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MODELLING METHODOLOGY FOR ASSESSING ATMOSPHERIC IMPACTS FROM SMART FARMING APPLICATION

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Abstract:
The project LIFE GAIA Sense targets environmental concerns related to agricultural practices through the development and application of an innovative "Smart Farming" system that aims at reducing the consumption of natural resources and minimising environmental impact, while increasing crop production. One of the main objectives of the project is to evaluate the environmental impact of the GAIA Sense application in terms of air, soil and water pollution by implementing 18 demonstration campaigns across Greece, Spain and Portugal. A methodology based on the combined use of dispersion modelling and continuous measurements of atmospheric pollutants is employed to assess the emission, dispersion and deposition of gases and particulates, taking advantage of near real-time collected meteorological data provided by the on-site GAIA sensors and meteorological stations. The modelling methodology relies on the calculation of realistic emissions data following a combined Tier1 and Tier 2 approach for emission calculation. To this purpose, detailed activity data of the specific Smart Farming application areas related to agricultural activities are acquired. Activity data for the specific smart farming applications is based on the compilation and analysis of the responses of participating farmers to targeted questionnaires. The calculation of realistic emissions data is the first step in quantifying the impact of agricultural activities on air quality and provides necessary input data in an integrated environmental evaluation using Life Cycle Analysis to demonstate the benefits of smart farming in agricultural sustainability.

Key words: air pollutant emissions, emissions from agriculture, air pollution modelling

INTRODUCTION

An important environmental pressure of agricultural activities relates to air quality deterioration. Agriculture is a common driver for both air pollution and climate change and these feedback mechanisms have to be considered when assessing the relevant environmental impacts of agricultural practices. Many agricultural activities rely on energy consumption of relevant machinery and equipment, resulting to significant emissions of Greenhouse Gases (GHG) and air pollutants, including carbon dioxide, nitrogen oxides and particulate matter (mainly $PM_{2.5}$ and PM_{10}). Activities throughout the Life Cycle of agricultural products and livestock that rely on fossil fuel usage, e.g. energy required for heating/lighting and cooling in greenhouses and livestock premises, for routine agricultural activities (ploughing, spraying, harvesting, shredding, etc.) and for the transport/loading of the products to shelves of retailers are important emitters. All the above agricultural activities also emit a significant amount of particulate matter, accounting for around 16% of PM_{10} emissions in the EU emission inventory of 2019 (EEA, 2019a). Furthermore, N_2O emission from croplands as a result of biological nitrification and denitrification processes in soils is an important contributor in GHGs emissions in Europe. According to the latest EU GHG inventory, GHG emissions in the agricultural sector represent almost 10% of the total EU GHG emissions (EEA, 2019b). Fertiliser application in agricultural soils is an important agricultural source of ammonia (NH_3), nitrogen oxides (NO_x) and nitrous oxide (N_2O) emissions, accounting for 93%, 8% (EEA, 2019a) and 5.9% (EEA, 2019b) of total EU emissions, respectively.

To reduce farming-related atmospheric emissions, appropriate supporting tools and methodologies to evaluate atmospheric impacts and suggest mitigation options at farm level may be of use to farmers and policy makers. In this frame, the GAIA Sense Smart Farming application has been developed as a resource efficiency tool for agricultural enterprises. The project LIFE GAIA Sense (https://lifegaiasense.eu) targets agriculture related environmental issues through the development and application of an innovative "Smart

Farming" (SF) system that aims at reducing the consumption of natural resources and minimising environmental impact, while increasing crop production. Its main purpose is to monitor crops, collect high-resolution environmental data and offer advices about irrigation, fertilisation and pesticides based on soil, weather and plant nutrition data. This philosophy leads to an increase of resource efficiency, promoting sustainable and circular economy in the agriculture sector. One of the main objectives of the project is to evaluate and quantify the environmental impact of the GAIA Sense application in terms of air, soil and water pollution by implementing 18 demonstration campaigns across Greece, Spain and Portugal.

This paper presents the methodology of calculating the emissions of atmospheric pollutants and GHGs resulting from the agricultural activities in seven GAIA Sense pilot areas in Greece, representing seven different crop types. The emissions calculation is the first step in a multi-scale coupled modelling methodology using local-scale real activity and meteorological data for assessing the impact of agricultural activities on the local air pollution levels.

