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The Priority of Nature-based over Engineered Negative Emission Technologies: Locating BECCS and DACCS within the Hierarchy of International Climate Law

Philipp Günther [1,2] and Felix Ekardt [1,3,*]

[1] Research Unit Sustainability and Climate Policy, 04229 Leipzig, Germany; philipp.guenther@wzb.eu (P.G.)

[2] WZB Berlin Social Science Center, 10785 Berlin, Germany

[3] Faculty of Law and Interdisciplinary Faculty, University of Rostock, 18051 Rostock, Germany

* Corresponding author. E-mail: felix.ekardt@uni-rostock.de (F.E.)

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ABSTRACT: Drastically reducing emissions is essential to achieve the Paris Agreement's (PA) goal of keeping global temperature well below 2 °C, ideally at 1.5 °C. With regard to residual emissions, however, a demand for negative emission technologies (NETs), also known as carbon dioxide removal (CDR), remains. NETs are particularly necessary to reach net-zero goals by offsetting emissions in hard-to-abate sectors. This article examines the distinction between "engineered" and "nature-based" removals from the perspective of international climate change law. To that end, the relevant legal norms in the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol (KP), and the PA are interpreted—with a particular emphasis on two engineered removals: bioenergy with carbon capture and storage (BECCS) and direct air carbon capture and storage (DACCS). We posit that the three treaties establish a normative hierarchy that is more favorable towards so-called nature-based removals and less favorable to engineered removals (and even more favorable towards emission reductions).

Keywords: Climate law; Environmental law; Negative emission technologies; BECCS; DACCS; Paris Agreement; UNFCCC; Climate change

1. Introduction

In its latest report, the Intergovernmental Panel on Climate Change (IPCC) stated that greenhouse gas (GHG) emissions between 2010 and 2019 were higher than in any previous decade [1]. Article 2 para. 1 lit. a Paris Agreement (PA or the Agreement) obliges states to limit global warming well below 2 °C and pursue efforts to stay below 1.5 °C, which can be achieved most effectively by phasing out fossil fuels and minimizing livestock farming [2,3]. However, states have largely failed to reduce emissions in most sectors—and, even more importantly, some residual emissions will remain in any case [4,5]. As a result, negative emission technologies (NETs)—also known as carbon dioxide removal (CDR)—have risen on the climate agenda in recent years due to their promise to remove GHGs [6–9]. Their deployment will be necessary to compensate for emissions in hard-to-abate sectors in order to reach net-zero goals [1]. Researchers have introduced several methodologies to distinguish between the different NET approaches, most notably the distinction between "engineered" and "nature-based" removals [10–13]. Engineered removals typically include, inter alia, two NETs: bioenergy with carbon capture and storage (BECCS), and direct air carbon capture and storage (DACCS). Both technologies have been at the center of recent academic and public debate [16,17], and they have featured prominently in the latest IPCC climate scenarios [1]. However, both BECCS and DACCS remain unproven at scale, and their large-scale deployment may cause significant environmental effects and infringe upon human rights [18–20]. In contrast to engineered removals, nature-based removals (e.g., forestry, peatland management, ecosystem restoration) have largely proven to be effective in sequestrating carbon dioxide (CO_2) while simultaneously providing co-benefits to biodiversity [21–23]—provided they are not managed monoculturally [12,24–26]. In addition, their deployment is typically not associated with significant risks to human rights [13]. Although engineered and nature-based removals differ with regard to their impact on human rights, some scholars posit that all NETs are treated equally by the relevant legal instruments of the international climate regime [7,27,28]. In the following article, we will explore why the distinction between nature-based and engineered removals is merited not only from a human rights perspective but also from the viewpoint of international climate change law. However, we do not argue for a specific distinction regarding NETs, since those are only of limited epistemic value [29]. Instead, we will show that the United Nations Framework Convention on Climate Change (UNFCCC or the Convention), Kyoto Protocol (KP or the Protocol), and PA establish and maintain

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a normative hierarchy that is more favorable towards so-called nature-based removals and less favorable to the NETs known as engineered removals.

This article is not only relevant because it contributes to a novel legal perspective to the debate surrounding nature-based and engineered removals [13], but it also addresses the following research gap: Several authors have previously argued that emission reductions have legal priority over NET measures [3,13,27,30]. Furthermore, it has been established that solar radiation management (SRM) cannot be regarded as "mitigation of climate change" under the UNFCCC and is incompatible with human rights law and should therefore be subordinated to any other climate change-related measures [13]. Likewise, it was previously shown that some large-scale BECCS and DACCS scenarios are also likely to be incompatible with human rights law and are therefore less favorable than emission reductions and nature-based solutions [18]. However, there has been no research on the legal relationship and the hierarchy of different NET approaches and the legal relationship between them on the basis of the UNFCCC, KP, and PA. This paper aims to fill this gap by conducting a legal textual analysis based on the relevant provisions by focusing on the two main forms of engineered removals, BECCS and DACCS. We focus on these two technologies because this allows us to contrast them with nature-based removals in a compact manner, since it would fall outside the scope of this paper to also focus on each nature-based removal method. Moreover, BECCS and DACCS are currently the NET approaches receiving the most attention from researchers, governments, and businesses—which is why they merit enhanced scrutiny.

2. Methodology and Materials

2.1. Legal Interpretation as Methodology

Methodologically, we will proceed as follows: Firstly, we will explain the distinction between engineered and nature-based removals from a natural-scientific perspective. To that end, we will briefly overview the literature on BECCS and DACCS deployment, particularly emphasizing their projected carbon removal potential and associated risks. Nature-based removals and their prospects and drawbacks will likewise be featured and contrasted with engineered removals. Secondly, we will conduct a legal interpretation of the relevant international legal norms of the climate change regime—namely, the UNFCCC, KP, and PA—in order to establish that these treaties establish a legal hierarchy between nature-based and engineered removals. We will begin by defining the concept of legal hierarchy between different mitigation measures before turning to the legal interpretation of the specific norms. Legal interpretation as a method (in international law) primarily involves the rules of interpretation under Articles 31 and 32 Vienna Convention on the Law of Treaties (VCLT). According to these rules, norms are interpreted grammatically, systematically, teleologically, and historically. This means that their literal meaning, relationship to other relevant legal norms, intended purpose, and historical development are taken into consideration [3,29,31,32]. In the civil law sphere, case law would typically serve as an additional source of interpretation. In our case, however, there are no cases or judgments that touch upon the issues relevant to our analysis.

