Research Article

Greenhouse gases emissions and climate change - beyond mainstream

Abstract

Reactions to climate changes induced by anthropogenic greenhouse gases (GHG) usually tackle emissions from fossil fuels and industrial and agricultural sources. Attempts to replace fossil fuels with renewable energy or lower the consumption of animal products per capita remain rather undetectable in consumerist daily routine. Although popular, such approaches tend to oversimplify or even ignore essential aspects of the anthropogenic carbon cycle. Drainage of wetlands for agricultural occupation is often seen as desirable, overlooking the fact that peat is the major depositor for carbon stock and carbon sink, as well for GHG emissions, which results from accelerated degradation rates. Living biomass in forests is also considered as carbon stock, due to degradation and accumulated carbon in soil over millennia. In agriculture, depletion of soil does not only mean poor harvests, but is also one of the major contributors to GHG emission. Based on the example of Estonia, a small nation in North-Eastern Europe known by its "dirty" energy sector, we show that the emission from the drained areas actually exceeds GHG release over the fossil fuels. Similarly it may occur in many countries worldwide where marshes are actively drained, permafrost is melting due to global warming, woodland clearance is widespread for agricultural or commercial purposes, or croplands are overexploited. A drastic cut in GHG emissions remains unreachable as long the society is not ready for highly unpopular political decisions.

Keywords: GHG emissions, environmentally friendly, energy sector, Scandinavia and the Pyrenees

Volume 4 Issue 1 - 2020

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Received: December 14, 2019 | **Published:** January 31, 2020

Introduction

Climate change caused by increased GHG emissions has become as one of the major global topic. Although discussions are oriented to separate aspects of these extremely complicated sets of problems, the outcome tends to clash with the commercial and political interests. Therefore, comprehensive overview is missing. Emissions from the fossil fuels are most targeted, as there are at least theoretical solutions to reduce them. For example, replacement of coal with wood pellets actually increases GHG emissions, as the calorific value of pellets is lower and the recapture of CO_2 takes place in a timeframe of about 100 years. Replacement of gasoline-fueled cars with electric or biofuel using cars seems very environmentally friendly at first glance but the GHG emissions of these "green" cars during the whole life cycle exceed emissions of the fossil fuel using cars. Wind and solar energy are effective only in case of sufficient amount of hydropower to ensure the stability of the power supply networks. In Europe, such ability exists only in Scandinavia and the Pyrenees. If hydropower is not available or is limited, additional fossil fuel fired power plants are required as backup.

The total active pool of carbon at the Earth's surface for durations of less than 10,000 years is roughly 40,000gig tons C (Gt C, a gigaton is one billion tons, or the weight of approximately 6 million blue whales), and about 95% (~38,000Gt C) is stored in the ocean, mostly as dissolved inorganic carbon.[1,2] However, GHG emissions from agricultural and LULUCF (land use, land use change, and forestry) sectors are often underestimated or even ignored. It contributes about one third of total estimated emissions and its share in total emission is increasing. Any agricultural activity causes increase in oxidation of organic carbon stock of soil stored there over millennia; the only exception is herding in grasslands that on the basis of provided measurements continue to bind carbon from atmosphere. Organic farming has particularly twice higher carbon footprint due to larger use of mechanisms requiring fossil fuels, and lower yield1. When forest or peat land is converted to cropland, the accumulated organic carbon emits as CO_2 very rapidly. Pearland draining for any purpose (agricultural, silvicultural, infrastructural works or peat mining) causes the largest GHG emission, since the peat is almost pure deposit of the organic carbon (ca 60% C_{org}), which forms at the first step in coal formation process. In this work, GHG emissions in Estonia are presented according to official statistics and on soil and peat carbon oxidation models. Estonia is a very small country, with a population of 1.3million, of which 45 % lives in two larger cities. In the countryside, the population density is among the lowest in Europe. In terms of GHG emissions, Estonia is a "dirty" country since most of its energy is produced from solid fuel (oil shale) with a low calorific value. The peculiarity of Estonia is that peat lands form 22% of the whole territory, of which 3/4 is drained for forestland and agricultural use. The drained peat land is is the major carbon dioxide emitter, despite the high emission from solid fuel power plants. Approximately half of a territory of Estonia is covered by forests; therefore a large fraction of logged wood is used as fuel both domestically or exported to the EU or UK for the same purpose.

