



# On the Development Principle and Governance Choices of Negative Emission Technology

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## Abstract

Negative emission technology is an important choice to achieve the goal of carbon peak carbon neutrality. With the increase of emission reduction pressure, the development of various negative emission technologies has been put on the agenda, but the corresponding governance problems have also become prominent. Based on the introduction of negative emission technology, this paper analyzes the principles to be followed in the development of negative emission, including the principles of cost-effectiveness, ecological footprint minimization and social acceptance. Based on the above principles, the paper puts forward the main countermeasures to promote the healthy development of negative emission technology.

## Subject Areas

Natural Resource Management

## Keywords

Negative Emission Technologies, Governance Principles, Climate Policy, Climate Change

## 1. Introduction

As pressure grows to meet the climate targets set out in the Paris Agreement, so does the need to reduce anthropogenic emissions of greenhouse gases, especially carbon dioxide, quickly and aggressively. As a primary means of achieving the Paris climate goals, the Parties agreed to “strive to reach a global peak in greenhouse gas emissions as soon as possible. With a view to achieving a balance between anthropogenic emissions and removals by sinks of greenhouse gases in the second half of this century”. The IPCC (2014) calculates how much more

CO<sub>2</sub> can be tolerated in the atmosphere for a given temperature rise and introduces the concept of a carbon budget, the total amount of CO<sub>2</sub> that can be added without exceeding the target temperature. With a 66% probability, the budget for meeting the 2°C target of the Paris Agreement is about 1000 GtCO<sub>2</sub> (GtCO<sub>2</sub>) [1]. Given that global emissions, including those from land use change, are close to 40 Gt per year, the Paris Agreement sets out a requirement to achieve zero net emissions in the second half of this century. The CO<sub>2</sub> emission reduction method with energy transition as the main means as the main source control method has been the main means for countries to achieve their autonomous emission reduction targets. However, the energy transition process is constrained by the path-dependent effects of energy security and socio-technological systems, and its speed and scale are still insufficient compared with the CO<sub>2</sub> reduction needs. Taking into account the slow pace of global greenhouse gas emission reduction and the gradual nature of the energy transition, the importance of negative emission technologies has gradually become prominent and an important choice for countries to achieve their own emission reduction targets. As an emerging technology embedded in the traditional social and economic process, how to make arrangements for the development of negative emission technologies and provide appropriate governance systems has become a key challenge to better play its role. On the basis of introducing the concept and types of negative emission technologies, this paper will explore the general principles and governance options for the development of negative emission technologies. This paper aims to provide discussions about the governance dimension of negative emission technologies, which has only attracted limited attention in the development and application of related technologies.

## 2. The Concept and Type of Negative Emission Technology

Negative emission technologies (NETs) are technologies that remove CO<sub>2</sub> from the atmosphere and return it to geological reservoirs and terrestrial ecosystems after it has been released into the atmosphere. Nets are designed to recover and store greenhouse gases such as carbon dioxide released into the air through engineering techniques, so that they do not affect the increase of atmospheric greenhouse gas concentrations.

On the basis of different technical bases, negative emission technologies can be divided into nature-based negative emission technologies and physicochemical process-based negative emission technologies. From the specific technology path, negative emission technologies mainly include afforestation and reforestation, land management to increase soil carbon content, bioenergy with carbon capture and storage and storage, and carbon capture, utilization and storage technology.

### 2.1. Afforestation and Reforestation

Afforestation and reforestation absorb CO<sub>2</sub> through plant growth. Given a suffi-

ciently large land area (320 to 970 million hectares, about 20% - 60% of the current global arable area), the global capacity for afforestation and reforestation potential is estimated at 1.1 - 3.3 GtC/year [2]. Emissions from deforestation continue at a high rate, at about 3 billion tonnes (TPA) per year as of 2010, accounting for about 10% of global emissions, mostly in tropical forests [3]. In the context of the net transfer of carbon from forests to the atmosphere, future scenarios have been calculated to reverse these trends and to use extensive reforestation as a means of removing large amounts of CO<sub>2</sub> from the atmosphere.

