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Review of the implementation of the 2020–2021 workplan: policy

Draft guidance document on reduction of emissions from agricultural residue burning*

Summary

The draft guidance document on reduction of emissions from agricultural residue burning was prepared by the Task Force on Techno-economic Issues in cooperation with the International Cryosphere Climate Initiative and the Task Force on Reactive Nitrogen in accordance with item 2.2.2 of the 2020–2021 workplan for the implementation of the Convention (ECE/EB.AIR/144/Add.2). The document aims to support Parties in reducing emissions of air pollutants, including those that are also short-lived climate pollutants, from agricultural residue burning, thus reducing their negative effects on human health, environment and economy.

The Working Group on Strategies and Review discussed the document at its fifty-ninth session (Geneva, 18–21 May 2021) and forwarded it as revised during the session to the Executive Body for consideration at its forty-first session. The Executive Body is invited to adopt the document.

* The present document is being issued without formal editing.

I. Introduction

1. The Executive Body of the Convention on Long-range Transboundary Air Pollution adopted the 2020–2021 workplan for the implementation of the Convention (ECE/EB.AIR/144/Add.2) at its thirty-ninth session (Geneva, 9–13 December 2019). Under item 2.2.2 of the workplan, the Task Force on Techno-economic Issues, as leading body, was tasked with developing a guidance document on reduction of emissions from agricultural residue burning, in collaboration with the Task Force on Reactive Nitrogen. At the special technical session on agricultural opening burning (Ottawa, 24 October 2019), held back-to-back with the fifth annual meeting of the Task Force on Techno-economic Issues (Ottawa, 22–24 October 2019), experts discussed, among other things, definitions and best practices related to agricultural residue burning, and agreed that a draft document be prepared by the International Cryosphere Climate Initiative.

2. The current document contains a draft report on best available techniques and practices as revised and forwarded to the Executive Body by the Working Group on Strategies and Review at its fifty-ninth session (Geneva, 18–21 May 2021). The main objective of the document is to support Parties in reducing their emissions of air pollutants and short-lived climate pollutants (in particular, black carbon) – drivers of climate change emitted as a result of agriculture residue burning, defined as all use of fire in agriculture as practised throughout the United Nations Economic Commission for Europe (ECE) region on cultivated lands – and their negative impact on human health and environment. The document does not include in its scope wildland management fires, but comments in brief on best available practices (BAPs) and best available techniques (BATs) in connection with the necessary use of fire in both cultivated and wildland types. The guidance document includes descriptions of monitoring and characterization of agricultural residue burning and its emissions and practices and techniques to limit such emissions.

II. Subject matter and scope

3. The purpose of this document is to provide the deliverable related to item 2.2.2. in the 2020–2021 workplan for the implementation of the Convention, consisting of the present guidance document on reduction of emissions from agricultural residue burning (ARB). The document will focus on the following issues:

(a) Environmental and economic impacts of ARB;

(b) Best available techniques and practices to reduce emissions from ARB. This primarily focuses on fire-free alternatives as these comprise BATs and BAPs, especially in a warmer and more drought-prone climate where wildfire spread, greater erosion and higher water needs occur in conjunction with fire use. However, it also touches upon circumstances where fire use may prove unavoidable, and BATs and BAPs in connection with such use, primarily on cultivated lands;

(c) Additional policy measures that can contribute to the reduction of emissions from ARB, such as subsidies for fire-free practices and loan support for alternative techniques including equipment (see subsection V.C below). Subsection IV.E also provides a brief survey of existing policy and regulatory measures that may contribute to adoption of BATs and BAPs to reduce ARB, as successfully deployed in some ECE countries.

4. The present document also responds to the need to inform Parties to the Convention and other stakeholders, including those outside the ECE region, about the available best practices and techniques for reducing ARB, as appropriate measures also for adaptation to a warmer climate with greater weather extremes that threaten agriculture especially.

III. Definitions

5. The following definitions apply:

(a) "Agriculture residue burning" is defined as all intentional burning in the agroforestry sector, including stubble and pastureland burning and use of fire to clear fallow lands, clearing of understory and forest harvest residue; whether in-situ or pile burning (off-site or ex-situ); and the wildfires that spread from such set intentional burning in the agroforestry sector. It excludes only prescribed burns on wildlands for the prevention of wildfire, or to restore fire-dependent ecosystems; or burning ex situ as an energy source (for example, pellets for district heating);

(b) "Biomass" refers to the biodegradable fraction of products, waste and residues of biological origin from agriculture (including vegetal and animal substances), forestry and related industries;

(c) "Conservation agriculture" or "no-till agriculture" refers to a set of practices that involve no tilling (ploughing) of the soil, in concert with other practices, such as use of cover crops;

(d) "Low-till agriculture" involves minimal tilling of the soil (ploughing only the very top layer);

(e) "Conventional tillage" involves the use of multiple instruments – ploughs, seeders, rotors, etc. – that deeply work the soil;

(f) "Fallow lands" denote fields once used for agriculture that have been abandoned with various levels of incursion from vegetation and succession;

(g) "Wildlands" refer to forests and grasslands that have never been used for agriculture, or restored to a natural or wild state from previous agricultural use;

(h) "Prescribed burns", as used in the present document, refers only to use of fires in wildlands or to prevent spread of wildfires;

(i) "Managed burns", as used in the present document, refers to permitted use of fire on agricultural lands;

(j) "Pile burns" refer to the practice of gathering residue off-site (normally along the edges of fields) in order to burn in a more controlled fashion. Such piles are also used to gather residue for alternate use (fodder, conversion to pellets, etc.);

(k) "Bioenergy" involves use of biomass and other biological material (manure) for production of energy, including fuels such as pellets, biogas and ethanol;

(l) "Wildfires" are fires that either spread unintentionally from human activity, or from factors such as lightning strikes (primarily in high altitude or high latitude boreal regions) or spontaneous combustion under extremely dry conditions. Estimates show that up to 85 per cent of wildfires spread primarily from practices like ARB[1], especially when near forests; but human causes also include trash fires, sparks from electrical transmission lines or human actions such as hot items thrown from highways vehicles or trains.

IV. Impacts, existing policy and regulatory measures

A. General background

6. Use of fire in agriculture is a practice with deep historical roots. Farmers burn for a variety of reasons, and rarely simply as a tradition. For example, the practice is used: to cheaply remove excess straw that might otherwise snare or break ploughs; to remove insect pests and weeds; especially in forestry, to remove understory or forest harvest residues; or

[1] Jennifer K. Balch and others, "Human-started wildfires expand the fire niche across the United States", Proceedings of the National Academy of Sciences of the United States of America, vol. 114, No. 11, pp. 2946–2951.

due to the mistaken perception that burning “fertilizes” the soil with ash.[2] In subsequent sections, it will become clear that, to effectively reduce emissions from ARB, BATs and BAPs should address these underlying reasons for burning by providing effective alternatives to fire use.