Relationships between soil CO_2 emissions and atmospheric CO_2 levels

Humus contains 58% of carbon (C_{org}) on average. Photosynthesis carried out by plants captures CO_2 and transforms it to organic matter. Most of the organic carbon returns to atmosphere via decomposition, but a partly remains in soil as humic substance. When undisturbed, accumulation of carbon exceeds its oxidation, and therefore the soil acts as a natural carbon reservoir. Soil contains 3 times more C_{org} compared to atmosphere and 5 times more than produced by all vegetation on the Earth. Every small change with the carbon quantities in soil causes significant changes in the atmospheric CO_2 concentration. High carbon levels deposited in peat land soils are very vulnerable to the environment changes, especially to the drainage of mires that are leading to very fast organic degradation. The organic carbon degradation is a process with a positive feedback loop. Increase of the CO_2 concentration in atmosphere forces the decomposition process and the amount of CO_2 emitted.

The organic carbon balance in soil can be described.[2] with Hénin-Dupuis model that considers two pools of C_{org}: the C_{org} in the plant residues and the humified C_{orgi}. The time step is the year and the annual variation of the humified carbon reserve can be calculated as:

$$\frac{\Delta C}{\Delta t} = k_1 m - k_2 c$$

where C is the total humus carbon pool, m is the annual C application of plant residues, k_1 is the 'isohumic' coefficient representing the yield of the transformation into humified carbon of plant residues and k_2 is the mineralization rate constant of the humified carbon. If the residue returns can be considered constant over the integration interval, the formula is as follows:

$$c = c_0.e^{-k_2 t} + m\frac{k_1}{k_2}(1 - e^{kt})$$

The longer is the integration interval, more within-year variability may be ignored and this turns k_1 and k_2 to mean annual coefficients. The term m depends on the various factors and therefore its value may range. Depending on conditions, part of the organic carbon is transformed to humic substances, which are relatively stable and in high concentrations (as occurring in peat) transform into lignite and afterward into coal.

Hénin-Dupuis' model can be modified by separating the organic matter into a stable and an active fraction. In this three-compartment model, the evolution of the carbon reserve may be described by the following equations:

$$c = c_s + c_{A0}.\mathrm{e}^{-kt} + \frac{k1}{k}(c - e^{kt})$$

$$c = c_s + c_{A0}$$

$$q = k_1.m$$

Where Cs is the stable C content, C_{A0} is the initial active C content, C_0 is the initial total C content, m is the mass of annual C input, k_1 is the isohumic coefficient, k is the annual coefficient of mineralization of the active fraction, and q is the mass of carbon humified annually.

Hénin-Dupuis model is an old one and has its limits. In the model, a single section of OM is considered in the soil, as well as for each of the flows by which OM entering into the soil. It has the advantage of requiring only few parameters. On the other hand, the Hénin-Dupuis model only considers a single section of OM in the soil. However, due to the diverse nature of this OM, several dynamic sections need to be taken into account.

Two compartment Hénin-Dupuis model is not satisfactory due to the simultaneous estimation of the model parameters not having consistent values of k_1, and because the independent estimate of k_2 does not indicate the problem of systematic bias: the model undervalues the initial fall in C content in the first years, and overvalues it later years.

In the modified Hénin-Dupuis model given by Andriulo et al.[2] there has been implemented using at least two SOM fractions each with a specific turnover rate: a labile fraction supplied from crop residues and a large, more stable, fraction of transformed 'humified' products and then a deriving model with three compartments.[2] Soil organic matter has been divided into active and stable OM by using 13C isotopic tracing. The 13C tracing shows the size of each soil fraction and outlines their changes to be followed. The three parameters of k_1, k and CS can be therefore measured more accurately. Modified model enables cropping systems beneficial to the estimation of the organic carbon fate of cultivated soils to be evaluated over the medium time interval.[2]

