Climate change and its effects on agricultural production in Finland – research efforts during the past 50 years

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Climate change has concerned the scientific community since the 1970´s, stimulating research into its impacts, adaptation and mitigation. In 1988 the Intergovernmental Panel on Climate Change (IPCC) was established to coordinate the research. The first scientific publications on the effects of climate change on agriculture and forestry in Finland appeared in the early 1980´s. After the launch of the Finnish Research Program on Climate Change (SILMU) in 1990, the number of climate-related projects and publications, and the input of Finnish researchers in the work of the IPCC started to increase. During the subsequent programs, the initial optimism about future crop production conditions changed into an awareness of the threats represented by climate change. Diversity of production and breeding of heat and flooding tolerant, disease resistant and nutrient-use efficient crop varieties were identified as being crucial for adaptation of agriculture. Efficient water management, measures to limit nutrient leaching and timely control of pests and pathogens are also crucial adaptation measures. Carbon storage in soils and biomass and reduced use of organic fields are suggested to be mitigation measures. By 2019, the awareness of the threats of climate change prompted citizens worldwide to demand action, and government programs have begun to include policies addressing reduction of greenhouse gas emissions.

Key words: carbon dioxide, emissions, greenhouse gases, GHG, IPCC, agriculture

Introduction

Atmospheric gases, including water vapor and CO_2, allow most solar radiation to penetrate the earth's surface and warm it. On the other hand, such so-termed greenhouse gases (GHG) prevent a major part of the thermal long wave radiation emitted by the earth from escaping into the space, thus maintaining suitable temperatures for life in our planet. This property of the atmosphere, the greenhouse effect, was introduced to science by the French mathematician Jean-Baptiste Joseph Fourier almost 200 years ago (Bolin 2007). Later Arrhenius (1896) pointed out that CO_2 plays a crucial role in the greenhouse effect.

The anthropogenic emissions of CO_2 and other GHGs, and their effects on the global climate, became a serious topic of discussion in the 1930s. Callendar (1938) stated that during the 50 years between the 1890s and 1930s there had been 150000 million tons of CO_2 emitted into the atmosphere by burning fossil fuels, and that three quarters of this remained in the atmosphere. He estimated that these emissions increased global temperatures by 0.005 °C annually during the 50 years, with the largest increases taking place in the northern high-latitude areas. Accordingly, he estimated that an atmospheric CO_2 concentration of 400 ppm would result in about 0.7 °C higher temperatures than those in the 1930s, when the CO_2 concentration was about 300 ppm (Fig. 1). What he could not see was the rate of increase in the CO_2 concentrations: he estimated the concentrations to be about 330 ppm in the 21st century and 360 in the 22nd century. In 2019 the CO_2 concentration measured in Mauna Loa Observatory was about 410 ppm (https://scripps.ucsd.edu/programs/keelingcurve/).

The concern of the effects of the increasing atmospheric CO_2 concentration increased gradually in the 1950´s. Initiatives for measuring the GHG concentrations and the anthropogenic impact of their increase, as well as research into the effects of GHGs on the climate, have been taken from the beginning of the 1950's. In 1954, a series of weather stations for monitoring the atmospheric CO_2 concentrations was established in Scandinavia. The average concentration of CO_2 measured at the stations was 329 ppm in 1955, ranging between 319 and 347 ppm (Fonselius et al. 1956). Although the CO_2 concentrations were still low in 1955, their increase was already regarded as a possible problem. Callendar (1958) proposed a direct relationship between the use of fossil fuels and increase in CO_2 concentrations. From a basic average level of 290 ppm in 1900, he reported a 30–40 ppm increase in CO_2 concentrations by 1955. Knowledge of the effects of GHG on climate has increased ever since, but has resulted in concrete mitigation measures only in the 21st century.

