensable as already assumed in RCP2.6 (IPCC, 2014; Gasser et al., 2015; Haszeldine et al., 2018). Several tNETs, e.g. Bioenergy with Carbon Capture and Storage (BECCS) Afforestation/Reforestation (AR) or Enhanced Weathering (EW), rely on natural processes and could therefore be designated as "green" forms of geoengineering. "Green" tNETs are intended to sustainably mitigate global warming and thus adverse consequences for life on Earth. However, even those "green" forms of geoengineering might have undesirable side-effects. In this paper, which is an updated short version of my Master Thesis, I investigated whether the deployment of BECCS, AR and EW on a scale sufficient to limit global warming "to well below 2 °C" would lead to moral conflicts regarding the human right to adequate food. This paper can be positioned at the intersection between climate ethics, the discourse about NETs and food security.

2 "Green" forms of geoengineering

Negative Emission Technologies (NETs) aim to reduce the concentration of atmospheric carbon dioxide (CO_2). In the context of geoengineering they are thus also designated as Carbon Dioxide Removal (CDR) technologies (cf. Shepherd et al., 2009; Rickels et al., 2011; Caldeira et al., 2013). Geoengineering is commonly defined as "the *deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change*" (Shepherd et al., 2009: 1). It can be divided into two broad categories: CDR and Solar Radiation Management (SRM). SRM, however, does not lead to negative emissions but only reduces the radiative forcing by "reflecting some sunlight away from Earth" (Caldeira et al., 2013: 233). Thus, SRM does not address the root cause of climate change, which are anthropogenic GHG emissions. Due to this, several ethical arguments exist against SRM, e.g. the "moral hazard" argument (Morrow, 2014; Baatz, 2016) or the "slippery slope" argument (Ott, 2012). The term "moral hazard" has its origin in the insurance-economy and designates a behaviour that becomes less risk-averse if an insurance will incur the cost of a possible risk. This in turn may cause more financial claims on the insurer (Shepherd et al., 2009). In case of geoengineering and particularly SRM, "moral hazard" may occur as a reduction of efforts for mitigation and/or adaptation. Since SRM will limit global warming even if annual emissions of GHGs continue to remain on a high level or rise even further, people might care less about abating emissions, which might result in catastrophic events due to a rapid increase of temperature if the respective SRM measures are abruptly terminated (Gardiner, 2011; Morrow, 2014; Baatz, 2016). According to the "slippery slope" argument, the deployment of an expensive technology becomes even more likely, the more effort and money to develop it has been invested. It might even be the case that we are already on a "slippery slope" regarding SRM because in 2017 the Harvard University has launched a USD 20 million solar geoengineering study to research the effects of Stratospheric Aerosol Injection (SAI), which is a form of SRM (Neslen, 2017). And it seems not too unlikely that this study is only the beginning. That is quite worrisome, because once we have started SRM as a means against global warming, we are forced to stick to it continuously as long as the atmospheric CO_2 concentration does not decrease below a certain level. CDR technologies, instead, are in general less controversially discussed. That is because most CDR technologies, e.g. BECCS, AR, EW, rely on enhanced natural processes to sequester CO_2 (Rickels et al., 2011). Therefore, I call these technologies "green" forms of geoengineering.

2.1 Bioenergy with carbon capture and storage

BECCS combines the use of biomass to produce bioenergy (BE) with the subsequent sequestration and permanent storage of carbon dioxide via carbon capture and storage (CCS) technology (cf. Canadell and Schulze, 2014; Caldeira et al., 2013; Rickels et al., 2011). During the growth of biomass, CO_2 is naturally removed from the atmosphere by photosynthesis and stored as organic carbon in crops, plants and trees. Subsequently, the harvested biomass gets processed either by combustion, fermentation, aerobic digestion or gasification, to result in corresponding bioenergy products, such as heat, biomethane or electricity. The CO_2 emissions that occur during the processing of the biomass are being sequestered and permanently stored in geological formations, e.g. saline aquifers (Canadell and Schulze, 2014). A large-scale implementation of BECCS is assumed in most of the scenarios consistent with the 2 °C target as assessed by the IPCC in its latest assessment report (Anderson and Peters, 2016). However, achieving the level of BECCS that would be necessary to achieve the 2 °C target comprises vast challenges and uncertainties (Fuss et al., 2014). Moreover, it has been questioned whether BECCS is really a "green" form of geoengineering (Heck et al., 2016). Even though the technology is basically ready, more research is needed to address all CO_2 emissions and to better understand chemical processes that occur due to the injection and long-term storage of CO_2 in geological formations (Smit, 2016).

2.2 Afforestation and reforestation

Following the definitions from the United Nations Framework Convention on Climate Change (UNFCCC) Clean Development Mechanism (CDM) Afforestation is defined as "the direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources" (Parker et al., 2009: 131). Reforestation is defined as "the direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested but that has been converted to non-forested land" (Parker et al., 2009: 132). Afforestation and thus Reforestation is, along with BECCS, the second CDR strategy that is assumed to be a potential and widely available means against climate change from the second half of the 21st century in most of the scenarios of the latest IPCC assessment report (Fuss et al., 2014).