Our workgroup has elaborated modified Hénin-Dupuis' model describing the carbon capture and emission of peat lands and methodology for ascertaining the coefficients based on peat profile chemical analysis (in cooperation with proof Peep Midle, Institute of Mathematics of Tartu University). Data of the most Estonian mires and peat lands are collected over several years and is partly available in open access digital database, developed by Teletech (prof M. Orr). Most of the data (botanical composition, degree of decomposition, ash content, acidity (pH), and natural humidity) were systematized from manual reports. By now, data from three counties (145 peat lands total, more than 10000 measuring points) are publicly available.[3]

CO_2 emission of agricultural lands

One of the biggest carbon dioxide emitters in the world, much not talked about, is plant production. Since 1850, about 80PgC has been emitted from the C reservoir of soil (270Pg from burning fossil fuels). When plowing breaks down the vegetation layer, organic carbon (C_{org}) accumulated in the soil during thousands of years begins to oxidize rapidly. Of course, such emissions are particularly high in tropical areas, but according to studies conducted in Estonia.[4] carbon release is significant also in temperate zones: on average, each hectare releases more than 2 t of carbon per year, equivalent to about 10 t of CO_2. The only agricultural land that absorbs carbon (does not emit) it is grassland.[4]

Depending on the soil moisture regime, changes in the Corg stock in temperate, wet and marsh soils vary significantly in arable and grassland. Arable land has the highest annual decrease in Corg reserves of -8.31t/ha on marshy soils. Adsorbing ability of grassland is approximately 0.30t/ha per year.[4] Emissions from organic farming is significantly higher If .to consider lower productivity per area unit and a greater need for hail for farm work, organic farming can be one of the most polluting types of human activity.

Soil degradation due to the intensive agricultural use and poor land management leads to loss of soil fertility and a decrease of agricultural productivity. More than 75% offertile land of Earth is partially degraded, 30% seriously, every year 1,550sq km of fertile land turns into desert.[5]

As soon as on year 2025 Earth can produce only half of food needs by increasing population. Generating three centimeters of top soil takes 1,000 years, and if current rates of degradation continue all of the world's top soil could be gone within 60 years.[6]

Forests as a carbon reservoir

The ability of the world's forests to absorb atmospheric carbon makes them into large carbon stocks. Forests, mainly tree trunks, twigs and leaves contain 80% of terrestrial and 40% of the underground (including tree roots) bound C, their total carbon content is estimated from 352-532PgC (various IPCC reports) to 987-990PgC.[7] This includes older sources of literature generally indicating a higher carbon stock in forests than newer ones. Much quoted in Dixon RK et al.[8] indicate that forest biomass and soils contain 1146PgC globally, with 37% of this carbon contained in low-latitude (tropical) forests, 14% in medium-latitude and 49% in high-latitude forests mainly in boreal forests. 2/3 of the carbon sequestered in forests is located in forest soils and only 1/3 in the plant mass. For example, for the total stock estimate, 987PgC, the plant material incl. roots have a carbon content of 331GtC and soils have a carbon content of 656GtC.[7]

The temperate zone and boreal forests are particularly important for carbon sequestration, with carbon capture in boreal forests of 0.5PgC/yr and 0.8PgC/yr in temperate forests.[9,10] All the forests of the world bind 2Pg of carbon per year. A distinctive feature of boreal forests is that although they account for only 13% of global terrestrial biomass, 43% of their global volume of litter fall and soil carbon.[11] Tropical forests are not carbon sinks in the balance sheet, and carbon capture and release are in balance because the amount of carbon sequestered by biomass growth is close to that of biomass degradation and deforestation.[12] Comparing the annual carbon emissions of the world's forests to the anthropogenic emissions, forests over the last two decades have bound almost one third of the total anthropogenic emissions of GHG.[13]

European forests absorb an increasing amount of carbon each year from their biomass, 0.43 Pg of CO_2[14] which means almost 10% of the total annual anthropogenic emissions of greenhouse gases of Europe are captured by forests. Finnish and Swedish forests bind annually almost half of the country's anthropogenic emissions. In Finnish forests with average fertility, the CO_2 capture in trees reaches its maximum in about 30-year-old forests at 1.5kg CO_2/m^2 year. The amount of CO_2 entering the frost reaches its maximum in about 50 years old forest, being about 1000 g CO_2/m^2 year and remaining relatively stable or slowly decreasing as the forest age increases. In Estonia, hardwood stands are better studied in terms of carbon stock and carbon sequestration. For example, different age-specific crop habitat type birch forests are carbon-dependent ecosystems, with the annual amount of bound carbon ranging from 3.7-4.9t C per ha. Carbon is predominantly stored in tree biomass.[15] Carbon stock accumulated in mature woods in Estonia amounted to approximately 150 t ha, of which more than 60% was stored in the above-ground biomass of trees. Of course, it must be taken into account that most of harvested forest biomass turns again into the carbon dioxide after short (used as propellant) or longer (construction, wooden products) time.

