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MITIGATION OF GREENHOUSE GASES EMISSIONS BY MANAGEMENT OF TERRESTRIAL ECOSYSTEM

ABSORPCJA CO_2 PRZEZ EKOSYSTEMY LĄDOWE JAKO SPOSÓB NA PRZECIWDZIAŁANIE WZROSTOWI JEGO STĘŻENIA W ATMOSFERZE

Abstract: Carbon dioxide fluxes between ecosystems of the Earth are presented. It was shown that intensifying its absorption of terrestrial ecosystems by 3.2% would prove sufficient to neutralize carbon dioxide emissions from the combustion of fossil fuels and cement production. It was shown that Polish forests absorb 84.6 million tons of CO_2/year, that is 26% of emissions from fossil fuel combustion and cement production, while agricultural crops absorb 103 million tons of CO_2/year. Total carbon dioxide sequestration by forests and agricultural crops amounts to 187.5 million tons of CO_2/year, which is tantamount to 59% of emissions from fossil fuel combustion and cement production. Forestation of marginal soils would further increase carbon dioxide absorption in Poland by 20.6 million tons of CO_2/year. Moreover, if plants were sown in order to produce green manure - instead of leaving soil fallow - sequestration could still be boosted by another 6.2 million tons of CO_2/year.

Keywords: climate change, CO_2 sequestration, CO_2 absorption by terrestrial ecosystems, global CO_2 fluxes

Introduction

According to Intergovernmental Panel for Climate Change, one of the greatest threats to the development of modern world is the climate warming caused by increased concentration of greenhouse gases in the atmosphere, which retain the heat radiated from the surface of the Earth.

It should be noted that the greenhouse effect per se is a beneficial phenomenon, were the heat not retained by the greenhouse gases and water vapour, the mean temperature on the surface of the Earth would amount approximately to –14°C. The problem consists in an exceeding amount of greenhouse gases emitted by the present-day civilization, mainly due to fossil fuel combustion, cement production, and changes in land use, which lead to a further increase of temperature on Earth.

According to the reports of Intergovernmental Panel for Climate Change, the rise of temperature on Earth leads to disastrous climatic changes.

Although most scientists concur with this viewpoint, it should be mentioned that there are also contradictory opinions. For instance, Richard Lindzen - an outstanding American

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climatologist - does not negate the existence of greenhouse effect; however, he expects that the magnitude of climatic changes will be far milder [1]. According to Lindzen, taking decisive actions aimed at curbing CO_2 emissions, achieved mainly through limiting fossil fuels combustion, is unjustified; especially as they are disadvantageous for the economies of numerous countries.

Excessively one-sided approach of mitigating CO_2 emission from anthropogenic sources, focusing on limiting fossil fuel combustion, may slow down the economic development of many countries [2, 3]. Generation of energy from renewable sources - especially advocated in the EU - which aims at the mitigation of CO_2 emissions, often leads to the creation of socio-economic problems [2, 3] and is coupled with negligible efficiency in CO_2 reduction. Negative examples include the production of biodiesel fuel from the oil obtained from coconut palms, grown in Indonesia on the land acquired by burning off tropical forests or the production of ethanol from corn [4, 5]. Promotion of biofuels was based on a simplified analysis and the assumption that the amount of CO_2 produced during biofuels combustion is equal to the amount absorbed from the atmosphere in photosynthesis.

Although this statement is true, it does not account for additional energy costs connected with the cultivation, harvest, and processing the plants into biofuel. Moreover, such assumption omits the fact that in order to create a plantation, another ecosystem was destroyed - such as a tropical forest or peatland - which would absorb greater amounts of CO_2 from the atmosphere. These losses in CO_2 adsorption are known as CO_2 absorption losses caused by changes in land use [6].

Therefore, introducing renewable energy sources requires an in-depth analysis of both socio-economic and environmental effects. Brazil is a country which successfully introduced ethanol for fuelling cars on a large scale. A comprehensive programme of utilizing sugar cane for ethanol production was developed, which also took into consideration the socio-economic and environmental conditions [7].