7. Whatever the reasons for ARB, use of fire carries many negative near- and long-term economic and environmental impacts. ARB exacerbates the impacts of tillage and erosion by making the soil more brittle due to loss of organic matter both on and below the soil surface. Such bare and brittle soil structure is prone to wind and water erosion, losing organic matter to burning in the surface horizon, which is the richest layer. Not only stubble or grass burns, in other words, the organic matter (or humus) in the soil is also lost. ARB also results in significant loss of nutrients, especially nitrogen (N)[3] and phosphorus (P). Use of fire in agricultural and forest management systems is also a cause of net loss of carbon due to loss of soil organic matter, and also results in large burst emissions of carbon dioxide (CO_2), methane (CH_4), and other greenhouse gases such as nitrous oxide (N_2O) into the atmosphere, particularly when ARB results in wildfire spread. Loss of soil organic matter due to its combustion carries other consequences, such as reduction in soil infiltration rates and other tangible economic impacts to the farmer. In addition, a quarter of all living organisms exist in the upper soil levels affected by ARB[4], so global biodiversity is also impacted.

8. This “burned off” loss of fertility should be countered by greater use of expensive fertilizer (25–35 per cent)[5] to maintain crop yields, accompanied by the greater erosion and soil run-off caused by the more brittle burned soil structure as outlined above. Additional environmental impacts of ARB therefore include degradation of local water systems from added fertilizer and soil incursion, and greater need for water resources for irrigation, at a time when such resources are already under stress from climate change and glacial loss. Additional use of fertilizers also implies additional emissions of air pollutants such as ammonia (NH_3), causing secondary particle formation.[6] These negative environmental impacts are accompanied by negative direct human health impacts from air pollutant emissions and smoke, which in some cases can be extreme (such as Moscow, 2010;[7] New Delhi, 2017 and 2019)[8].

9. In contrast, fire-free methods not only eliminate emissions of particulate matter ($PM_{2.5}$), volatile organic compounds (VOCs), black carbon (BC) and greenhouse gases (GHGs), but also provide some level of adaptation and resilience to climate change and extreme weather events. This is particularly the case for low-till and especially, no-till methods, especially when combined with the use of cover crops and injected manure (a suite of agricultural methods termed “conservation agriculture”). Other methods also aid sustainable development, for example use of straw stubble for bioenergy or cook stove fuel to preserve forest resources.

[2] Pam Pearson and others, “Fire in the Fields: Moving Beyond the Damage of Open Agricultural Burning on Communities, Soil and the Cryosphere. A CCAC Project Summary Report: Impacts and Reduction of Open Burning in the Andes, Himalayas – and Globally” (2015).

[3] John Heard, Curtis Cavers and Greg Adrian, “The nutrient loss with straw removal or burning in Manitoba”. Available at www.umanitoba.ca/faculties/afs/MAC_proceedings/2001/pdf/heard2.pdf.

[4] E.M. Bach and D.H. Wall, "Trends in Global Biodiversity: Soil Biota and Processes." Encyclopedia of the Anthropocene (2018), pp. 125-130.

[5] Alison J. Eagle and others, “Nitrogen dynamics and fertilizer use efficiency in rice following straw incorporation and winter flooding”, *Agronomy Journal*, vol. 93, No. 6 (November 2001), pp. 1346–1354; Alison J. Eagle and others, “Rice yield and nitrogen utilization efficiency under alternative straw management practices”, *Agronomy Journal*, vol. 92, No. 6 (November 2000), pp. 1096–1103.

[6] Elias Giannakis and others, “Costs and benefits of agricultural ammonia emission abatement options for compliance with European air quality regulations”, *Environmental Sciences Europe*, vol. 31, art. No. 93 (2019).

[7] Boris Porfiriev, “Evaluation of human losses from disasters: The case of the 2010 heat waves and forest fires in Russia”, *International Journal of Disaster Risk Reduction*, vol. 7 (March 2014), pp. 91–99.

[8] Santosh H. Kulkarni and others, “How much does large-scale crop residue burning affect the air quality in Delhi?”, *Environmental Science and Technology*, vol. 54, No. 8 (April 2020), pp. 4790–4799.

10. The negative impacts of ARB, especially crop yield loss and increased fertilizer costs, translate into decreased income for farmers. Once demonstrated, this impact on profits eventually drives demand for alternatives. In many regions of Latin America with large agri-businesses – Argentina, Brazil, eastern Bolivia – this transition to no-burn methods has already occurred entirely for economic reasons.[9] In Western Europe and North America, human health impacts (including traffic accidents caused by smoke from ARB), together with regulatory measures and incentives, have driven this transition more quickly. With accession to the European Union, Poland and the Baltic States decreased burning by 90 per cent in just five years, showing that a transition to no-burn methods can occur rapidly with such supports (a combination of phasing in increasingly-strict European Union regulations, with farmer subsidies to ease the transition) and documented by a 2006 fire mapping study.[10] However, in a number of countries throughout the ECE region, including those in the European Union and North America, farmers still make use of open burning for a variety of purposes. In a warming climate, such use of fire has led to extensive wildfires, especially in Southern Europe[11] and Siberia (Russian Federation),[12] in recent years.

B. Human health impact

11. Recently, authorities have begun focusing on more long-term health impacts, either from a single fire event or a single fire season, especially among children, in populations subject to long-range transport, as well as economic health impacts from fires. A 2019 retrospective study in Canada recently estimated annual premature mortalities ranging from 54–240 attributable to short-term exposure, and 570–2,500 premature mortalities attributable to long-term exposure, as well as many non-fatal cardio-respiratory health outcomes. The annual economic value of population health impacts in Canada from fires was estimated at $410 million–$1.8 billion for acute health impacts; and $4.3 billion–$19 billion for chronic health impacts for the 5-year study period.[13]

12. Much of this research interest is due to more frequent single wildfire exposure events, as well as more long-term wildfire and related smoke conditions in a drier and warmer climate. For example, emergency room visits for respiratory distress in one community in Montana (United States of America), more than doubled in 2017 compared to 2016 after an extended summer smoke exposure event, with highest admissions beginning a month after the event, in addition to earlier studies showing such higher numbers of visits only during or soon after the actual fire.[14] It is possible that the effects of a single exposure incident may be long-term, with the very young (<4 years), the elderly and those with existing respiratory conditions most seriously affected. Consistent evidence from a review of more than 50 peer-reviewed articles from Asia, Australia, Europe and North America shows that smoke

[9] R. Peiretti and J. Dumanski, “The transformation of agriculture in Argentina through soil conservation, *International Soil and Water Conservation Research*, vol. 2, No. 1 (March 2014), pp. 14–20.

[10] Ashley Pettus, “Agricultural fires and Arctic climate change: A special CATF report” (Clean Air Task Force, 2009).

[11] Bruno Marcos and others, “Improving the detection of wildfire disturbances in space and time based on indicators extracted from MODIS data: a case study in northern Portugal”, *International Journal of Applied Earth Observation and Geoinformation*, vol. 78 (June 2019), pp. 77–85.