## 2.2. Land Management to Increase Soil Carbon

Changing agricultural practices offers the potential to increase soil carbon stocks, which is already the goal of the post-COP21 “4 per mile” initiative which many EU countries have joined. Smith (2016) estimates that increasing soil organic carbon (SOC) could remove up to 0.7 Gt carbon/year from the atmosphere [2]. Soil is an important carbon reservoir. The goals of the “4 per mile” initiative that followed the COP21 conference in Paris in December 2015. The report notes that global soils are estimated to contain 1500 GT of carbon at a depth of 1 metre and 2,400 GT at a depth of 2 metres. By increasing the carbon content by 0.4% per year, enough carbon would be sequestered to stop the current increase in atmospheric CO<sub>2</sub> concentrations of 2 - 3 ppm per year.

## 2.3. Bioenergy with Carbon Capture and Storage (BECCS)

BECCS has been seen as a backup technology for removing CO<sub>2</sub> from the atmosphere in the event that the world faces a climate system emergency, such as a dangerous carbon cycle feedback [4]. This involves specific energy crops (such as fast-growing perennial grasses, or short rotation cultivation) or increasing forest biomass to replace fossil fuels as a source of heat energy, and capturing the resulting CO<sub>2</sub> and storing it underground. In some IPCC scenarios, BECCS already have clear characteristics: For example, the median BECCS deployment is about 3.3 GtC/year in scenarios consistent with the <2°C target (430 - 480 ppmco2eq) [5].

## 2.4. Carbon Capture, Utilization and Storage (CCUS)

CCUS is of great significance for global greenhouse gas (GHG) reduction. Carbon dioxide capture, utilization and Storage (CCUS) refers to the process of separating carbon dioxide from industrial processes, energy use or the atmosphere and directly using it or injecting it into the formation to achieve emission reductions. CCUS has significant implications for global greenhouse gas (GHG) reduction. Carbon dioxide capture, utilization and Storage (CCUS) refers to the process of separating carbon dioxide from industrial processes, energy use or the atmosphere and directly using it or injecting it into the formation to achieve emission reductions. The Intergovernmental Panel on Climate Change (IPCC) believes that CCUS will play a vital role in meeting the global target of 450 ppm CO<sub>2</sub> equivalent by 2100 (limiting global temperature rise to 2°C).

### 3. General Principles for the Development of Negative Emission Technologies

The application of negative emission technologies is a challenge to the traditional social and economic development. The characterizations of the application of negative emission technologies include higher cost, immature technology innovation, uncertainty of impacts. Therefore, cautious measures and policy designs are needed. The following sections will put forward the core principles that would be observed when developing negative emission technologies.

#### 3.1. Cost-Benefit Principle

The problem of reducing carbon dioxide and other greenhouse gases is essentially a correction for the negative externalities of socio-economic development. Excessive emission of carbon dioxide will lead to global warming, which in turn will affect human production and life. This phenomenon can be regarded as negative externality, that is, an economic behavior has a negative impact on other people or society other than the actor, which is not reflected in the market transaction. Negative externality is when the behavior of one economic agent has a negative effect on other economic agents or society, but this effect is not reflected in market transactions. In this case, the market mechanism cannot achieve the optimal allocation of resources, which leads to the reduction of social benefits. Carbon dioxide is the main greenhouse gas that causes global warming, and excessive carbon dioxide emissions will exacerbate climate warming, which will bring many negative effects to mankind. These impacts include frequent extreme weather events, destruction of ecosystems, and disruption of agricultural production.

Correcting negative externalities will require more investment in capital and technology. The principle of cost efficiency means that in the process of technology application, it is necessary to reduce the cost and improve the benefit to the maximum extent on the premise of ensuring that the expected goal is reached. Negative emission technologies have a crucial role to play in achieving carbon peaking, carbon neutrality and the corresponding climate targets. In essence, it is a corrective to the problem of negative externalities in socio-economic development. Therefore, the issue of cost becomes a key factor in assessing the feasibility of technology. The application of negative carbon emission technologies is subject to trade-offs between socio-economic and environmental costs and benefits. In the process of achieving climate goals, we need to fully consider the costs of technology deployment and follow the principle of cost-effectiveness. This means that in selecting and deploying negative emission technologies, both their economic and environmental benefits should be taken into account, ensuring that the cost of the technology is reasonable while achieving good ecological benefits.