For example, in 2007 around 3.6 billion m^3 of round wood was harvested from the forests, of which 53% was used as firewood (90% in developing countries). The remaining 47% was used for industrial purposes.[16] The annual supply of industrial round wood contains approximately 424million tons of carbon. Some of it is contained in short-term products, while others are contained in products that survive over decades or even centuries. The global carbon stock of wood products is estimated to grow by 150 million tons per year. This corresponds approximately to 54 million tons of CO_2 sequestration per year from the atmosphere.

Pearland management and GHG emissions

Peat lands cover vast areas in the temperate and cold climate zones of North Eurasia and North America. In the tropics, most peat soil wetlands are found in Indo-Malayan region, equatorial Africa and Amazonia**.** Although the main purpose of mires drainage is to lower the water level to for forest growth or to allow peat production ditching in the surrounding marshland, the carbon loss predominates. Aeration of the peat layer leads to organic carbon release (during decomposition process) and to increased greenhouse gas emissions.[18] increased carbon dioxide emissions are major contributors to drainage of mires that adversely affects the carbon balance. Layer of peat that is constantly or seasonally exposed to air oxygen improves the vertical rainwater movement. The level of water thickens lovers and it facilitates faster mineralization of deposited organic matter and emission of carbon dioxide. However, the fact that drained Pearland are significant source of GHG emission is mostly overlooked. The higher strata of the peat were historically used as a local fuel.

Presently the higher, less decomposed strata are used as a horticultural substrate, but the usage of decomposed peat is essentially ceased (it can be used in balneological practice). In Estonia it is estimated that CO_2 emissions from drained peat lands are 9.6Mt/yr[19] which even exceeds the emissions from the power plants in the country. Partly, this emission is caused by the peat mining, which leads to the loss of water from the upper surface of peat. O oxidation of organic matter in the peat deposits follows, and this in turn, leads to compaction and subsidence of the surface. Drainage of peat rapidly increases the emissions of CO_2 and NO_x. The emission rates depend on the temperature of the peat, the groundwater level and the moisture content.

In Finland, nearly 62% of the peat lands have drained, to enable growth for forestry (5.7million ha) but also for farming. Peat lands under cultivation have thought to contribute around 8% of the human produced CO_2 and 25% of N_2O emissions in Finland. The most important sites to be restored in Finland are considered to be densely wooded nutrient-rich peat lands, including threatened forest species and Pearland with a specific landscape value. In former drained areas, restoration reverts them to an original habitat type. Duration of the drainage affects the length of the reverse process. Restoring could lead to a 'new natural state', being not the same as it was but different from drained peat land. The restoration of water regime could be made using damming or filling in ditches.

The regulations of Pearland restoration in Estonia indicate that the peat layer thickness should be more than 0.5 m. In Estonia, until now, no human initiated restoration projects have been applied on cut-away peat lands. Restoration activities for other purposes lead to rewetting of some managed peat lands. Earlier, the blockings of the outlets of peat pits of old block cuttings were used for collecting the water against fire on nearby ongoing peat harvesting areas. To find adequate management procedures for restoration, spontaneous revegetation has been studied since 1996 on the largest Estonian peat harvesting area (Lavassaare), which covers about 1500ha in West Estonia.[20]

The total CO_2 emission from drained peat lands of Estonia is ranging between 9 and 14Gt/y19. According to Salm, just 0, 2Gt of these emissions are directly related to the peat mining.[21] The same study shows that due to drainage and therefore lowered water level most of the mires have become the sources (versus sinks) of GHG and they have altered their role in global ecosystems. Additional and constant pressure on mires comes from the oil shale mining and processing.[22] However, the main cause for the reduction of mire areas has been drainage for agricultural and forestry purposes. Approximately 70% of Estonian peat lands have been affected by drainage. In these areas,

