Efficient Carbon Capture by Growing and Subsequent Separation of Wood

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Abstract: Our world has the problem of global warming. Physically, that warming is explained as a consequence of the global increase of the concentration of carbon dioxide in the atmosphere. Therefore, the problem of carbon capture arises. In fact, worldwide, wood does capture huge amounts of carbon dioxide. However, in nature, organisms transform the wood back to carbon dioxide. Consequently, in free nature, woods have only a strongly reduced net effect of carbon capture. In this paper, a possible separation of wood is analyzed. Based on present - day techniques of forest operation, the cost efficiency of wood separation is investigated. Possible efficient methods for carbon capture by growing and subsequent separation of wood are presented.

Key–Words: global warming, carbon capture, wood, growth, separation, cost efficiency, global significance, global solution of global warming

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1 Introduction

In this paper, the question is investigated: How can wood become an effective sink of carbon dioxide?

Basic problem: Our world has the problem of global warming, see WMO (2025). Physically, that warming is explained as a consequence of the global increase of the concentration of carbon dioxide in the atmosphere, see e. g. IPCC (2021). Therefore, the problem of carbon capture arises, see WMO (2005).

Potential solution by wood: In fact, worldwide, wood does capture huge amounts of carbon dioxide, see e. g. Mo (2024); Braby (2024); Kleidon (2021). However, wood can either be a sink of carbon dioxide, or wood can emit carbon dioxide, see Bolte et al. (2021).

Secondary problem: In the ecosystem wood, a net circular flow takes place, see Bolte et al. (2021): In a first step, trees transform carbon dioxide to biomass. In a second step, that biomass transforms to humus, or it becomes dead wood. In a third step, dead wood is decomposed, or humus mineralizes. In this step, in both cases, the uptake of biomass in the first step is reversed. Altogether, the ecosystem wood exhibits a circular flow of carbon, in which there is hardly a net uptake of carbon dioxide from the atmosphere, in a longtime time average. Therefore, the secondary problem arises, that the ecosystem wood exhibits a circular flow of carbon, without efficient net uptake of carbon dioxide. Accordingly, the following question arises:

Essential question: How can wood become an effective sink of carbon dioxide?

Organization of the paper: In section two, the problem is elaborated. In section three, the carbon and capture process is proposed. The cost of that process is analyzed in section (4). That cost is compared with market prices and related investigations, see section (5). In part (6), the energy analysis and the global impact of the proposed process are investigated. The results are summarized and discussed in section (7).

2 Problem of finding an efficient procedure for carbon capture

In this section, the problem is elaborated. The problem consists of three parts, see sections (2.1, 2.2, 2.3).

2.1 Problem of global warming

Earth has the problem of global warming, see WMO (2025). Physically, that warming is explained as a consequence of the global increase of the concentration of carbon dioxide in the atmosphere, see e. g. IPCC (2021). Renewable energies are a part of the solution, but this is insufficient, therefore, the problem of carbon capture arises, see WMO (2005). Accordingly, the European Union decided that large amounts of carbon capture has to be realized in by the EU, see EU (2024).

2.2 Problem of carbon capture

As a matter of fact, worldwide, wood does capture huge amounts of carbon dioxide, see e. g. Mo (2024); Braby (2024); Kleidon (2021). However, forests can either be a sink of carbon dioxide, or forests can emit carbon dioxide, see Bolte et al. (2021).

2.3 Problem of efficient net carbon capture by forests

In the ecosystem forest, a net circular flow takes place, see Bolte et al. (2021): In a first step, trees transform carbon dioxide to biomass. In a second step, that biomass transforms to humus, or it becomes dead wood. In a third step, dead wood is decomposed, or humus mineralizes. In this step, in both cases, the uptake of biomass in the first step is reversed. Altogether, the ecosystem forest exhibits a circular flow of carbon, in which there is hardly a net uptake of carbon dioxide from the atmosphere, in a longtime time average. Therefore, the following problem arises: The ecosystem forest should be managed with help of a procedure, that replaces the present - day dominant circular flow of carbon dioxide by an efficient net uptake of carbon dioxide.

3 Proposed process

In this section, a particular process for carbon capture and separation is proposed:

(1) Used leftovers: When trees are being felled, then, usually, the trunks are harvested, whereas the branches and twigs remain unused. These harvest leftovers make up

$$p_{leftover,1} = 15\% \text{ and } m_{leftover,1} = p_{leftover,1} \cdot m_{tree}, \tag{1}$$

of the tree's mass, see Perry (1982).