2.3 Enhanced weathering

The chemical processes that underlie EW are grounded on the natural dissolution of silicate minerals (Hartmann et al., 2013). During the dissolution, several cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) are released from the silicate and brought into solution. This transfer increases total alkalinity (TA) and hence the pH of the solution and produces carbonate ions (CO_3^{2-}) and bicarbonate (HCO_3^{-}) by consuming CO_2. The dissolution products are transported over geological time scales into the oceans and thereby counteracting ocean acidification, too. However, natural weathering is very slow and the respective annual CO_2 consumption rates of weathering silicate as well as carbonate minerals are assumed to be $\sim 0.25\,\mathrm{Gt\,C}$ ($\sim 0.92\,\mathrm{Gt\,CO_2}$), which is only about 2.5 % of emissions from fossil fuels and industry (Hartmann et al., 2013; Taylor et al., 2015; Le Quere et al., 2018). Thus, to be an effective means against global warming, natural weathering rates need to be increased significantly. EW aims to increase the dissolution kinetics of silicate minerals which can be achieved "by (1) increasing mineral surface area (e.g., by grinding), (2) changing the pH of reacting solutions, (3) increasing temperature, (4) increasing pressure, (5) choosing appropriate rocks with highly reactive minerals, (6) changing the flow regime [of the dissolution], and (7) making use of biological metabolism (e.g., certain plant species remove selectively released elements and change thus the saturation state of aqueous solutions close to their root system)." (Hartmann et al., 2013: 117) Olivine (chemically $(Mg,Fe)_2SiO_4$) and more particularly forsterite (Mg_2SiO_4), which is the Mg-rich end-member of the mineral olivine, is supposed to be the most suitable silicate mineral for EW due to its comparably high reactivity and its broad availability. Therefore, mafic and ultramafic rocks are of special interest, since they contain high shares of Mg-olivine and are widely abundant. Moreover, they contain other suitable minerals, such as pyroxene, as well (Hartmann et al., 2013; Moosdorf et al., 2014 and references in there). Even though EW is not assumed as a means against climate change in the latest assessment report of the IPCC, it might be a potent means against climate change.

3 Moral conflicts regarding the human right to adequate food

The human right to adequate food should guarantee "the availability of food in a quantity and quality sufficient to satisfy the dietary needs of individuals" (CESCR, 1999: paragraph 8) for both present and future generations. However, even though there is a broadly agreed human right to adequate food, the number of undernourished[1] people globally has increased since 2014 from 775 million to 777 million in 2015, 815 million in 2016 and 821 million (equal to about 11 % of global population) in 2017 (FAO et al., 2018). Of these, an estimated 515 million people were undernourished in Asia (equal to 11.4 % of Asian population), more than 256 million people in Africa (more than 21 % of African population; the share of undernourished people in eastern Africa is even at 31.4 % of the population) and more than 39.3 million in Latin America and the Caribbean (more than 6.1 % of population). Thus, almost all people suffering from chronic food deprivation live in economically poorer regions of the world. If we do not take immediate action to stop undernourishment especially in those regions, even more people will likely suffer from chronic food deprivation in the future because of global population growth. According to the recent medium variant projection of the UN, global population will increase up to 9.7 billion in 2050 and up to 10.9 billion in

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[1] According to the recent publication of FAO et al. (2018: 161), "[u]ndernourishment is defined as the condition in which an individual's habitual food consumption is insufficient to provide the amount of dietary energy required to maintain a normal, active, healthy life." This is sufficient for and in line with the Right to Adequate Food as defined above. However, other forms of malnutrition, e.g. overweight, obesity, or undernutrition are not regarded.

2100. A large part of this expected 2 billion growth in population between 2019 and 2050 will occur in Sub-Saharan Africa (1.05 billion) and Central and Southern Asia (505 million) (UN DESA, 2019). After 2050, further substantial population growth is expected only for Africa. This development will change Africa's share of global population from about 17 % in 2019 to about 26 % by 2050 and up to about 40 % by 2100. Independent of the scenario or variant used to project the future development of global population, "Sub-Saharan Africa will account for most of the growth of the world's population over the coming decades" (UN DESA, 2019: 6). Moreover, a large share in population growth until 2050 and until 2100 will occur in the least developed countries (LDCs) – a group of 47 countries defined by the United Nations General Assembly of which 33 are located in Africa (UN DESA, 2019). The total population of these countries is presently (2019) about 1 billion, but will almost double to about 1.9 billion in 2050 and might even increase up to 3 billion in 2100. According to calculations of the FAO (2017), global agricultural production needs to increase by about 50 % until 2050 (compared to 2013) to meet the global demand for food, feed and biofuel. This increase is mainly driven by Sub-Saharan Africa and South Asia, where demand of agricultural products in 2050 will almost double. Agricultural demand in the rest of the world will increase by about 1/3 until 2050. Although even bigger increases in agricultural production than that necessary has been achieved in the past, recent trends, however, are alarming. Average annual yield increases of maize, rice and wheat have been slightly more than 1 % since the 1990s and those of soybeans and sugarcane have even been below 1 %. And it is not clear whether these growth rates can be maintained over the coming decades. Assuming that about 80 % of the increase in food production in developing countries until 2050 would be achieved via higher yields, an average annual growth rate of 0.9 % is required. Thus, "cereal yield growth rates below 1 percent a year would be a worrying signal" (FAO, 2017: 47). However, substantial yield gaps (compared to potential yields) of more than 50 % in major crops, such as cereals, roots and tubers, pulses, sugar crops, oil crops and vegetables, occur in many low-income countries (FAO, 2017). Closing these yield gaps in a sustainable manner would be a large step towards the achievement of the second Sustainable Development Goal (SDG 2) of the United Nations. SDG 2, designated as "End hunger, achieve food security and improved nutrition and promote sustainable agriculture" aims to end hunger and all forms of malnutrition by 2030 (UN, 2015). Whether all these aims or at least some of them will be achieved by 2030, however, is questionable. This holds especially in regard of the recent upward trend of people suffering globally from chronic food deprivation. But it also holds in regard of the recent increase of conflicts around the globe, which in turn increase the prevalence of undernourishment in the respective regions (FAO et al., 2018). Moreover, climate change will disproportionately affect the poorer regions of the world (IPCC, 2014, 2018). A higher variability of precipitation combined with more and longer droughts and stronger floods are predicted to be a result of global warming in low-latitude countries. Those events would reduce yields significantly in the long run, as has been shown by a meta-analysis of 1090 studies on major crops such as wheat, maize, rice and soybeans (FAO, 2017). Thus, to fulfil our moral obligations in regard of the right to adequate food and hence achieve the aims of SDG 2 at least in near future, climate change needs to be mitigated.