Citation: Liiv J, Zekker I, Tämm K, et al. Greenhouse gases emissions and climate change - beyond mainstream. *MOJ Biorg Org Chem.* 2020;4(1):11‒16. DOI: 10.15406/mojboc.2020.04.00104

the peat accumulation has ceased and mineralization of organic matter has replaced the carbon accumulation. According to Paal & Leibak,[23] the area of preserved mires is even smaller – based on the field inventories in 2009 and 2010, mires form at least 240,000–245,000 ha or ca 5.5% of Estonian territory, which is 2.6–2.8x less than 60 years ago. On a global level, nearly 30% of soil carbon is held in northern peat lands, [24] stored at an estimate rate of 23g cm^{-2} y–1 25. Peat lands have accumulated 34–46% of the roughly 796Gt of C currently held in the atmosphere as CO_2. [26]

The data used in current study is based on the inventory of Estonian peat lands carried out by the Geological Survey of Estonia.[27] In the peat inventory for all 9836 peat lands with area over 1ha the thickness of the peat layers was determined. Most of the peat lands were fens with a relatively thin (0.9-1.6m) peat layer. 539 peat lands with a thick peat layer and typical genesis were investigated in more detail. Samples were taken for the determination of botanical composition, degree of humification, natural Moisture content, ash content, and pH value of peat. In addition, the vegetation and hydrological conditions of peat lands were described.

GHG emissions in Estonia - official data vs mathematical estimations

GHG emissions from various economic sectors of Estonia in 2017 based on the national inventory report of greenhouse gas emissions[28] are presented in Figure 3.

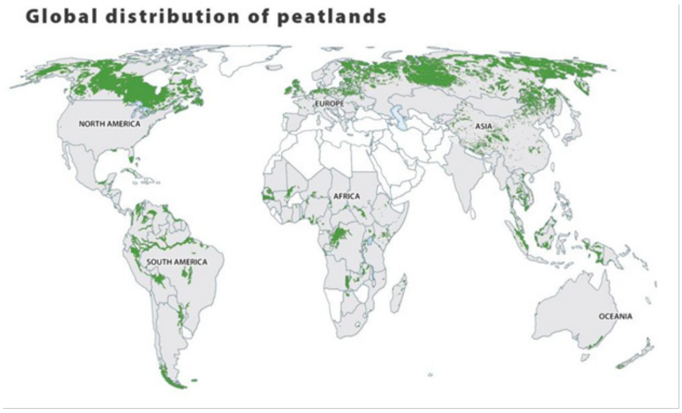

Figure 1 Global distribution of peatlands. Cartography by Levi Westerveld17.

Figure 3 Estonian GHG emissions in 2017 expressed as per cents of total and kilotons (official data).

The emissions are given in kilotons and are expressed as CO_2 equivalents in global warming potential. In 2017, the main GHG in Estonia was carbon dioxide (CO_2), contributing 89.34% to total national GHG emissions (including indirect CO_2), followed by methane (CH_4), 5.13%, and nitrous oxide (N_2O), 4.39%. So-called 'F-gases', fluorocarbons and sulphur hexafluoride (SF_6), contribute approximately 1.14% of the total emissions. The energy sector contributes 88.76% to the total GHG emissions, followed by agriculture (6.61%), industrial processes and product use (3.06%) (Including indirect CO_2) and waste (1.57%).[28] Figure 3 demonstrates the fuel consumption in manufacturing industries and other sectors, such as transport, construction, and also smaller quantity in commercial, institutional and residential activities, agriculture, forestry, fisheries, etc. Nearly ¾ of the primary energy supply is made up of oil shale. The latter consists of 5-25% organic fraction (kerogene); the rest is mineral, mostly carbonaceous fraction. When fired, partial to nearly complete thermal dissociation of $CaCO_3$ takes place, depending on incineration technology. The released CO_2 adds up to the total emission.