METHODOLOGY OF EMISSIONS CALCULATION

Realistic emission data are a pre-requisite for reliable modelling estimation of the agricultural activities on local air quality and climate. Availability of high temporal and spatial resolution of pollutant emissions in smart farming applications is of particular importance in order to assess the local impact on the atmospheric environment. Atmospheric pollutant emissions are calculated by multiplying the activity rate with an emission factor. In the suggested methodology, emission factors from the EMEP/EEA air pollutant emission inventory guidebook 2019 (EMEP/EEA, 2019) and particularly of the 1A (mobile machinery) and 3D (Crop production and agricultural soils) NFR categories were used for most of the studied pollutants. In particular, for the calculation of N_2O emissions resulting from fertilisation of agricultural soil, the IPCC reference emission factor of 1% of kg N fertiliser applied is used. The proposed modelling methodology relies on the calculation of realistic emissions data following a combined Tier 1 and Tier 2 approach for emission calculation. For this purpose, detailed activity data of the specific SF application areas, related to agricultural activities, were acquired.

Activity estimation for the specific smart farming applications was based on the compilation and analysis of the responses of participating farmers to targeted questionnaires sent by the project coordinator to the agronomists participating in the project. The questionnaires are structured including three categories of questions in relation to social, economic and environmental indicators in order to obtain the necessary quantitative information for an integrated impact assessment of the SF system in the participating agricultural parcels. The calculation of the indicators is used as a basis for Life Cycle Assessment analysis to evaluate the impact of the implementation of the suggested tool. A set of environmental indicators specifically targeted the impact on the atmospheric environment were included to provide quantitative activity data for calculating the related atmospheric pollutant emissions. These indicators in particular included the use of fertilisers and energy use. The related questions required specifically the following information:

1. Use of chemical and organic fertilisers – type (name) and quantity (annual quantity in *kg* or per *ha*) of fertiliser for the specific crop type and the application frequency (e.g. per year or season)
2. Energy use – annual consumption of transport fuel in litres, annual energy use in *kWh* (including energy for irrigation, e.g. pumping, drilling), and annual consumption of machine lubricants in litres.

The quantitative replies of the farmers in the aforementioned questions were combined with the information they entered in their agricultural logbooks and with specific information regarding soil properties (pH in particular) from GAIA Sense monitoring IoT devices, called GAIAtrons. GAIAtrons are telemetric autonomous stations that collect data from sensors installed in the field and record atmospheric and soil parameters in the GAIA Sense pilot farm areas.

Based on the on-site activity and soil data acquired from the questionnaires and field monitors, a methodology to calculate realistic emissions of atmospheric pollutants and GHGs was structured depending on pollutant type, as follows:

- Tier 1 methodology was applied to calculate emissions of PM_{10}, $PM_{2.5}$, NO, NMVOC, using the default emission factors (EFs) for NFR Source category 3.D (Crop production and agricultural soils) from Table 3.1 of the EMEPEMEP/EEA air pollutant emission inventory guidebook 2019 (EMEP/EEA, 2019). This source category includes emissions related to the application of N fertilisers (for NO), emissions from cultivated crops (for NMVOC) and farm-level agricultural operations (for particulate matter), such as ploughing, spraying, harvesting and storage/handling of agricultural product. On-site data for quantities of fertiliser (kg of fertiliser N) applied and size of the cultivated area (ha) were derived from farmers' questionnaires and logbooks. The percentage of N of each fertiliser was estimated from the fertiliser commercial name and composition.

- Tier 1 methodology was used for emissions calculation of GHGs (CH_4, CO_2, N_2O) and atmospheric pollutants (NH_3, NMVOC, NO_x, PM_{10} and $PM_{2.5}$), employing the default EFs for NFR Source category 1.A.4.c.ii-Agriculture from Table 3-1 (Tier 1 emission factors for off-road machinery) of the EMEPEMEP/EEA air pollutant emission inventory guidebook 2019 (EMEP/EEA, 2019).This source category includes exhaust emissions related to fuel consumption of off-road vehicles and other machinery used in agriculture. On-site activity data on fuel consumption were derived from farmers' questionnaires.
- Tier 1 methodology was used for calculating N_2O emissions from fertiliser application in agricultural soils, according to the default value of 1% of kg^{-1}fertiliser N applied of IPCC (IPCC, 2006b).
- Tier 2 methodology was applied for the calculation of NH_3 emissions resulting from soil fertilisation, taking into account the climate zone of the pilot farm, the soil pH and the amount of N applied to the soil as calculated from the information in the farmers' questionnaires and logbooks. The EFs were selected based on the fertiliser type as recorded by the farmer and applied on each pilot farm, according to Table 3.2 EFs for NH_3 emissions from fertilisers (in g NH_3 (kg N applied)$^{-1}$) from the EMEPEMEP/EEA air pollutant emission inventory guidebook 2019 (EMEP/EEA, 2019).

