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Climate Change and the Ethics of Technology

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Abstract

Climate change is considered one of the most pressing problems for life on Earth. Climate engineering technologies, it is believed, can offer a potential response to climate change and effective solutions to deal with its effects. However, these technologies may also pose risks. This chapter explores the ethical issues raised by climate engineering. It is divided into two parts. The first part asks what the ethical constraints of the technology might be and how moral responsibility in climate engineering technologies might be articulated. The second part explores the role that artificial intelligence (AI) in information and communication technologies (ICTs) could play in relation to climate change and mitigation and adaptation measures.

Keywords: Engineering ethics -Climate engineering -Value sensitive design -The use of artificial intelligence for climate change mitigation and adaptation -Climate change and ethics of technology

Introduction

Climate change is widely acknowledged as one of the most acute threats to life on our planet that human society is required to address. Global warming and climate change exert an immense impact on humanity, and experts predict that this impact will intensify in the coming decades. Moreover, several irrevocable changes have already occurred. As such, the obligation to meet the world's growing energy needs and protect the Earth's delicate climate and ecological balances under threat constitutes one of the greatest scientific, technological, and social challenges facing humankind in the future. Climate engineering technologies (e.g., geoengineering or "solar radiation management", designed to cool the Earth by reflecting solar energy back into space, or carbon dioxide removal techniques aimed at eliminating CO_2 from the atmosphere) have been identified as potential responses to climate change and effective solutions that may help attenuate its effects. Two broad types of solution to climate change have been proposed: *mitigation* (i.e., rendering the impact of climate change less severe by preventing or reducing, for example, the emission of greenhouse gases into the atmosphere) and *adaptation* (i.e., anticipating the adverse effects of climate change and taking appropriate measures to prevent or minimize the damage it may cause or exploit the opportunities that may arise). In the context of climate change solutions, mitigation may be defined as human and technological interventions that reduce the sources of greenhouse gas emissions and/or strengthen sinks. It may be achieved by, for example, increasing the share of renewable energy, creating a cleaner mobility system or enhancing carbon storage (e.g., by increasing the size of forests). Adaptation may be understood as the process of adjusting to the current and future effects of climate change. Examples of adaptation measures include large-scale infrastructural changes, such as the installation of safeguards to protect against rising sea levels, and behavioral changes, such as the reduction of food waste. Both solution types rely considerably on the development of innovative technologies that can support and propel mitigation and adaptation responses to global warming.

Nevertheless, climate engineering technologies raise serious ethical questions. These technologies are highly controversial and have given rise to debate regarding whether and under what conditions they should be considered. The need to address climate change is not simply limited to the development and use of certain technologies (e.g., technologies for capturing and storing excess carbon dioxide, preventing global warming, and mitigating the greenhouse effect) or the engineering design process grounded in technical and scientific knowledge.

Herein, we shall identify and analyze the ethical issues that climate engineering has highlighted. The chapter is divided into two parts. In the first part, we offer arguments in favor of the idea that ethics can contribute to framing the moral issues that technology generally raises beyond the specific case of climate engineering and explore whether, how and under what conditions the ethical debate in technology might precipitate positive change in the world. We shall further demonstrate why ethical concerns should be addressed during the initial stages of technological development by anticipating potential future social consequences, identifying the ethical constraints that apply to technology and determining how moral responsibility can be articulated for those in the engineering profession. In the second part, we explore the role that artificial intelligence (AI) in information and communications technology (ICT) might play in relation to climate change from a philosophical perspective. More precisely, we demonstrate how AI might be used in mitigation and adaptation measures.

Engineering Ethics: What Kind of Future Are We Designing?

It has become evident that the use of technology and, in particular, engineering processes, cannot be wholly exempted from social, ethical, and ecological considerations. An interdisciplinary approach is warranted so that professionals may cultivate greater awareness of the ethical, environmental, health, political, and social aspects of technology (Terrone & Tripodi, *2022*; Kroes & Verbeek, *2014*; Sclove, *1995*). This new awareness in technology and engineering calls for a thorough assessment of its ethical implications so that any unintended and adverse environmental and social consequences may be minimized, with a particular focus on ethical issues in technology and engineering. Climate engineering technologies may pose several risks and potentially harm vast numbers of people. Equity should thus be a prime consideration for engineers working to address climate change, with full consideration afforded to inequities in climate change impacts and how engineering decisions might exacerbate or alleviate them by incorporating more social science into engineering design and bringing ethical considerations to bear on engineering practice. While applied ethics is required to assess the implications of ecological engineering, engineers must also effectively and concretely evaluate the feasibility and potential merits or demerits of their novel technological framework. During the design process, engineers should consider the potential unintended consequences that might exacerbate existing inequities, particularly those rooted in poverty and gender discrimination.