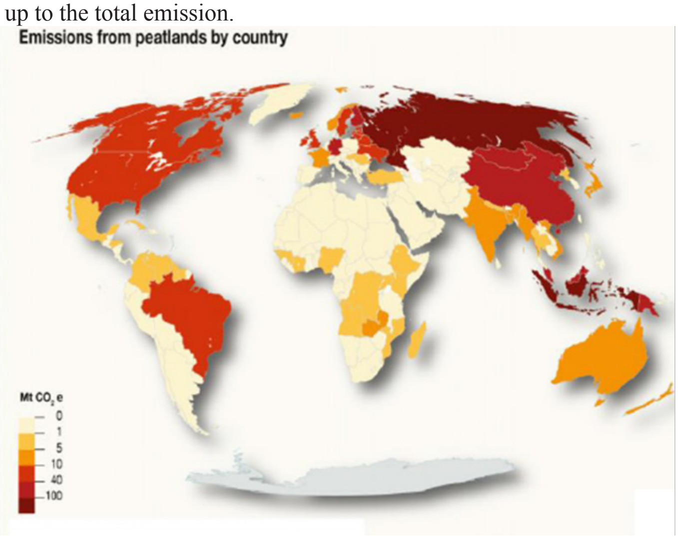

Figure 2 CO2 emissions from peatlands. Cartography by Nieves Lopez Izquierdo17.

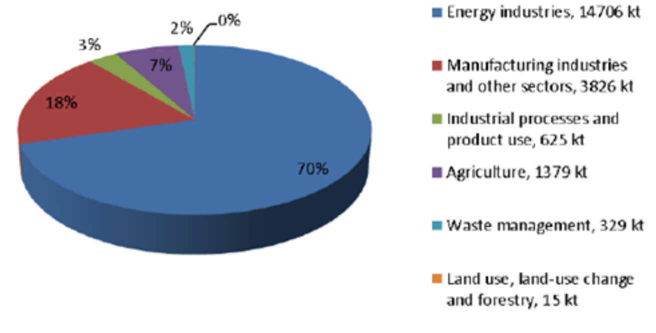

Figure 3 Estonian GHG emissions in 2017 expressed as per cents of total and kilotons (official data).

Emissions from agriculture include CH_4 from enteric fermentation of 16 sub-categories of livestock, CH_4, direct and indirect N_2O emissions from manure management, direct and indirect N_2O emissions from agricultural soils, and release of CO_2 due to soil liming and urea application. Industrial processes and product categories include production of cement, lime, glass and ceramics, use of limestone for flue gas desulphurization, chemical industries, production of rare and rare earth metals and their compounds, production of secondary lead, use of lubricants and paraffin wax, product uses as substitutes for ODS and other product manufacture, etc. Waste sector includes solid waste disposal, biological treatment of solid waste, waste incineration and open burning of waste, wastewater treatment and discharge and biogas flaring.[28]

The national inventory claims that as of 2017, the LULUCF sector acts as a CO_2 sink, which results with a net carbon uptake of about 1792.74 ktCO_2 equivalent., meaning. That total capture from this sector exceeded the total emissions. The national inventory provides

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incomplete statistics on CO$_2$ emissions from LULUCF. For the total sector, only estimated net uptake is given, but no data on actual CO$_2$ emissions. Net emissions are given for CH$_4$ and N$_2$O, 15.2ktCO$_2$ eq, totally. More detailed report is expected to be published in the 2019 annual submission of GHG inventory.

Currently, Estonia does not have country-specific emission factors for soils and litter for most of the land-use categories. As an interim approach, carbon stock change estimates of these pools are based on emission factors from the Sweden National Inventory Report 2018.[29] Estonia has launched several projects aimed at elaborating on country-specific data regarding omitted pools for future submissions (see Chapters 6.2.6, 6.3.6 & 6.4.6 Category-specific planned improvements). Also, studies by Kõlli et al.[30,31] were used for development of new country-specific factors for estimating C stock changes in mineral soils during land-use changes between Forest land, Cropland and Grassland.