2.2. Engineered and Nature-based Removals in Context

Both engineered and nature-based removals have become ubiquitous in the climate discourse. According to the 2022 IPCC report, the deployment of NETs to "counterbalance hard-to-abate residual emissions is unavoidable if net zero CO2 or GHG emissions are to be achieved" [1] (p. 36). While the UNFCCC and its succeeding legal documents mostly use the terms "sinks" or "reservoirs" to refer to NETs, the categorizations of these methods used by the IPCC and the research landscape in general have changed repeatedly in the past. Previously, all NETs were typically lumped together with SRM under the umbrella terms of "geoengineering" or "climate engineering" (CE) [13,29]. However, since most researchers now agree that SRM and NETs cannot be equated in terms of deployment risks and mitigation effectiveness [13], the debate has shifted towards the role of NETs and how to distinguish between the different forms of these approaches. Two concepts have emerged from this debate: "nature-based" and "engineered removals." While the former refers primarily to the conservation and enhancement of existing natural sinks, the latter describes the deployment of industrial carbon and capture facilities to remove CO2 from the air and store it underground. Some scholars have criticized these opposing concepts as being false dichotomies [33,34]. It is certainly true that these concepts and respective technologies are not always distinguishable as "engineered" or "nature-based" removals. Such distinctions are never accurate from an epistemic standpoint [29]. However, they are relevant because they clarify the intent of our legal analysis—namely, to examine the previously overlooked legal relevance of this distinction. In the following, we will thus summarize the fundamental concepts, benefits, and risks associated with both approaches—with a particular focus on BECCS and DACCS systems.

Engineered removals rely on human-made technologies to remove and sequester GHGs. These removals are usually categorized as two different but related procedures: On the one hand, BECCS describes the process of capturing the CO_2 that is emitted during the combustion of bioenergy fuels [35–39]. On the other hand, DACCS plants directly capture the CO_2 from ambient air via chemical agents [16,40–43]. Both technologies rely on carbon capture and storage technologies (CCS) that separate the CO_2 from the air or exhaust fumes, a particularly energy-intensive process. After the CO_2 has been captured in a BECCS or DACCS plant, it is subsequently compressed, liquified, and stored in underground facilities or utilized for other industrial purposes [44–49].

BECCS is first and foremost reliant on bioenergy, which binds the atmospheric CO_2 through photosynthesis. BECCS systems can utilize woody biomass, food waste, or other agricultural residues as fuels [35,50,51]. However, the technology is only likely to be able to sequester CO_2 at Gigatonne (Gt) scale if large amounts of energy crops are used as fuels [9,37,52]. To date, first-generation energy crops (which compete with food crops) are utilized in conventional bioenergy plants, which in turn implies a host of issues for a potential BECCS scale-up [53]. Second-generation energy crops (e.g., willow or *Miscanthus*) do not directly compete with food crops but could nonetheless adversely impact food security through direct or indirect land-use change [53]. The harvested biomass is usually combusted inside a bioenergy plant that uses a CCS system (either pre-combustion, post-combustion, oxy-fuel-combustion, or chemical looping) [36,54–56] to separate the CO_2 from the other chemical byproducts and subsequently compresses and liquifies the CO_2. The CO_2 is subsequently transported via pipelines to an underground storage facility, either onshore or underwater [47,57–59], which then results in the "production" of negative emissions. However, there are several unresolved issues in a typical BECCS life cycle—such as unaccounted supply chain emissions and significant carbon debt. These call into question the technology's promised sequestration potential [60–63].

DACCS is the only engineered NET that can remove CO_2 directly from the air. There are two main approaches: high-temperature and low-temperature DACCS. High-temperature DACCS involves pressing large amounts of ambient air through a system of fans and onto a surface lined with liquid sorbents, which bind the CO_2 molecules [64–67]. The sorbents are then reheated at high temperatures (typically between 600–1,000 °C) to release the CO_2, which is subsequently liquified and stored in a geological facility [43,64,65,68]. Low-temperature DACCS, in contrast, involves the process of adsorption of CO_2 via solid amine compounds [58,68–71]. The separation process for low-temperature DACCS systems is significantly less energy-intensive and typically requires temperatures around 100 °C [72]. However, there is currently no sorbent material that can ensure annual sequestration rates at Gt scale [68]. The biggest drawback of any DACCS system is its energy consumption, which is due to the CO_2 separation process. As a result, DACCS is currently the most expensive NET by far, with recent estimates ranging between 600–1200 USD per ton of CO_2 removed [8,9,40,73,74]. As was shown elsewhere, this excessive energy demand is not only a cost issue but is also potentially problematic from a human rights perspective [18].

BECCS and DACCS have gained in popularity in recent years—although they only account for approximately 0.1 percent of all removals to date [75]—because many models predict that they could theoretically sequester significant amounts of carbon. In the latest IPCC report, the Working Group III predicted that under a scenario that limits warming to 1.5 °C (with a certainty of 50 percent) with no or limited overshoot, BECCS is expected to sequester between 30–780 $GtCO_2$, while DACCS is intended to remove 0–310 $GtCO_2$ by 2100 [1]. However, the scenarios produced by these models must be questioned [76–80]. First, they are subject to discount rates and overly optimistic assumptions about future economic developments that are uncertain to materialize [81]. Second, these predictions underestimate the serious challenges regarding bioenergy [18,53,82]. Third, there has been little development of actual BECCS and DACCS projects to date. Currently, there are only a handful of BECCS and DACCS installations, and they only capture about 0.002 GtCO2 and 0.00001 GtCO2 per year, respectively [83,84]. Even if BECCS and DACCS plants could be scaled up as fast solar power—which required around 70 years until it became competitive with other energy sources [85]—the issues surrounding land-use changes and energy demand will remain salient and may pose a significant risk for several human rights [18].