[12] Elena A. Kukavskaya and others, “The impact of increasing fire frequency on forest transformations in southern Siberia”, *Forest Ecology and Management*, vol. 382 (December 2016), pp. 225–235.

[13] Carlyn J. Matz and others, “Health impact analysis of PM2.5 from wildfire smoke in Canada (2013–2015, 2017–2018)”, *Science of the Total Environment*, vol. 725 (July 2020).

[14] Justine A. Hutchinson and others, “The San Diego 2007 wildfires and Medi-Cal emergency department presentations, inpatient hospitalizations, and outpatient visits: An observational study of smoke exposure periods and a bidirectional case-crossover analysis”, *PLoS Medicine*, vol. 15, No. 7 (July 2018); and Sarah B. Henderson and others, “Three measures of forest fire smoke exposure and their associations with respiratory and cardiovascular health outcomes in a population-based cohort”, *Environmental Health Perspectives*, vol. 119, No. (9) (September 2011), pp. 1266–1271.

exposure from biomass burning is associated with respiratory morbidity in general, with specific exacerbations of asthma and chronic obstructive pulmonary disease.[15]

C. Climate impacts

13. Climate impacts from ARB arise from both CO_2 and other GHG emissions, and those of so-called short-lived climate pollutants (SLCPs). SLCPs in this context refer primarily to the three pollutants CH_4, BC and ground-level ozone (which is not emitted directly but arises from interactions between sunlight and other emitted pollutants (precursors), especially VOC, including CH_4, CO and NOx). SLCPs remain in the atmosphere for a few days to several weeks (BC and tropospheric ozone), and up to 12 years (CH_4). This means their abatement can have an almost immediate positive impact on climate and temperature.

14. BC is an especially potent warming agent when it wafts over or especially, deposits directly on, ice and snow, and has been associated with greater rates of snowpack and glacier loss. While emissions from fires not close to the cryosphere (snowy and icy regions such as the Arctic, the Alps or the Rocky Mountains) or other highly reflective surfaces might be cooling in the short-term due to co-emitted substances such as light organic carbon or sulphates, close to the cryosphere all fires warm regionally due to this albedo feedback; and GHG emissions from fires are of course warming under all conditions. ARB and wildfires (including non-anthropogenic) comprise the single largest source of BC emissions globally, at over one-third of the annual total (approximately 2,700 Gg, or 36 per cent).[16]

15. In terms of CO_2 emissions, ARB was long considered essentially “carbon neutral”, because it was assumed the same amount of carbon lost to fire would be fixed by the subsequent year’s crop. As understanding of soil carbon cycles has grown however, it has become clear to the vast majority of researchers that, due to loss of humus, soil structure and the soil itself[17], more carbon is lost from the soil annually than can be replaced by any subsequent crop. The amount of carbon lost varies between soils and cropping systems; but of note, the heavily burned and cultivated soils of Punjab, India, today are essentially devoid of carbon. This is a very active current area of research, also in terms of the degree to which changes in cropping systems might serve as future carbon sinks in more modern, no-burn cropping and forestry systems.

16. With ARB no longer seen as carbon neutral, these emissions from open agricultural burning have the potential to eclipse current national GHG emissions estimates. Historically, most countries either have not included, or have underestimated, open burning emissions due to the difficulty of tracking fires year-to-year, as well as reporting bias given that many countries have (largely unenforced) laws banning burning, leading to an erroneous emissions estimate of “zero”. However, developments in satellite monitoring technology over the past decade have provided an unusually accurate and neutral method for calculating open burning emissions today.[18] Current visible infrared imaging radiometer suite (VIIRS) satellite technology has allowed for increasingly fine resolution not only of fires or burned areas, but also the existing crop prior to burning, allowing for far more accurate emissions estimates of CO_2, CH_4, BC and other species from a given crop burned under given conditions (see subsection V.D below). Furthermore, consistent burning of managed grasslands in Europe

[15] Colleen E. Reid and others, “Critical review of health impacts of wildfire smoke exposure”, *Environmental Health Perspectives*, vol. 124, No. 9 (September 2016), pp. 1334–1343.

[16] T.C. Bond and others, “Bounding the role of black carbon in the climate system: A scientific assessment”, *Journal of Geophysical Research: Atmospheres*, Vol. 118, No. 11 (June 2013), pp. 5380–5552.

[17] Shiv Kumar Lohan and others, "Burning issues of paddy residue management in north-west states of India," Renewable and Sustainable Energy Reviews, vol. 81 (2018), pp. 693-706.

[18] Paolo Prosperi and others, “New estimates of greenhouse gas emissions from biomass burning and peat fires using MODIS Collection 6 burned areas”, *Climatic Change*, vol. 161, No. 3 (August 2020), pp. 415–432.

has been shown to reduce biodiversity[19] even when used for effective litter removal, calling into question timing (i.e., fire return interval) of the practice.

D. Agricultural impacts

17. Open burning primarily decreases soil's productive capacity by destroying the humus (organic matter) and soil consistency that are vital to good yields. Studies show that crop yields on burned fields average 20–35 per cent less. Conversely, burned fields require around 25 per cent more fertilizer to maintain yields, increasing costs to the farmer. With each successive burn, soils lose more nutrients – not only nitrogen and phosphorus, but also carbon.

18. Lack of soil organic carbon and the high heat of burning also compact the soil, making it more brittle and prone to erosion by both wind and water. Such erosion is most evident on hillsides, but also occurs by wind erosion on flatlands, where soil levels drop each year as burning and ploughing cause topsoil levels to diminish. Erosion impacts can be seen on agricultural lands where cement wells and water cisterns, originally dug at soil level, now sit some meters above the current ground. Where irrigation is necessary, larger amounts of water have to be used to compensate for such brittle soils, further depleting supplies already under stress in a warmer climate.

19. After burning and related erosion, whatever remaining natural fertility in the soil comes from the deeper layers under the burned portion; reaching successively deeper and deeper into the earth as soils erode until at some point, no topsoil remains, as can be seen in some portions of the Andes today. Greater fertilizer run-off also occurs from brittle soils less able to hold fertilizer in place.

20. These negative impacts hold for all uses of fire in the agroforestry sector, though are greatest where fire occurs annually or even two to three times each year; on marginal lands such as those in high boreal regions; or in mountainous regions with only a thin layer of topsoil. Use of fire even once in such ecosystems can limit agricultural use to just a few seasons or crops; after which time the user moves on, leaving a depleted and eroded landscape difficult or impossible to restore to its prior condition.

21. This rule also holds true for forestry burning used to clear before tree harvest on steep lands with little topsoil. Once the trees are harvested, the remaining land, even if planted with new seedlings, remains more prone to erosion and landslides. Pasturelands similarly do not benefit in "fertility" after a burn: while some non-grass and invasive species may be removed, the quality and livestock nutrition of burned pastures is lessened without fertilizer use[20], an investment rarely employed by herdsmen especially in developing countries.

22. To summarize, while burning may meet certain short-term needs, the overall damage to soil structure and fertility, and even complete loss due to erosion, make its use in the agricultural and forestry sectors non-viable economically in the long-term.