How can ethics help frame the moral issues pertaining to the use of technology in addressing the challenges associated with global climate change? Is a specific ethical framework required? What role might ethics play in developing technologies designed to "engineer" the climate (i.e., the broad set of methods that aim to deliberately alter the climate system to limit the impacts of climate change on a planetary scale) or those designed to mitigate climate change and support adaptation strategies? To address these questions, let us first examine more generally the role that ethics might play in framing the moral issues of technological innovation and design.

The past two decades have witnessed an increase in the ethical study of specific technologies, particularly computer ethics (the conceptual foundations of which are at the core of information ethics), which recently turned its attention to robotics, AI, machine ethics, and ethics of algorithms, while biotechnology, nanotechnology, and geoengineering also feature prominently. These new fields of ethical reflection have broadly emerged in response to the acceleration of technological progress in tandem with the development of engineering across various research fields (e.g., aeronautics and space, bio-medical, civil, environmental and territorial, industrial and information, construction, etc.). These new fields of ethical reflection are manifestations of applied ethics—that is, the application of theories, concepts and methods rooted in moral philosophy—which is closely linked to modern society's processes of self-reflection and reflects society's division into multiple subsystems and institutions.

Does this technological progress necessarily require the emergence of new modes of applied ethics? Can the issues that new technologies and engineering fields pose be addressed using the tools of traditional ethics? Might different fields of ethical reflection on specific technologies raise their *own* philosophical and ethical questions? Does technological progress justify the emergence of research sub-disciplines and new branches in ethics? Philosophical answers to these questions are rather discordant. For example, we may assume that the development of nano-ethics framework is unnecessary on the grounds that nanotechnology raises no new ethical questions but rather variants of existing ethical questions (Franssen et al., *2022*; McGinn, *2010*; Tavani, *2002*). For this reason, the questions that nanotechnologies pose may be addressed using existing conceptual tools from moral philosophy. At best, the application of traditional ethical principles may yield insights that prompt a reformulation or improvement of existing concepts and theories. Otherwise, we may assume that traditional moral philosophical theories and concepts are not sufficiently generalizable for application to any specific moral problem and that ethical issues in specific technological fields require new concepts and frameworks. For example, in computer and information ethics, it has become necessary to reconceptualize the notion of "privacy" in the specific context of the Internet age (Franssen et al., *2022*; Johnson, *2003*). The notion of privacy is relatively modern, and, as such, it is a concept about which traditional philosophy can tell us little. That is to say, in this particular case, we cannot draw on the philosophical tradition since the privacy issue – as we know it today – was completely unknown to ancient and modern philosophers. New ventures in technological research may, therefore, give rise to new philosophical questions. The definition and investigation of these hitherto unexplored questions may demand new research methodologies and delineate new fields of ethical application and may thus warrant detailed knowledge of specific technologies. Moreover, the emergence of multiple sub-disciplines in applied ethics calls for increased interaction with experts in disciplines that are not ostensibly philosophical, such as law, psychology, medicine, economics, science, and technology, in the belief that much can be learned from interaction and discussion among ethicists who have specific expertise with respect to certain technologies and experts in other fields. However, scholars have lamented the fact that such interaction remains infrequent or wholly absent today, with few exceptions (Franssen et al., 2022).

In the last two decades, the moral debate surrounding questions of technology and responsibility has focused not only on the question of whether a given technology is ethically appreciable but also on the different phases of its design. The idea driving this debate is that technology is still malleable and revisable at the design stage and that negative social consequences are less easily avoided and positive effects less easily obtained when a technology is already in use. As such, the ethical question arises as early as the design stage. Thus, to exert a real and positive impact on society, ethical constraints should be applied to shape technology during the design phase before said technology is already in use (Santoni de Sio & van den Hoven, 2018).