As already stated, the large-scale implementation of BECCS and AR from the second half of the 21st century is assumed in most of the scenarios assessed by the IPCC that are consistent with limiting global warming with a chance of more than 66 % "to well below 2 °C". Yet, it is not clear whether such an implementation is feasible in the real world or how it should be governed (Rickels et al., 2011). However, given that these problems may be solved somehow and a large-scale implementation would be technically and economically feasible, moral conflicts regarding the right to adequate food would unavoidably emerge. Most important for that is the area that would be required to implement either BECCS or AR or even both on a scale sufficient to meet the negative emissions necessary to limit global warming. In regard of BECCS, Smith et al. (2016) argue that, according to the assumptions made in most of the IAMs which "likely" limit global warming "to well below 2 °C" an area between 320 and 700 Mha of biomass plantations would be necessary by 2100, depending on the material used to produce bioenergy. Following a particular RCP2.6 scenario, Boysen et al. (2017) assume an area of 441 Mha (almost the size of the European Union) that needs to be converted into biomass plantations until 2100. These conversions would mainly be realised at the cost of highly productive agricultural land, which is predominantly located in tropical regions and in parts of Northern America. If agricultural areas are converted that are less productive than those mentioned, then even more area would be necessary. Moreover, if we follow only a partially mitigated pathway (equal to RCP4.5 and therefore almost equal to the current pledges made by the parties of the Paris Agreement in their NDCs), which would result in an average warming of about 2.5 °C by 2100 and if the conversion into biomass plantations begins as early as 2050, it would be necessary to convert even more than 1/4 of the most productive agricultural land globally (more than 1.1 Gha) to reach the 2 °C target by 2100. Humpenöder et al. (2014) project an increase of bioenergy area to 508 Mha until 2095 depending on the introduction of a carbon price and driven mainly at the cost of agricultural land. In this context, it is noteworthy that without the introduction of a price on carbon the area used to grow food crops is projected to increase by about 300 Mha until 2095. Yet, this projection depends on economic assumptions and does not reflect actual future food demands as can be seen from the projection of the FAO (2017), which states that globally agricultural area needs to increase by about 490 Mha already until

2050 to meet the expected growth in global food demand. Since global population will even increase further until 2100 and beyond, it seems almost implausible that the total agricultural area that would be needed to meet the demands in 2095 will decrease again by about 200 Mha. Moreover, all these figures about land requirements for BECCS are idealised projections, which rely on many uncertain assumptions about future yield improvements, conversion efficiencies, levels of irrigation and use of fertilizer. Kato and Yamagata (2014) has shown that only the most productive second generation bioenergy crops (switchgrass and "Miscanthus x gigantheus") could achieve the yields required in most of the IAMs that limit global warming "to well below 2 °C". The land requirements mentioned above already rely on these crops and on substantial yield improvements. High quantities of water for irrigation are also taken for granted as well as additional input of fertilizer. According to Smith et al. (2016), not using irrigation for biomass plantations would increase land demands by about 40 %. Boysen et al. (2017) argue that without irrigation, high input of fertilizer and a comparably high conversion efficiency it would be impossible to achieve the 2 °C target, if biomass plantations are deployed on 441 Mha. Moreover, Creutzig (2016) explicitly argues that without substantial yield improvements severe land-use conflicts threatening food production would occur.