In contrast to engineered removals, nature-based removals rely on natural processes to capture CO_2 from the atmosphere. Notable examples include soil carbon sequestration, peatland management [25,86–88], afforestation/reforestation [12,26], and ecosystem restoration. Currently, 99.9 percent of all anthropogenic carbon removals—meaning that they are additional to the natural carbon cycle—come from these "conventional" CDR approaches on land [75]. One salient benefit of these removal approaches is that they not only remove and store CO_2 but also benefit local ecosystems, as long as they are deployed sustainably [26]. For instance, afforestation/reforestation can improve water quality and provide habitat for wildlife [89,90]. Additionally, soil carbon sequestration can increase soil health and food production capacity [1]. Nature-based removals are also crucial to adapt to the adverse impacts of climate change, particularly for flood and erosion control, local cooling benefits, and the regulation of air and water flows, and should therefore be understood as joint mitigation and adaptation approaches [26]. Furthermore, compared to engineered removals, nature-based removals have been tested for decades and can be deployed at comparatively low costs and require little energy [91,92]. However, there are also several disadvantages of nature-based solutions. For instance, many approaches are difficult to scale since they may require the conversion of land currently used for other purposes, such as food production or habitat protection [26,91,93–95]. For this reason, afforestation/reforestation and peatland management can only play a limited role in the overall climate protection portfolio [12,26]. In any case, due to methodological issues, it is difficult to accurately depict and account for the amounts of GHGs that nature-based solutions are able to remove [25,29,53,96–99].

3. The Normative Hierarchy in the International Climate Change Regime

Neither engineered nor nature-based removals are first-best solutions in the fight against climate change. However, compared to nature-based removals, BECCS and DACCS remain unproven at scale, and their deployment may have much more significant adverse effects on human rights and biodiversity [7,18,19]. While many legal scholars agree that nature-based and engineered removals constitute different technologies and should be evaluated accordingly, they nonetheless maintain the notion that international law treats them as equal mitigation options [7]. In the following section, we will show that the different provisions of the UNFCCC, the KP, and the PA suggest that nature-based removals should have legal priority over BECCS and DACCS if contracting states aim to implement NETs. Before analyzing the concrete provisions, we will first briefly discuss what we mean when we talk about the "normative hierarchy" of climate mitigation measures. In the context of climate mitigation measures, many scholars assert that emission reductions are normatively superior to other measures [3,13,27,30,100] but do not always elaborate on what should follow from this distinction. For our purposes, a "normative hierarchy" or "legal hierarchy" does not refer to the overarching hierarchical ordering of a legal system and its sources [101], but rather to a "mode of legal reasoning" that is "naturally hierarchical, establishing relationships and order between normative statements and levels of authority" [102] (p. 291). Therefore, a hierarchy between emission reductions and NETs means that NETs can be considered as a secondary option besides a fast and complete phasing-out of fossil fuels and a drastic reduction of livestock farming—especially with regard to residual emissions [2,13]. Since all the relevant norms in the UNFCCC, KP, and PA are of equal legal status, we are not primarily interested in the hierarchical relationship of the norms, but rather in the kind of hierarchies they produce when they are applied by the contracting parties seeking to implement NET policies. Consequently, two questions arise: Do the relevant provisions in the international climate regime favor certain removal approaches over others? And if yes, what kind of practical considerations can we derive from this assessment?

3.1. United Nations Framework Convention on Climate Change

The UNFCCC was adopted in 1993 and constitutes the fundamental framework for climate mitigation policy under international law [27,30,100,103–105]. Concerning the regulation of NETs, the most relevant provisions in the Convention are codified under Article 4 para. 1 UNFCCC. Article 4 para. 1 lit. b UNFCCC stipulates that the contracting parties should, according to their common but differentiated responsibilities, "[f]ormulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change by addressing anthropogenic emissions by sources and removals by sinks […]."

The provision establishes two main forms of climate change mitigation: emissions reductions and GHG removals. Generally, the literature agrees that the Convention's ultimate objective prioritizes emission reductions before other mitigation options, as mentioned earlier [27,30,106,107]. Whether or not engineered removals, such as BECCS and DACCS, can be considered appropriate mitigation measures at all, and in which hierarchy to other options in turn depends (inter alia) on whether they are "sinks" according to the UNFCCC. Under Article 1 no. 8 UNFCCC, sinks are "any process, activity or mechanism which removes a greenhouse gas […] from the atmosphere." When international decision-makers drafted the UNFCCC in the early 1990s, it was clear that the Convention was primarily referring to nature-based sinks and reservoirs as opposed to the engineered approaches, which were not available at the time [28,106,108]. However, interpreting the ordinary meaning of the phrasing "any process, activity or mechanism" under Article 31 para. 1 VCLT suggests that engineered removals may also be regarded as sinks under the Convention. Likewise, if we apply the theory of evolutionary treaty interpretation [109–111], we find that the drafters of UNFCCC were likely open to the idea of categorizing new technologies as "mitigation of climate change," as long as the ultimate objective of limiting global warming was supported by their use [7,28,112]. Even though categorizing BECCS is especially complicated because it is a mixture of natural and technological approaches, the relevant UNFCCC articles do not explicitly exclude such options a priori. Admittedly, BECCS is the NET that most likely fits under the "geoengineering" umbrella term because its large-scale use may result in unpredictable externalities. However, since the Convention's objective is GHG neutrality, and BECCS employment has a high theoretical GHG sequestration potential [1], it does not automatically fall outside the scope of the Convention.

A similar argument can be made as regards DACCS. Although it is a purely technological approach and its process does not rely on the enhancement of existing nature-based sinks, DACCS captures and sequesters CO_2 and is therefore able to contribute to the UNFCCC's ultimate objective under Article 2. In sum, both types of engineered removals are not geoengineering measures in the "traditional" sense since they reduce atmospheric GHG levels. If we utilize an extensive understanding of the term "sinks"—meaning any process that removes GHGs—we can also interpret BECCS and DACCS as "sinks" [27]. Geological storage options for both technologies thus also fall within the purview of "reservoirs" pursuant to Article 1 lit. 7 UNFCCC. Consequently, both BECCS and DACCS can be used as "measures to mitigate climate change" under Article 4 para. 1 lit. b UNFCCC [20,27,28,107,113,114].