E. Existing policy and regulatory measures

23. Use of fire in agricultural systems has been regulated in some ECE countries since the early 1980s, often at the subnational level, in order to deal with specific local conditions and policy goals. These differing underlying motivations often have an impact on the scope of such measures, especially as they evolve over time. These include:

(a) Prevention of wildfire spread, by controlling when burning can occur, for example, requiring permits to prevent burns under overly-dry conditions;

[19] Orsolya Valkó and others, "Litter removal does not compensate detrimental fire effects on biodiversity in regularly burned semi-natural grasslands", *Science of the Total Environment*, vols. 622–623 (May 2018), pp. 783–789.

[20] Derek W. Bailey, "Identification and creation of optimum habitat conditions for livestock," *Rangeland Ecology & Management*, vol. 58, no. 2 (2005), pp. 109-118.

(b) Visibility concerns for aircraft and ground vehicles, which may require permits per the above, or prevent use of fire near airports or major highways;

(c) Air quality concerns, often connected to overall PM_{10} or $PM_{2.5}$ emissions limit values and benzo(a)pyrene target values,, including compliance with the European Union Ambient Air Quality Directives[21] and National Emission Reduction Commitments Directive,[22] resulting in such stringent requirements for burning as to comprise a de facto ban. Most European Union member States (with a few exceptions) have banned agricultural burning under Good Agricultural and Environmental Condition (GAEC) standards. Annex II on rules on cross-compliance to European Union regulation 1306/2013 on common agricultural policy[23] includes GAEC standard 6: "Maintenance of soil organic matter level through appropriate practices including ban on burning arable stubble, except for plant health reasons";

(d) Concerns with soil quality and erosion, especially the prevention of large-scale dust storms and loss of topsoil, also have comprised de facto bans in jurisdictions of both the European Union and North America.

24. These varying goals often have led to patchworks of measures. Some jurisdictions maintain a system of permitted burns, in an attempt to prevent wildfire spread, by requiring practitioners to obtain permits that are meant to be denied under unusually dry conditions. Given the increasing incidence of wildfires under drought conditions, as well as growing evidence of the negative soil, agricultural yield and carbon budget impacts of burning, there is a clear trend over time of policies moving towards de facto bans, due to the large geographic area over which smoke and dust may spread and cause negative health impacts. Where permitting systems exist, these may not be uniformly enforced and, in some countries, they may broadly ignored by both farmers and local authorities; especially where farmer support and education (often referred to as "agricultural extension services") are weak or non-existent in supporting farmers to use science-based approaches to cultivation.

V. Considerations for effective measures to reduce emissions from agricultural residue burning

25. In the past, efforts to reduce emissions from ARB have focused on "managed" or "permitted" burning. Such permitted burning however aims only at preventing the spread of wildfire (and associated air pollution and infrastructure risk) by prohibiting use of fire under dangerously dry conditions. It does not address the economic disbenefits arising from soil fertility loss and other negative impacts on the farmer and local communities; nor the direct emissions, the impact of which often can be significant on human health, requiring stay-indoors guidance during the burning season. In addition, in a warmer and drier climate, even permitted burns now often spread to become wildfires. The BATs and BAPs outlined below

[21] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe, Official Journal of the European Union, L 152 (2008), p. 1–44; and Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air, Official Journal of the European Union, L 23 (2005), p. 3–16. The Ambient Air Quality Directives, inter alia, set limit values for PM2.5 and PM10, as well as target values for Benzo(a)pyrene.

[22] Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC (Text with EEA relevance), *Official Journal of the European Union*, L 344 (2016), pp. 1–31. Part 2.B of annex III to the National Emission reduction Commitments Directive informs the European Union member States about potential black carbon reduction measures with respect to agricultural residue burning.

[23] Regulation (EU) No 1306/2013 of the European Parliament and of the Council of 17 December 2013 on the financing, management and monitoring of the common agricultural policy and repealing Council Regulations (EEC) No 352/78, (EC) No 165/94, (EC) No 2799/98, (EC) No 814/2000, (EC) No 1290/2005 and (EC) No 485/2008, Official Journal of the European Union, L 347 (2013), pp. 549–607.

therefore focus primarily on fire-free methods, with additional information on constraining emissions from use of fire where unavoidable.

A. Integrated approach

26. The most appropriate fire-free methods will vary dependent on a number of factors: crop, pasture, forestry etc; relative scale of cultivation; and availability of alternative equipment, including financing needs. Successful interventions have largely taken a "three legs" approach to introduction of fire-free agricultural systems:

(a) Mapping and monitoring to define the problem. Activities may encompass satellite and on-ground mapping open burning patterns from the field- to regional-level, including retroactive satellite mapping over a period of at least several years, to identify the largest and most persistent open burning emission sources (see subsection V.D, below);

(b) Education of farmers. Activities may encompass education, primarily within the agroforestry sector, on both the negative impacts of fire use and demonstration of the available solutions to the largest and most relevant open burning practices to farmers through provision of extension services, including local partnerships with entities focused on more sustainable agricultural practices (NGOs, civil society, State and federal extension services, agribusinesses). Within the agroforestry community, extension education focused on soil quality, crop yields and economic benefits has proven most effective,[24] more theoretical education on health and air quality less so;

(c) Growing regulation in concert with farmer education and extension services, including potential incentives for adoption. Activities may encompass introduction of measures, both regulatory and supportive (subsidies, equipment loan guarantees, etc.) specific to the most relevant uses of fire, in order to both support the transition, and ensure compliance by those who may lag behind.

27. It is important to note that these "three legs" should occur sequentially to ensure the most effective (in terms of both emission reductions and resource use) measures. Mapping should occur first to ensure that the most important sources are prioritized. Farmer education and support should occur prior to, or at least in concert with, any regulatory measures. The most significant failures in addressing open burning over the past 40 years (and there have been many) have occurred when authorities introduced burning bans without adequate support and extension services already in place. In general:

(a) With proper agriculture extension services and training, alternative methods help farmers save money on manual labour, fuel, water and fertilizer; and can equal or improve yields;

(b) Demonstrating the economic benefits of fire-free methods versus the economics of conventional aids adoption;

(c) With the proper resources (human and capital), burning in some examples has been reduced at very low or negative costs by 90 per cent or more.[25]

B. Available alternatives to agricultural residue burning

28. Although no-burn technology and methods are available for all agroforestry systems, plots, crops, farmers and weather conditions may vary considerably from place to place,

[24] P. Shyamsundar and others, "Fields on fire: Alternatives to crop residue burning in India", *Science*, vol. 365, No. 6453 (August 2019), pp. 536–538.

[25] H. S. Dhaliwal, Harmeet Kaur and Dharvinder Singh, "Rice Residue Management: Punjab Agricultural Management and Extension Training Institute (PAMETI) - United Nations Environment Programme Project on Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants" (Ludhiana, India, PAMETI).

requiring region-specific approaches.[26] Below are outlined some of the chief methods or systemic approaches. These systems can encompass in-situ (on-field) and ex-situ (off-field or off-farm) residue management strategies.