In regard of AR, the demand for land to limit global warming "to well below 2 °C" is even higher. Smith et al. (2016) state that about 970 Mha need to be converted into forests to meet the needed negative emissions under a pathway comparable to RCP2.6. Again, the conversion would mainly come at the cost of agricultural land. This holds as well for the scenarios of Kreidenweis et al. (2016), who argue that the introduction of a price on carbon provides an incentive to grow forests. Depending on the area allowed to grow forests, more than 2500 Mha could be converted until 2100. This figure is similar to those of Humpenöder et al. (2014), who project a conversion of 2773 Mha globally until 2095. However, AR as a means against climate change is predominantly useful only in low latitudes. That is because not only the natural carbon uptake is affected by AR but the local albedo as well. Due to biogeophysical changes of the Earth surface, less sunlight is reflected and hence the positive biogeochemical effects of AR are lowered, if not even reversed (Arora and Montenegro, 2011). Therefore, large-scale AR should only be implemented in tropical regions. Yet, this would disproportionately affect people living in the poorer regions of the world because due to the competition for suitable land food prices would rise particularly in the respective regions (Kreidenweis et al., 2016). Other possibilities to use forests as a means against climate change that are less land-intensive than AR and thus less threatening in view of food security are the cessation of Deforestation and the natural regeneration of degraded forests, both especially in tropical regions. Deforestation as well as degradation of tropical forest areas account for about 8 %–15 % of total annual carbon emissions (equal to about 2.9–5.4 Gt CO_2) (Houghton et al., 2015). Moreover, allowing second growth forests to regenerate naturally could sequester up to 6.48 Gt CO_2 annually in the coming decades (Chazdon et al., 2016). The role of Brazil is crucial in both contexts, since it has by far the largest potentials in avoiding further Deforestation as well as for second growth forests to regenerate. According to the recent FAO Global Forest Resource Assessment from 2015, the annual net loss rate of natural forests in tropical regions has declined from annually 10.4 Mha in the 1990s to 6.4 Mha between 2010 and 2015. The annual net loss rate of Brazil has even declined by about 60 % compared to the 1990s to 0.98 Mha yr^{-1}. Moreover, several initiatives like the REDD+ programme of the UN, the Bonn Challenge or the New York Declaration on Forests are first steps to end Deforestation and to restore degraded forest areas. Yet, ending Deforestation and allowing the natural regrowth of secondary forests would not be sufficient to meet the required negative emissions. However, in regard of BECCS and AR, what is at stake is a classical dilemma: implementing either BECCS or AR or even both on a scale sufficient to limit global warming necessitates cropland area to grow some sort of biomass (e.g. bioenergy crops, trees). Yet, an increasing global population also needs additional cropland to meet future food demands. Availability of suitable land, however, is limited. If we do not limit climate change, future yields would be reduced inter alia in those regions where local populations already suffer the most from chronic food deprivation and, moreover, where population growth will be highest in the future. This would most likely lead to even more people suffering from undernourishment in those regions for three reasons. First, because local farmers living in rural areas, who depend on locally grown food, would not be able to harvest enough food for their own supply anymore. This in turn would force more and particularly young people to migrate into urban areas, which means that, second, relative food availability in urban areas would be lowered and therefore result in higher food prices. This again would disproportionately disadvantage the poor because they could not afford to pay these higher prices. Finally, since less food would be grown locally, more food needs to be imported from foreign countries, which would likely result in both higher food prices as well as even more GHG emissions and therefore aggravate climate change even more. Hence, given our obligations to future generations to secure their human right to adequate food, we should limit climate change from a moral perspective. But, if we do limit climate change by implementing either BECCS or AR or even both on a scale sufficient to limit global warming "to well below 2 °C", we would need to convert large areas of cropland presently used to produce food crops into dedicated biomass plantations or use them for Afforestation and Reforestation. This conversion would obviously reduce food availability in general and, moreover, especially disadvantage people in the poorer regions of the world for two reasons. First, because large parts of the most productive agricultural areas regarded for conversion would be in exactly those regions and, second, because food prices in general would increase due to less available food. This increase would again be especially significant in the poorer regions of the world. Moreover, additional demand of water for irrigation and high input of fertilizer would stress local ecosystems and could thus negatively impact food production and quality. Particularly additional water withdrawals would aggravate water scarcity in the poorer regions of the world and therefore disadvantage people living in the respective regions and jeopardize their right to adequate food even more. Thus, seen from a moral perspective and in regard of the human right of adequate food, we should not implement BECCS and/or AR on a large scale. We should rather end Deforestation and restore degraded tropical forest areas to mitigate climate change at least a few. Nevertheless, limiting climate change is a necessary precondition to fulfil our obligations to present and future generations in regard of their right to adequate food. Yet, the implementation of BECCS or AR or even both on a scale sufficient to meet the required negative emissions would imply several moral conflicts regarding this right.

Another possibility to meet climate change and to limit global warming is to reduce atmospheric CO_2 through EW. In contrast to both BECCS and AR, a deployment of EW would not compete with other forms of land-use and thereby not threatening food production. Several studies (cf. Moosdorf et al., 2014; Kantola et al., 2017; Smith et al., 2016) even argue that terrestrial EW might benefit the respective soils through the release of dissolution products, e.g. cations, and a pH adjustment. Moreover, water demands for EW are considerably lower than for BECCS or AR. Smith et al. (2016) state that the sequestration of 1 Gt C eq. (3.664 Gt CO_2 eq.) (which is assumed to be the annual maximum sequestration potential of EW) requires only 1.5 km^3 water, compared to 240 km^3 for BECCS and $\sim 347\,km^3$ for AR. On the other side, EW is assumed to require large amounts of energy that needs to be produced. Given the present share of emissions from the energy sector, which are decisive for climate change, implementing EW on a large scale would likely offset the negative emissions that would occur due to its deployment. This holds particularly for open ocean EW but for terrestrial and coastal EW, too. Using renewable sources of energy, like solar power or wind power might be a feasible way to produce the required energy in a sustainable manner, but the expansion of those "green" energy sources on a global scale is at least at present not sufficient to meet the demand (Walsh et al., 2016). Relying on bioenergy from BECCS is also not a feasible option, since it would conflict with the human right to adequate food, as described above. Nuclear power might be a feasible option but should be excluded for reasons of security, too. Therefore, EW does not seem to be a feasible means to limit global warming "to well below 2 °C" by the end of the 21st century.