The area of different land-use categories in 2017 was the following: forest land 2438.4 kilohectars (kha), cropland 1 031.6, grassland 274.4, unmanaged wetlands 391.3, exploited peat lands 13.3, flooded wetlands 6.2, settlements 342.5, other land 36.228. CO$_2$ annual emissions from the croplands of 1.82-2.62 t Corg/ha (avg. 2.22 t Corg/ha) and CO$_2$ annual uptake by the grasslands of 0.30t C$_{org}$/ha corresponds to 8409kt annual CO2 emissions from the croplands and 302 kt annual CO$_2$ uptake by the grasslands. Resulting in a net emission of 8108 kt CO.[24]

Detailed studies are still required how logging and accompanying disturbances to soil affect the GHG emissions from the forest land. Considering the emissions from drained peat lands, which are currently under forest reaching 9600kt and summary emissions from agricultural lands 9487kt, the GHG emission diagram forms as presented in Figure 4.

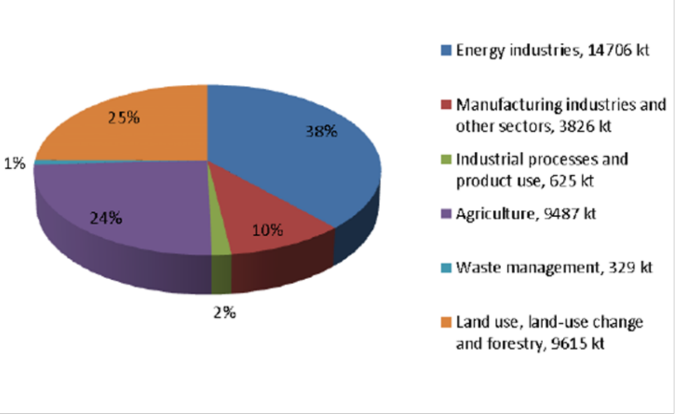

Figure 4 GHG emissions of Estonian (based on described considerations.

As shown in Figure 4, the combined emission from agricultural and LULUCF sectors of year 2017 equals with, or may even exceed, the emissions from all other sectors combined. In 2017 and 2018, the fuel use and power output of oil-shale fired power plants decreased substantially, meaning that agricultural and LULUCF sectors became dominantly of the largest sources of GHG emission in Estonia.

Large infrastructure construction projects, such as planned high-speed railroad Rail Baltica, would increase the emissions even more. The planned route of Rail Baltic largely runs over marshy areas (about 60% of total length.) The project of railway tracks envisages excavation of peat soil, its removal from construction site and backfilling the trench with substitution soil with a higher load-bearing capacity. These excavation and construction works require draining of surrounding area with a perimeter of several kilometers. Thus, the hydrological regime will be spoiled over a vast area of wetlands, and the drained body of peat will be exposed to atmospheric air and subjected to decomposition. This leads to a release of CO$_2$, but also N$_2$O and CH$_4$. Estimate, 50-250 Get of CO$_2$ will be released over the next 50 years with a major share of it within the first 10 years.

Conclusion

Emission from the agriculture and LULUCF may form a far larger part of the GHG emission as indicated by official statistics.. Of course, most of the numbers presented in current review are measurements based mathematical estimations and rather generally tend to reflect the whole situation. Notably, one of the largest sources of GHG emissions of Estonia are drained peat lands. Similar situation may occur in many larger countries, such as South-Eastern Asian or Amazonia, where large forest areas or peat lands are converted into cropland.

Comparable situation is also present in boreal countries like Scandinavia, Russia, Canada and USA, where climate warming has caused melting of permafrost, which causes rapid oxidation of formerly frozen peat deposits and consequently emissions of GHG.

However, no direct actions can be taken to reverse these trends, as the need for additional lands for food production in the situation of continuing world population growth and decrease in fertility of agricultural lands. Certain fractions of the fossil fuel use can be replaced by the nuclear energy as well with the “green” energy in a limited extent, but transferring the transport sector to clean energy sources is not feasible at the current technological level. The climate models are imperfect and there is actually no warranty that the point of “no return” has reached. However, in any case the sustainability of human civilization requires at least two major actions :(i) significant cut in consumption, which renders the current free market model unsustainable and, (ii) abrupt reduction of current world population. For the understandable reasons, neither measure is popular.

Acknowledgements

None.

Conflicts of interest

The authors declare that there is no conflict of interest.

Funding

None.

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Citation: Liiv J, Zekker I, Tämm K, et al. Greenhouse gases emissions and climate change - beyond mainstream. *MOJ Biorg Org Chem.* 2020;4(1):11–16. DOI: 10.15406/mojboc.2020.04.00104

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