Moreover, usually, the trunks are used for some time, and then, also the trunks are leftovers. Alternatively, the trunks of trees that are not used are leftovers as well. The trunk leftovers should also be used for carbon capture, see Perry (1982):

$$p_{leftover,2} = 60\% \text{ and } m_{leftover,2} = p_{leftover,2} \cdot m_{tree}, \tag{2}$$

For instance, such leftovers occur at sawmills, factories for wood products, or in garbage collection.

Furthermore, a tree takes up a mass $m_{CO_2\ via\ photonsynthesis}$ of CO_2 by photosynthesis. Therefrom, 18.3 % is transformed to nonwoody litter falling to the ground, such as foliage, see Fig. (1) in Luo et al. (2025):

$$p_{leftover,3} = 18.3\% \text{ and } m_{nonwoody\ litter} = p_{leftover,3} \cdot m_{CO_2\ via\ photonsynthesis} \tag{3}$$

Such nonwoody leftovers can only be used in special environments that hinder the anaerobic transformation of biomass to methane. Such environments are very dry soils, very cold soils, or soils with sufficient acid, such as peat bog. Woody leftovers are protected by the lignin inside the wood, see p. 21 in Zeng and Hausmann (2022). This possibility to use nonwoody leftovers is not considered in this paper.

The woody part including trunk, branches, twigs, leaves and roots amounts to 13.6 % of the mass $m_{CO_2\ via\ photonsynthesis}$, see Fig. (1) in Luo et al. (2025):

$$p_{woody} = 13.6\% \text{ and } m_{woody} = p_{woody} \cdot m_{CO_2\ via\ photonsynthesis}. \tag{4}$$

The power of the used leftovers is the sum:

$$p_{leftover} = p_{leftover,1} + p_{leftover,2} = 75\% \text{ and } m_{leftover} = p_{leftover} \cdot m_{tree}. \tag{5}$$

Therefore,

$$\begin{aligned} & m_{leftover} \\ &= p_{leftover} \cdot p_{woody} \cdot m_{CO_2\ via\ photonsynthesis} \\ &= 0.75 \cdot 0.136 \cdot m_{CO_2\ via\ photonsynthesis} \\ &= p_{leftover,\ complete} \cdot m_{CO_2\ via\ photonsynthesis}, \\ & \text{with } p_{leftover,\ complete} = 0.0968. \end{aligned} \tag{6}$$

(2) Burial of leftovers: The leftovers in the above part (1) should be permanently separated from the atmosphere. For it, these leftovers should be buried. Thereby, that biomass should be covered by soil so that no large amounts of oxygen can reach these leftovers. As a consequence, this covered biomass cannot be transformed to carbon dioxide, and that covered biomass cannot release significant amounts of CO_2. Therefore, the biomass of these leftovers is protected from any transformation into carbon dioxide for thousands of years, see Zeng et al. (2024). In this manner, the secondary problem is solved for the case of the tree's branches, twigs and leaves, as well as for trunks.

(3) In situ burial: In principle, there are many possibilities to bury woody leftovers, see e. g. Zeng and Hausmann (2022). Here, a low cost solution is proposed: Therefore, the leftovers should be buried locally or in situ. That is, when several trees in a small region are felled, then the branches, twigs and leaves are cut off the trunks. Consequently, these leftovers are already collected as a result of the work procedure of felling and cutting. Thereby, these leftovers are provided in a small region. These leftovers should be buried in a hole in that region, and this hole should be covered by a clay, loam or a similar dense material, that is available nearby. In that case, the cost of transportation is low, see Eq. (7). Woody leftovers of trunks should be buried in the vicinity of the places at which they are collected.

(4) Burial of the root system of the hole: In the in situ burying of the leftovers, a hole is digged in the wood. Thereby, the root system covering the hole must be considered. The root system of a tree represents 20 % of the biomass of the tree, see p. 198 in Perry (1982). Hereby, the root system has a relevant depth of 60 cm, see p. 6045 in Xia et al. (2020). Thereby, in the uppermost 40 cm, $\frac{5}{6}$ of the root system are present, and the carbon dioxide is emitted to the atmosphere in fast or slow processes, see p. 6045 in Xia et al. (2020). Therefore, that thin layer of 60 cm should be buried in the hole together with the leftovers. This has the additional advantage, that in the upper part of $\frac{5}{6}$ of the root system, the carbon dioxide cannot easily be emitted to the atmosphere. Finally, the hole should be filled with dense and locally available soil, and locally available trees should be planted on the closed hole.