While engineered approaches can be regarded as "sinks" under the Convention, we suggest that nature-based removals have a normative priority—meaning that states should primarily utilize them before resorting to deploying BECCS and DACCS. We will show that this legal hierarchy is also reflected in the language of the Convention, most notably in Article 4 para. 1 lit. d UNFCCC: "Promote sustainable management, and promote and cooperate in the conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouse gases not controlled by the Montreal Protocol, including biomass, forests and oceans as well as other terrestrial, coastal and marine ecosystems […]." Some authors argue that Article 4 para. 1 lit. d UNFCCC and the broad definition of sinks under Article 1 no. 8 UNFCCC support all CDR techniques equally [20,27,107,115], since all NETs remove GHGs, either via the enhancement of existing sinks, the creation of new ecological sinks, or CO_2 removal from the air. This is correct in the sense that the language of Article 1 no. 8 UNFCCC does not differentiate between NET approaches. Even though the drafters most likely envisioned small-scale interventions [113], the Convention itself does not distinguish between large and small-scale measures. However, the interpretation of the ordinary meaning of the provisions has priority over the drafting history pursuant to Article 32 VCLT [116,117]. In the case of Article 4 para. 1 lit. d UNFCCC, the ordinary meaning, as well as the relation to other norms of the Convention, and the ultimate objective suggest that there is indeed a normative hierarchy of nature-based removals over BECCS and DACCS.

There are a number of reasons why this may be the case. First, Article 4 para. 1 lit. d UNFCCC stipulates that states should pursue the "conservation" and "enhancement" of sinks. In contrast to the term "sinks," the Convention does not define these two activities. Let us therefore examine the ordinary meaning of these activities. The noun "conservation" means "the protection of the natural environment," [118] while the verb to "conserve" implies "to protect something and prevent it from being changed or destroyed" [119]. In the context of climate mitigation measures, "conservation" would therefore be limited to nature-based removals that address already existing carbon sinks, such as natural forests, peatlands, or comparable policies. Both the noun "enhancement" and the verb to "enhance" refer to "the act of increasing or further improving the good quality, value or status of somebody/something" [120,121]. The act of enhancing a sink requires that one already exists, which can further be improved. Consequently, only natural sinks would fall within the ambit of "enhancement." In contrast, engineered removals do not increase the sink capacity of existing natural sinks but may even cause significant deterioration to those sinks.

A different opinion is held by Krüger, who claims that "enhancement […] of sinks" refers to the augmentation of all sink processes occurring within the earth's atmosphere [27]. Since BECCS and DACCS support the global carbon cycle by sequestering CO2, Krüger argues that they enhance the global sink process. However, the language of Article 4 para. 1 lit. d UNFCCC does not refer to an overarching global sink system but to specific existing sinks. Moreover, Krüger's broad interpretation would imply that "enhancement […] of sinks" is identical to the Convention's ultimate objective, namely the "stabilization of greenhouse gas concentrations in the atmosphere." But Article 4 para. 1 lit. d UNFCCC is intended to specify this objective and not to repeat it in abstract terms. The process of enhancing sinks therefore primarily applies to nature-based removals [122]. This does not mean, however, that engineered removals are excluded per se. Such a far-reaching interpretation would run counter to the Convention's ultimate objective. However, the provision's language implies a normative hierarchy between nature-based removals and other NETs [123].

Second, other provisions in the UNFCCC also point in the same direction. Most notably, Article 2 UNFCCC defines the Convention's ultimate objective of stabilizing atmospheric GHG levels but also underlines the importance of other legally protected interests, such as biodiversity and stable food production. In that context, Article 2 UNFCCC requires that states stabilize atmospheric GHG levels "within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened […]." Although Article 2 UNFCCC does not explicitly indicate that nature-based removals should be prioritized, the direct reference to the legally protected interests means that technologies that may adversely impact ecosystems and food supplies should only have a secondary role in the overall mitigation portfolio. The large-scale deployment of NETs that have extensive environmental side effects, notably BECCS, would not just affect the legally protected interests under Article 2 UNFCCC; the related ecological degradation, which is mostly due to land-use changes, would likely result in a deterioration of already existing carbon sinks [124]. This is the exact opposite of what the objective of Article 4 para. 1 lit. d UNFCCC intends to accomplish.

Third, the qualification "as appropriate" in Article 4 para. 1 lit. d UNFCCC further supports this conclusion. While it is true that this wording primarily gives leeway to national decision-makers—as in the case of the chapeau of Article 4 para. 1 UNFCCC [27,125]—it also has an additional meaning, namely that the measures must be appropriate given the ultimate objective under Article 2 UNFCCC. If states nonetheless pursue large-scale BECCS projects that harm existing carbon sinks, a violation of "good faith" under Article 2 UNFCCC in connection with Article 26 VCLT may also become relevant [30,126]. However, this does not mean that large-scale BECCS policies are prohibited prima facie, even if they may be detrimental to biodiversity and food supply. After all, Article 4 para. 1 lit. d UNFCCC only establishes a duty of promotion and cooperation. Nevertheless, states should prefer nature-based removals, since they are likely to be more appropriate in terms of compatibility with the legally protected interests under Article 2 UNFCCC.

Does this legal priority also apply to DACCS, although this technology does not pose a significant threat to biodiversity and a stable food supply? While it is true that DACCS likely has limited environmental impact compared to BECCS [58,127,128], we should not underestimate its effect on biodiversity—especially if DACCS is directly coupled with renewable energy sources and PtX units, leading to higher land demand [16]. This means that even a mitigation strategy narrowly focused on DACCS deployment may also cause deterioration of existing natural sinks. In that context, nature-based removals are still preferable under Article 4 para. 1 lit. d UNFCCC because they enhance existing sinks and are more in line with the ultimate objective under Article 2 UNFCCC—provided they are managed sustainably. However, we suggest that DACCS has a legal priority over BECCS with regard to Article 2 UNFCCC, since the adverse effects of the latter technology on the legally protected rights are much more apparent.