In terms of cost, different negative emission technologies have different levels of maturity and economic costs. Based on available research, the main negative

emission technologies cost ranges are: Soil carbon sequestration (\$0 to \$50 per ton), ecosystem restoration (\$0 to \$87.50), afforestation and reforestation (\$0 to \$50), blue carbon and seagrass (\$0 to \$75) and biochar (\$20 to \$100). All of these technologies had the highest median cost of less than \$100, the lowest median cost of less than \$20, and most were zero or close to zero; Enhanced weathering (range \$30 to \$200), carbon capture and storage (\$50 to \$200), ocean alkalization or fertilization (\$50 to \$225), carbon capture and storage (\$75 to \$200)); And finally, the most expensive NET option is Direct Air capture (DAC), which covers a range of engineered systems that involve first removing CO<sub>2</sub> from the air and then burying it underground in old oil and gas reservoirs or saltwater aquifers, with a median expected cost ranging from \$100 to \$500 [6]. Even for the same negative-emission technology, different technology paths can have a significant impact on costs. For example, the properties of the solvents used in direct air capture vary, as do the energy inputs required to use the technology, the carbon emissions generated, the efficiency of CO<sub>2</sub> capture, and the associated costs.

### 3.2. Principles of Ecological Footprint Minimization

Although negative emission technology has the main function of reducing carbon emissions, like other technologies, its application will bring new environmental resource problems. The environmental and resource problems brought by different negative emission technologies are different. Nature-based negative emission technologies often bring about competition for different resource utilization goals. For example, afforestation and carbon capture in afforestation technologies, bioenergy often bring about problems of land resources, food production, biodiversity conservation and so on. Methods of increasing annual agricultural soil uptake and storage may result in increased nitrogen oxide emissions. Afforestation in dry areas often affects water resources. Negative-emission technologies also involve energy inputs, which create a new carbon footprint. In addition, negative emission technologies involve carbon leakage. For example, geologically sequestered carbon dioxide may leak out of brackish water layers and even cause geological disasters. Carbon sequestration through vegetation can involve natural or human-induced degradation, logging or destruction of vegetation, resulting in carbon leakage.

Taking BECCS for example, as it scales up, regulations must be put in place to ensure that biomass does not deplete resources, especially forests [7]. Thus, BECCS value chain optimization is inherently multi-objective, and by focusing on costs or trade-offs between economic and environmental performance, one can easily gloss over the complex interplay that exists between BECCS' environmental impacts. According to the IPCC Assessment 5 Report, BECCS needs to be used as one of the main mitigation instruments to achieve the target of reducing CO<sub>2</sub> emissions by 12 Gt by 2100, and the energy crops needed to grow for this account for approximately one-third of the world's arable land. In its 2015 review of negative emission technologies, the National Research Council of

the US Academy of Sciences (2015) assessed the land, water and nutrient requirements of dedicated energy crops. They estimated that producing 100 EJ per year (about 20% of global energy production) could require 5% of current land area (excluding Greenland and Antarctica), or 500 million hectares [8].

### 3.3. The Principle of Social Acceptance

Public awareness of CCUS is relatively poor due to its technical nature. Public acceptance and support have a big impact on the large-scale deployment of CCUS [9]. Benefits and risk perception are important determinants of public acceptance. Chinese public acceptance of CCUS is lower than that of renewable energy. Individuals are more concerned about the potential health, safety and environmental risks of CCUS, such as seismic disturbances, land deformation, contamination of drinking water supplies and adverse impacts on ecosystems [10]. The risk of CCUS projects is concentrated in the CO<sub>2</sub> transport and sequestration process. During CO<sub>2</sub> transportation, there may be a risk of leakage. During the CO<sub>2</sub> storage process, there is a risk of air leakage in the geological layer, which may lead to the stored carbon dioxide leaking to the surface, while the long-term storage of CO<sub>2</sub> may directly cause surface deformation and induce earthquakes. The leaked carbon dioxide may cause a range of environmental and health risks, including soil pollution, water pollution and air pollution. Since the risks in terms of environmental safety are difficult to predict, the CCUS project may cause concern and unease among the surrounding residents. In addition, once a leak occurs, it may have a negative impact on the surrounding economic activities such as agriculture, fishing and tourism, and affect the local social and economic development. Social acceptance is critical to the deployment of CCUS. To increase public acceptance, the associated risks should be reduced. In this regard, planning is a factor in the risk and harm of CCUS. Given the uncertainty of CCUS implementation, carbon sequestration sites should receive more attention. For example, CCUS projects should not be planned in arid areas or densely populated areas, which could exacerbate pressure on water supplies.

