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The role of CO_2 in the Earth's ecosystem and the possibility of controlling flows between subsystems

Introduction

The mainstream debate about the greenhouse effect is focused on the energy market. A number of actions have been taken to achieve a low carbon economy. Most of the projects aimed at reducing CO_2 emissions have focused on the problems associated with energy production to such an extent that the European Union directed that biofuels account for 10% of transport fuels by 2020. The main criterion for the introduction of this directive was to ensure sustainable development through a reduction of CO_2 emissions into the atmosphere (Pieńkowski 2012; Wall 2013; Grunwald 2014; Xue et al. 2014; Kostecka 2014).

This approach does not, however, take into account options available in the carbon dioxide market. Carbon dioxide can also be used as an industrial raw material, e.g. as a substrate in the synthesis of plastics or in biofuels and fuels production. In its supercritical state, it is used in the food and perfume industries during extraction. As it is neither corrosive nor toxic, it is increasingly being used to transport heat in heating and refrigeration systems. Injecting CO_2 into depleted oil wells not only allows for its safe storage, but also allows for improved yields from oil fields.

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Thus it is clear that the CO_2 sector is identifying many new potential uses for CO_2 in various industries. Therefore, a unilateral approach to counteracting the greenhouse effect by making profound changes to energy policy focussing only on reducing CO_2 emissions is not fully justified. It now appears that the widespread use of biofuels leads to serious environmental and economic consequences, and significantly – in many cases – their usage causes an increase in CO_2 emissions. The negative environmental consequences result from establishing plantation crops for the production of biofuels in areas where tropical forests have been cut down. In addition, the advancement of crop cultivation for biofuels has increased food prices, which is contrary to the paradigm of intra-generational justice, an important criterion for sustainable development (Dasgupta 2013; Duran et al. 2013; Ecimovic et al. 2014; Venkatest 2014). Initially, it was incorrectly assumed that combustion of biofuels will only yield as much CO_2 as the vegetation absorbed during growth. In this assessment, including the energy expenditure necessary for growing, harvesting, and processing the crops into biofuels was neglected. It was later found that in the case of biofuels, such as bioethanol obtained from maize or biodiesel obtained from sunflower seeds, the amount of energy consumed in the entire production cycle is greater than that obtained by the combustion of bioethanol or biodiesel, and thus their very use rather than decreasing CO_2 emissions increases them (Duran et al. 2013; Grunwald 2014; Konarski 2014).

This is an example which shows that decisions taken without fully analysing the consequences of the recommended projects produces results opposite those intended.

Many more such examples regarding energy management can be found. It is therefore appropriate to examine the full Carbon Cycle in the Earth's ecosystem and assess the potential impact of each individual project.

Although the existence of the greenhouse effect is undisputable, there are discrepancies between the magnitudes of the projected changes. An eminent American climatologist, Richard Lindzen (2010), has sown doubts about the level of the IPCC (IPCC 2013) forecasted temperature rise on Earth, but does not question the need for action to deal with a rise in the Earth's average temperature.

As will be shown below, only human activity is responsible for the increase in atmospheric CO_2 concentrations and that burning fossil fuels is just one of the reasons. Other factors such as changes in land use turns out to be equally important.

Furthermore, what is not common knowledge is that the anthropogenic CO_2 emission flow is only a small fraction of the natural CO_2 flows in the Earth's ecosystem, flows such as photosynthesis, respiration, or absorption and desorption in the seas and oceans. This means that increasing photosynthesis by only a few percent, or reducing CO_2 emissions from soils, can produce a similar effect to that of costly projects in the field of energy management. Focusing only on reducing CO_2 emissions through changes in energy policy in such countries as Poland may turn out to be not only ineffective but also very expensive.

For a better understanding of the role CO_2 emissions (from burning fossil fuels) play, it is necessary to perform a detailed analysis of the exchange fluxes of all CO_2 flows in the Earth's ecosystem.

For clearer discourse it is necessary to split the Earth's ecosystem into subsystems which play an important role in transferring CO_2. As a criterion for the individual subsystems, the form in which CO_2 is concentrated has been adopted.