1. Conservation agriculture

29. Conservation agriculture is seen as the most important alternative to conventional burning-tillage agriculture, replacing conventional agriculture globally at the annual rate of some 10 million ha of cropland because it offers many benefits to farmers and society. In 2016, conservation agriculture cropland area covered some 180 million ha globally (12.5 per cent of global cropland)[27]. Conservation agriculture systems are ecologically underpinned by three interlinked principles of:

(a) No or minimum mechanical soil disturbance (through the practice of no-till, direct seeding and crop establishment and no-till weeding);

(b) Maintenance of soil mulch cover (through the practice of retaining crop residue, stubble and biomass from cover crops);

(c) Diversified cropping (through the practice of crop rotations or sequences or associations; including use of cover crops involving annuals and perennials such as legumes, which increase soil fertility).

30. The main reasons for adopting conservation agriculture can be summarized as follows:

(a) Better farm economy (reduction of production inputs of seeds, fertilizer, pesticides and water, and lower costs in machinery and fuel, and time-saving in the operations that permit the development of other agricultural and non-agricultural complementary activities);

(b) Flexible technical possibilities for sowing, fertilizer application and weed control (allowing for more timely operations);

(c) Equal yields or yield increases (depending on the starting level of soil degradation), greater yield stability (as long-term effect) and higher overall seasonal production;

(d) Soil protection against water and wind erosion;

(e) Greater nutrient use efficiency and retention;

(f) Fewer crop protection problems and costs;

(g) Better water-use efficiency and retention, and better water economy, including in dryland areas.

31. No-till and cover crops can also be used between rows of perennial crops such as olives, nuts and grapes or fruit orchards, and in palm oil plantation systems. Conservation agriculture can be used for winter crops, for traditional rotations with legumes, sunflower and canola, and in field crops under irrigation where it can help optimize irrigation system management to conserve water, energy and soil quality, reduce salinity problems and to make fertilizer use more efficient.

32. The above-mentioned principles, when put into practice with locally formulated adapted practices, along with other best management practices of integrated crop, nutrient, pest, water, energy, labour and farm power management, have shown on all continents the ability to transition from conventional burn-tillage agriculture.

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[26] S. Bhuvaneshwari, Hiroshan Hettiarachchi and Jay N. Meegoda, “Crop residue burning in India: Policy challenges and potential solutions”, *International Journal of Environmental Research and Public Health*, vol. 16, No. 5 (March 2019).

[27] Amir Kassam and others, “Global spread of conservation agriculture,” International Journal of Environmental Studies, vol. 76, no. 1 (2019), pp. 29-51.

2. Low-till practices

33. Low-till involves some use of ploughing and tillage equipment, but this is minimal and residues are incorporated back into the soil. It shares some of the advantages of full conservation agriculture, and for many farmers represents an intermediate step. It is also a necessary tool in some ecosystems where organic matter does not decompose quickly enough or where there is insufficient growing time to deploy cover crops, for example in very cold and dry regions. This alternative requires that farmers have access to the appropriate machinery and fuel, as well as the capital to pay for it; but is often the least capital- and labour-intensive of all no-burn alternatives. It also tends to find easier acceptance from farmers, as it simply involves omitting burning from field preparation.

34. Support for higher-quality steel ploughs that break through thick stubble is sometimes enough to halt burning entirely. Choppers added to harvesting combines can also better enable incorporation of stubble into the soil. Where soil has suffered from decades of burning, incorporation may be a necessity simply to restore the soil to a more fertile state, one that requires less fertilizer and irrigation. In addition to minimal tillage of entire fields, some farming systems employ strip till, which involves working the soil to still deeper depth, but only in narrow strips where seeds are actually planted.

3. Alternative use practices

35. Alternative ex situ uses of crop and forest residues range from low-tech, on-farm uses such as animal fodder and bedding, to advanced technologies such as pulp, bioplastics and district heating plants using biogas or pellets manufactured from crop or forest residue. Both require additional equipment and investment to gather the residue, and (for the high-tech alternatives) creation of a market value chain and, initially, high levels of investment in, for example, district heating plants. These high-tech alternatives are therefore more long-term in nature compared to in situ best practices and technologies, and are also dependent on other market conditions such as costs for fossil fuels or creation of subsidies. In addition, emissions from transport of residues, and greater risk of plant disease spread from transported residues should be carefully considered.

Animal feed and bedding

36. Some crop residues can also be used as animal food and bedding. Even if its nutritional value is not the same as residues from pasture, it can be also of great value for small-scale farmers. In some countries, loss of a viable livestock industry has been the proximate cause of increased burning, when this alternative use was no longer needed. Certain crop remnants such as maize have sufficient nutrition to serve as alternate fodder; less digestible residues may be used for bedding.

Bioenergy

37. Various crop and forest residues can be converted into biochar, pellets, briquettes and building materials. Compared to open burning, these techniques produce lower emissions of air pollutants, and at the same time can reduce reliance on fossil fuels for energy purposes. The use of agricultural residues for energy, unless it occurs directly on-farm, requires refineries, transportation and a distribution network. Nevertheless, especially with initial subsidies, this method is being increasingly practised at both the on-farm and regional levels in a number of ECE countries. For descriptions of on-farm energy production, district heating and biofuel production, seeing the following:

(a) On-farm energy production most often occurs on farms with both livestock and crop production, where crop residues are mixed with manure to produce biogas in smaller on-farm "cookers/digesters". The biogas is then burned to provide the farm with energy, and the excess may be sold to local distribution networks;

(b) District heating normally refers to heating from pellets produced from crop and forest residues. It is especially used in conjunction with forest understory clearing and timber waste products (see subsection V.B.4 below);

(c) Biofuel production:

(i) Biogas is normally produced as part of an integrated approach to waste management, often in close proximity to urban areas and where residues are mixed with manure and other organic materials from businesses and households. Producing biogas solely from crop and forest residues is not currently a viable technology, and most biogas technologies can only incorporate 10-20 per cent crop residues in the total biomass used, with manure or food waste being the chief component. The biogas is then used as fuel for a variety of purposes similarly to natural gas, from biogas vehicles to stoves and furnaces;

(ii) Ethanol can be produced solely from crop residues, in contrast to biogas. However, ethanol as a fuel is rarely in demand in ECE member States, although there is interest in development at-scale in some countries in Eastern Europe, the Caucasus and Central Asia.

4. Forest/Orchard/Fallow land residues

38. Emissions from forest/timber farms, orchard or fallow land residues comprise a potentially large source of emissions in the ECE region, especially when the risk of wildfire spread is taken into account. Timber farms produce large amounts of residue through both periodic clearing of underbrush to promote commercial tree growth, and during the harvesting process, when trees are entirely stripped of branches for easier transport. Underbrush or residue from forest harvest can present a fire risk, as well as present barriers for timber growth or regrowth. Orchards similarly require clearing of undergrowth, as well as periodic pruning of branches that need disposal. Fallow agricultural lands placed back into production require clearing of anything from low grass and brush, to removal of larger trees and bushes.