4 Conclusions

In this paper, I investigated whether moral conflicts regarding the human right to adequate food would occur due to the large-scale deployment of BECCS, AR and EW sufficient to limit global warming "to well below 2 °C". To this end, I reviewed several recent articles regarding BECCS, AR and EW. Each of these technologies relies on natural processes and aims to sustainably reduce atmospheric CO_2 concentrations. Therefore, I designate them as "green" forms of geoengineering. However, even those "green" forms of geoengineering have negative side effects. I found that BECCS as well as AR would likely provoke moral conflicts regarding the human right to adequate food, since large areas currently used to produce food crops would need to be converted into biomass plantations and/or forests to achieve the negative emissions necessary to limit global warming "to well below 2 °C" by 2100 even in a strong mitigation scenario. Moreover, a large part of these conversions would likely occur in tropical regions and therefore in regions, which are predominantly located in the poorer parts of the world. High shares of the population in these regions, especially in Africa and Asia, already suffer from undernourishment and water scarcity. Converting large areas of productive land into biomass plantations or use them for AR would likely aggravate the prevalence of chronic food deprivation. Additional water demands for irrigation would further reduce availability of water for other purposes, like freshwater supply. The consequences of a large-scale deployment of BECCS and/or AR would especially affect future generations because substantial population growth until 2050 is expected to occur predominantly in Asia and Africa and after 2050 almost only in Africa. Due to these reasons, I argue that we should not rely on BECCS and/or AR as single CDR strategies to limit global warming. In regard of EW, I found that a large-scale deployment would not conflict with the human right to adequate food but would rather even be beneficial to agricultural production, since extra nutrients would be added to the respective soils. Another positive side-effect of EW would be a reduction of ocean acidification. Yet, a large-scale deployment of EW would require considerable amounts of energy, since suitable rocks were needed to be grinded into small-size particles. This would likely offset the negative emissions from EW, which are assumed to be at max 1 Gt C eq. (3.664 Gt CO_2 eq.) annually. Due to this, I conclude that EW would also not be a suitable means to limit global warming "to well below 2 °C" if used as a single CDR strategy. However, every CDR strategy considered in this paper could contribute to a more comprehensive strategy to achieve the main goal of the Paris Agreement (Fuss et al., 2018; Werner et al., 2018; Minx et al., 2017). Such a strategy needs to encompass further other natural climate solutions, such as the protection and proper management of peats and soils, as well as more and stronger mitigation efforts, such as a global carbon trade system to efficiently reduce carbon dioxide emissions, a tax on kerosene, a large-scale roll-out of renewable energies and a stronger awareness of everyone for climate change and its causes. Because we – as individuals of the developed world – could do a lot more to help mitigate climate change, e.g. use energy more efficient, rather use bikes or public transport, than private cars or plains, change our own diets (less meat, more local foods), buy less new things but re- and upcycle more. The Paris Agreement addresses not only governments but private actors, too. Every one of us, either as a private person or as part of a company, is able to do something. It is not sufficient for us to just lay back, do as always, rely on others to do something and wait for changes. Every one of us needs to act now to make a change and to limit global warming to a level which will not threaten the well-being of present and future generations.

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References

Anderson, K. and Peters, G.: The trouble with negative emissions, Science, 354, 182–183, https://doi.org/10.1126/science.aah4567, 2016.

Arora, V. K. and Montenegro, A.: Small temperature benefits provided by realistic afforestation efforts, Nat. Geosci., 4, 514–518, https://doi.org/10.1038/ngeo1182, 2011.

Baatz, C.: Can We Have It Both Ways? On Potential Trade-Offs Between Mitigation and Solar Radiation Management, Environ. Value, 25, 29–49, https://doi.org/10.3197/096327115X14497392134847, 2016.

Böhm, F. and Ott, K.: Impacts of Ocean Acidification. An analysis from an environmental ethics perspective, in: Beiträge zur Theorie und Praxis starker Nachhaltigkeit, 11, Metropolis, Marburg, 2019.

Boysen, L. R., Lucht, W., Gerten, D., Heck, V., Lenton, T. M., and Schellnhuber, H. J.: The limits to global-warming mitigation by terrestrial carbon removal, Earth's Future, 5, 463–474, https://doi.org/10.1002/2016EF000469, 2017.

Caldeira, K., Bala, G., and Cao, L.: The Science of Geoengineering, Annu. Rev. Earth Pl. Sc., 41, 231–256, https://doi.org/10.1146/annurev-earth-042711-105548, 2013.

Canadell, J. G. and Schulze, E. D.: Global potential of biospheric carbon management for climate mitigation, Nat. Commun., 5, 5282, https://doi.org/10.1038/ncomms6282, 2014.

CESCR (Committee on Economic, Social and Cultural Rights): General Comment No. 12: The Right to Adequate Food (Art. 11), available at: http://tbinternet.ohchr.org/_layouts/treatybodyexternal/TBSearch.aspx?Lang=en&TreatyID=9&DocTypeID=11 (last access: 4 May 2019), 1999.