While Article 4 para. 1 lit. b and lit. d UNFCCC primarily concern states' efforts to cooperate and promote sink enhancement, Article 4 para. 1 lit. f UNFCCC seeks to minimize the negative environmental, economic, and public health impacts of climate mitigation policies by obliging states to take "appropriate methods, for example, impact assessments, formulated and determined nationally, with a view to minimizing adverse effects on the economy, on public health and on the quality of the environment, of projects or measures undertaken by them to mitigate or adapt to climate change […]." Since BECCS and DACCS are both considered measures to mitigate climate change, Article 4 para. 1 lit. f UNFCCC is applicable in the context of their potential deployment [27,125,129]. Like the previously discussed provisions of the Convention, Article 4 para. 1 lit. f UNFCCC is ambiguous and leaves much leeway for diverging interpretations. However, it establishes legal guidelines that states should observe when implementing climate mitigation policies. In that context, the provision states that contracting parties should utilize "appropriate methods" on the domestic level to monitor mitigation measures. As an example of such a method, the provision explicitly mentions "impact assessments." Whether the contracting parties indeed use impact assessments or other methods is at the discretion of the respective state [130]. The ordinary meaning of the term "appropriate methods" implies that other methodologies are likewise applicable. However, the enumeration of the legally protected interests "economy, […] public health and […] quality of the environment" signifies that the respective methods must be capable of adequately identifying the potential impact of the mitigation measures on these interests. Contracting parties therefore have an obligation to accumulate relevant facts. Some authors thus suggest that states will be effectively obliged to carry out some form of impact assessments, even though the language of the provision allows for other interpretations [131,132].

In addition to "impact assessments," we argue that the act of legal balancing—meaning the weighing of divergent interests and overlapping spheres of freedoms [29]—is also one of the "appropriate methods" under Article 4 para. 1 lit. f UNFCCC. This means that states are not only required to accumulate the relevant facts regarding the impacts of mitigation measures; additionally, national decision-makers should also weigh the various conflicting rights and interests associated with using NETs, such as BECCS and DACCS. The wording of Article 4 para. 1 lit. f UNFCCC allows for such an interpretation, and the explicit listing of the three legally protected interests in the provision further suggests that some form of legal balancing must be conducted in any case.

In our scenario, the objective of such a balancing test would be to minimize the adverse effects of BECCS and DACCS deployment. In that context, the term "minimizing" indicates an approximate direction but not an overarching standard. Indeed, the wording of Article 4 para. 1 lit. f UNFCCC gives a wide margin of appreciation to states when it comes to balancing. However, the Convention explicitly mentions three legally protected interests that could be adversely affected by mitigation measures: "economy, […] public health and […] quality of the environment." The protection of some of these interests will necessarily come at the expense of other ones [29]. For instance, protecting economic concerns is often at odds with protecting public health and the environment [133–135]. Environmental conservation efforts, in contrast, are almost always beneficial to public health [136,137]. Since not all three legally protected interests can be equally considered when assessing appropriate mitigation measures, states will need to weigh up the conflicting interests.

The act of balancing the three legally protected interests is an open-ended process, but Article 4 para. 1 lit. f UNFCCC and its relationship with other international treaties provide important guidelines. In that context, it must be noted that, in addition to the UNFCCC, several other international treaties are also concerned with the three legally protected interests mentioned in Article 4 para. 1 lit. f UNFCCC. These primarily include the Convention on Biological Diversity (CBD) (regarding the "environment") and international human rights covenants such as the International Covenant on Economic, Social and Cultural Rights (ICESCR) (concerning "public health" and the "economy")—which have been discussed in earlier contributions with regard to their relation to NETs [13,18]. Although these have markedly different legal orientations and scopes, they are still relevant for interpreting the UNFCCC in overlapping substantive subject areas. Moreover, much like the UNFCCC, the CBD has nearly universal participation, which means that almost all contracting states to the UNFCCC are also parties to the CBD. Likewise, the pertinent human rights guarantee concerning public health—Article 12 ICESCR—is also considered to be part of customary international law [138,139] and therefore binding upon all parties to the UNFCCC. In order to avoid conflicts between these different legal regimes, the relevant standards from the CBD and the ICESCR should thus be taken into account in the framework of Article 4 para. 1 lit. f UNFCCC.

While the process of balancing the three legally protected interests depends on the circumstances of each potential mitigation policy, we suggest that, in most cases, BECCS and DACCS would have more adverse effects on the three legally protected interests than nature-based removals. We will demonstrate this proposition as follows: Take the example of a large-scale BECCS policy. A standard impact assessment would likely conclude that such a policy would have detrimental effects on biodiversity due to related land-use changes. This would likely be incompatible with the CBD's objective of conserving biological diversity under Article 1 CBD. Regarding the minimization of harm to public health, it is unclear how BECCS or DACCS would affect public health in the long run. However, if NETs cause mitigation deterrence and prompt states to forego emission cuts, there may be significant public health risks [140]. Furthermore, as soon as BECCS policies affect the food supply and prices, the threat to public health becomes apparent. Finally, regarding economic concerns, it will be difficult for decision-makers to ascertain the adverse impact on the "economy," since the notion is virtually all-encompassing. Moreover, different aspects of the "economy" may also be in conflict when it comes to deploying different forms of NETs [27]. While the current scientific consensus suggests that BECCS is among the cheaper NET options [9], the notion of "economy" not only refers to the costs of deployment but also the livelihoods of the people most likely affected by BECCS usage. Even if BECCS were to become a cheap mitigation option in the future, its real cost would still depend on how much vulnerable populations are affected by its related land-use changes. Compared to a typical nature-based solution, such as peatland management—which has mostly positive effects on biodiversity, public health, and economic concerns [94]—BECCS would likely be legally subordinated if a diligent balancing test were to be carried out.

3.2. Kyoto Protocol

The Kyoto Protocol was adopted in 1997 and is the first treaty adopted within the ambit of the UNFCCC's framework. Even though the KP currently has relatively little legal relevance [30,141], it contains several provisions that offer insights into how the parties have decided to regulate NETs and thus are important for our legal analysis. The major legal novelty of the Protocol was that it introduced quantified emission reduction targets for Annex I Parties (so-called "developed countries") with a corresponding timetable for their achievement [142]. The Protocol also acknowledges the role of sinks in achieving the necessary emission reductions pursuant to Article 3 para. 1 KP. In that context, Article 3 para. 3 KP stipulates that "[t]he net changes in greenhouse gas emissions by sources and removals by sinks […] shall be used to meet the commitments under this Article of each Party included in Annex I." Accordingly, Annex I parties can meet their commitments under Article 3 para. 1 KP by deploying some form of NETs. However, states are mostly limited to land-use and forestry projects. They cannot use engineered removals to achieve their commitments [143]. Keep in mind that the inclusion of any carbon sinks was heatedly debated among the contracting parties and opposed by some coalitions, such as the EU [103,142]. The fact that nature-based removals can contribute to the objective of Article 3—the Protocol's core provision [30,142,144]—implies that, despite controversial discussions, the contracting parties were able to agree that nature-based removals can make an important contribution to the fight against climate change. In contrast, engineered removals or CCS technologies are not mentioned in the provision. The normative hierarchy between nature-based and engineered removals is therefore present in the KP's central obligation.