While the use of plants as a source of energy is widely advocated as a remedy for CO_2 emissions, the role of terrestrial ecosystems, including agriculture, in mitigating the increase of CO_2 concentration in the atmosphere remains underappreciated. It should be noted that the emissions from fossil fuels combustion and cement production constitutes only about 4.7% of CO_2 emissions from the natural sources, *i.e.* terrestrial ecosystems and oceans. The CO_2 absorption of these two main ecosystems equals 253 Gt C/year (10^9 tons of carbon per year = 10^{15} g C/year). Therefore, in order to neutralize the emission from anthropogenic sources, which in 2011 amounted to 9.8 ±0.5 Gt C/year, it would be enough to intensify the CO_2 absorption of the afore-mentioned ecosystems by 4.8%.

Hence, there is the question of whether adopting the strategy of focusing on mitigating CO_2 emission from anthropogenic sources - through extensive, costly changes in energy acquisition with geological CO_2 sequestration - was reasonable, if small, about five-percent changes in CO_2 absorption by terrestrial ecosystems can achieve a similar effect.

Therefore, simultaneously increasing CO_2 absorption and reducing its emission by terrestrial ecosystems can significantly contribute towards the mitigation of the greenhouse effect.

Characteristic of CO_2 fluxes in terrestrial ecosystems

According to the data published by le Quere [8], the average emissions of CO_2 into the atmosphere originating from the combustion of fossil fuels and cement production are constantly on the rise - Table 1 (also Fig. 1 in [8]).

Table 1

CO_2 emissions from fossil fuel combustion and cement production [8]

Years / Emission	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2005-2014	2014
Emission [Gt C/year]	3.1 ±0.2	4.7 ±0.2	5.5 ±0.3	6.4 ±0.3	7.8 ±0.4	9.0 ±0.5	9.8 ±0.5
Emission [Gt CO_2/year]	11.4 ±0.7	17.2 ±0.7	20.2 ±1.1	23.5 ±1.1	28.6 ±1.5	33 ±1.8	35.9 ±1.8

Apart from the industrial emissions, changes in land use constitute another source of anthropologic emissions, and mainly involve deforestation and drying of marshes (Table 2) [9].

Table 2

CO_2 emissions caused by changes in land use, mainly including deforestation and drying of marshes [8]

Years	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2005-2014	2014
Emission [Gt C/year]	1.5 ±0.5	1.3 ±0.5	1.4 ±0.5	1.6 ±0.5	1.0 ±0.5	0.9 ±0.5	1.1 ±0.5
Emission [Gt CO_2/ year]	5.5 ±1.8	4.8 ±1.8	5.1 ±1.8	5.9 ±1.8	3.7 ±1.8	3.3 ±1.8	4.0 ±1.8

As it turns out, the natural fluxes of CO_2 are much bigger. Terrestrial systems absorb 123 ±8 Gt C/year, converting it to biomass [10, 11] and emit 119 ±1 Gt C/year (Table 3).

Table 3

Net CO_2 absorption by terrestrial ecosystems [8]

Years	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2005-2014	2014
Absorption [Gt C/year]	1.7 ±0.7	1.7 ±0.8	1.6 ±0.8	2.6 ±0.8	2.4 ±0.8	3.0 ±0.8	4.1 ±0.9
Absorption [Gt CO_2/ year]	6.2 ±2.6	6.2 ±2.9	5.9 ±2.9	9.5 ±2.9	8.8 ±2.9	11 ±2.9	15 ±3.3

The observed increase of CO_2 absorption by terrestrial ecosystems is caused by the fertilising effect of rising atmospheric concentration of CO_2 on plant growth, as well as the fertilising effect of nitrogen compounds, mostly nitrogen oxides emitted from industrial plants. To a certain extent, lengthening of the growing season in northern temperate and boreal areas also affects the process.