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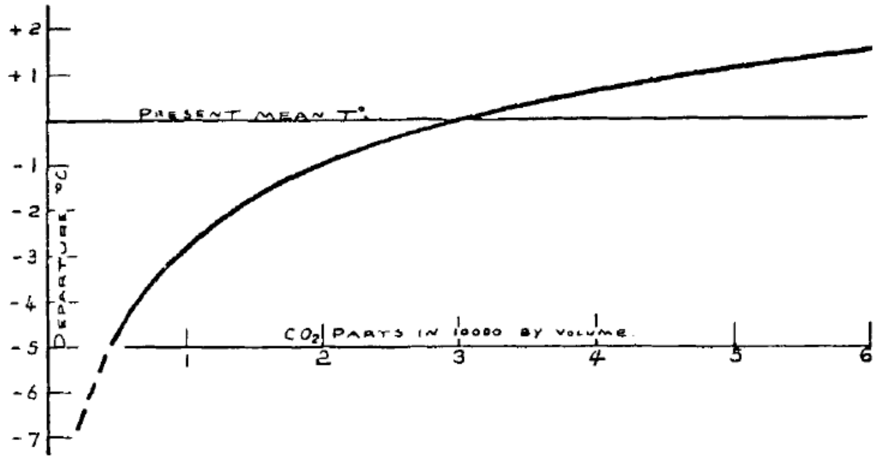

Fig. 1. The effect of atmospheric CO_2 concentrations on global temperatures (Callendar 1938).

This review presents a short history of the research in climate change and launch of the Intergovernmental Panel on Climate Change (IPCC), with special emphasis on the research into the effects of climate change on agricultural production in Finland. The description of the history and current status of the IPCC is based on the IPCC website information (www.ipcc.ch) and on the reviews by Bolin (2007) and Porter et al. (2019). The information on climate change-related research programs in Finland is based on the climate change information website chapter “Adaptation - Research supports climate change adaptation” of the Finnish Meteorological Institute (https://ilmasto-opas.fi/en/) and the websites and reports of the individual programs.

Beginning of climate change science and foundation of the IPCC

Interest in anthropogenic GHG emissions and their role in climate change had been increasing since the 1950’s, with research projects launched and articles published worldwide. At the request of the World Meteorological Organization (WMO) in the early 1970’s, a synthesis report on the knowledge gathered about climate change was compiled and the text approved in 1976 by the WMO executive committee (WMO 1976). At the same time, an effort was initiated to coordinate climate change studies internationally. Dr. William W. Kellogg was asked to prepare a report on “the influence of human activities on climate” (Kellogg 1977). He pointed out that while it is difficult to predict natural changes in climate, it is possible to create scenarios for the course of changes due to anthropogenic influence. This time not only CO_2, but also other GHGs, including nitrous oxides, were taken into account. The best estimate at that time was that the anthropogenic influence on the global temperature would be 1 °C by 2000 and, if emissions of the GHGs were not restricted, about 3 °C by 2050, with a doubling of the atmospheric concentration of CO_2 from the level in 1977. The report warned about the effects of climate change, especially extreme events, on human beings, societies, the economy, and food production, especially regarding increasing world population (Kellogg 1977).

The Kellogg (1977) report called for international co-operation of scientists in research, to share data and information about past climatic changes, their effects on different fields of society, predictions about future effects and recommendations for actions to prevent serious consequences of climate change. In 1988 the coordination of these activities was allocated to IPCC, founded by the United Nations Environment Programme (UNEP) and the WMO. The goal was to “provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts” (https://www.ipcc.ch/reports/ipcc-30th-anniversary/). The work was arranged in three working groups (WGs), the tasks of which were 1) to assess the science (the physical basis) of climate change (WG1), 2) to assess the environmental and socio-economic impacts of climate change (WG2) and 3) to formulate response strategies (mitigation) to climate change (WG3) (Bolin 2007). The First IPCC Assessment Report (AR1) was prepared by WG1 (IPCC 1990a). In the same year reports from the other two WGs were also published (IPCC 1990b, 1990c). The total number of pages of the three AR1 reports was 995, shared quite evenly among the WGs.