This conclusion is further supported by Article 3 para. 4 KP, which provides rules for additional sink removals. In that context, Article 3 para. 4 KP obliges the parties to "decide upon modalities, rules and guidelines as to how, and which, additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties included in Annex I […]." Like Article 3 para. 3 KP, the accounting modalities for additional sink activities under Article 3 para. 4 KP again only concern nature-based removals. States were free to undertake sink activities in the areas of revegetation, cropland management, and grazing land management during the first commitment period [100,145]. In order to implement these rules on accounting, obligated by Article 3 para. 4 KP, the contracting parties adopted the Marrakech Accords in 2001 [146], which spelled out how removals by additional sink activities can be counted towards the targeted emissions reductions under Article 3 para. 1 KP. During the second commitment period from 2013 to 2020, forest management was made a mandatory sink activity for accounting purposes, and wetland drainage and rewetting were included as additional optional measures that states could implement if they wished to do so [147].

Because of this limited list of sink activities available for accounting, Proelß and Güssow argue that the Kyoto Protocol clarifies the UNCCC's vague definition of "sinks" and effectively excludes any engineered CDR activities [100]. However, this interpretation is too narrow and goes against the object and purpose of the UNFCCC. Furthermore, the argument by Proelß and Güssow is based on the premise that the sink activities listed in Article 3 para. 3 KP and Article 3 para. 4 KP cannot be understood as CDR. This view is incorrect because forestry, land-use change practices, and soil management are all forms of CDR if they are deliberately deployed to remove GHG from the atmosphere [8,148]. We therefore suggest a more balanced interpretation. On the one hand, engineered removals can also qualify as "sinks" under the UNFCCC's legal architecture and should not be excluded as potential mitigation measures. On the other hand, the language of Article 3 KP implies that nature-based removals take legal priority over engineered removals, such as BECCS and DACCS.

Article 2 KP proposes a number of policies and measures that Annex I countries may adopt in order to achieve their quantified emission limits and reductions under Article 3 para. 1 KP [30,149]. The provision consists of a non-exhaustive list of potential mitigation measures because the drafters were not able to reach a consensus regarding the adoption of mandatory and coordination policies for all Annex I countries [103,142]. In the following, we will highlight two provisions that reflect the aforementioned normative hierarchy between nature-based and engineered removals.

Article 2 para. 1 lit. a (ii) KP is the first provision in the Protocol that concerns the usage of sinks to mitigate climate change. It recommends the following measure for Annex I parties: "Protection and enhancement of sinks and reservoirs of greenhouse gases not controlled by the Montreal Protocol, taking into account its commitments under relevant international environmental agreements; promotion of sustainable forest management practices, afforestation and reforestation […]." The language of the provision closely resembles that of Article 4 para. 1 lit. d UNFCCC, which obliges contracting parties to "promote and cooperate in the conservation and enhancement, as appropriate, of sinks and reservoirs." However, Article 2 para. 1 lit. a (ii) KP differs in several respects regarding its wording and how it relates to other provisions of the Protocol. First, the Protocol omits the term "conservation" and replaces it with the word "protection." The ordinary meaning of both terms are similar, although the protection extends beyond environmental contexts. More importantly, the underlying sentiment visible in the Convention—that both "conservation and "protection" prima facie refer to nature-based removals—is also expressed in the Protocol. This conclusion is further supported by the explicit reference to several nature-based removals at the end of the provision, namely "sustainable forest management practices, afforestation and reforestation." While the exclusion of engineered removals, such as BECCS and DACCS, from the ambit of Article 2 para. 1 lit. a (ii) KP would be incompatible with the object and purpose of the Protocol, the normative preference for nature-based removals is evident since the KP's drafters decided to employ similar language regarding sinks.

Article 2 para. 1 lit. a (ii) KP introduces a novel duty to consider "commitments under relevant international environmental agreements" while Annex I parties use sink enhancement policies. In that context, the provision provides a balancing mechanism similar to Article 2 UNFCCC and Article 4 para. 1 lit. f UNFCCC, which list relevant legally protected interests that need to be considered when implementing measures to combat climate change. Article 2 para. 1 lit. a (ii) KP goes beyond the aforementioned provisions of the Convention in that it not only mentions abstract legal interests but explicitly refers to the "commitments under relevant international environmental law." We suggest that Article 2 para. 1 lit. a (ii) KP primarily refers to international environmental treaty law since a state's participation in a given treaty requires such a commitment. Hence, Article 2 para. 1 lit. a (ii) KP establishes a balancing mechanism according to which states need to observe the duties and obligations arising from relevant international environmental treaties when implementing sink enhancement policies such as BECCS and DACCS. In the event that the fulfillment of Article 2 para. 1 lit. a (ii) KP leads to a legal conflict with another international environmental regime, the latter will take legal priority over the KP [27].

The reference to relevant international environmental treaties suggests that, in most cases, the qualification that states need to comply with "commitments under relevant international environmental law" means that they should deploy nature-based removals before considering NETs, which are more detrimental to the environment. For instance, imagine that a state wishes to fulfill its obligations under Article 3 para. 1 KP by enhancing sinks. The state may then choose from a plethora of NET approaches. However, "commitments under relevant international environmental law" must be observed. In most cases, this will mean that the CBD and its pertinent provisions must be considered. The CBD is the most relevant treaty for Article 2 para. 1 lit. a (ii) KP, since it also has near-universal participation. According to Article 1 CBD, one of the Convention's central objectives are "the conservation of biological diversity" and "the sustainable use of its components." Contracting parties to the KP and the CBD that want to use NETs therefore have to choose the NET approach most compatible with biological diversity and the sustainable use of its components. In most cases, this would mean that BECCS and DACCS should be subordinated to other NET approaches that have a comparatively smaller biodiversity footprint [127].