The most important subsystem is the atmosphere (because it plays a major role in begetting the greenhouse effect), in which approximately 828 billion tonnes of C_{CO_2} is concentrated (Prather et al. 2012; Joos et al. 2013). In contrast, most of the carbon – mainly in the form of carbonates – is contained in sedimentary rocks. It is estimated that in this subsystem there are about 1,000,000 billion tonnes of C_{CO_2} but due to low carbon mobility it only plays a minor role in the transfer of CO_2 in the Earth's ecosystem.

Another subsystem is soils, which contain about 1,500–2,400 billion tonnes of C_{org}, i.e. carbon occurring mainly in the form of organic compounds. It is estimated that in addition there are between 300 and 700 billion tonnes of carbon accumulated in wetlands (Bridgham et al. 2006). The land ecosystems contain between 450 and 650 million tonnes of C_{org} in the form of biomass.

The seas and oceans play an important role in the accumulation of carbon which, in their upper layers, contain about 900 billion tons of carbon, mainly in the form of carbonates. It is estimated that the amount of carbon contained in the flora and fauna in the surface layers of the seas and oceans is only about 3 billion tonnes of C_{org}, of which about 0.2 billion tonnes C_{org}/year (in the form of dead organisms) sink to the bottom (Hansell et al. 2009; Denman et al. 2007). In contrast, in the ocean depths about 38,000 billion tonnes C_{CO_2} have accumulated mainly in the form of soluble carbonates. The permafrost regions constitute a subsystem containing large amounts of carbon – about 1,400 billion tonnes C (Tarnocai et al. 2009). It is estimated that the fossil fuels subsystem (coal seams, oil, and gas) contains about 4,000 billion tonnes of carbon.

In the above mentioned subsystems, sedimentary rocks and deep ocean waters play a minimal role in the Carbon Cycle, like the eternal permafrost, although in the case of the latter climate warming may have a significant effect on increasing CO_2 and CH_4 emissions into the atmosphere.

In reality the remaining subsystems, with a total carbon accumulation of 3,950 billion tonnes, play a noticeable role in the Carbon Cycle in the Earth's ecosystem.

1. The exchange of carbon between the major subsystems

From the viewpoint of the greenhouse effect, the exchange of CO_2 between the atmosphere and the other subsystems is the most important, with the greatest volumes exchanged between the atmosphere and the land ecosystems. Photosynthesis binds approximately 123 ± 8 billion tonnes of C_{CO_2}/year, which is converted into biomass (Beer et al. 2010). Simultaneously, respiration from all organisms releases 119 ± 1 billion tonnes C_{CO_2}/year into the atmosphere. This means that land ecosystems annually absorb a net 2.6 ± 1.2 billion tonnes C_{CO_2}/year from the atmosphere (IPCC 2013). Approximately 1.7 billion tonnes of C_{org}/year

is transferred from land ecosystems into rivers, of which a certain proportion is released into the atmosphere as CO_2 due to mineralisation. Another proportion is deposited as sediment, whilst the remainder of about 0.9 billion tonnes of C_{org}/year flows into the seas and oceans (Tranvik et al. 2009).

The second largest CO_2 exchange is that between the atmosphere and the seas and ocean subsystem, which annually absorbs 80 billion tonnes of C_{CO_2}/year while simultaneously releasing 78±1 billion C_{CO_2}/year (IPCC 2007).

Thus, the seas and oceans annually absorb more than 2 billion tonnes of C_{CO_2}/year.

As a result of volcanic eruptions, about 0.1 billion tonnes of C_{CO_2}/year are released into the atmosphere. Weathering fixes about 0.3 billion tonnes C_{CO_2}/year, of which 0.2 billion tonnes C_{CO_2}/year is transported by the surface waters into the seas and oceans where it is deposited in sedimentary rocks. The remaining 0.1 billion tonnes of C_{CO_2}/year remain on land. These have to be included in the Earth ecosystem's natural exchanges.

After 1750, the observed rise in CO_2 absorption by the above mentioned subsystems has been due to increased atmospheric CO_2 concentrations arising from emissions from anthropogenic sources.