The IPCC's work has continued with increasingly elaborate and bulky ARs prepared at about 5–7 year intervals: AR2 in 1996, AR3 in 2001, AR4 in 2007 and AR5 in 2013–2014 (https://www.ipcc.ch/reports/). The total number of pages in the latest report, AR5, was 4102, with 1535 pages in the WG1 report (IPCC 2013), 1132 in the WG2 report (IPCC 2014a) and 1435 in the WG3 report (IPCC 2014b). The sixth assessment report, AR6, is to be published in 2021–2022 (https://www.ipcc.ch/news/). The work for AR6 started soon after the publication of the AR5, with the call for nominations of contributors arranged between September and October 2017. The preparation of AR6 thus began 4–5 years before its planned publication. In addition to the ARs, IPCC produces several other reports and publications. The latest special report, "Global warming of 1.5 °C" (IPCC 2018), received considerable attention and even prompted mitigation actions internationally.

The scientific interest in climate change, its effects and mitigation challenges, has been growing, especially since the establishment of IPCC. The number of scientific publications concerning the issue has grown from year to year, to a level impossible to cover by any individual specialist. Here the IPCC work is especially valuable, as its goal is to gather and interpret periodically all published scientific information about climate change.

The interest in climate change and the resulting research funding and increased availability of reports on the effects of climate change now allow a detailed and flexible basis for estimating the effects of climate change in most areas of society. The increasingly high number of studies and publications has enabled development of complex models that can take into account relationships among different variables (e.g., grid-based regional assessments, yield variability, nutrient status of yields, etc.; Porter et al. 2019). However, reports on the effects of climate change are limited to a restricted number of crop species. In addition, few reports are published on animal husbandry and several limiting factors for crop production, such as weeds, pests and pathogens. This reduces the modeling strength of climate change impacts on food production (Porter et al. 2019). The fact that large areas affected by climate change, yet crucial for food production, are largely unaccounted for, still 30 years since the foundation of IPCC, points to the difficulty of the IPCC to have an impact on research in climate change in acting as a global coordinating, but not financing organization. While reporting quite efficiently the published research (in English), IPCC lacks the means to guide governments in concerted actions to investigate all aspects of climate change.

The input of expert and government reviews of the ARs is crucial in forming a balanced overview of the status of climate change, its impacts and mitigation options. It is highly recommendable that the lead authors of the ARs take into account the input of the reviewers, also when the reviewers disagree with the authors. The reviewers may have access to sources of information on currently inadequately reported issues, such as animal husbandry or crop growth limitations.

Climate change-induced crop production research in Finland

Studies on the impacts of climate change on agriculture and forestry started to appear in Finnish scientific literature in the early 1980's. One of the first researchers to evaluate the impacts was Pekka Kauppi from the University of Helsinki (Kauppi 1982, Kauppi and Posch 1985, Kauppi 1989). In late 1970's and 1980's, professor Jaakko Mukula and researcher Olli Rantanen of MTTK (Agricultural Research Centre, then Agrifood Research Finland, MTT, since 2015 Natural Resources Institute Finland, Luke) published a series of articles about the connections between crop production and climate in Finland, with some references to impacts of climate change (Mukula et al. 1978, Mukula and Rantanen 1987, 1989a-e). In 1988, a book about the effects of climate change on global agriculture and forestry was published by Parry et al. (1988). Chapter IV (The Effects of Climatic Variations on Agriculture in Finland) summarized knowledge about the possible effects of climate change (climate warming and increased CO_2 concentrations) on agricultural production and effects on its profitability in Finland. The authors of the chapter were Lauri Kettunen, Jaakko Mukula, Veli Pohjonen, Olli Rantanen and Uuno Varjo. The authors, together with one of the editors of the book, Tim Carter, laid the foundation for later studies about the effects of climate and climate change on agricultural production in Finland. Professor Timo Mela from MTT took the lead in this research in the early 1990's as a part of the large SILMU program of the Academy of Finland.

The first climate change program in Finland, SILMU

The Finnish Research Program on Climate Change, SILMU (1990–1995) (https://www.aka.fi/globalassets/awanhat/documents/tiedostot/asiakirjat/silmu.pdf) was the first serious and well-financed program concentrating on climate change in Finland. The goals of SILMU were to increase knowledge about climate change in general, strengthen research, promote international contacts of Finnish researchers in the field and disseminate information about climate change in Finland. The total funding was 87 million marks (about 14.5 million euros).