Scholars have recently proposed expanding the remit of engineering ethics (Herkert, 2001; van de Poel & Royakkers, 2011), focusing primarily on two specific concerns. The first is that the traditional approach in engineering ethics tends to take for granted a certain working context within which engineers operate. Here, however, the main ethical issues pertain to how this working context is organized. The second concern relates to the traditional failure to sufficiently consider the impact that technology has on society and the decisions and choices that influence technological design. The purpose of engineering ethics, then, must be to afford greater attention to issues of societal concern. In computer ethics, in particular, as we shall demonstrate below, the so-called Value-Sensitive Design was developed explicitly with the aim of addressing design's ethical aspects as opposed to limiting the consideration to criteria such as maintainability, cost, and reliability and to examine the ways in which ethical values (including safety, sustainability, and human well-being) can be operationalized and incorporated into the design (Bhamra & Lofthouse, 2007; Birkeland, 2002). In line with this approach, decisions concerning a given project's appropriateness are no longer made by considering exclusively economic parameters (i.e., whether a project is monetizable and measurable in physical or qualitative terms).

Engineering ethics is a relatively recent area of inquiry and philosophical research. It is also concerned with the actions completed (or which may be omitted) and decisions made (or which may not be made) individually or collegially by those in professional engineering practice. Engineering is also a liberal profession akin to that of the lawyer or the doctor. The work that engineers perform can directly influence the quality of life enjoyed by members of a given community. Like physicians and other professionals, engineers perform work that has a special social relevance; their work affects factors that are considered fundamental to life and public sustainability (such as safety, pollution, energy use, and public health). Consequently, as members of a professional category, engineers are expected to conduct themselves in accordance with the highest standards of honesty and moral integrity, loyalty, and independence (Davis, 1998; van de Poel, 2015, p. 669; Pritchard, 2009), and the services they provide should be inspired by values such as impartiality, fairness, and equity. These values are often acknowledged as paramount in professional codes of ethics.

Moreover, these services should be oriented toward respect for and protection of public health and collective welfare. Ethical reflection on the issue of engineers' responsibility requires that, first, we delineate more precisely what a "profession" is and how exactly it is defined. While no consensus exists with respect to how this concept should be defined, we can identify several general characteristics that professional practice presupposes. According to Davis (1998, p. 417), a profession may be defined as "a number of individuals in the same occupation voluntarily organized to earn a living by openly serving a certain moral ideal in a morally permissible way beyond what law, market, and morality would otherwise require". Further to this, we may state that professional practice requires specific knowledge and skills acquired over a lengthy study and training period;

that members of the same profession can evaluate the quality of a colleague's work (if it has been competently performed); that it serves society and thus provides products and services that are considered socially useful and beneficial; and that its daily practice is governed by ethical standards geared toward serving society. What, then, are the professional obligations of engineers outlined in the codes of ethics adopted by engineering societies? What role should the engineer assume relative to the design team? How can an engineer fully assume responsibility and shape the world for the better? How should cases of whistleblowing (the reporting of illegal or fraudulent activities) and conflicts of interest be approached (Martin & Schinzinger, 2005; Harris et al., 2008; Santoro & Kumar, 2018)? These questions are all pertinent to the issue of engineering ethics; to address them, the next section examines what it means for a project to implement and embody ethical values.

Do Technologies Present a Moral Hazard?

Value-sensitive design is a theoretical approach to technological design that aims to synthesize methods and applications in a design process that involves human values at every stage (Friedman & Kahn, 2003; van den Hoven, 2007, 2013). This approach aims to combine three different types of analysis (conceptual, empirical, and technological) and to integrate ethical principles, such as sustainability, inclusivity, and affectivity, into the design phase (Franssen et al., 2022). For example, one might say that an *inclusive* design (Clarkson, 2003; Desmet, 2013; Erlandson, 2008) is one that aims to achieve something that is accessible to all members of a community—that is, one that does not exclude society's most vulnerable actors, such as the elderly, children, women, and the differently abled. An *affective* design is one that aims to evoke positive emotions in those who use a certain type of technology and contribute to individual well-being. A *sustainable* design, meanwhile, aims, for example, to exert no negative environmental impacts, such as endangering the survival of certain animal species or jeopardizing biodiversity. How might engineers implement such an approach and how might they determine which values they should prioritize?