Chazdon, R. L., Broadbent, E. N., Rozendaal, D. M. A., Bongers, F., Zambrano, A. M. A., Aide, T. M., Balvanera, P., Becknell, J. M., Boukili, V., Brancalion, P. H. S., Craven, D., Almeida-Cortez, J. S., Cabral, G. A. L., de Jong, B., Denslow, J. S., Dent, D. H., DeWalt, S. J., Dupuy, J. M., Duràn, S. M., Espìrito-Santo, M. M., Fandino, M. C., César, R. G., Hall, J. S., Hernández-Stefanoni, J. L., Jakovac, C. C., Junqueira, A. B., Kennard, D., Letcher, S. G., Lohbeck, M., Martínez-Ramos, M., Massoca, P., Meave, J. A., Mesquita, R., Mora, F., Muñoz, R., Muscarella, R., Nunes, Y. R. F., Ochoa-Gaona, S., Orihuela-Belmonte, E., Peña-Claros, M., Pérez-García, E. A., Piotto, D., Powers, J. S., Rodríguez-Velazquez, J., Romereo-Pérez, I. E., Ruíz, J., Saldarriaga, J. G., Sanchez-Azofeifa, A., Schwartz, N. B., Steininger, M. K., Swenson, N. G., Uriarte, M., van Breugel, M., van der Wal, H., Veloso, M. D. M., Vester, H., Vieira, I. C. G., Bentos, T. V., Williamson, G. B., and Poorter, L.: Carbon sequestration potential of second-growth forest regeneration in the Latin American tropics, Sci. Adv., 2, e1501639, https://doi.org/10.1126/sciadv.1501639, 2016.

Creutzig, F.: Economic and ecological views on climate change mitigation with bioenergy and negative emissions, GCB Bioenergy, 8, 4–10, https://doi.org/10.1111/gcbb.12235, 2016.

FAO: The future of food and agriculture – Trends and challenges, Rome, available at: http://www.fao.org/3/a-i6583e.pdf (last access: 6 May 2019), 2017.

FAO, IFAD, UNICEF, WFP and WHO: The State of Food Security and Nutrition in the World 2018. Building climate resilience for food security and nutrition, available at: http://www.fao.org/3/i9553en/i9553en.pdf (last access: 8 May 2019), Rome, FAO, 2018.

Fuss, S., Canadell, J. G., Peters, G. P., Tavoni, M., Andrew, R. M., Ciais, P., Jackson, R. B., Jones, C. D., Kraxner, F., Nakicenovic, N., Le Quéré, C., Raupach, M. R., Sharifi, A., Smith, P., and Yamagata, Y.: Betting on negative emissions, Nat. Clim. Change, 4, 850–853, https://doi.org/10.1038/nclimate2392, 2014.

Fuss, S., Lamb, W. F., Callaghan, M. W., Hilaire, J., Creutzig, F., Amann, T., Beringer, T., Garcia, W. d. O., Hartmann, J., Khanna, T., Luderer, G., Nemet, G. F., Rogelj, J., Smith, P., Vicente, J. L. V., Wilcox, J., Dominguez, M. d. M. Z., and Minx, J. C.: Negative emissions – Part 2: Costs, potentials and side effects, Environ. Res. Lett., 13, 063002, https://doi.org/10.1088/1748-9326/aabf9f, 2018.

Gardiner, S. M.: Some Early Ethics of Geoengineering the Climate: A Commentary on the Values of the Royal Society Report, Environ. Value., 20, 163–188, https://doi.org/10.3197/096327111X12997574391689, 2011.

Gasser, T., Guivarch, C., Tachiiri, K., Jones, C. D., and Ciais, P.: Negative emissions physically needed to keep global warming below 2 °C, Nat. Commun., 6, 7958, https://doi.org/10.1038/ncomms8958, 2015.

Hartmann, J., West, A. J., Renforth, P., Köhler, P., De La Rocha, C. L., Wolf-Gladrow, D. A., Dürr, H. H., and Scheffran, J.: Enhanced chemical weathering as a geoengineering strategy to reduce atmospheric carbon dioxide, supply nutrients, and mitigate ocean acidification, Rev. Geophys., 51, 113–149, https://doi.org/10.1002/rog.20004, 2013.

Haszeldine, R. S., Flude, S., Johnson, G., and Scott, V.: Negative emissions technologies and carbon capture and storage to achieve the Paris Agreement commitments, Philos. T. R. Soc. A, 376, 20160447, https://doi.org/10.1098/rsta.2016.0447, 2018.

Houghton, R. A., Byers, B., and Nassikas, A. A.: A role for tropical forests in stabilizing atmospheric CO_2, Nat. Clim. Change, 5, 1022–1023, https://doi.org/10.1038/nclimate2869, 2015.

Heck, V., Gerten, D., Lucht, W., and Boysen, L. R.: Is extensive terrestrial carbon dioxide removal a "green" form of geoengineering? A global modelling study, Global Planet. Change, 137, 123–30, 2016.

Humpenöder, F., Popp, A., Dietrich, J. P., Klein, D., Lotze-Campen, H., Bonsch, M., Bodirsky, B. L., Weindl, I., Stevanovic, M., and Müller, C.: Investigating afforestation and bioenergy CCS as climate change mitigation strategies, Environ. Res. Lett., 9, 064029, https://doi.org/10.1088/1748-9326/9/6/064029, 2014.