Man affects the carbon cycle in nature by changing land use, burning fossil fuels, cement production, and other industrial processes, of which the first three are the most important.

Between 1750 and 2011, as a result of burning fossil fuels and cement production, 375±30 billion tonnes of C_{CO_2} were released into the atmosphere. For the same period, due to changes in land use, CO_2 absorption by land vegetation was reduced by 180±80 billion tonnes C_{CO_2} primarily through deforestation. Since this reduction in CO_2 absorption can be classified as an additional emission, the total emissions from burning fossil fuels, cement production, and changes in land use for the 1750–2011 period totalled 555±80 billion tons of C_{CO_2}. Of this, less than half (240±10 billion tonnes C_{CO_2}) remain in the atmosphere. The majority has been absorbed mainly by the land ecosystems (160±90 billion tonnes C_{CO_2}) and the seas and oceans (155±30 billion tonnes C). It therefore follows that due to increased photosynthesis, CO_2 absorption for the 1750–2011 period increased by 30±45 billion tonnes C_{CO_2}. An increase in atmospheric CO_2 concentration causes a similar effect to that of fertilisation in land ecosystems.

According to the IPCC (IPCC – Fourth Report) emissions from burning fossil fuels and cement production continuously grow. They reached a value of 5.5±0.4 billion tonnes of C_{CO_2}/year between 1980 and 1989, 6.4±0.5 billion tonnes C_{CO_2}/year between 1990 and 1999, 7.8±0.6 billion tonnes C_{CO_2}/year between 2000 and 2009, and 8.3±0.7 billion tonnes C_{CO_2}/year in the period from 2002–2012. Emissions in 2010 amounted to 9.2±0.8 billion tonnes of C_{CO_2}/year, and in 2011 this increased to 9.5±0.8 billion tons C_{CO_2}/year (Francey et al. 2013).

It is worth noting that during the 2008–2009 economic crisis, CO_2 emissions fell in 2009 by 0.3%, but increased by 5.1% in 2010, and in 2011 by a further 3.0% (Peters et al. 2013).

Deforestation and infrastructure developments (roads, towns, etc.) resulted in a reduction of CO_2 absorption by land ecosystems. These reductions were 1.3±0.7 billion tonnes of

C_{CO_2}/year between 1980 and 1989, 1.2±0.6 billion tonnes C_{CO_2}/year between 1990 and 1999, 1.1±0.8 billion tonnes C_{CO_2}/year between 2000 and 2009, and 0.8±0.6 billion tonnes C_{CO_2}/year in the period 2000–2009.

It should be noted that the observed increase in absorption by land ecosystems in recent years has been caused by new afforestation and a slowing down in deforestation. As a consequence of these changes, total CO_2 absorption by land ecosystems increased by 1.5±1.1 billion tonnes of C_{CO_2}/year between 1980 and 1989, 2.6±1.2 billion tonnes C_{CO_2}/year between 1990 and 2009, but slightly decreased to 2.5±1.2 billion tonnes C_{CO_2}/year in the period 2002–2011. The years 2010 and 2011 are responsible for this decline, a probable cause being tropical deforestation for the purpose of growing crops for biofuels (IPCC Fifth Report; Prather et al. 2012; Houghton et al. 2012; Le Quere et al. 2013; Zaehle et al. 2011; Mason Earles et al. 2013).

Consequently, a continuous rise in CO_2 emissions into the atmosphere has been observed. Whilst on average 3.4±0.2 billion tonnes of C_{CO_2}/year were released between 1980 and 1989, the figure was 6.4±0.5 billion tonnes C_{CO_2}/year between 1990 and 1999, 7.8±0.6 billion tons C_{CO_2}/year between 2000 and 2009, and 8.3 billion tonnes C_{CO_2}/year for the period from 2002–2011. In 2011, 9.5±0.8 billion tonnes of C_{CO_2}/year were released (IPCC-Fifth report).