The idea of incorporating values in design may be articulated in various ways. During the various phases of the design process, a distinction is made between instrumental values (such as effectiveness, quality, economic profit, efficiency, reliability, and maintainability) and final values (such as human well-being, justice, safety, health, and sustainability). These phases typically comprise a series of essential activities, including "analysis (of the design problem), synthesis (of possible design solutions), evaluation (of the possible solutions in the light of the problem), and choice (of one design solution)" (van de Poel, 2015, p. 672–674). During all phases, values can play different and varied roles. For example, in the analysis phase, the design problem is conceptualized by the designer and the team. In this phase, the values that are incorporated may affect how the problem is conceived and framed. The analysis phase, then, culminates in a particular formulation of the design problem and certain design constraints that an ethically good or acceptable solution must satisfy; alternatively, it may be necessary to revise the problem formulation or design requirements. During the evaluation phase, the simulation results of various project solutions are evaluated in different ways (e.g., keeping in mind the satisfaction of functional or cost requirements and the instrumental and final values). At this stage, it is necessary to choose which conceptual project will be pursued and developed. Here, the decision will be informed by the evaluation results of various projects, and values are a key decision criterion. However, difficulties may arise at this stage: it may not be possible to choose a project that meets all design requirements and satisfies all instrumental or final values. Therefore, it is necessary to choose between conflicting values. For example, as has been noted (Franssen et al., *2022*), a safer car is not necessarily the most eco-sustainable option. In this case, safety and eco-sustainability are two conflicting ethical principles. Where conflict arises between principles, the challenge is to determine at the design stage which principle takes precedence over the other by establishing a hierarchy among the different principles. The methods that engineers implement in dealing with conflicts of this nature include not only cost–benefit analysis but also multi-criteria analysis, which also considers environmental and social impacts to be relevant in assessing a project's cost-effectiveness. However, several open ethical questions remain unanswered with respect to how the values to be normatively incorporated into a design should be chosen, how conflicting values should be handled at the design stage, and how to determine whether a project embodies or represents the values that informed its design (van de Poel, *2015*, p. 686) (Flanagan et al., *2008*).

Attempts to incorporate moral values in design are not immune to critical issues, including the major issue mentioned above relating to managing the conflict between ethical principles and the elimination of possible risks. As various researchers have highlighted (Asveld & Roeser, *2009*; Hansson, *2003*, *2009*; Shrader-Frechette, *1991*; Roeser, *2012*), risk elimination is not always a viable option; sometimes, it may not even be desirable. In some cases, risk elimination is not possible because not all technological devices are completely safe. Therefore, safety is a standard that cannot always be guaranteed. In other cases, however, while risk reduction may be feasible, it may not be ethically appreciable. In fact, risk reduction often comes at a high cost; safer technological devices and artifacts are sometimes less user-friendly and less sustainable with respect to environmental protection. Therefore, the moral questions with respect to the question of responsibility in the terms we are developing here are as follows: What makes a risk acceptable or unacceptable? When is a technological device definable as "safe enough", and What precisely is meant by "safe enough"?

The process that examines technological risk assessment may be broadly divided into three stages: assessment, valuation, and management (Cranor, *1990*; Shrader-Frechette, *1991*). Of these three stages, the most relevant from an ethical perspective is the second. However, some have observed (Franssen et al., *2022*) that the stage at which risk is ascertained may already include some value judgment (e.g., which type of risk should be ascertained primarily). At this stage, the question regarding the degree of evidence that is required to establish a risk is ethically important. In decreeing a risk in accordance with a set of empirical data, two types of error may arise: one might erroneously determine that there is a risk when in fact, that risk is not there (error type 1); alternatively, one might erroneously come to believe the opposite—that is, that there is no risk when, in fact, there is some risk (error type 2) (Franssen et al., *2022*). Traditionally, science has been tasked with avoiding error type 1. In the context of a specific risk, the ascertainment stage may be regarded as the most crucial in avoiding error type 2. The ascertainment of a risk aims not only to establish scientific truths but also to achieve practical purposes—that is, to establish the requisite knowledge that facilitates sound decisions regarding the desirability or undesirability of reducing or avoiding a certain risk with the aim of protecting individuals and communities.

The assessment stage may be approached in different ways (Shrader-Frechette, *1985*). One approach is to estimate the acceptability of a risk by comparing it to other risks or to certain standards; for example, one might compare a technological risk with a natural risk. A key limitation of this approach, however, is that it falls into a naturalistic fallacy: the fact that a natural risk may sometimes be inevitable does not necessarily make it acceptable from an ethical perspective.

Another option is to evaluate risk by means of cost–benefit analysis and based on the weight that may be assigned to risks over benefits. As a rule, the following criterion is applied in cost–benefit analysis: a risk is acceptable if—and only if—the ultimate benefits of exposure to the risk outweigh the likely disadvantages.