IPBES: Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Inteergovernmental Science-Policy Platform on Biodiveristy and Ecosystem Services – Advance Unedited Version – 6 May 2019, available at: https://www.ipbes.net, last access: 21 May 2019.

IPCC: Climate Change: The 1990 and 1992 IPCC Assessments. IPCC First Assessment Report. Overview and Policymaker Summaries and 1992 IPPC Supplement, IPCC, Canada, 1992.

IPCC: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Core Writing Team, Pachauri, R. K., and Meyer L. A., IPCC, Geneva, Switzerland, 151 pp., 2014.

IPCC: Summary for Policymakers, in: Global warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, edited by: Masson-Delmotte, V., Zhai, P., Pörtner, H. O., Roberts, D., Skea, J., Shukla, P. R., Pirani, A., Moufouma-Okia, W., Peìan, C., Pidcock, R., Connors, S., Matthews, J. B. R., Chen, Y., Zhou, X., Gomis, M. I., Lonnoy, E., Maycock, T., Tignor, M., Waterfield, T., World Meteorological Organization, Geneva, Switzerland, 32 pp., 2018.

Kato, E. and Yamagata, Y.: BECCS capability of dedicated bioenergy crops under a future land-use scenario targeting net negative carbon emissions, Earth's Future, 2, 421–439, https://doi.org/10.1002/2014EF000249, 2014.

Kantola, I. B., Masters, M. D., Beerling, D. J., Long, S. P., and DeLucia, E. H.: Potential of global croplands and bioenergy crops for climate change mitigation through deployment for enhanced weathering, Biol. Lett., 13, 20160714, https://doi.org/10.1098/rsbl.2016.0714, 2017.

Kreidenweis, U., Humpenöder, F., Stevanović, M., Bodirsky, B. L., Kriegler, E., Lotze-Campen, H., and Popp, A.: Afforestation to mitigate climate change: impacts on food prices under consideration of albedo effects, Environ. Res. Lett., 11, 085001, https://doi.org/10.1088/1748-9326/11/8/085001, 2016.

Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Hauck, J., Pongratz, J., Pickers, P. A., Korsbakken, J. I., Peters, G. P., Canadell, J. G., Arneth, A., Arora, V. K., Barbero, L., Bastos, A., Bopp, L., Chevallier, F., Chini, L. P., Ciais, P., Doney, S. C., Gkritzalis, T., Goll, D. S., Harris, I., Haverd, V., Hoffman, F. M., Hoppema, M., Houghton, R. A., Hurtt, G., Ilyina, T., Jain, A. K., Johannessen, T., Jones, C. D., Kato, E., Keeling, R. F., Goldewijk, K. K., Landschützer, P., Lefèvre, N., Lienert, S., Liu, Z., Lombardozzi, D., Metzl, N., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S.-I., Neill, C., Olsen, A., Ono, T., Patra, P., Peregon, A., Peters, W., Peylin, P., Pfeil, B., Pierrot, D., Poulter, B., Rehder, G., Resplandy, L., Robertson, E., Rocher, M., Rödenbeck, C., Schuster, U., Schwinger, J., Séférian, R., Skjelvan, I., Steinhoff, T., Sutton, A., Tans, P. P., Tian, H., Tilbrook, B., Tubiello, F. N., van der Laan-Luijkx, I. T., van der Werf, G. R., Viovy, N., Walker, A. P., Wiltshire, A. J., Wright, R., Zaehle, S., and Zheng, B.: Global Carbon Budget 2018, Earth Syst. Sci. Data, 10, 2141–2194, https://doi.org/10.5194/essd-10-2141-2018, 2018.

Minx, J. C., Lamb, W. F., Callaghan, M. W., Bornmann, L., and Fuss, S.: Fast growing research on negative emissions, Environ. Res. Lett., 12, 035007, https://doi.org/10.1088/1748-9326/aa5ee5, 2017.

Moosdorf, N., Renforth, P., and Hartmann, J.: Carbon Dioxide Efficiency of Terrestrial Enhanced Weathering, Environ. Sci. Technol., 48, 4809–4816, https://doi.org/10.1021/es4052022, 2014.

Morrow, D.: Ethical aspects of the mitigation obstruction argument against climate engineering research, Philos. T. R. Soc. A, 372, 20140062, https://doi.org/10.1098/rsta.2014.0062, 2014.

Parker, C., Mitchell, A., Trivedi, M., Mardas, N., and Sosis, K.: The Little REDD+ Book, available at: http://redd.unfccc.int/uploads/2_162_redd_20091201_gcp.pdf (last access: 12 May 2019), 2009.

Neslen, A.: US scientist launch world's biggest solar geoengineering study, available at: https://www.theguardian.com/environment/2017/mar/24/us-scientists-launch-worlds-biggest-solar-geoengineering-study (last access: 29 July 2019), 2017.

Ott, K.: Might solar radiation management constitute a dilemma?, in: Engineering the Climate: The Ethics of Solar Radiation Management, edited by: Preston, C., 113–131, Lanham, Lexington Books, 2013.