Table 4

Net CO_2 absorption by oceans [8]

Years	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2005-2014	2014
Absorption [GtC/year]	1.1 ±0.5	1.5 ±0.5	2.0 ±0.5	2.2 ±0.5	2.3 ±0.5	2.6 ±0.5	2.9 ±0.5
Absorption [GtCO_2/ year]	4.0 ±1.8	5.5 ±1.8	7.3 ±1.8	8.1 ±1.8	8.4 ±1.8	9.5 ±1.8	10.6 ±1.8

Simultaneously, CO_2 is absorbed by oceans. According to IPCC assessment [12], oceans absorb 92 Gt C/year and release 90 Gt C/year at the same time. The increase of CO_2 concentration in the atmosphere shifts the balance in favour of CO_2 absorption by oceans (Table 4).

As a result, the content of CO_2 in the atmosphere has been increasing at a slower rate than it would seem from the anthropogenic emission (Table 5).

Table 5

Increase of CO_2 content in the atmosphere [8]

Years	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2005-2014	2014
CO_2 content in the atmosphere [Gt C/year]	-	1.7 ±0.1	3.4 ±0.1	3.1 ±0.1	4.0 ±0.1	4.4 ±0.1	3.9 ±0.2
CO_2 content in the atmosphere [Gt CO_2/ year]	-	6.2 ±0.4	12.5 ±0.4	11.4 ±0.4	14.7 ±0.4	16.1 ±0.4	14.3 ±0.8

It resulted in an increase of its concentration in the atmosphere (*e.g.* Fig. 2 in [8]).

While comparing the net CO_2 emissions from anthropogenic sources, amounting to 3.9 ±0.2 Gt C/year in 2014, with the CO_2 absorption by terrestrial ecosystems, equal to 123 Gt C/year, it can be easily seen that raising CO_2 absorption of terrestrial plants merely by 3.2% could inhibit the increase of CO_2 in the atmosphere.

Therefore, it seems reasonable to check whether it is possible to stop the increase of CO_2 concentration in the atmosphere by appropriate management of CO_2 absorption in terrestrial ecosystems.

Role of terrestrial ecosystems in the regulation of CO_2 cycle

Terrestrial ecosystems are essential to the regulation of CO_2 fluxes. The greatest amount of CO_2, *i.e.* 547.8 Gt C, is found in tropical and subtropical forests, as well as peatlands [13-20]. Out of this amount, 406 Gt C is contained in tropical forests (190 Gt C in plant biomass on the surface and 226 Gt C in soil). Tropical forests are one of the most important terrestrial ecosystems, which absorb approximately net 1.3 Gt C/year: 0.6 Gt C/year in Central and South America, 0.4 Gt C/year in Africa and 0.25 Gt C/year in Asia [21, 22]. One hectare of tropical forests contains 90 to 200 tons of carbon.

It is estimated that 6.5 to 14.8 million ha of tropical forests is cut down in this area, increasing the annual emission by additional 0.8-2.2 Gt C [23, 24].

Peatlands play an extremely important role in the absorption of CO_2. It is estimated that approximately peatlands contain 550 Gt C, and 1 ha holds 1450 t of carbon. Unfortunately, drying of peatlands to create agricultural lands, often for the purpose of cultivating biofuel plants, leads to their rapid degradation and release of CO_2 into the atmosphere. It was found that elimination of 6 million ha of peatlands contributes to the annual emission with additional 0.5-0.8 Gt C [25-27].

It is worth noting that biodiesel produced from coconut palm grown on peatlands converted to coconut farms does not fulfill the essential role of biofuels, *i.e.* decreasing CO_2 emissions. On the contrary, it increases the emission three- to nine-fold [9, 10].

The third important ecosystem includes tropical and subtropical meadows, savannahs and shrubs, which contain 463.6 Gt C. They are vulnerable to fires that increase the annual

CO_2 emission by 0.5-4.2 Gt C. Nevertheless, these ecosystems have an annual net absorption of 0.5 Gt C [18, 27-30].