The funding was divided into five thematic groups: Atmosphere, Waters, Terrestrial ecosystems (forestry, agriculture), Human dimensions and Integration. The key research areas were 1) quantification of the greenhouse effect and climate change, 2) assessing the effects of climate change on terrestrial and aquatic ecosystems and 3) developing strategies for mitigation of climate change. About two hundred scientists from seven Finnish universities and eleven research institutions took part in the program. The effects of climate change on agriculture were studied in MTT and the University of Helsinki. Scientific experiments with agricultural and horticultural crops were performed in laboratories, growth chambers and open top chambers (OTC). The OTCs were installed in Jokioinen (southern Finland) and Rovaniemi (Lapland). The crops were sown directly in the field soil. The experimental fields were covered with plastic structures to allow simulations for ambient conditions, ambient temperatures with increased CO_2 and elevated temperatures with or without increased CO_2 (Hakala et al. 1996) (Fig. 2). The results of the work were disseminated in popular newspaper articles, seminars and scientific articles. Experiments were also used for validating models aimed at predicting the effects of climate change on crop production in the future (Carter et al. 1996, Kaukoranta 1996, Kleemola and Karvonen 1996, Laurila 1995, 2001).

a)

b)

Fig. 2. a) OTCs in an automatic climate simulation system in MTT Jokioinen in 1993, b) OTCs were placed over fields with canopies of wheat and meadow fescue. Photos: Jari Poikulainen

At the beginning of the SILMU program, the expectations for the future regarding climate change were still quite optimistic. Yields of all crops were expected to increase as a result of higher temperature sums, longer growing seasons and increased CO_2 concentrations. The SILMU experiments confirmed some of the expectations, but cast doubt on the overly positive expectation of significant increases in yields of cereal crops (Kimball 1983, Hakala and Mela 1996, Hakala 1998). According to the climate and growth models, the introduction of new crops such as maize (*Zea mays* L.) and more productive varieties of the current crops would gradually be possible in Finland,resulting in better yields and higher farmer income. However, risks and income losses caused by variations in climate and increased pressure by pests and pathogens were noted as possible threats already then (Carter et al. 1996, Kaukoranta 1996, Kettunen 1996). At present, threats by climate change are increasingly emphasized in the published literature (e.g., Hakala et al. 2011, Peltonen-Sainio et al. 2016).

FIGARE and FINADAPT, programs for mitigation of and adaptation to climate change

Knowing the reasons for and the effects of climate change, the need arose to find ways to adapt to the inevitable changes and mitigate the climate change as much as possible. The first research program in Finland charged with these goals was FIGARE (Academy of Finland, 1999–2002), with 36 research projects arranged in 18 consortia (Kuusisto and Käyhkö 2004). FIGARE tackled a wide variety of climate change related subjects, including carbon cycling in boreal lakes, global policies and energy markets, carbon storage in forest soils, land use change in Central America, effects of solar UV-B radiation, and the effects of global change on tropical, subarctic and arctic ecosystems (Kuusisto and Käyhkö 2004). The consortium working with agricultural questions was AGROGAS (Agricultural soils as sinks and sources for greenhouse gases in Finland). The five projects of AGROGAS were set to evaluate the GHG emissions from different agricultural soils under various crops and find ways to lower them, thus mitigating climate change. It was found that the emissions of N_2O, an important GHG, were significantly higher from peat soils than from mineral soils, and that high soil humidity increased the emissions (Regina et al. 2004). The emissions were higher in southern than in northern Finland because there were no wintertime thaw periods in the north. In the south, the emissions were highest during winter and spring thaw periods, especially at temperatures around zero. Emissions of CO_2 were also higher on peat soils than on mineral soils (Lohila et al. 2003). The data provided by AGROGAS could be used to fine-tune the IPCC calculations of GHG emissions from the soil. A major finding was the role of organic soils as major GHG emitters. This finding could be used by the decision-makers when developing guidelines and subsidy policies concerning land use in Finland.