The Tier 1 EFs used to calculate the total emissions are presented in Table 1. Tier 2 EFs for NH3 calculation are related to the fertiliser type applied and can be found in Table 3.2 of the EMEP/EEA air pollutant emission inventory guidebook 2019 (EMEP/EEA, 2019).

Table 1. Emission Factors (EFs) from NFR categories [(1),(4)]

	NFR category			
Pollutants	**Fertiliser application (NFR 3D)**	**Non-road machinery (NFR 1.A.4 cii)**	**Standing crops (NFR 3D) ($kg \cdot ha^{-1}$)**	**Agricultural operations (NFR 3D) ($kg \cdot ha^{-1}$)**
PM_{10}	-	1913 $g \cdot tonnes^{-1}$ fuel	-	1.56
$PM_{2.5}$	-	1913 $g \cdot tonnes^{-1}$ fuel	-	0.06
NO_x	-	34457 $g \cdot tonnes^{-1}$ fuel	-	-
NO	0.04 kg NO_2 kg^{-1} fertiliser N applied	-	-	-
NMVOC	-	3542 $g \cdot tonnes^{-1}$ fuel	0.86	-
NH_3	Table 3.2 [(3)]	8 $g \cdot tonnes^{-1}$ fuel	-	-
N_2O	0.01 kg N_2O–N (kg N)$^{-1}$ [(2)]	136 $g \cdot tonnes^{-1}$ fuel	-	-
CO_2	-	3160 $kg \cdot tonnes^{-1}$ fuel	-	-
CH_4	-	87 $g \cdot tonnes^{-1}$ fuel	-	-

[(1)]All emission factors (except the EF of N_2O from fertiliser application) are based on EMEP/EEA air pollutant emission inventory guidebook 2019

[(2)] EF of N_2O from fertilizer application is based on 2006 IPCC Guidelines for National Greenhouse Gas Inventories
[(3)] See Table 3.2 in EMEP/EEA air pollutant emission inventory guidebook 2019
[(4)] All EFs are Tier 1, except the ones of NH_3 from fertiliser application which are Tier 2

RESULTS OF EMISSIONS CALCULATION

The results of emissions calculation indicate the correlation of the studied pollutants to major contributing emissions sources in agriculture. CO_2 emissions (in kg·ha^{-1}) are almost linearly correlated to fuel consumption (Figure 1, left), with tomato crop emitting significantly higher amount of CO_2 compared to the other crops equal to 10963.27 kg·ha^{-1}, as a result of the higher fuel consumption (4000 lt) for agricultural activities. N_2O emissions result primarily from fertiliser application in agricultural soil but are also related to fuel consumption, with an EF of 136 g tonnes^{-1} fuel. This is demonstrated in Figure 1 (right), in which N_2O emissions for the majority of the crop types follow the trendline of the amount of fertiliser applied, except for the tomato crop. The high N_2O emissions for tomato (3551.9 g·ha^{-1}) cannot be attributed solely to the amount of fertiliser applied but can be explained on the basis of the particularly high fuel consumption compared to the other crops.

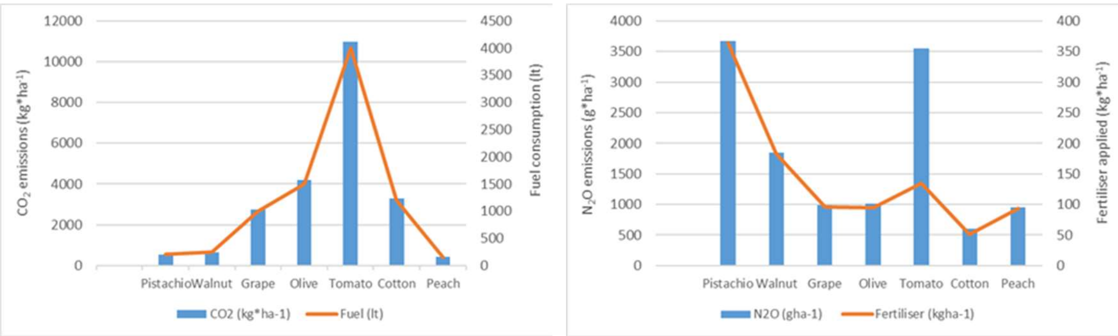

Figure 1. Total emissions of CO_2 (in kg·ha^{-1}) in relation to fuel consumption (left) and total N_2O emissions (in g·ha^{-1}) in relation to the amount of fertiliser applied (right)

Figure 2 presents the correlation between the total emissions (in g·ha^{-1}) of NO, NH_3 and N_2O and the amount of fertiliser applied. In the methodology section it is explained that EFs for the calculation of NO emissions are exclusively from the NFR category of fertiliser application, and this direct correlation is reflected in Figure 2. Pistachio has the highest amount of fertiliser applied (364.5 kg·ha^{-1}) and the highest NO emissions (14580g·ha^{-1}), while the lowest amount of fertiliser is applied in the case of cotton production (51.6 kg·ha^{-1}) which results to the lowest NO emissions (2064g·ha^{-1}) between the different crop types.