As a result of the above-mentioned natural processes, approximately 201 billion tonnes of C_{CO_2}/year are transferred from the atmosphere into the remaining subsystems (primarily seas and oceans and land ecosystems). The dissolution of CO_2 into the seas and oceans and CO_2 assimilation by vegetation through photosynthesis are the two dominant processes. In turn, these subsystems annually release 197±2 billion tons of C_{CO_2}/year due to respiration by living organisms and the release of CO_2 from the seas and oceans. According to IPCC assessments (Fifth Report) between 1990 and 1999, on average, there was a net absorption of 2.2±0.7 billion tonnes of C_{CO_2}/year by the seas and oceans (i.e. more absorbed than desorbed). For the period 2000–2009, this figure was 2.3±0.7 billion tonnes C_{CO_2}/year. The increase in the amount of desorbed CO_2 is caused by an increase in atmospheric CO_2 concentration. Different researchers provide different figures. The smallest increase in CO_2 absorption by the seas and oceans was calculated by Graven et al. (2012), who estimated that this increase was 0.15 billion tonnes of C_{CO_2}/year in the period 1980–1990 and 0.25 billion tonnes C_{CO_2}/year in the period 1990–2000. In turn, Mikaloff-Fletcher et al. (2006) estimated much higher increases of 0.40 billion tonnes C_{CO_2}/year and 0.44 billion tonnes C_{CO_2}/year respectively for the same periods.

The values provided by other researchers lie between these limits. The average increase based on all publications (Khatiwala et al., 2009; Mikaloff-Fletcher et al. 2006; Assmann et al. 2010; Graven et al. 2012; Doney et al. 2009; La Quere et al. 2010) was estimated at 0.23±0.15 billion tonnes of C_{CO_2}/year and 0.33±0.13 billion tonnes of C_{CO_2}/year respectively.

It should be mentioned that values for CO_2 absorption from the atmosphere through photosynthesis, and desorption due to respiration, vary depending on the season. The figures provided above were treated as averages over the whole year.

The emissions resulting from human activity – i.e. burning fossil fuels, cement production, and changes in land use – constitute only about 5% of the emissions from the seas, oceans, and land ecosystems. Nonetheless, they significantly affect the atmospheric CO_2 concentration, which has a direct impact on climate change.

While the atmospheric CO_2 concentration at the beginning of the industrial revolution in 1750 was 278±5 ppm, by 2011 it had increased by 40% to 390.5±0.1 ppm. Between 1960 and 2005 the annual increase in concentration was 1.4±0.0 ppm/year, between 1995 and 2005 it had increased to 1.9±0.1 ppm/year, while for 2002–2011 it was 2.0±0.1 ppm/year. Thus the rate of increase in CO_2 concentration has clearly steepened over time.

It has been predicted (IPCC 2013) that an increase in atmospheric CO_2 concentration will increase its solubility in the sea and oceanic waters, as well as its adsorption during photosynthesis. The barrier to increased solubility in the sea and oceanic waters will be a lowering in the pH value due to the resulting carbonic acid (H_2CO_3). The increase in CO_2 sorption during photosynthesis may be inhibited by a deficiency in nitrogen and phosphorus compounds.

2. Engineering methods for CO_2 sequestration

Extensive research on reducing CO_2 emissions by technical means (in particular those processes related to energy production) is being carried out. Great opportunities lie in energy savings through the use of more energy efficient appliances.

In this regard, progress has been manifesting itself in GDP growth compared to the energy consumed. For example, in Poland the consumption of 1 kg of oil equivalent in 1990 produced goods with a value of USD 2.2; in 2000 this value had risen to USD 4.5, and in 2012 to USD 8.9.

Another method for reducing CO_2 emissions which is being investigated by energy companies is sequestration in geological works. The most beneficial is injecting CO_2 into oil wells post-production when the injected CO_2 allows for enhanced recovery of residual oil from the deposits – oil which otherwise can no longer flow spontaneously on its own. Carbon dioxide is also used to displace methane from coal seams. In a report by the OECD/IEA (2011), information was provided that a pilot installation for filtering out CO_2 using amines will be built in the power plant in Bełchatów by the end of 2015. The filtered CO_2 will then be pumped a distance of between 60 and 140 km before being injected into underground brine deposits. The cost of the entire project is estimated at PLN 2–6 billion, of which 30%, (PZN 780 million) will be from EU funds.