Half of the seven million euro funding of FIGARE was covered by the Academy of Finland, and the rest by different smaller financers, including five ministries and the innovation financing institute TEKES (now Business Finland, https://www.businessfinland.fi/en). The universities and institutes discharged their responsibility as providers of research platforms and qualified personnel for the research. Nevertheless, the program received just about half of the financing of the first climate change program SILMU. Although FIGARE was in many ways successful, cuts in funding were partly responsible for it not fulfilling all the tasks well enough. The most serious problems were lack of inter- and intra -project collaboration and inefficient dissemination of results (Figare 2003).

The research continued in the FINADAPT program (2004–2005), financed by the Ministries of the Environment, Agriculture and Forestry, Transport and Communications, as well as TEKES and several universities and research institutions (Carter and Kankaanpää 2007). The program concentrated on finding ways to adapt different fields of society to climate change. In co-operation with 11 research institutions, FINADAPT published a series of 15 working papers on agriculture, forestry, water resources, biodiversity of natural environment, traffic, human health, built environment, energy infrastructure, tourism and urban planning (Annex). Researchers of MTT and the Finnish Environment Institute (SYKE) prepared the working paper on adaptation to climate change in agriculture (Hildén et al. 2005). The paper points out that the effects of climate change on agricultural production in Finland have to be considered in connection with changes in domestic and global economy. The increase in yields attributable to climate change may lead to little net advantage for the Finnish agriculture, unless the market for Finnish products grows. Major changes in, for example, Asian food consumption could increase demand and product prices to a level where their export becomes profitable. To cope with climate change in the future, special attention and support should be given to adaptation measures that are not spontaneous: water and nutrient management, investment in infrastructure and technology, focused long-term breeding, monitoring systems of pests and pathogens, cropping system diversity and agricultural policies (Hildén et al. 2005).

The largest benefit brought about by FINADAPT was the bringing together researchers involved in climate change research. On the basis of the work and researchers in SILMU, FIGARE and FINADAPT, the Ministry of Agriculture and Forestry of Finland published the first in EU National Adaptation Strategy to climate change (MMM 2005, Biesbroek et al. 2010).

ISTO program to implement climate change strategy

To implement the National Adaptation Strategy, a new large five year research program ISTO (National Climate Change Adaptation Program) was launched in 2006. ISTO was mainly financed by the Ministry of Agriculture and Forestry, Ministry of Environment, Foreign Office and Ministry of Transport and Communications. With its 30 research projects, ISTO tackled the most challenging effects of climate change, such as extreme events, and offered concrete measures to adapt to them in agriculture, forestry, fishery and the built environment. Also biodiversity and social effects were treated within the projects (http://www.finessi.info/ISTO/?lang=en&page=overview). The scientific activity around the ISTO program promoted publishing of an array of scientific reports, domestic adaptation plans and guidelines for adaptation and mitigation measures. The majority of the scientific articles concerning climate change effects on agriculture in Finland were published by the research projects ILMASOPU (Adaptation of Finnish agro-food sector to climate change) led by Pirjo Peltonen-Sainio, ADACAPA (Enhancement of adaptive capacity of Finnish agricultural and food sector) led by Helena Kahiluoto and TUPOLEV (Alien pest species in agriculture and horticulture in Finland) led by Terho Hyvönen. An attempt to integrate the findings of ISTO into straightforward instructions for different stakeholders was taken in the final report of the program (Ruuhela 2012). Agriculture was addressed in the report by Hakala et al. (2012a).