Article 2 para. 1 lit. a (iv) KP also introduces a legal distinction between sinks and "carbon dioxide sequestration technologies." As such, the contracting parties are required to do the following: "Research on, and promotion, development and increased use of, new and renewable forms of energy, of carbon dioxide sequestration technologies and of advanced and innovative environmentally sound technologies." On its face, the term "carbon sequestration technologies" may be interpreted as encompassing all forms of NETs [20,27,132,150]. However, if all forms of NETs are "carbon sequestration technologies," then there would be no meaningful difference between the "enhancement of sinks and reservoirs" under Article 2 para. 1 lit. a (ii) KP and "carbon sequestration technologies pursuant to Article 2 para. 1 lit. a (iv) KP. While "carbon sequestration technologies" may belong to the general category of "sinks," the ordinary meaning and the context of the provision suggest that it is a distinct sub-category of "sinks." First, the wording "sequestration technology" implies that these technologies are designed to artificially store CO_2 underground for an unlimited amount of time. Natural sinks, in contrast, are subject to the carbon cycle and can only store CO_2 for a limited period of time. More importantly, the term "technology" stands in stark contrast to nature-based removals that do not require a certain level of technological intervention to store CO_2, as is the case for BECCS or DACCS deployment. Accordingly, Article 2 para. 1 lit. a (iv) KP only refers to the technologies that utilize CCS to store GHGs underground.

The fact that Article 2 para. 1 lit. a KP differentiates between the general category of enhancement of sinks and CCS approaches is also apparent when we compare the two pertinent provisions. Article 2 para. 1 lit. a (ii) explicitly lists the "promotion of sustainable forest management practices, afforestation and reforestation" as examples of sink enhancement policies. In contrast, engineered removals are not listed. Likewise, Article 2 para. 1 lit. a (iv) KP does not mention any nature-based removals. Hence, if we interpret the provision's relation to the Protocol's other provisions, it becomes clear that nature-based removals are not intended to be included within the purview of Article 2 para. 1 lit. a (iv) KP.

What does this legal distinction signify for BECCS and DACCS deployment? We have previously posited that Article 2 para. 1 lit. a (iv) KP only refers to CCS technologies. However, CCS technologies may also be used as "sink enhancement" under Article 2 para. 1 lit. a (ii) KP. Consequently, there must be distinct legal obligations that are only applicable when deploying CCS technologies. At this point, the normative hierarchy first introduced by the UNFCCC becomes apparent again. This can be explained by the fact that the ordinary meaning of the obligations under Article 2 para. 1 lit. a (iv) KP indicates that they are subordinate to sink enhancements under Article 2 para. 1 lit. a (ii) KP. The obligation to research, promote, develop, and increase the use of CCS technologies under Article 2 para. 1 lit. a (iv) KP suggests that these approaches are not yet fully developed and therefore do not have the same carbon removal potential as the proven nature-based removals under Article 2 para. 1 lit. a (ii) KP. This interpretation reflects both the limited stage of development of CCS technologies at the time of the adoption of the Protocol and their sluggish advancement to date [151]. In contrast, Article 2 para. 1 lit. a (ii) KP does not feature an obligation to conduct further research since the contracting parties were already cognizant of the fact that natural sinks are a crucial mitigation measure. Accordingly, the obligation under Article 2 para. 1 lit. a (ii) KP to enhance sinks is more encompassing, while Article 2 para. 1 lit. a (iv) KP is more focused on carrying out further research on CCS technologies.

3.2. Paris Agreement

The landmark Paris Agreement was adopted in 2015 and is the most ambitious legal instrument adopted under the UNFCCC's ambit to date with Article 2 para. lit. a PA constituting the first legally binding temperature limit. The role of NETs is highlighted by Article 4 para. 1 PA, which obliges states "to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century […]."

With regard to Article 2 para. 1 PA, we have previously demonstrated that the standard is not only legally binding but also takes precedence over Article 4 para 1 PA. The Agreement thus prioritizes emission reductions over NET utilization and favors nature-based solutions over engineered removals. Moreover, the standard necessitates achieving global zero emissions by the 2030s, as the remaining GHG budget would otherwise be exceeded [3,13,31]. In order to avoid repetition, we will not discuss these issues in this article, but only examine the question of whether additional statements can be gained from the PA that support our thesis.

Article 4 para. 1 PA obliges states to use "removals by sinks" to achieve the net-zero goal in the second half of the century. Nevertheless, Article 4 para. 1 PA cannot be construed as actively obliging states to use any form of NETs. Even if emission reductions were to be insufficient to achieve the desired GHG balance, Article 4 para. 1 PA only obliges states to "aim" to reach this goal—which is not an obligation of result [27]. Like the UNFCCC, the PA does not explicitly mention specific NETs or further distinguish between nature-based and engineered removals [152]. However, the wording of the provision, its relation to other provisions in the Agreement, and its relation to the UNFCCC all imply that removals by sinks primarily refer to nature-based removals. Conversely, engineered approaches, such as BECCS and DACCS, are normatively subordinated in the PA's legal architecture. Nevertheless, they may have a (smaller than commonly assumed) role in the overall mitigation portfolio, since it would be incompatible with the object and purpose of the Agreement to exclude them altogether [7].

According to Article 1 PA, the contracting parties have adopted Agreement the definitions introduced by the UNFCCC into the PA's framework, which includes "sinks" and "reservoirs." Although the Convention's definition of "removal by sinks" and "enhancement of sinks" is ostensibly neutral and could also include engineered approaches, there is a normative hierarchy inherent to the UNFCCC's provisions (and to some extent to the KP's) that affords legal priority to nature-based removals. The drafters of the PA did not introduce new terms or definitions regarding the management of sinks, which is why we argue that this normative hierarchy is also relevant in the context of the Agreement. Furthermore, while Article 5 para. 1 PA explicitly lists forestry as an example of sink enhancements, there are no direct references to "carbon sequestration technologies"—a term previously introduced in the KP. Consequently, we may assume that the PA's drafters did not intend to elevate the role of engineered approaches, such as BECCS and DACCS.