GIG (The Central Mining Institute), PIG (The Polish Geological Institute), and AGH University of Science and Technology are working on a geological map identifying potential sites for the underground storage of CO_2. According to the OECD/IEA-2011 report, it will be possible to inject between 6 and 7 million tonnes of C_{CO_2} into the Polish underground saline reservoirs. There are also some opportunities for injecting CO_2 into depleted oil wells

in western and south-eastern Poland. The oilfields in Borzęcin and Kamień Pomorski are particularly attractive.

The problem is that the carbon dioxide stored in underground seams should be produced from flue gas using expensive chemical methods. Burning fuel in oxygen should be considered, as the exhaust gases would be practically pure CO_2. Furthermore, such a process would not produce any nitrogen oxides. Burning fuel in oxygen would achieve greater energy efficiency.

Another interesting method to limit CO_2 emissions during combustion is CO_2 sorption in energy waste (Uliasz-Bocheńczyk and Mokrzycki et al. 2005, 2006, 2010, 2011, 2013). This is a method which, if applied as indicated by the above mentioned authors, would allow for the sequestration of about 12 million tonnes of C_{CO_2}/year. This method does not require expensive CO_2 filtering of flue gases and, furthermore, the absorbed CO_2 neutralises the suspended waste thereby reducing its negative impact on the environment.

It should be mentioned that research is being carried out into the use of CO_2 to synthesise methanol. The problem is that, so far, all attempts to use a photo-catalyst (TiO2) were uneconomical from an energy point of view because the CO_2/H_2O reaction occurs under UV light generated by UV lamps. Assuming that all the energy in the UV radiation is converted into the methanol's chemical energy, and that the UV radiation is generated from electricity with 100% efficiency, and taking into account that the average efficiency of converting fuel energy into electrical energy is about 35%, it is easy to calculate that in order to fix one CO_2 molecule, at least 3 molecules of CO_2 need to be released when fuel is burned during electricity generation.

Recently there have been reports on the use of CO_2 as a raw material in the production of ethanol and biodiesel. Joule, a company headquartered in Bedford, Massachusetts in the USA, claims to have developed a catalyst that enables ethanol and biodiesel to be produced.

According to the information available on the internet, Joule is building the first industrial plant in Mexico, with a planned capacity of 19,000 m^3 of fuel from a 1 ha site.

Information regarding Joule's ventures is not clear. Fixing CO_2 with the aid of a catalyst and using genetically modified cyanobacteria in its reactors are mentioned. After contacting one of the members of the company's Scientific Committee, prof. George M. Church from Harvard University, to inquire about the processes used by Joule, he provided an article (Robertson et al. 2011) describing achievements in the field of CO_2 sequestration using genetically modified cyanobacteria which produce hydrocarbons that can be processed into biodiesel. The genetic modification of cyanobacteria has led these cyanobacteria, at a 50 to 100-fold increase in CO_2 concentration, to produce greater amounts of hydrocarbons with a 50% triglyceride content while simultaneously producing minimal biomass and having reduced respiration. This allowed 25–29.8% of the solar energy reaching the Earth's surface to be used. It is therefore a very high utilisation rate of the solar energy given that in natural processes, plants use on average 1% of the solar radiation.

A number of studies have appeared regarding CO_2 absorption by cyanobacteria and other algae with the simultaneous production of hydrogen, ethanol, and hydrocarbons as

intermediary products in the production of biodiesel (Kumar et al. 2011; Bilanowic et al. 2009).

The Environmental News Service released information about Macquarie Generation, a company in Australia which, on an industrial scale, will use algae to fix CO_2. The installation will comprise 400 bioreactors, each approximately the size of a container. The entire cost will be AUD 140 million. The first stage will aim to fix 270,000 tonnes of C_{CO_2} and after a couple of years CO2 sequestration will be increased to 1.3 million tonnes C_{CO_2} (www.ens-newswire.com/2013/07/05/australia).