The results of different agriculture-related projects in ISTO pointed to the need to prepare Finnish agriculture for new opportunities for production (ILMASOPU: Peltonen-Sainio et al. 2009a, 2009b, 2011a, 2011b, 2016), but also for new pests, pathogens and weeds (TUPOLEV: Latvala-Kilby et al. 2009, Lehtinen et al. 2009, Hakala et al. 2011, Hannukkala 2011, Heikkilä 2011, Hyvönen 2011, Hyvönen and Jalli 2011, Hyvönen et al. 2011, Jalli et al. 2011, Lemmetty et al. 2011, Lilja et al. 2011, Vänninen et al. 2011, Hyvönen et al. 2012, Hyvönen and Ramula 2014). A need for a new level of resilience of farms, crops and cropping systems to meet the increasing frequency of extreme events, such as long periods of hot weather or heavy rains, was identified (ADACAPA: Hakala et al. 2012b, Kahiluoto et al. 2014, Trnka et al. 2014). Breeding of disease resistant and flooding and heat tolerant varieties of crops, monitoring and predicting invasions of pests and pathogens and developing farm buildings and technology for the future conditions were identified as measures to adapt to climate change (Hakala et al. 2012a). With higher temperatures, animal welfare could be threatened, and also new animal diseases could enter Finland. The changes require measures to improve the hygiene of both production and storage of the products (Hakala et al. 2012a). While climate change would in general improve the crop production conditions, diversity of production was identified as a crucial measure to maintain high production potential and increase resilience of the systems (Hakala et al. 2012b, Himanen et al. 2013a, 2013b, Kahiluoto et al. 2014).

Life after ISTO

After and during ISTO, the VACCIA project of the EU Life program (2009–2011) was set to estimate the vulnerability of ecosystem services and livelihoods in changing climate (https://www.syke.fi/projects/vaccia). Contributors were SYKE, the Finnish Meteorological Institute and the universities of Helsinki, Jyväskylä and Oulu. Agriculture was addressed in co-operation with MTT. VACCIA focused not only in the growth of future crop production potential, but also on its possible drawbacks caused by the extreme events and failure of overwintering of the winter crops in the milder and more variable winter conditions. The environmental risks represented by future conditions, especially increasing risk of nutrient leaching, were treated extensively within the project. Higher crop and management diversity and better planning of crop rotations and land use were suggested as the main adaptation measures to cope with climate change (Rankinen et al. 2013).

The next extensive research program FICCA (2011–2014) of the Finnish Academy was launched to support multidisciplinary research on the risks and vulnerability of societies, agriculture and natural environments in the changing climate (https://www.aka.fi/en/research-and-science-policy/academy-programmes/completed-programmes/ficca/). The project concerning agriculture, A-LA-CARTE (Assessing limits of adaptation to climate change and opportunities for resilience to be enhanced) was led by Tim Carter (SYKE). Researchers from SYKE, MTT and the universities of Helsinki, Jyväskylä and Eastern Finland took part in the research. The goals of the project were to assess the sensitivity and adaptive capacity of the sector, and to assess the likely impacts of climate change and the resilience of the system to the impacts. The project identified the need to increase the diversity of crops and/or their cultivars and to breed new, more tolerant cultivars of crops to increase the resilience of the system. In the worst case, cereal yields would decrease despite the measures taken. Change of cereal crops, for example, into more suitable grass crops was identified as a measure to cope with extreme climate change.

The work of the Finnish climate change research programs has initiated a flow of high-profile, frequently referenced scientific articles, mostly in co-operation with international researchers (e.g., Olesen et al. 2011, Rötter et al. 2011, Saikkonen et al. 2012, Asseng et al. 2013, Trnka et al. 2014, Kahiluoto et al. 2019). The active publishing of Finnish researchers in high quality journals and the participation of Finnish researchers in preparing and reviewing the IPCC reports (e.g., Tim Carter as an author in most IPCC ARs and Kaija Hakala as a reviewer in AR3 and AR4 and as a review editor in AR5, WG 2) have contributed to the understanding of climate change as a phenomenon and increased the awareness of its effects and the possibilities of its mitigation and adaptation. At present, climate change is a vital part of discussions in most topics concerning agriculture, forestry, fisheries, building, transport, as well as society and environment in general. For example, in the ongoing EU Rural Development Program 2014–2020 (https://ec.europa.eu/agriculture/rural-development-2014-2020_en), adaptation to and mitigation of climate change are among the main topics. The support of the program for climate change related advisory activities has generated abundant activity in the form of information transfer projects directed to farmers in Finland (e.g., ilmase.fi).