A third approach is to evaluate the acceptance of risk based on the consent of people who, having been adequately informed of the potential harms, are willing to accept that risk. The difficulty with this third approach lies largely in the fact that technological risk can impact very large populations. Informed consent may thus result in decision stalemates. To address these difficulties, alternatives to traditional risk assessment approaches have been proposed, and several reforms suggested for adoption in risk assessment or evaluation procedures. One approach might be to consider certain moral issues that are traditionally considered marginal. For example, at the valuation stage, it would serve to consider whether individuals might derive some benefit from the risk in question or whether the distribution of risks and benefits is equitable. By contrast, some authors have criticized the excessive focus on the risk factor. This position is motivated by the fact that it is not possible to reliably assess the risks of a new technology before it comes into use, given that the necessary information is not always available. That is, for the most part, we are unable to predict that something might go wrong since we do not always have sufficient information regarding the potential negative consequences of a given technology. In some cases, the focus on risks has weakened the moral evaluation of new technologies. Generally, only a certain type of impact is assessed as risky—the impact on physical well-being and safety, for example—while other types of impact, such as those of a social and psychological nature, are often overlooked.

This concludes the general part of this chapter, which sought to introduce several of the most relevant questions in the field of the ethics of technology and engineering. In the section that follows, we shall consider whether AI poses moral issues in relation to climate change and the moral principles to which engineers should adhere in promoting desirable and minimizing undesirable outcomes in the field and in the developmental process associated with AI in climate engineering and climate change response.

Does AI in Relation to Climate Change Pose Moral Issues in Relation to Climate Change?

AI has been defined and understood in various ways. We might understand AI broadly as “any kind of artificial computational system that shows intelligent behaviors, i.e., complex behaviors that is conducive to reaching goals” (Muller, *2021*). According to McCarthy et al., “for the present purpose the artificial intelligence problem is taken to be that of making a machine behave in ways that would be called intelligent if a human were so behaving”. (McCarthy et al., *2006*). According to a World Economic Forum report entitled “Harnessing Artificial Intelligence for the Earth”, the term AI refers to computer systems that “can sense their environment, think, learn, and act in response to what they sense and their programmed objectives”. AI may be applied across several areas (industry, agriculture, health care, education, finance), and its applications may include various techno-scientific branches, machine learning, and software. While there are ways in which AI can support efforts to address climate change, other applications of AI may actually exacerbate climate change and its effects. Despite technological advances, AI systems and solutions are often energy-intensive and produce significant volumes of carbon emissions, thus negatively impacting the climate. Although it is often regarded as “clean” technology, as some authors have argued, AI has a dual role in relation to climate change. On the one hand, AI accelerates the environment’s degradation because of the current dependence of electricity on fossil fuels and consequently affects human health, livelihoods, and security; on the other hand, technological progress in relation to AI is an essential component in solutions to ecological breakdown and may contribute to addressing the Earth's environmental challenges, particularly mitigating greenhouse gas emissions and supporting social adaptation to the adverse effects of global warming. At this juncture, let us consider first how AI in ICT impacts climate change.

According to several recent important studies on the carbon footprint (the total greenhouse gas emissions) caused by ICT, AI is largely unsustainable and exerts a significant environmental impact, and evidence suggests that, with greater use and diffusion of these technologies, their negative effects will intensify. A study conducted by Belkhir and Elmeligi (*2018*), which included the production and the operation energy of ICT devices (laptops, smartphones, and tablets), has shown that "the ICT GHGE [greenhouse gas emissions] contribution relative to worldwide footprint will roughly double from 1 to 1.6% in 2017 to 3–3.6% by 2020". They noted that "ICT's relative contribution would exceed 14% of the 2016-level worldwide GHGE by 2040". According to this study, the bulk of these emissions are generated by ICT infrastructure, including data centers and communication networks. Strubell et al. (*2019*) examined the carbon footprints of different AI models and found that the estimated emissions varied among the models. The training of AI for natural language processing (NLP) models was found to be associated with the highest emissions, with estimates suggesting that these emissions amount to approximately 300,000 kg CO_2e. Other studies have yielded similar conclusions. AI requires electricity to function, and this demand for electricity continues to rise. Most global electricity production is currently generated by coal-fired power stations. AI additionally relies on the production of hardware and other devices, such as computers, data services, cables, and batteries. This also includes the mining and the transportation of metals (such as lithium and cobalt), the production of components, and transportation of the final product to users and developers. Moreover, most digital technologies rely on rare minerals that are becoming increasingly scarce. Therefore, when calculating the emissions associated with the development, production, and various uses of AI, one might also consider the emissions generated by this production chain and that the energy requirements, which mean that this chain relies largely on fossil fuels. The environmental impact in terms of climate change is thus likely to be immense. It has been estimated, for example, that global CO_2 emissions from the ICT sector have now surpassed the airline industry in terms of impact.