Sayre (2010) analysed the use of algae in CO_2 sequestration and biofuels production. He noted their high productivity in which 1 kg of algae fixes between 1.6 and 2 kg of CO_2, which translates into a high biomass production per unit area. This allows 1 ha to produce between 20 and 60.5 m^3/year of oil which is a raw material for biodiesel production. This appears to be a very interesting direction in CO_2 sequestration combined with its use in large scale biofuels production.

In 2009, the Royal Society of Chemistry published information on the use of CO_2 as a raw material in the production of plastics. The company November, within the framework of a USDOE job order, developed a process using a cobalt catalyst (Thomas et al. 2010) which allows CO_2 to be fixed during polymerisation of cyclic ethers (epoxides) to form thermoplastics with a 40–50% CO_2 content by weight.

Developmental work into catalysts which would enable the use of CO_2 in the manufacture of plastics has progressed rapidly in recent years (O'Byrne et al. 2013; Zhang et al. 2010; Greenemeier 2009; Dodge 2014; Darensbourg 2007).

These plastics can be used to make bottles, photographic film, and laminates. The American company November along with the Dutch company DSM and Eastman Kodak intend to mass produce the above mentioned plastics.

The polymerisation reactions proceed best when pure CO_2 is injected into the reactor, which means that in order to take advantage of the CO_2 in the flue gases it must first be separated from the flue gases. This is another process requiring the use of pure CO_2, thus the aim is to acknowledge that combustion will be performed in pure oxygen.

Equally intensive research is being conducted into artificial photosynthesis (Styring 2011; Listorti et al. 2009; Mauro et al. 2011; Kalyanasundaram and Gratzel 2010; Andreiadis et al. 2011). Catalysts are being sought which will allow artificial photosynthesis to be carried out in order to create organic compounds out of CO_2 and H_2O.

Another line of research is looking into the photolysis of water into hydrogen and oxygen. The main difficulty lies in the fact that the catalysts tested to date restrict absorption to UV radiation, which is only a part of solar radiation. Work is continuing into finding catalysts which will enable the visible part of the solar spectrum to be used. It is worth noting that the US Joint Center for Artificial Photosynthesis was created in 2010, which received a grant of USD 122 million for conducting research into artificial photosynthesis. A review of the published documentation did not yield any information about the industrial applications of artificial photosynthesis.

Carbon dioxide, in its supercritical state, is used on an industrial scale (Janiszewska and Witrowa-Rajchert 2005; Dajas and Henczka 2012; Gurgenova and Wawrzyniak 2012) in the extraction of natural dyes (β-carotene, astaxanthin), removal of animal fats (from milk, egg yolk), fat and oil deodorisation, separation of phosphatides (lecithin), extraction of essential oils (peppermint, garlic, oregano), extraction of aromas and flavours (tropical and citrus fruits), extraction of esters from fatty acids, and extraction of aromas and flavours for beverages.

Certain amounts of CO_2 are used to produce non-combustible foam from plastics and as a medium for heat transfer in refrigerators and heat pumps. Attempts have been made to use carbon dioxide in its supercritical state in closed circuit turbines, operating at temperatures of approximately 500°C which can increase thermal efficiency by up to 40%.

These are additional industrial applications of CO_2; however, they have no significance from the viewpoint of CO_2 sequestration due to the relatively small amounts of CO_2 used.

3. Ways to counteract increases in atmospheric CO_2 concentrations

Discussions about counteracting climate change caused by increased atmospheric CO_2 concentrations are focussed mainly around reducing CO_2 emissions from anthropogenic sources.

The recommended methods of reducing CO_2 emissions concern themselves predominantly with combustion. Although burning fossil fuels is the main cause of increased atmospheric CO_2 concentrations, focusing only on reducing emissions from this source has led to the actions undertaken so far not being very effective. Although it is true that fuel decarbonisation increases annually by about 0.3%, this is thwarted by a simultaneous annual increase in total energy consumption by 2% (Grubler et al. 2012). It seems that there are greater opportunities to reduce atmospheric CO_2 concentrations by increasing photosynthesis in land ecosystems and reducing CO_2 emissions from soils. Both land ecosystems and soils belong to those subsystems which each year exchange very large amounts of CO_2 with the atmosphere. CO_2 absorption by photosynthesis in land ecosystems is 123±8 billion tonnes of C_{CO_2}/year. At the same time, respiration from land ecosystems is 60±3 billion tonnes C_{CO_2}/year, and the same amount of CO_2 is emitted from soils.