Concluding remarks

Large research programs such as SILMU are becoming increasingly rare in Finland. On the other hand, the smaller individual projects may cover a larger number of topics and perhaps involve researchers and stakeholders from more diverse fields of the society. Heated discussions are ongoing in science and among different interest groups about the role of nutrition, bioenergy, organic farming and carbon sequestration in the soils and forests in mitigation of climate change (e.g., Lal 2004, Tuomisto et al. 2012, Hakala et al. 2016, Minasny et al. 2017, Parodi et al. 2018). Climate change has become a matter of common knowledge. Even in the Finnish parliament elections in 2019, and the following EU parliament elections the same year, the leaders of different parties from left to right agreed on the severity of climate change and the need to take actions to mitigate it. A special wake-up call was the alarming report of the IPCC about the need for imminent actions to avoid the serious consequences if the global temperature rise exceeded 1.5 °C (IPCC 2018).

At the same time, GHG emissions have been decreasing in Europe, being 23.6% lower in EU and 21.4% lower in Finland in 2017 compared with the baseline emissions in 1990 (https://www.eea.europa.eu/publications/approximated-eu-ghg-inventory-proxy) (Fig. 3). Thus the EU is reaching the goals set in the Kyoto agreement in 1997 (https://en.wikipedia.org/wiki/Kyoto_Protocol). This is good news, but emissions should decrease worldwide to mitigate the effects of the changing climate. The global GHG emissions, having increased substantially until 2012, have lately leveled off (Janssens-Maenhout et al. 2017). China was the leading country in the increase of GHG, and it has had a major role also in the leveling off of the emissions since 2012. This has probably been due to increased energy efficiency and use of nuclear and renewable energy in place of coal in China (Janssens-Maenhout et al. 2017). Finland should not give up its mitigating efforts yet, as the per capita emissions in Finland are still higher than in China and most EU countries, and at the same level as in Russia. However, the ambitious goals of the new government in Finland for the election period 2019–2023 may elevate Finland to the first row of GHG emission reducers.

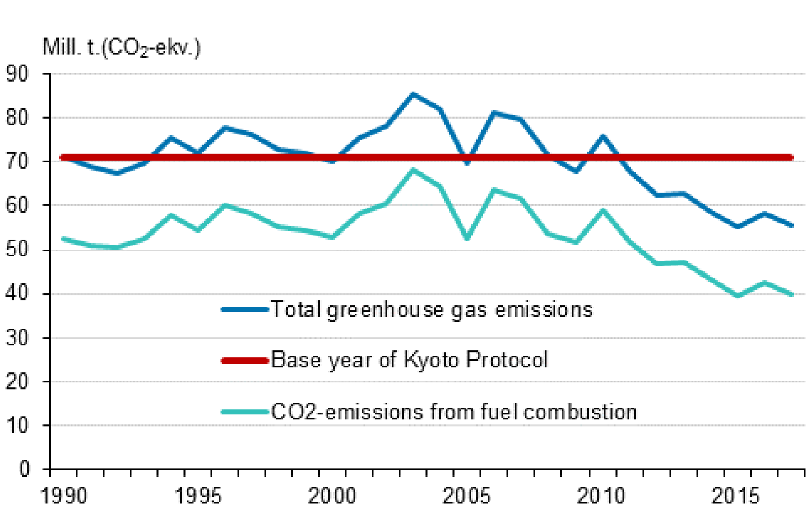

Fig. 3. Development of Finnish GHG emissions (Statistics Finland 2018)

What next?

Throughout history, the scientific community has been responsible for many developments leading to improvements in the living conditions of people. Unexpected, unpleasant and even threatening side effects have often followed. When confronted with problems, science has shown its capacity to initiate corrective measures. In the future we can still trust in improvements brought about by science, but the responsibility for accepting and taking into use the new developments rests on the shoulders of every citizen of the world. With all the abundant knowledge gathered there is no excuse to continue destructive life styles that rob the future from the generations to come.

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