39. In all these cases, use of fire presents an easy and cheap method to remove the excess biomass, though often with extreme risk of wildfire spread due to the nature of all these land use types, which by definition are in close proximity to other forests and fields. Risk of wildfire spread has grown as a result of climate change, with more frequent periods of drought and high temperature. However, burning under wetter conditions produces larger amounts of $PM_{2.5}$ and other pollutants due to the low fire temperature.[28]

40. Alternative fire-free methods do exist and are widely deployed in some ECE countries. In situ methods involve chopping and spreading the excess biomass, often with a single large machine, similar to no-till and low-till methods on croplands. This can be especially useful when clearing orchard understory or fallow lands for new production, building humus and decreasing the need for fertilizer.

41. On timber farms, excess branches and biomass often are placed in large piles near timber roadways, where they can most easily be transported for conversion to pellets for district heating; to wood mills where they are mixed with other timber by-products for a variety of uses such as paper; or chipped into mulch.

42. Unlike low-till and no-till methods on croplands however, these methods rarely prove negative cost to the producers, except over longer time spans. They therefore may require some level of supportive Government economic measures, to varying degrees based on rural economic conditions.

5. Pastureland practices

43. Burning of pastures remains a practice in some ECE member States, as well as globally, especially in the annually set savannah fires of sub-Saharan Africa (which might comprise the single largest global source of BC and $PM_{2.5}$ annually). Just as with cropland burning, pasture fires decrease soil fertility and, ultimately, yields of grass for grazing or hay for harvest. Pasture lands also host a variety of species, and loss of biodiversity due to ARB is significant.[29] Since pasture often forms part of livestock operations, farmers often spread manure on the surface of both burned and unburned fields in springtime to compensate for

[28] See ECE/EB.AIR/2019/5, paras. 29, 65 and 90.
[29] Dhaliwal, “Rice Residue Management”.

loss of fertility, a practice that can result in excess emissions of ammonia and eventually, N_2O emissions, a powerful GHG. Spreading of manure to compensate for nutrient loss from burning may also contribute to pollution of nearby waterways, especially because burned fields are more prone to erosion.

6. Wildland management

44. Protection of wildlands (protected forests not used for timber production; protected grasslands or savannah; and protected wetlands, peatlands, fens and bogs) may involve periodic use of fire. This use of fire is not considered "agricultural open burning" for three reasons:

(a) Some wildland ecosystems are dependent on periodic fire events to maintain their natural state, with a number of species actually fire-dependent for seed dispersal, germination or regeneration. Such lands require use of fire for ecological functioning. However, it is noteworthy that this kind of burning is far less frequent than in human agricultural systems, often occurring on multi-year or decadal scales, rather than the annual (and sometimes, three times annually) burning deployed on some croplands and range/pastoral systems;

(b) Reduction of wildfire risk under extremely dry or drought conditions sometimes requires prescribed burns (burning conducted professionally by wildland firefighters and forest managers, under extremely controlled conditions). Such burning is unavoidable especially when occurring during active wildfires. The need for such burning however can be lessened to some degree by regular proactive clearing of brush by mechanical means and for alternative use, as outlined in subsection V.B.4 above;

(c) Indigenous fire management (sometimes called "cultural burns"), practised by indigenous peoples who are the original inhabitants of a given region, occurs during the cooler, wetter seasons to maintain habitats and resources while also reducing wildfire risk and carbon emissions.[30]

45. For the purpose of decreasing ARB, it is important that wildland management fire practices not be conflated with other, unnecessary use of fire in agroforestry systems outlined in subsections V.B.1–V.B.6 above.

7. Managed use of fire to reduce emissions

46. In addition to use of fire where it forms an integral part of natural ecosystems (wildlands), so-called managed burning (sometimes called "permitted" burns) is used in some jurisdictions to reduce risk of wildfire spread, and thereby decrease emissions. For the purpose of reducing emissions, such fire use is not considered a BAT or BAP due to the negative soil, water and health impacts noted above, in summary:

(a) Emissions and other negative soil and water quality impacts from the set fire continue. This includes climate impacts, specifically in the Arctic and other cryosphere regions, where early studies noted that changing timing of burning (when less snow or ice exists, or when winds are favourable) might decrease regional climate impacts. In reality however, BC transport is sufficiently complicated, and farmer schedules for planting sufficiently tight as to make such approaches ineffective: even at the height of summer, widespread snow and ice remains in the Arctic region, and even burning during the sundown period results in BC deposition then activated during northern hemisphere summer;

(b) Wildfire spread risk is growing in a warmer and more drought-prone climate, and finding a "good" or even "acceptable" time to burn can be challenging, especially for farmers needing to proceed with ploughing or seeding, often on a tight timescale;

(c) While fire-free methods are often posited as too expensive for some farmers, such equipment is no more expensive than conventional equipment (for example, direct seeders are available in sizes ranging from walk-behind human-powered or even classic stick-

[30] William Nikolakis and others, "Goal setting and indigenous fire management: A holistic perspective", *International Journal of Wildland Fire*, vol. 29, No. 11 (January 2020), pp. 974–982.

and-hold broadcast, to large combine-style seeders); and the savings in fertilizer and petrol soon or immediately lead to economic gains;[31]

(d) Perhaps equally important, a paradigm shift is needed towards ARB in the ECE region, as well as globally. Managed burns imply official approval of the method, rather than making clear that fire use has negative impacts and should be seen as a rare exception, rather than the rule.

47. Some fire use however is necessary, similar to its use in wildlands, above. Most importantly in forestry, large timber die-offs from a combination of pests and drought may lead to conditions where risk of wildfire is extreme, and time insufficient for harvest or gathering of extremely dry underbrush. Certain crops also are prone to pest or mould infections that, at this point in time, may not be prevented effectively through fungicide use; or there exists a balance between the environmental impacts of fire versus those from fungicide. In addition, alternative use of forestry residue, as noted above, currently is one fire-free alternative that may not be negative-cost, depending on local market conditions; although potential future use of bioenergy with carbon capture and storage may increase the price point of such alternate residue use in future.

48. When fire is used, all methods to constrain the fire to the area of intentional burn should be deployed. This may include pile-burning (though this is labour- and fuel-intensive, and once gathered the residue might have economic value); and burns closely monitored and usually initiated by firefighting authorities.

C. Supportive services and measures

49. Successful implementation of the above-mentioned fire-free practices can be aided by a number of supportive services, measures and regulation; especially to enable more rapid adoption to decrease $PM_{2.5}$ and other emissions, such measures being economically advantageous to the farmer.

1. Extension services – training and education

50. Education, training and demonstration plots are key for the success of the transition to no-burn, fire-free agriculture. Many farmers remain unaware of the economic advantages of fire-free methods, as well as their implementation, and are risk-adverse to new methods. Experience from demonstration projects shows high levels of interest and demand for no-burn technologies and approaches once this connection is both made and concretely demonstrated. It is therefore important to develop knowledge of no-burn practices among agricultural extension service providers, whether public or private, to address the varying needs of different crop systems. Such services are capable of educating and training farmers in issues related to the new climate-smart agricultural paradigm to generate sustained change.