About half of the CO_2 emitted from anthropogenic sources is removed by increased absorption by the seas and oceans and land ecosystems. The rest (4.8±0.2 billion tonnes C_{CO_2}/year) remains in the atmosphere, increasing its CO_2 concentration. This quantity represents only a small part of the two main CO_2 flows from the atmosphere – photosynthesis and absorption by the seas and oceans. A small change (on average about 2%) in these natural flows could neutralise CO_2 emissions from anthropogenic sources.

Is this possible?

The greatest potential for reducing atmospheric CO_2 concentrations lies in increasing photosynthesis in land ecosystems and slowing CO_2 emissions from the soils. One of the

most important factors allowing for increased photosynthesis by land ecosystems is to increase overall forestation by slowing down tropical deforestation and increasing afforestation in other areas, particularly where there is low soil quality. In this way, atmospheric CO_2 absorption by land ecosystems can be increased between 40 and 70 billion tonnes of C_{CO_2}over 100 years (House et al. 2002; Canadell and Raupach 2008). Photosynthesis can also be increased by fertilising with nitrogen and phosphorus compounds; as far as production of nitrogenous fertilizers is virtually unlimited, phosphorus compounds are obtained from fossil deposits which are limited. Therefore, more attention should be given to recycling into the soil residual, unusable biomass containing phosphorus compounds. One missed opportunity is the cultivation of secondary crops that can also absorb CO_2. Extensive use of secondary crops as fertiliser can significantly increase CO_2 absorption by photosynthesis.

It would be sufficient to increase CO_2 absorption through photosynthesis by about 2.2% to practically alleviate the remaining approximately 50% of CO_2 emissions from anthropogenic sources. About 50% of emissions from anthropogenic sources are absorbed through increased CO_2 absorption by land ecosystems as well as the seas and oceans, caused by increased atmospheric CO_2 concentrations. This data suggests that more attention should be paid to increasing CO_2 absorption through photosynthesis.

Another important subsystem responsible for CO_2 emissions into the atmosphere is soils, which release into the atmosphere about 60 billion tonnes of C_{CO_2}/year. This is primarily due to respiration from microorganisms within the soils during decomposition of organic matter.

Ploughing is conducive to increasing oxidation of organic matter in the soils. Replacing ploughing with other cultivation methods may reduce CO_2 emissions from this subsystem into the atmosphere. Reducing respiration by microorganisms within the soils by about 4% would practically balance the emissions from anthropogenic sources (about 50% of total emissions).

In the case of seas and oceans some increase in CO_2 absorption can be obtained by stimulating plankton blooms, which is facilitated by fertilising the oceans with iron and phosphorus compounds (Ocean Iron Fertilisation). An experiment which involved seeding iron compounds over a 10 km^2 area produced moderate results (Boyd et al. 2007). Increased amounts of algae were observed but so too were increased amounts of zooplankton feeding on the algae. A large proportion of the algae eaten by the zooplankton were re-mineralised back into CO_2 during respiration.

Nonetheless, over half of the extra CO_2 absorbed, due to the seeding, sank to a depth greater than 1000 m (Smetacek et al. 2012). Some researchers have suggested (Buesseler et al. 2004; Blain et al. 2007) that certain quantities of carbon in the form of biomass can be permanently removed by sinking them into the ocean depths. Fertilising the oceans with iron for 100 years could reduce the atmospheric CO_2 concentration from 15 ppm (Zeebe and Archer 2005) to 33 ppm (Aumont and Boop 2006). Jin and Gruber (2003) conducted simulations which show that fertilising only those oceans in the equatorial zone with iron for 100 years could reduce the atmospheric CO_2 concentration by 66 ppm. Other researchers (Lovelock and Rapley 2007) suggested a solution whereby layers of water at greater depths,

but richer in nutritional substances, are drawn up close to the surface to promote the growth of algae. However, the above mentioned methods do not appear to be realistic.