In a temperate climate, meadows play a vital role in the regulation of CO_2 fluxes in the Earth's ecosystem. They contain 183.1 Gt C, with 133 Gt C/ha accumulated in soil [18].

Forests in temperate zones constitute another essential ecosystem. They contain 314.9 Gt of carbon. These forests are characterized by high carbon content, ranging from 150 to 320 tons of carbon per hectare. The area of forests in North America and Europe constantly increases. Currently, the European temperate forests absorb 7-12% of CO_2 emitted from anthropogenic sources [31, 32]. It should be expected that further forestation and appropriate management of forestry may become one of the main CO_2 sequestration mechanisms. Boreal forests in Russia, Alaska, and Scandinavian countries also contain huge amounts of carbon (approximately 384.2 Gt). Due to low temperatures, decomposition of dead biomass in these forests occurs slowly; thus, soil is rich in carbon (116-343 t/ha). They are an important element of CO_2 sequestration. One should bear in mind that net CO_2 absorption occurs only in young forests. It is suspected that mature forests balance the absorption and emission of CO_2, which means that old forests do not contribute to the net CO_2 absorption.

Tundra constitutes yet another ecosystem; it contains 155.4 Gt C [33, 34]. Tundra is found in the arctic areas in the Northern Canada, Scandinavian countries and Russia, as well as Greenland and Iceland. In this zone, both growth and decomposition occur slowly; hence, under a relatively thin layer of soil there is a permanently frozen layer called permafrost. It is estimated that the latter contains 1600 Gt C [31, 35-37].

There are concerns that CO_2 and CH_4 trapped in permafrost will be released due to the global warming. It is estimated [38] that this ecosystem may release 100 Gt C in the form of CO_2 and CH_4, which would increase the concentration of carbon in the atmosphere by as much as 47 ppm.

This means that the natural terrestrial ecosystems are enormous reservoirs of carbon. They contain approximately 2000 Gt C, and the annual net absorption equals about 1.5 Gt C. Tropical forests play an especially important role in carbon balance. It is estimated that till the year 2100, sequestration of carbon by natural ecosystems will prevent the increase of CO_2 in the atmosphere by 40-70 ppm.

Agriculture is a separate issue [39]. Deforestation and drying of peatlands - performed in order to convert them into agricultural lands - not only leads to a decrease of CO_2 absorption by plants, but also further increases the CO_2 emission due to the oxidation of organic carbon in soil, which is one of the biggest reservoirs of carbon [40]. IPCC report [18] estimates that the amount of carbon in organic compounds found in soil equals 1580 Gt. Lal [41] provides similar figures: 1550 Gt of organic carbon and 950 Gt of inorganic carbon.

This data shows that terrestrial ecosystems, especially forests are vital for the regulation of CO_2 content in the atmosphere, which was pointed out by J. Szyszko, Polish Minister of Environment.

Assessment of CO_2 sequestration by terrestrial ecosystems in Poland

The analysis of CO_2 fluxes between main ecosystems of the Earth shows that we should pay more attention to CO_2 sequestration in natural processes.

In Poland, the emission from the combustion of fossil fuel and cement production gradually decreases, mainly due to the elimination of industry resulting from so-called *Balcerowicz Plan*. In 2014, the total CO_2 emission in Poland amounted to 316.8 million t of CO_2 [40].

As far as mitigation of CO_2 emissions is concerned, forests are one of the most important ecosystems. In Poland, they cover an approximate area of 9.4 million ha [40]. Depending on the species and age of trees, 1 ha of forest absorbs 30-35 t CO_2/year. Thus, the total absorption of CO_2 by forests ranges from 283 to 329 million t CO_2. Simultaneously, forests emit CO_2 in the processes of respiration and organic matter decomposition.

Gaj [41], using data of Veroustraele and Sabie, reports that the net CO_2 absorption of Polish forests equals 9 t/ha per year, on average. This means that Polish forests absorb the net amount of 84.6 million t CO_2 annually, *i.e.* 26% of emission from anthropogenic sources.