4 Cost analysis of the proposed process

In this section, the cost of the proposed process is analyzed for the example of one solid cubic meter of wood, and for the case of the branches, twigs and leaves in .

Method of the cost analysis: As a method, the cost analysis starts with documented work procedures and their cost in Austria. These work procedures use modern machinery. Such machinery can in principle be used in each wood in the world. In practice, such machines must be transported to the workplace. For it, a ship, or a railroad, or a road can be used. Hereby, electrical engines using renewable energy can be utilized. If none of these is available, an infrastructure project should be applied first, that constructs at least one of these possibilities for general use. Therefore, the respective cost is not added here.

This includes the cost of the transportation and logistics of the machines, that is additionally confirmed by a comparison with p. 18 in Zeng and Hausmann (2022), see Eq. (11). Moreover, this includes the cost for digging in Eq. (8). The respective infrastructure logistics for digging and transport of the leftovers is analyzed in the above infrastructure project. Altogether, the proposed in situ burial does not need large or massive trenches in the wood.

Cost for felling: The cost for the felling a solid cubic meter of wood is 31.46 Euro, see table 7 in BOKU (2025). This cost is usually paid by the user of the tree's trunk. Exceptions will be analyzed in a follow up paper.

Cost for transportation: The cost C_t of the transportation of a used solid cubic meter of harvest leftovers is, see table 7 in BOKU (2025),

$$C_t = 3.82 \text{ Euro} \tag{7}$$

Cost for burying: One solid cubic meter is equal to 1.4 m^3, see Hahn (2007). The cost C_b of burying a cubic meter is 6.7 Euro, see p. 18 in Kropik (2022). Consequently, the cost of burying a solid cubic meter is

$$C_b = 6.7 \text{ Euro} \cdot 1.4 = 9.38 \text{ Euro}. \tag{8}$$

One solid cubic meter of stacked wood is equal to the volume of one cubic meter of pure wood.

Cost for separation: Therefore, the complete cost $C_{p\ s}$ for permanent separation of one cubic meter of wood is

$$C_{p\ s} = C_t + C_b = 13.2 \text{ Euro}. \tag{9}$$

One cubic meter of pure wood has the CO_2 equivalent of 1.2 t, see p. 5 in Fehrenbach et al. (2024). Therefore, in the proposed process, the cost for the carbon dioxide reduction, capture and storage is

$$C_{CO_2\ reduction\ and\ storage} = \frac{13.2 \frac{\text{Euro}}{\text{m}^3}}{1.2 \frac{\text{t}}{\text{m}^3}} = 11.0 \frac{\text{Euro}}{\text{t}}. \tag{10}$$

In addition, the derived cost of $11 \frac{\text{Euro}}{\text{t}}$ in Eq. (10) is compared with

$$14 \frac{\$}{\text{t}} \approx 12.5 \frac{\text{Euro}}{\text{t}}, \tag{11}$$

see p. 18 in Zeng and Hausmann (2022), this includes the cost of the transportation and logistics of the machines.

5 Comparison with related processes or market prices

In this section, the cost of reduction and storage of carbon dioxide in Eq. (10) is compared with possible alternative options.

Carbon pricing: The actual cost for the emission of one ton of CO_2 in the EU is 65 Euro, see Scheffler (2026),

$$C_{CO_2\ emission\ in\ the\ EU} = 65\ \frac{\mathrm{Euro}}{\mathrm{t}}. \tag{12}$$

In principle, in the EU, an emitter of one ton of CO_2 should either reduce and store one ton of CO_2, see Eq. (10), or pay the carbon pricing in Eq. (12). If the emitter had this choice, the emitter could decrease the cost of CO_2 emission by ca. the factor six. This would be very helpful for the atmosphere, as no net CO_2 would enter the atmosphere. Moreover, this would be very helpful for the emitter, as the carbon pricing would be reduced significantly. In fact, in the EU, carbon certificates can be traded, see Fallasch et al. (2024).