Nevertheless, as has been argued (Nordgren, *2022*), from an environmental perspective, AI may serve as a tool that can support better management of climate change and play a key role in strategies against climate warming, with the potential to deliver transformative solutions in this respect. While AI technology is not in itself sufficient to solve climate change, researchers have proposed various ways in which AI may best be applied to this end. AI facilitates automatic monitoring through remote sensing: as such, its use may allow us to detect deforestation or collect data on buildings and assess damage in the aftermath of environmental disasters. AI can accelerate some scientific processes and discoveries—for example, by suggesting new materials for batteries, construction, and carbon capture. AI allows us to optimize systems to improve efficiency (e.g., consolidating freight transport, designing carbon markets, and reducing food waste). It can also accelerate physical simulations computationally through hybrid modeling (such as climate models and energy programming models). Additionally, the development of AI-based techniques may help improve short-, medium-, and long-term forecasts (e.g., on an annual scale) in the future. Let us now consider in greater detail some of these proposals regarding how AI might reduce greenhouse gas emissions and help mitigate the adverse effects of climate change.

One key proposal concerns energy efficiency and machine learning models training. Individual practitioners and organizations can take concrete actions that target key aspects of a neural network to mitigate carbon emissions. These aspects may include “the location of the server used for training and the energy grid that it uses, the length of the training procedure, and even the make and model of hardware on which the training takes place” (Lacoste et al., 2019) and the selection of more efficient hardware. As noted above, the energy consumption of AI systems—machine learning, in particular—has doubled in recent years. According to experts, several factors affect the carbon footprint of neural networks, including where the server used for training is located, the energy network to which it is connected, the size of the dataset, and the hardware in which the training takes place. AI training and use may be more energy-efficient in terms of model performance and environmental impact, but a reduction is warranted, since training a machine learning model generates significant amounts of carbon emissions while using no more data than is necessary. Therefore, the use of increasingly energy-efficient processing units, servers, storage, devices, and hyperscale data centers is important in reducing greenhouse gas emissions.

Another proposal is that the AI model should be trained using mainly electricity from renewable sources as a means of reducing the carbon footprint. Some suggest making efficiency an evaluation criterion: AI researchers, when publishing results relating to new models, should report the financial costs of developing, training, and running the models to help make AI more sustainable (Schwartz et al., 2019). Some have also suggested that the data centers at which algorithms are trained should be selected consciously and located in countries in which cloud providers are low-carbon and powered by renewable energy sources. Another proposal is to distinguish where possible between luxury consumption, wastefulness, and sufficiency. This may suggest that the use of AI to counter phenomena such as droughts, unsafe levels of air pollution, the depletion of fishing stocks, toxins in rivers and soils, overflowing levels of waste on land and in the ocean, biodiversity loss, and deforestation or to make health care and people’s welfare more effective is ethically appreciable, while other uses of AI—for entertainment purposes, for example—are not.

Proposals regarding the use of AI for climate change mitigation include the idea that machine learning may help prevent methane (an extremely potent greenhouse gas) leakage from natural gas pipelines and compressor stations. Mitigation methods include reducing emissions from fossil fuels, minimizing waste associated with electricity delivery, and flexibly managing demand to minimize the impact of emissions: “reduce emissions from freight transportation of solid fuels, identify and manage storage sites for CO_2 sequestered from power plant flue gas, and optimize power plant parameters to reduce CO_2 emissions” (Rolnick et al., 2019, p. 11). AI may further help to enhance energy efficiency; improve energy storage; make cities more energy-efficient and liveable; monitor ecosystems; monitor drinking water quality and manage residential water use; detect underground leaks in drinking water supply systems and predict when water plants need maintenance; simulate weather events and natural disasters; and improve the accuracy of climate change projections. Moreover, AI may be useful in determining the best times to plant, water, and harvest crops and prevent plant diseases, allowing for greater efficiency in reducing water use as well as the use of fertilizers and pesticides.