Similar intensity of CO_2 absorption characterizes orchards, which cover 341.8 thousand ha in Poland and absorb 3.1 million tons of CO_2/year.

Significant degree of CO_2 absorption is displayed by pastures (4.8 t CO_2/ha per year) and grasslands (2.6 t CO_2/ha per year) [42-44]. Pastures in Poland extend over an area of 486 thousand ha. Hence, the annual CO_2 sequestration equals 1.9 million t CO_2/year. On the other hand, the area covered by grasslands is far greater and amounts to 2.6 million ha. Thus, the annual CO_2 sequestration in this case equals 6.8 million t CO_2/year.

By far, the greatest area of land - 7.48 million ha - is occupied by cereal crops [40, 41, 45-47]. According to the available data on CO_2 sequestration for Spain [48], wheat absorbs 13.9 t CO_2/ha per year, while oat - 11.7 t CO_2/ha per year. However, sequestration in the climatic zone of Poland is less efficient. With this data, it is possible to estimate that the CO_2 sequestration by cereal crops is about 74.8 million t CO_2/year. The total CO_2 sequestration by orchards, cereal crops, pastures, and grasslands amounts to about 86.6 million t of CO_2/year, *i.e.* about 25% of annual anthropogenic emission in Poland. Moreover, industrial crops cover 1.16 million ha, whereas potatoes occupy 267 thousand ha [40]. There is no data on CO_2 sequestration for these plants. It can be assumed that it will be similar to the sequestration of such vegetables as cauliflower, broccoli, artichoke, and tomato. According to [42, 49], these vegetables are characterized by the following CO_2 sequestration values: cauliflower - 36 t CO_2/ha per year, broccoli - 22 t CO_2/ha per year, artichoke - 13 t CO_2/ha per year, tomato - 24 t CO_2/ha per year. Assuming that the CO_2 sequestration of potatoes is similar to artichokes, it can be calculated that they are absorbing approximately 3.5 million t CO_2/year. For industrial crops, assuming the sequestration level of cereal crops, *i.e.* 11 t CO_2/ha per year, absorption of CO_2 is equal to 12.8 million t CO_2/year.

The above-mentioned calculations show that CO_2 sequestration of agricultural crops equals 103 million t CO_2/year. If we combine this with forests, the sum will total 187.5 million t CO_2/year, which roughly corresponds to 59% of emissions from fossil fuel combustion and cement production. In other words, 59% of CO_2 emissions from these two sources is absorbed by agricultural crops and forests.

Potentially, it would be possible to increase CO_2 sequestration of terrestrial ecosystems in Poland. Sajnog and Wojcik [43] estimate that in Poland there is 2.3 million ha of marginal soils. Forestation of these areas would increase CO_2 sequestration in the future by 20.5 million t CO_2/year.

Moreover, 475 thousand ha is left fallow. These lands could be used for CO_2 sequestration, which could be done by growing plants for green manure. Benefits of this solution are twofold. It would enable to increase CO_2 sequestration in the country by 6.2 million t CO_2/year and improve soil fertility by increasing humus and nutrient content. Undoubtedly, it would reduce the demand for mineral fertilizers, especially if nitrogen-fixing plant were to be grown. As a result, the emission of greenhouse gases connected with the production of mineral fertilizers would be cut.

Conclusions

CO_2 sequestration by terrestrial ecosystems is an essential, albeit not fully utilized method of mitigating CO_2 emission to the atmosphere. The authors of this work are not experts on plant cultivation and hence the data presented should be treated as approximations. It would make sense to perform an in-depth analysis of the existing and prospective possibilities of CO_2 sequestration by terrestrial ecosystems in Poland. It is all the more important, considering that the work presented possible methods of improving CO_2 sequestration through further forestation and utilization of fallow land for the production of green manure, which would absorb at least 27 million t CO_2/year. One of possible way to increase CO_2 sequestration by forests is its fertilisation [44]. It would allow for a further reduction of anthropogenic CO_2 emissions in Poland by additional 8.5%.

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