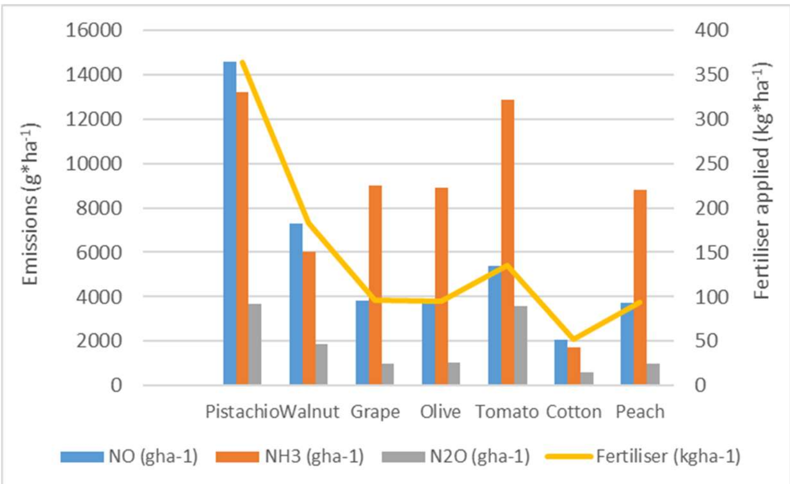

Figure 2. Total emissions of NO, NH_3 and N_2O in relation to the amount of fertiliser applied

NH_3 emissions result primarily from fertiliser application, while fuel consumption contributes in a substantially smaller degree, with a relevant EF of only 8 g·tonnes^{-1} fuel (Table 1). The intercrop variations in NH_3 emissions, as demonstrated in Figure 2, are related not only to the difference in the amount of fertiliser applied, but also to the different EF allocated to the specific fertiliser type used. The Tier 2 EFs used for the calculation of NH_3 emissions vary considerably according to the fertiliser type. For example, NPK mixtures, such as the ones apllied in the case of grape and olive crops, have high EFs of 94 g NH_3 per kg of N fertiliser for temperate climate and high pH, whereas for the same climatic and soil conditions, the EF of AN mixtures, such as those used in the case of cotton and walnut, is only 33 g NH_3 per kg of N fertiliser.

The calculated total emissions of atmospheric pollutants and GHGs for the seven crop types studied are presented in Table 2.

Table 2. Total emissions of atmospheric pollutants and GHGs (in g·ha^{-1}) for seven crop types

	Type of crop						
Pollutants	**Pistachio**	**Walnut**	**Grape**	**Olive**	**Tomato**	**Cotton**	**Peach**
PM_{10}	1891.85	1878.83	2024.59	2481.07	32532.38	2707.8	1870.86
$PM_{2.5}$	391.85	378.83	524.59	981.07	31032.38	1207.8	370.86
NO_x	5977.23	5742.83	8368.13	16590.41	557875.24	20674.2	5599.26
NO	14580	7308.67	3840	3800	5400	2064	3744
NMVOC	1474.43	1450.33	1720.2	2565.41	58206.67	2985.2	1435.58
NH_3	13219.39	6030.92	9025.94	8933.85	12864.17	1707.6	8799.7
N_2O	3668.59	1849.83	993.03	1015.48	3551.9	597.6	958.1
CO_2	548163.27	644897.96	2740816.33	4191836.74	10963265.31	3288979.59	419183.67
CH_4	15.09	14.5	21.13	41.89	1408.57	52.2	14.14

CONCLUSIONS

The LIFE GAIA Sense project aims at presenting an efficient and robust tool for implementing the EU policies in the areas of water, waste and air management, by reducing the contribution of the agricultural sector over the major environmental burdens through the application of the SF solution. The atmospheric modelling is one of several components contributing to the comprehensive evaluation of the environmental impact of SF GAIA Sense application. The multi-scale modelling methodology proposed for atmospheric simulations relies in a large degree on realistic atmospheric emissions data. The methodology for calculating emissions of atmospheric pollutants and GHGs related to the agricultural activities of the participating pilot farms is based on a combined Tier 1 and Tier 2 approach from the EMEP/EEA and IPCC guidebooks and on farm-level activity information from farmers' logbooks and replies to targeted questionnaires. The calculated emissions will be used as input data to the mathematical models, but also for performing Life Cycle Analysis in the final stages of the project for assessing the environmental efficiency of the SF GAIA Sense system.

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