AI may also be instrumental in raising awareness and encouraging people toward more climate-friendly lifestyles while helping governments and various institutions to achieve national and international climate goals by making nudging activities more efficient (Coeckelbergh, 2020, p. 69). AI can also influence human behavior by incentivizing more climate-friendly actions. More specifically, AI can help prompt people to waste less energy, generate less waste, avoid using cars, and encourage travel by more environmentally friendly means, such as cycling. Gentle nudging will not force people to change but rather will encourage users, consumers, and citizens to choose certain options over others. For example, food retail outlets could be designed to ensure that products that are more climate-friendly and have a lower carbon footprint are afforded the locations with the greatest visibility. Encouragement of this nature does not restrict people's freedom but exploits their propensity to make biased decisions, albeit for positive environmental purposes in this case. These nudging operations exploit heuristics and cognitive biases, such as framing, confirmatory bias, and negativity bias, which have been shown to simplify decision-making in multiple contexts.

Let us now consider some of the proposals put forward regarding the use of AI for climate change adaptation. AI may be used to develop more resilient designs for buildings, landscapes, and communities capable of withstanding the effects of extreme weather, natural and man-made disasters, and climate change such as including rising sea levels, heatwaves, droughts, severe storms, flooding, wildfire, and other impacts that are expected to result from a warming climate. AI may be useful in identifying design solutions based on future climate conditions rather than relying on past data; creating buildings that can maintain liveable conditions during prolonged power or heating fuel shortages and capable of withstanding hurricanes and other high winds; optimizing the use of on-site renewable energy; and implementing water conservation practices and water resources that replenish themselves (rainwater harvesting). It may also improve weather forecasting and protection against extreme weather events, help predict the trajectories of hurricanes and other storms as well as the onset of natural phenomena, such as droughts or floods. In addition, AI may prove to be a useful agricultural tool in terms of adjusting planting times.

Any application of AI in climate change mitigation and adaptation should ensure that negative environmental impacts do not affect society's most vulnerable and that the benefits are not exclusive to the richest and most technologically advanced countries.

Based on this brief examination, the AI developer and programmer community should begin working toward new paradigms and models that, for example, do not require high energy use. Energy efficiency is an evaluation criterion for research—namely, using more computationally efficient hardware and algorithms and tools (such as machine learning emissions calculators) that can help estimate the amount of carbon emissions produced by training AI models. In this context, it has been proposed that, for example, published findings relating to new AI models should include data on how much energy was expended in model development or that contracts with fossil fuel companies should be canceled. Ethical questions pertaining to the application of AI in climate change mitigation and adaptation increasingly emerge as a fundamental challenge. How should engineers determine which values they should prioritize during the design stage (Dym et al., *2014*)? What risks does the deployment of these technologies entail? What tradeoffs might emerge as a result of their deployment? In the following paragraph, we shall explore and further define several key final values that are instrumental in climate engineering—more specifically during the design process—and the development and use of AI in relation to climate change. In doing so, we shall turn our attention to some ethical values that engineers might incorporate into the technologies that they design and develop.

Final Ethical Values and Climate Engineering

One of the final values considered relevant to climate engineering design and often mentioned in ethical codes is safety. As noted, there is no such thing as risk-free climate protection, and none of the climate geoengineering pathways (in particular, radical geoengineering technologies such as space mirrors, ocean iron fertilization, and cirrus cloud thinning designed to modify the Earth's climate system) is inherently safe (Sovacool et al., 2022). Every possibility offered by climate geoengineering has associated risks. For example, low-cost carbon storage options (such as afforestation or ecosystem restoration) may have negative outcomes in terms of ecosystem health and functionality. Afforestation and ecosystem options, in fact, require considerably more land and irrigation if no fertilizer is used (the best option for local ecosystems). However, to double or triple the yield, environmentally harmful nitrogen fertilizers must be introduced. Sovacool et al. (2022) suggested a framework that clusters the risk–risk tradeoffs into three categories: institutional and governance, technological and environmental risk, and behavioral and temporal. As a final institutional tradeoff, they write, "the urgency and immediacy of addressing climate change could generate a powerful incentive to deploy geoengineering options as soon as possible— but this also means there will be fewer tests, possibly less stringent safety protocols, and greater uncertainty about their impacts. In this way, urgency lies in direct tension to safety" (Sovacool et al., 2022, p. 8). Their research recognizes a total of 12 risk–risk tradeoffs in climate geoengineering that must be weighed against the risks of climate change itself. It may be difficult to manage some of these tradeoffs—for example, weaponization or social backlash. This may render some options unmanageable. Nonetheless, the authors maintain that "while these approaches pose risks of their own across different types of populations and ecosystems, they also have the (greater) potential to significantly reduce the pending impacts of climate change to humans" (Sovacool et al., 2022, p. 2).