2. Equipment

51. Mechanization covers all levels of farming and processing technologies, from simple, basic hand tools to more sophisticated, motorized equipment. Demonstration of conservation agriculture and low-till equipment can help communities make the transition. There are different options according to the size of the farm/plot: manual, animal-driven or tractor-driven; with many manufacturers and options throughout the ECE region. However, this is also a national opportunity to develop national equipment adapted to regional conditions. In addition to potential support for equipment purchase, leasing or community ownership (see subsection C.5, below), manufacturer or extension support for troubleshooting and to ensure proper equipment maintenance is key to continued and sustained use.

[31] Theodor Freidrich, Rolf Derpsch and Amir Kassam, “Overview of the global spread of conservation agriculture”, *Field Actions Science Reports*, Special Issue (2012).

3. Communication: awareness-raising, community engagement and advocacy

52. Open burning is also a behavioural problem and can be addressed through changing the mind-set of farmers and society alike by providing appropriate training and information. Constant engagement and updated, timely and concise knowledge about advances in the field of agriculture brings changes in attitude and behaviour. Involving local institutions such as schools and farmer cooperatives can also effectively address issues around open burning. Other examples of supportive communications measures may include:

(a) Distribution and publication of residue management manuals for farmers, informative leaflets (for example, through local post offices);

(b) Real-time mapping of fire seasons for the general public as well as farmers, to better associate negative air quality events, as well as wildfire spread, with burning in the agroforestry sector, thus emphasizing both current negative impacts as well as potential future benefits;

(c) Media broadcasts, infographic videos and websites, social media;

(d) Seminars, press tours, and other media support to facilitate accurate solution-oriented coverage;

(e) Farmer-agronomist meetings, field days with exposure visits to demonstration plots and farms of progressive farmers associated with crop residue management;

(f) Engagement of institutions such as local administrations, schools and universities, identifying and training of ambassador farmers/opinion leaders.

4. Market development

53. A number of academic and commercial start-ups have developed different systems that use straw and/or biomass to produce bioenergy at the community level. For longer-term solutions, value chain creation for use of agricultural and forestry residue might be supported where such energy needs exist through public finance, private entrepreneurship or public-private partnerships.

5. Financing

54. Farmers often need access, including financial assistance, to purchase or lease appropriate equipment. Government subsidies for locally manufactured farming equipment that helps to avoid burning (among many other benefits) have often proven to be a useful tool.

55. Such financing is not a universal barrier and due to the greater crop yields and smaller amounts of fertilizers used, an issue of initial transition only. There are no reported instances of regions that have adopted no-burn techniques, especially conservation agriculture, techniques returning to use of fire. Farmers simply save money through higher yields and lower costs for fertilizers and fuel.

56. The potential role of direct subsidies for rapid conversion to no-burn methods should not be ignored, much as supports currently exist for leaving some degree of croplands fallow for ecological management purposes. Current satellite technologies (see subsection V.D, below) could serve a monitoring function for such programmes, with subsidies paid out immediately upon planting with a new crop, regardless of the no-burn method chosen. If immediate cessation of burning is desired, this might prove the best initial approach, with more sustainable solutions introduced over time.

57. Financial incentives even for larger farms might therefore speed this transition. Farmers with medium- or small-size farms are more likely to require initial financial support, lacking the capital needed for initial investment in no-burn equipment such as direct seeders, cover crop seeds, or (on a more expensive scale) equipment for electricity, pellet or biogas production from different residues. Regardless, provision of training and education to farmers with farms of all sizes could be the most desirable and effective public financing alternative.

58. Additional supported investments could be devoted to equipment to inject manure into the soil (for combined animal husbandry and crop production), harvest pasturelands for hay rather than burning off excess growth, or support purchase of initial cover crops (plants such as clover or other legumes planted in-between cash crops, in essence providing a fertilizing function).

6. Governance and regulatory measures

59. In those countries in the ECE region with effective regulation for use of fire in agroforestry, such measures generally have been introduced successfully only in concert with other farmer-supportive measures, as noted above. Rarely, if ever, are across-the-board bans without such supportive measures either effective or enforced, as they do not address the underlying reasons for the specific use of fire under different agroecological conditions.

60. Some countries or subnational regions, rather than supporting transition to fire-free agricultural methods, have instead deployed "managed" or permitted burning on croplands. Such permitted burning, however, aims only to prevent the spread of wildfire and associated air pollution and infrastructure damage by prohibiting use of fire under dangerously dry conditions. It does not address the economic disbenefits arising from soil fertility loss and other negative impacts on the farmer and local communities. Some wildfire spread still can occur with permitted agricultural burning, and satellite studies have demonstrated that levels of emissions in regions that allow managed burns are still approximately twice as high as the levels in those regions that effectively prohibit use of fire except under exceptional circumstances.[32]

61. Specific inclusion of conservation agriculture (or other no-burn practices) could be added to national or subnational regulatory mixes, especially in regions where satellite monitoring shows persistent use of fire. By means of the Common Agricultural Policy, for example, the European Union member States have been able to provide incentives to farmers to adopt soil and water conservation practices that are also climate smart.

D. Monitoring and evaluation: new satellite technology and support

62. One key aspect to ensuring valid reductions of emissions of $PM_{2.5}$, BC, ground-level ozone and VOCs, as well as GHGs, and related co-benefits is the recent ability to characterize the crop vegetation in question via satellite monitoring, and therefore the related decrease in emissions arising from adoption of fire-free agricultural practices and technologies. Several global fire emission databases have been designed to monitor fires across all land cover types,[33] including the Global Fire Emissions Database,[34] the Copernicus Atmosphere Monitoring Service Global Fire Assimilation System[35] and the Fire INventory from NCAR,[36]

[32] The World Bank and the International Cryosphere Climate Initiative (ICCI), *On thin ice: How cutting pollution can slow warming and save lives – A joint report of the World Bank and the International Cryosphere Climate Initiative* (Washington, DC, 2013).

[33] Xiaohua Pan and others, "Six global biomass burning emission data sets: Intercomparison and application in one global aerosol model", *Atmospheric Chemistry and Physics*, vol. 20, No. 2 (January 2020), pp. 969–994.

[34] Guido R. Van Der Werf and others, "Global fire emissions estimates during 1997–2016", *Earth System Science Data*, vol. 9, No. 2, pp. 697–720; Global Fire Emissions Database available at www.globalfiredata.org/.

[35] J. W. Kaiser and others, "Biomass burning emissions estimated with a global fire assimilation system based on observed fire radiative power", *Biogeosciences*, vol. 9, No. 1 (January 2012), pp. 527–554; Copernicus Atmosphere Monitoring Service Global Fire Assimilation System available at https://apps.ecmwf.int/datasets/data/cams-gfas.