Other technologies of carbon capture: In the Direct Air Carbon Capture (DACC) technology, see table 3-2 in Strasser et al. (2025), the cost for the carbon dioxide capture is

$$C_{CO_2\ capture\ via\ DACC} = 86 - 456\ \frac{\mathrm{Euro}}{\mathrm{t}}. \tag{13}$$

In the Bioenergy with Carbon Capture and Storage (BECCS) technology, Monometanolamine (MEA) can be used, see table 3-2 in Strasser et al. (2025). In that case, the cost for the carbon dioxide capture and storage is

$$C_{CO_2\ capture\ via\ MEA-BECCS} = 44 - 240\ \frac{\mathrm{Euro}}{\mathrm{t}}. \tag{14}$$

Similarly, in the BECCS technology, Temperature Swing Adsorption (TSA) can be applied, see table 3-2 in Strasser et al. (2025). With this method, the cost for the carbon dioxide capture and storage is

$$C_{CO_2\ capture\ via\ TSA-BECCS} = 60 - 240\ \frac{\mathrm{Euro}}{\mathrm{t}}.$$

Additionally, in the BECCS technology, Hot Potassium Carbonate (HPC) can be utilized, see table 3-2 in Strasser et al. (2025). On that basis, the cost for the carbon dioxide capture and storage is

$$C_{CO_2\ capture\ via\ HPC-BECCS} = 60 - 240\ \frac{\mathrm{Euro}}{\mathrm{t}}. \tag{15}$$

Moreover, in the BECCS technology, a Chemical Combustion Loop (CLC) can be built as follows: In a first step, a metal is oxidized. In step two, the metal oxide is in contact with the fuel, so that the metal is reduced, and with the released oxygen, the fuel is oxidized. The resulting CO_2 is not mixed with air or its nitrogen, so that it can be captured more easily. In step three, the reduced metal is transported back to the air reactor of step one. With that CLC, the cost for the carbon dioxide capture and storage is as follows, see table 3-2 in Strasser et al. (2025),

$$C_{CO_2\ capture\ via\ CLC-BECCS} = 40 - 75\ \frac{\mathrm{Euro}}{\mathrm{t}}. \tag{16}$$

Altogether, the alternative carbon capture technologies can reduce the cost of carbon emission in Eq. (12) by ca. 38 % in Eq. (16), from 65 Euro to 40 Euro, whereas the price for carbon emission is reduced by the proposed carbon reduction and storage by ca. 500 %. Therefore, the proposed process of carbon reduction and storage can significantly improve the carbon capture and storage. Moreover, the effect, purpose, limitations and role of CO_2 pricing are analyzed in a forthcoming followup paper.

Interests and activities by students and pupils: The present paper is based on scientific results and on the respective literature. Additionally, fortunately, students and pupils are interested in questions about climate change, possible solutions, and respective activities. Moreover, it has been realized that education must enable pupils and students to understand and solve problems of sustainable development, see UNESCO (2024), Vaughter (2016), Kultusministerium (2021). For instance, in 2025, in my astronomy club, we investigated the feasibility of a carbon reduction and capture process based on wood. In my research club, the feasibility of a carbon reduction and capture process based on wood has been presented by Wallhöfer (2026) at a Jugend forscht competition.

Wood vaulting: A similar process has been proposed in order to build up a carbon reserve, see Zeng and Hausmann (2022). In both processes, in the Zeng and Hausmann (2022) carbon reserve process, and in the present carbon reduction and storage process, wood is buried, so that it is significantly separated from oxygen. There is significant evidence for the practicability of such a method, see Zeng et al. (2024), Johnson et al. (2025).

Moreover, in the present analysis, a concept is elaborated for capturing the *cumulative anthropogenic emissions since 1958*. Thereby, the *cumulative anthropogenic emissions since 1958* is the CO_2, that has been added to the atmospheric carbon dioxide content of the year 1958, namely the mole fraction of 315 ppm. In fact, this mole fraction of 315 ppm is known, as the Keeling et al. (1976) curve started in 1958. Moreover, the climate change essentially started at ca. 1958, see Fig (TS.9) in IPCC (2021), Statista (2025a).