The reference in Article 5 para. 1 PA to the need to "conserve" and "enhance" sinks further underlines our point that the PA has adopted the normative hierarchy as regards nature and engineered approaches. Moreover, the Agreement's preamble explicitly recognizes "the importance of the conservation and enhancement, as appropriate, of sinks and reservoirs of the greenhouse gases referred to in the Convention." As we have previously shown, the ordinary meaning of "conservation" and "enhancement" logically only applies to natural sinks but not to engineered removals, such as BECCS and DACCS. While the mention of "forests" as a sink-enhancing measure under Article 5 para. 1 PA is only intended to be an example policy on a non-exhaustive list [153], it underlines the following notion: The contracting parties were only willing to agree that a nature-based solution represents the typical case of "removal by sinks," which again carries normative significance [154]. Although BECCS, DACCS, and other engineered approaches were conceivable as policy measures at the time the Agreement was drafted, the parties ultimately chose to omit them as examples of "sinks."

This interpretation is also not invalidated by the fact that Article 4 para. 13 and Article 14 PA refer to "anthropogenic emissions and removals." In this context, Fuglestvedt and colleagues posit that only anthropogenic removals should count toward the desired GHG balance under Article 4 para. 1 PA. They argue that "[b]oth the Spanish and the French versions of the Agreement state explicitly that the required balance applies to anthropogenic emissions and anthropogenic removals" [155] (p. 4). In contrast, the Arabic, Chinese, English, and Russian versions only refer to anthropogenic emissions and removals. Under Article 29 PA, all five versions of the Agreement are authentic, but the more concrete versions featuring "anthropogenic removals" can be construed to be compatible with the other versions. However, even if the PA were only referring to "anthropogenic removals," this would not mean that only engineered removals fall within the ambit of Article 4 PA. In a non-binding document released by the UNFCCC's Secretariat, "anthropogenic removals" are defined as the "withdrawal of GHGs from the atmosphere as a result of deliberate human activities. These include, for example, enhancing biological sinks of CO_2 or using chemical engineering to achieve its long-term removal and storage." This definition is also in line with the IPCC's understanding of anthropogenic removals [156]. In any case, it would go against the PA's object and purpose if only engineered removals could be used to achieve the goal under Article 4 para. 1 PA. Lin goes even further and asserts that the "mentions of anthropogenic removals arguably refer first and foremost to forest-related strategies that have already been integrated into the international climate regime." [112] (p. 548). Consequently, the introduction of the term "anthropogenic" in the legal structure of the PA does not undermine the aforementioned normative hierarchy that favors nature-based removals over BECCS and DACCS deployment.

4. Discussion and Conclusions

According to Craik and Burns, "[d]rawing a distinction between CDR and other forms of GHG removal on a technological basis, as the term CE as a distinct category of climate response suggests, is difficult to maintain." [7] (p. 7). This statement has some merit because the UNFCCC, KP, and PA do not ostensibly establish legally binding obligations that prohibit the deployment of engineered removals over nature-based removals. However, our preceding legal analysis has shown that the Convention and its succeeding legal instruments establish a normative hierarchy that generally favors nature-based removals over engineered removals. This normative hierarchy is based on the following principal arguments: The ordinary meaning of the term "sinks," its relation to the Convention's ultimate objective, and its subsequent usage in the KP and PA all suggest that nature-based removals are intended to be the primary policies to remove emissions from the atmosphere. Engineered removals may fall under the ambit of the definition of "sinks," but Article 4 para. 1 lit. f UNFCCC establishes a balancing mechanism that generally favors those NETs with fewer adverse effects on food security and biodiversity. In most cases, engineered would not be favored under this balancing mechanism. The normative hierarchy is also present in the KP, which explicitly features only nature-based removals in Article 3 paras. 3 and 4 KP as means to remove emissions. Additionally, the KP establishes a similar balancing mechanism as the UNFCCC regarding the deployment of NETs; here, too, the mechanism would likely favor nature-based removals in the majority of cases. While the concept of CCS—a main component of engineered removals—is first introduced in the Protocol, it does not have the same legal significance as the already established nature-based removals. In parallel, the PA does not mention CCS at all but uses the legal understanding of "sinks" introduced by the UNFCCC in its legal architecture—thereby also reproducing the inherent normative hierarchy between nature-based and engineered removals. All of this is also underlined by the obligation under Article 2 para. 1 PA.

What does this normative hierarchy mean in practice? As we have stated above, it does not imply that engineered removals, such as BECCS or DACCS, are prohibited under the UNFCCC, KP, or PA. Instead, Article 2 UNFCCC—the ultimate objective of the Convention—and Article 2 para. 1 PA favor emission reduction over other mitigation measures [3,13,18,27,30,107]. Thus, states have a primary obligation to reduce emissions; as mentioned earlier, phasing out fossil fuels and a drastic reduction of livestock farming are to be achieved in a few years [29,31]. Nevertheless, there is a need for NETs to compensate for residual emissions in hard-to-abate sectors (e.g., cement, chemicals, and steel) [8,9,157,158]. In this context, states should primarily rely on nature-based removals rather than engineered removals, as the previous legal analysis has shown. Furthermore, nature-based removals can also be used to curb rising temperatures [91,93,94], even though their potential in that case is limited and should not distract from the priority of emissions reductions via phasing out of fossil fuels and minimizing livestock farming [29,86]. States should also be aware of the drawbacks and risks associated with nature-based removals—inter alia, regarding additionality and long-term storage [91,159,160]. Moreover, our analysis should not be misinterpreted to imply that ecomodernist approaches to climate change, such as engineered removals and other technological solutions, should be abandoned in favor of nature-based solutions. For reasons of space, we also do not discuss possible further societal effects that could be expected from a strong focus on nature-based solutions—such as a partial re-agriculturalization of modern societies, including the sociologically associated effects. As long as climate protection is primarily pursued via post-fossilization and reduced livestock farming—as is required—such far-reaching sociologically interesting phenomena are also unlikely. In any case, engineered removals may also have a role that is supplementary to that of nature-based removals—but only if they have no significant effects on other legally protected interests, such as human rights and biodiversity.

Author Contributions

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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