Rickels, W., Klepper, G., Dovern, J., Betz, G., Brachatzek, N., Cacean, S., Güssow, K., Heintzenberg J., Hiller, S., Hoose, C., Leisner, T., Oschlies, A., Platt, U., Proelß, A., Renn, O., Schäfer, S., and Zürn, M.: Gezielte Eingriffe in das Klima? Eine Bestandsaufnahme der Debatte zu Climate Engineering. Sondierungsstudie für das Bundesministerium für Bildung und Forschung, available at: http://www.kiel-earth-institute.de/sondierungsstudie-climate-engineering.html (last access: 4 May 2019), 2011.

Rogelj, J., den Elzen, M., Höhne, N., Fransen, T., Fekete, H., Winkler, H., Schaeffer, R., Sha, F., Riahi, K., and Meinshausen, M.: Paris Agreement climate proposals need a boost to keep warming well below 2 °C, Nature, 534, 631–639, https://doi.org/10.1038/nature18307, 2016.

Sanderson, B. M., O'Neill, B., and Tebaldi, C.: What would it take to achieve the Paris temperature targets?, Geophys. Res. Lett., 43, 7133–7142, https://doi.org/10.1002/2016GL069563, 2016.

Shepherd, J., Caldeira, K., Haigh, J., Keith, D., Launder, B., Mace, G., MacKerron, G., Pyle, J., Rayner, S., Redgwell, C., Cox, P., and Watson, A.: Geoengineering the climate: science, governance, and uncertainty, available at: https://royalsociety.org/~/media/Royal_Society_Content/policy/publications/2009/8693.pdf (last access: 3 May 2019), 2009.

Smit, B.: Carbon Capture and Storage: introductory lecture, Faraday Discuss., 192, 9–25, https://doi.org/10.1039/C6FD00148C, 2016.

Smith, P., Davis, S. J., Creutzig, F., Fuss, S., Minx, J., Gabrielle, B., Kato, E., Jackson, R. B., Cowie, A., Kriegler, E., van Vuuren, D. P., Rogelj, J., Ciais, P., Milne, J., Canadall, J. G., McCollum, D., Peters, G., Andrew, R., Krey, V., Shrestha, G., Friedlingstein, P., Gasser, T., Grübler, A., Heidug, W. K., Jonas, M., Jones, C. D., Kraxner, F., Littleton, E., Lowe, J., Moreira, J. R., Nakicenovic, N., Obersteiner, M., Patwardhan, A., Rogner, M., Rubin, E., Sharifi, A., Torvanger, A., Yamagata, Y., Edmonds, J., and Yongsung, C.: Biophysical and economic limits to negative CO_2 emissions, Nat. Clim. Change, 6, 42–50, https://doi.org/10.1038/nclimate2870, 2016.

Taylor, L. L., Quirk, J., Thorley, R. M. S., Kharecha, P. A, Hansen, J., Ridgwell, A., Lomas, M. R., Banwart, S. A., and Beerling, D. J.: Enhanced weathering strategies for stabilizing climate and averting ocean acidification, Nat. Clim. Change, 6, 403–408, https://doi.org/10.1038/NCLIMATE2882, 2015.

UNEP: The Emissions Gap Report 2018. United Nations Environment Programme (UNEP), Nairobi, available at: https://www.unenvironment.org/resources/emissions-gap-report-2018 (last access: 14 May 2019), 2018.

UNFCCC: Adoption of the Paris Agreement. Report No. FCCC/CP/2015/L.9/Rev.1, available at: http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf (last access: 2 May 2019), 2015a.

UNFCCC: Synthesis report on the aggregate effect of the intended nationally determined contributions. Report No. FCCC/CP/2015/7, available at: http://unfccc.int/resource/docs/2015/cop21/eng/07.pdf (last access: 1 May 2019), 2015b.

UNFCCC: Nationally Determined Contributions (NDC), available at: http://unfccc.int/paris_agreement/items/9485.php (last access: 29 April 2019), 2017.

United Nations: United Nation Framework Convention on Climate Change (UNFCCC), available at: https://unfccc.int/resource/docs/convkp/conveng.pdf (last access 3 May 2019), 1992a.

United Nations: Convention on Biological Diversity, available at: https://www.cbd.int/doc/legal/cbd-en.pdf (last access: 7 May 2019), 1992b.

United Nations: Transforming our World: the 2030 Agenda for Sustainable Development, Resolution adopted by the General Assembly on 25 September 2015, available at: http://www.un.org/ga/search/view_doc.asp?symbol=_A/RES/70/1&Lang=_E (last access: 5 May 2019), 2015.

United Nations, Department of Economic and Social Affairs, Population Division (DESA): World Population Prospects: Highlights (ST/ESA/SER.A/423), available at: https://population.un.org/wpp/Publications/, last access: 14 August, 2019.

Walsh, B., Ciais, P., Janssens, I. A., Peñuelas, J., Riahi, K., Rydzak, F., van Vuuren, D. P., and Obersteiner, M.: Pathways for balancing CO_2 emissions and sinks, Nat. Commun., 8, 14856, https://doi.org/10.1038/ncomms14856, 2017.

Werner, C., Schmidt, H.-P., Gerten, D., Lucht, W., and Kammann, C.: Biogeochemical potential of biomass pyrolysis systems for limiting global warming to 1.5 °C, Environ. Res. Lett., 13, 044036, https://doi.org/10.1088/1748-9326/aabb0e, 2018.