The concept for capturing the *cumulative anthropogenic emissions since 1958* with help of the proposed carbon reduction and storage process is presented in the next section:

6 Energetic analysis of the proposed process

In this section, the concept is elaborated for capturing the *cumulative anthropogenic emissions since 1958* with help of the proposed carbon reduction and storage process.

(1) Power of the photosynthesis of global forests: The energy that arrives Earth from Sun is described by the solar constant, see e. g. Tipler and Llewellyn (2008),

$$S_E = 1367 \, \frac{\text{W}}{\text{m}^2}. \tag{17}$$

Worldwide, the wood's area is as follows, see Statista (2025b):

$$A_{wood} = 40.4 \cdot 10^{12} \text{ m}^2. \tag{18}$$

The wood's efficiency to transform light to biomass is at most 1.8 %, see p. 231 in Kleidon (2021). A more definite information is, see Rayalu and Anuradha (2024):

$$\eta = 0.015 \pm 0.005 = 0.015 \pm 0.33\%. \tag{19}$$

Ca. thirty percent of the radiation is reflected, and seventy percent is transmitted, see e. g. elementary climate models in WMO (2003) or Carmesin et al. (2023), so the percentage of transmission is

$$p_{transmission} = 0.7. \tag{20}$$

In general, Sun's light reaches Earth's area at relatively flat angles. Moreover, at night, an area is in Earth's shadow. That effect can be analyzed as follows: The power reaching Earth is equal to an effective solar constant S_{eff} multiplied by $A_E = 4\pi R_E^2$, which is equal to the solar constant S_E reaching Earth's cross-sectional area πR_E^2, whereby R_E is Earth's radius:

$$S_{eff} \cdot 4\pi R_E^2 = S_E \cdot \pi R_E^2 \rightarrow S_{eff} = \frac{S_E}{4}. \tag{21}$$

Therefore, the power used by the process is the product of the effective solar constant S_{eff}, wood's area A_{wood}, the percentage of transmission $p_{transmission}$, and the efficiency η:

$$\begin{aligned} & p_{photosynthesis\ wood} \\ &= \frac{S_E}{4} \cdot A_{wood} \cdot p_{transmission} \cdot \eta \\ &= 1.45 \cdot 10^{14} \text{ W}. \end{aligned} \tag{22}$$

Consequently, during one year, the global forests transform the following energy by photosynthesis:

$$\begin{aligned} & E_{photosynthesis\ wood} = \\ & p_{photosynthesis\ wood} \cdot 365.25 \cdot 24 \cdot 3600 \text{ s} \\ &= 4.57 \cdot 10^9 \text{ TJ, each year.} \end{aligned} \tag{23}$$

In wood, one TJ corresponds to 100,0 tons of CO_2, and one ton of wood represents 1.35 tons of CO_2, see table (2) in Fehrenbach et al. (2024). Consequently, each year, by photosynthesis, the global woods transform the following mass of CO_2 or rate:

$$r_{photosynthesis\ wood} = 617.6 \pm 33\% \, \frac{\text{Gt}}{\text{year}}. \tag{24}$$

(2) Comparison: Each year, by photosynthesis, the managed forests transform the following mass of CO_2, see Fig. (1) in Luo et al. (2025):

$$r_{photosynthesis\ wood} = 173 \pm 28\% \, \frac{\text{Gt}}{\text{year}}. \tag{25}$$

This value is increased by the factor $2.87 \pm 23\%$, see Fig. (1) in Luo et al. (2025). As a consequence, each year, by photosynthesis, the global forests transform the following mass of CO_2, see Fig. (1) in Luo et al. (2025):

$$r_{photosynthesis\ wood} = 495.7 \pm 51\% \, \frac{\text{Gt}}{\text{year}}. \tag{26}$$

This result differs by 20 % from the value derived in Eq. (24). As various plants have different efficiency of the photosynthesis, see Eq. (19), this confirms the deduction presented here.