## 4. Policy Recommendations

### 4.1. Combine Active Government with Efficient Markets

The development and industry of carbon-negative technologies usually require a large amount of capital investment, and the accumulation of enterprises themselves may be far from enough. Stable and diversified financing channels can provide important financial support for the continuous technology research and development and industrialization of enterprises, and can also be rationally allocated to the required enterprises. For example, on May 8, 2023, Shenzhen Municipal Development and Reform Commission issued 2023 guidelines for the application of special funds for strategic emerging industries (the first batch). Clearly energy storage low-carbon zero carbon fluorocarbon and other fields subsidy rules, energy storage new technology and new product demonstration

application promotion support industrial park energy storage, optical storage and charging demonstration and other two directions, according to the total investment of 30% to give post-funding, up to 10 million yuan. At the same time, the future development policy of negative carbon technology needs to strengthen the construction of financial markets and financial market supervision, and provide a good financial system for the development of negative carbon technology.

#### **4.2. Implementation of Ecological Footprint Assessment**

For the application of various negative emission technologies, an ecological footprint assessment system should be established to judge their ecological environmental impact through expert assessment, and the selection of ecological services with low environmental risk and good ecological footprint accounting requirements should cover all the ecological services included in the goods entering the production and consumption process. It can reflect the whole process of the production, flow and consumption of ecological services, the asymmetric interaction between the ecosystem and the social and economic system, and the abuse and underutilization of ecosystem services. For negative emission technologies that may cause adverse environmental impacts, environmental impact assessment should be strengthened, and the ecological footprint concept should be introduced to carry out ecological footprint and environmental impact assessment of the whole life cycle, so as to find the best negative emission technology. This also means that nature-based solutions are often more ecologically friendly than engineering-based solutions, and other environmental risks may be considered when selecting technologies such as CCUS.

#### **4.3. Promotion of Multi-Strategic Synergies**

The implementation of negative emission technologies should contribute to both socio-economic development and emission reduction targets. This requires attention to the implementation of multiple synergistic strategies in the application of negative emission technologies. Public participation is an important way to ensure the synergy of multiple goals. The needs of different interest groups can be expressed through public participation. Good governance that emphasizes public participation in key decisions is also necessary. For example, effective public participation can enhance individuals' understanding of CCUS and provide space to reflect on their concerns, which will enhance the public's trust and willingness to consider projects. In addition, as neighboring communities bear the risk of a CCUS project, they should also be compensated. It is worth noting that profit-sharing arrangements are the most critical factor in gaining public support for projects in China. Therefore, appropriate institutional arrangements should be made to ensure that the application of negative emission technologies leads to Pareto improvements and to achieve synergies between socio-economic and eco-environmental objectives.

## 5. Conclusions

With the increasing pressure of emission reduction, the application of negative emission technologies faces great demand, but different technologies have significant differences in socio-economic and environmental impacts. When selecting negative emission technologies, it is necessary to follow the principles of cost-benefit, ecological footprint minimization and social acceptance, and comprehensively consider the multiple impacts brought by a technology application. In order to enhance the comprehensive benefits of negative emission technologies and maximize social benefits, in the process of promoting the application of negative emission technologies, we should adhere to the link between the government and the effective market, implement ecological footprint assessment, and promote the diversified strategic synergy of social economy and ecology through public participation. This paper focuses on the development of negative emission technologies

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## Conflicts of Interest

The author declares no conflicts of interest.

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