[36] C. Wiedinmyer and others, "The Fire INventory from NCAR (FINN): A high resolution global model to estimate the emissions from open burning", *Geoscientific Model Development*, vol. 4, No. 3 (July 2011), pp. 625–641; Fire Inventory from NCAR (FINN) available at www2.acom.ucar.edu/modeling/finn-fire-inventory-ncar.

which currently rely mainly on Moderate Resolution Imaging Spectroradiometer (MODIS) active fire detections - though improvements are expected rapidly.[37]

63. Current satellite technology (VIIRS) has allowed for increasingly finer resolution, not only of fires or burned areas but also of the existing crop prior to burning, than the older MODIS technology. This allows for both verification of compliance and calculation of avoided emissions over time. Current resolution was confirmed in 2017 studies as accurate down to the 50 m^2 level.[38] It may also be an effective way of improving national emission inventories of $PM_{2.5}$ and BC. Additional fusion approaches from open-source imagery at 30 m (Landsat) to 10 m (Sentinel constellation) allow for field-level verification of VIIRS active fire and generation of burned area at the weekly time scale.

64. Although not easily quantifiable, some of these emissions occurred from wildland fires, rather than fires on agroforestry holdings. However, a large majority of wildfires and related emissions spread from set fires in the agricultural sector or other human activities such as trash burning, with estimates of around 85 per cent in the United States of America, for example between 1992 and 2012, based on published Government data.[39] Such wildfires, which are occurring with greater incidence given higher frequency of hot and dry conditions, will also be avoided through increased use of no-burn methods in the agricultural sector: an important co-benefit that can also be monitored at the regional and national levels as use of fire in the agricultural sector decreases.

65. In addition, while negative carbon emissions within agriculture remain difficult to quantify with acceptable uncertainty, ongoing research in this field might make it possible to further characterize or monetize the benefits accruing from no-burn methods over time in terms of carbon drawdown into the soil, especially when conservation agriculture methods are used as the alternative to burning.

VI. Situation in Eastern Europe, the Caucasus and Central Asia

66. Countries in Eastern Europe, the Caucasus and Central Asia, including the Russian Federation, have significant potential to decrease emissions from open agricultural burning, which are on average eight to nine times[40] higher than those of other ECE member States as clearly reflected by satellite images, due to a variety of factors; often tied to changing agricultural economic conditions. The scale of emissions, if brought to other ECE region levels, would easily exceed by many times the reduction levels noted in the revised Protocol to Abate Acidification, Eutrophication and Ground-level Ozone for countries in Eastern Europe, the Caucasus and Central Asia, as well as increase food security and resilience in a changing climate. The crop patterns, and therefore the required fire-free practices and techniques, are similar to those deployed elsewhere in the ECE region.

67. To assist in this transition, some countries in the sub-region need access to a number of resources, including potential financing for programmes deploying extension services and equipment. This includes the Global Environment Facility, the Green Climate Fund (GCF) and, potentially, the European Investment Bank.

68. For the GCF, support for fire-free BATs and BAPs is especially attractive for several reasons related to GCF goals and requirements, because these fire-free approaches combine

[37] Niels Andela and others, "The Global Fire Atlas of individual fire size, duration, speed and direction", *Earth System Science Data*, vol. 11, No. 2 (April 2019), pp. 529–552.

[38] Patricia Oliva and Wilfrid Schroeder, "Assessment of VIIRS 375 m active fire detection product for direct burned area mapping", *Remote Sensing of Environment*, vol. 160 (April 2015), pp. 144–155; Tianran Zhang and others, "Approaches for synergistically exploiting VIIRS I-and M-Band data in regional active fire detection and FRP assessment: A demonstration with respect to agricultural residue burning in Eastern China", *Remote Sensing of Environment*, vol. 198 (September 2017), pp. 407–424.

[39] 2000–2017 data based on Wildland Fire Management Information, United States Department of Interior, and United States Forest Service Research Data Archive.

[40] The World Bank and the International Cryosphere Climate Initiative (ICCI*), On thin ice: How cutting pollution can slow warming and save lives – A joint report of the World Bank and the International Cryosphere Climate Initiative* (Washington, DC, 2013), pp. 79 and 80.

both adaptation and mitigation. For mitigation, measurement of both avoided emissions, and monitoring for compliance can be achieved in an unusually reliable, real-time, cost-effective manner through use of the new VIIRS satellite technologies and algorithms. Avoided emissions also include an unusually broad array of greenhouse gases, including CO_2, CH_4 and N_2O; as well as BC, VOCs and $PM_{2.5}$ (as co-benefits).[41] Additional avoided environmental impacts and co-benefits under the GCF definition include avoided erosion, water pollution, eutrophication and flooding from more brittle burned soils.

69. GCF-defined adaptation benefits include enhanced resilience to extreme weather events (both extreme rain and droughts, due to higher organic matter in soils); and lower water use for irrigation (where appropriate), again due to more organic-rich soils with higher water retention. Economic co-benefits include lower costs for the farmer from lower fertilizer and petrol use (for alternatives that involve incorporation or no-till), and/or additional income from alternative straw use and sale (where applicable markets exist), with the GCF financing making available technologies to realize these alternatives and providing education/training for their use.

70. Necessary pre-conditions for a successful GCF application, however, present some barriers. In particular, support from both the national ministries of agriculture and of finance (which is usually the GCF National Designated Entity, as denominated in the United Nations Framework Convention on Climate Change), as well as the ministry of environment, is needed.

71. Basic mapping of burning patterns and identification of main burned crops and sectors, as well as alternatives to burning specific to that crop and environment, could serve as an implementation plan for transition to fire-free agriculture. Such a plan would also comprise an important intermediate step in support of future GCF funding applications.

VII. Conclusions and recommendations

72. ARB is a challenge in many countries in the ECE region, as well as at the global level. Substantial and clear evidence exists that fire use has negative impact on soil organic matter by reducing soil fertility and ultimately reducing yields. Moreover, the emissions generated by ARB contribute to air pollution and are important drivers of climate change, with harmful effects on both human health and the environment at the global level.

73. Alternative methods, practices and techniques exist to eliminate or reduce ARB and its negative effects. The advantages of adopting the fire-free practices, illustrated in the present guidance, are demonstrated by various successful experiences in several countries within the ECE region. The transition from ARB to fire-free methods is proven to be successful and cost-effective when based upon three main pillars: (a) mapping and monitoring to define the problem; (b) education and training of farmers; and (c) developing regulations and financial support. Awareness-raising, training and dissemination of relevant information on the alternatives to ARB are essential to reach all concerned stakeholders.

74. The use of the present guidance is recommended to the Parties to the Convention on Long-range Transboundary Air Pollution, although on a voluntary basis. The implementation of the practices, methods, approaches and technical instruments described in the present guidance may significantly contribute to reducing air pollution from residue burning in agriculture and its negative impact on human health and the environment, within the ECE region and beyond.

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[41] Megan Sever, “What is left in the air after a wildfire depends on exactly what burned”, Eos, 23 January 2020.