(3) Aim: From 1958 to 2026, the CO_2 concentration in the atmosphere increased from 315 ppm to 420 ppm. Consequently, it increased by 105 ppm. One ppm CO_2 in the atmosphere corresponds to 7.8 Gt

CO_2. Therefore, the aim is to remove the following amount of CO_2 from the atmosphere:

$$m_{CO_2} = 7.8\ \frac{\text{Gt}}{\text{ppm}} \cdot 105\ \text{ppm} = 819\ \text{Gt}. \quad (27)$$

(4) Used rate: In the proposed process, the used leftovers correspond to the following mass, see Eq. (6):

$$r_{photosynthesis\ wood\ leftover} = r_{photosynthesis\ wood} \cdot p_{leftover,\ complete} = 59.78\ \frac{\text{Gt}}{\text{year}}. \quad (28)$$

(5) Required time: The used leftovers in Eq. (28) remove the mass of CO_2 in Eq. (27) from the atmosphere within the following time:

$$t_{aim} = \frac{m_{CO_2}}{r_{photosynthesis\ wood\ leftover}} = 13.7\ \text{years}. \quad (29)$$

(6) Cost of CO_2 removal: The removed mass in Eq. (27) is multiplied by the cost per ton in Eq. (10):

$$C_{CO_2\ removal} = m_{CO_2} \cdot 11.0\ \frac{\text{Euro}}{\text{t}} = 9.01 \cdot 10^{12}\ \text{Euro}. \quad (30)$$

If this cost is provided equally by $8 \cdot 10^9$ people living on Earth, the cost per person is

$$C_{CO_2\ removal\ per\ person} = \frac{C_{CO_2\ removal}}{8 \cdot 10^9} = 1130\ \frac{\text{Euro}}{\text{person}}. \quad (31)$$

As the process lasts for 13.7 years, the cost per person and year during that process is

$$C_{CO_2\ removal\ per\ person\ and\ year} = \frac{C_{CO_2\ removal\ per\ person}}{13.7\,\text{year}} = 82.2\ \frac{\text{Euro}}{\text{person and year}}. \quad (32)$$

These results show that the problem of global warming could be solved completely within 13.7 years at a cost of 82.2 Euro per person and year, with help of the proposed carbon removal process.

7 Discussion

The basic problem of global warming is an essential issue to all of us and to mankind. As a solution, a permanent capturing of carbon dioxide should be achieved. Wood has a high potential for such a solution. However, in the natural wood ecosystem, carbon is hardly captured permanently. Instead, carbon exhibits a circular flow in a natural wood. This is an important secondary problem.

In principle, the secondary problem can be solved by burying wood in such a manner, that wood is significantly and for thousands of years separated from oxygen. The burying of wood has been proposed in order build a carbon reserve, see Zeng and Hausmann (2022), or in order to serve as a carbon dioxide sink. In fact, there is already evidence for the practicability of such burying of wood, see for instance Zeng et al. (2024), Johnson et al. (2025).

In this paper, a very efficient process of burying wood for thousands of years is proposed, analyzed economically, energetically as well as globally, and the following properties are derived:

(1) The proposed process is especially efficient, as harvest leftovers are used. Therefore, the cost of burying one ton of CO_2 is only 11 Euro.

(2) As a consequence, the proposed method can be used in order to reduce the present - day carbon pricing by a factor of ca. six.

(3) The proposed process is very efficient energetically: The *cumulative anthropogenic emissions since 1958* can be captured completely in only 13.7 years. In this manner, both problems can be solved at a global level: The problem of global warming is reversed to the state of 1958. And the secondary problem is solved by separating wood from the circular flow of wood in a natural wood ecosystem.

(4) The proposed process is very efficient economically: The *cumulative anthropogenic emissions since 1958* can be captured at the cost of 1130 Euro per person on Earth. Consequently, the *cumulative anthropogenic emissions since 1958* can be captured at the cost of 82.2 Euro per person on Earth and per year, during the 13.7 years the process requires.

(5) The process is based on woody biomass, as wood is protected by lignin. As a consequence, for the case of wood, an anaerobic formation of methane cannot take place. Therefore, wood is especially suited for such a removal of carbon dioxide from the atmosphere for thousands of years.

(6) In this paper, a proposed process for the removal of wood from oxygen, a particular procedure is used. More generally, the process can in principle become even faster, when nonwoody biomass is buried in a dry or cold environment, or in an environment with sufficient acid.

(7) In this paper, it has been shown how the *cumulative anthropogenic emissions since 1958* can be captured at low cost during the 13.7 years. Therefore, that global removal of these CO_2 emissions can be achieved by ca. one generation. This feasibility opens a motivating perspective. Thereby, a major challenge is that many people cooperate. An analytic basis of related issues of policy and economics will be modeled and investigated in a forthcoming paper.

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