Proposals to remove atmospheric CO_2 through enhanced weathering should also be mentioned. Minerals such as olivine and basalt, from the silicates group which occur in the earth's crust, react with CO_2 and become soluble. Kelemen and Mater (2008) believe that spreading these ground minerals over moist, tropical areas may lead to the absorption of 0.25–1 billion tonnes of C_{CO_2}/year. The dissolved minerals would flow in the waters into the oceans (Schuiling and Krijgsman 2006). Renforth (2012) estimates that the mineral resources from the silicates group found in the UK would allow for about 100 billion tonnes C_{CO_2}/year of to be removed using this method.

In their estimates, the above mentioned authors did not take into account the energy demands and consequently the CO_2 emissions associated with the generation of energy required to extract, mill, transport, and disperse the minerals. Therefore, it seems that removing CO_2 through enhanced weathering is not realistic from a practical point of view.

In summary, the methods with the greatest potential for reducing atmospheric CO_2 concentrations are those involving increased photosynthesis, particularly in land ecosystems on the one hand, and restricting CO_2 emissions from soils on the other.

It seems that appropriately steering these processes can restrain increases in atmospheric CO_2 concentrations without costly changes to the energy economy.

This article has thus far been devoted to the role CO_2 plays in the Earth's ecosystem. It will conclude by also addressing methane (CH_4), which is the second most important greenhouse gas. The three most important sources of its emissions include rice paddy fields, ruminants (e.g. cattle), and municipal waste landfills. Restricting emissions from the first two sources is not easy. Rice is the staple diet for a large proportion of the human population, and it is difficult to change eating habits on the scale required. Both milk and beef are also important components of the diet for a large proportion of the human population.

However, opportunities do exist to reduce methane emissions from municipal landfills by applying low cost, biologically active overlays in which methane can be oxidised (Stępniewski and Pawłowska 1996; Pawłowska et al. 2006; Pawłowska and Stępniewski 2003, 2004, 2006) in self-running biofilters (Pawłowska et al. 2008, 2011), or by the addition of sewage sludge to increase methane production, enabling it to be collected for energy use (Pawłowska and Siepak 2006; Pawłowska et al. 2008).

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ROLA CO_2 W EKOSYSTEMIE ZIEMI I MOŻLIWOŚCI STEROWANIA PRZEPŁYWAMI CO_2 POMIEDZY PODSYSTEMAMI

Słowa kluczowe

gospodarka energią, gospodarka CO_2, emisja CO_2, fotosynteza, sekwestracja, biopaliwa

Streszczenie

W artykule scharakteryzowano przepływy CO_2 w ekosystemie Ziemi. Omówiono zastosowania CO_2 w różnych sektorach gospodarki: jako surowca do syntezy tworzyw i paliw, do ekstrakcji w przemyśle spożywczym i perfumeryjnym, do przenoszenia ciepła i chłodu w ciepłownictwie i chłodnictwie oraz do hodowli genetycznie zmodyfikowanych alg służących do produkcji biopaliw. Wskazano także na możliwości redukcji stężenia CO_2 w atmosferze poprzez antropogeniczną modyfikację naturalnych przepływów pomiędzy podsystemami w ekosystemie Ziemi.

THE ROLE OF CO_2 IN THE EARTH'S ECOSYSTEM AND THE POSSIBILITY OF CONTROLLING FLOWS BETWEEN SUBSYSTEMS

Key words

energy sector, carbon dioxide sector, carbon dioxide emissions, photosynthesis, carbon dioxide sequestration, biofuels

Abstract

This article describes CO_2 flows in the Earth's ecosystem. It also describes how CO_2 is made use of in various market sectors – as a raw material in the synthesis of plastics and fuels, during extraction in the food and perfume industries, for the transfer of heat in heating and refrigeration systems, and in the breeding of genetically modified algae for the production of biofuels. Additionally, the article explores the possibility of reducing atmospheric CO_2 concentrations and the anthropogenic modification of natural flows between the various subsystems in the Earth's ecosystem.