Another relevant final value for engineering is that of "human well-being" and "health". According to the World Health Organization (WHO), "health" may be defined as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (World Health Organization, 2006). From this perspective, "the enjoyment of the highest attainable standard of health is one of the fundamental rights of every human being without distinction of race, religion, political belief, economic or social condition". As noted above, climate change is already affecting human health and human well-being. The effects of these changes can exacerbate various diseases (e.g., heart and lung diseases). Intense weather events (e.g., heatwaves, droughts, bushfires, storms, and floods) caused by these changes also have major impacts on electricity supply, transportation, and communication systems. These effects, in turn, impact the ability to meet increased demands for health services. Climate engineering should address climate risks by reducing carbon footprints and health damages and improving the sustainability of health systems and the effects that climate change has on the delivery of these services. Technologically supported use of AI in public health is essential for climate-resilient health systems and the transition away from existing coal. In climate engineering, the goal should be to avoid negative influences on human health and to contribute positively to human well-being.

The relevance of human rights as ultimate ethical value in the contribution that engineering can make to the fight against climate change has been outlined. The effects of climate change manifest themselves not only as weather phenomena. These ecological disasters have dramatic consequences for human populations. Migration, violence, poverty, inequalities, and exploitation are negative consequences of some of the effects of climate change. Moreover, these changes also involve violations of the rights of unconsenting individuals, such as children and future generations. It should also be noted that, as some data indicate, the poorest women in developing countries are one of the social groups most vulnerable to the effects of climate change (Tripodi, 2023). Excessive greenhouse gas emissions and the causes of global warming may also be framed as a violation of certain human rights (Zwolinski, 2014; Torpman, 2021). Evidence suggests that populations with lower emissions are more affected by climate change than those that consume more as climate change affects their lives and their rights. As several authors have noted, climate change poses serious social injustice problems and jeopardizes people's ability to enjoy the full range of human rights. According to the United Nations Universal Declaration of Human Rights, "everyone has the right to life, liberty and security of person". Climate engineering should thus incorporate a human rights-based approach to duties, rights, and participation (Suarez et al., *2010*, *2013*; Suarez & van Aalst, *2016*; Svoboda et al., *2019*).

Climate engineering should increasingly incorporate environmental values in terms of sustainability with an eye toward future generations as well. According to the Brundtland Commission (WCED, *1987*), "sustainable development" entails "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". According to The United Nations Sustainable Development Goals, many of the challenges facing humanity relate directly to the environment and human influence on it. To meet the needs of current and future generations, there must be a balance between economic growth, environmental protection, and social welfare. Climate engineering must address climate change in ways that optimize innovations to advance transformations toward sustainability, ensure that the transition to low-carbon energy systems is equitable, and create new and sustainable mobility systems. Technological innovation should be used to conserve and use the oceans, seas, and marine resources for sustainable development; protect, restore, and promote the sustainable use of terrestrial ecosystems, biodiversity, and endangered species; combat desertification; develop sustainable cities; and provide affordable clean energy. Sustainable development can only be achieved through climate action, and climate engineering should help to create sustainable outcomes for humanity and the planet we inhabit. The challenge is to make sustainability considerations central to the development and use of AI in general. Other final values mentioned and considered relevant in this engineering field include autonomy (understood as the citizens' right to participate in research as potential subjects of climate change impact), integrity (in relation to conducting scientific research for the common good and freedom of scientific research and its limits), and freedom of research on climate engineering.

Conclusions

Ethical values play a key role in engineering climate change design. Strategies aimed at counteracting the effects of global warming cannot be limited to (i) the identification of innovative strategies for monitoring and analysis of climate change, (ii) the mitigation of this change through in-depth analysis of the cycle of resources and materials in their overall supply chain, from extraction to use, resulting in emissions or re-emissions to the environment, and (iii) the technological and planning solutions for adaptation to climatic variations. Rather, climate engineering warrants careful ethical consideration, and attempts to address the issue of climate change also require reflection on what interests and rights are at stake and, at the technological design stage, which moral principle should take precedence over another.

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