Energy consumption and emissions of agricultural machinery for different arable land types

Šimun Lončarević[1,*], Petar Ilinčić[2], Goran Šagi[2], Zoran Lulić[2]
Energy Institute Hrvoje Požar, Zagreb, Croatia [1]
University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Zagreb, Croatia[2]
sloncarevic@eihp.hr

Abstract: *In this research, a survey was conducted in the Republic of Croatia in order to determine energy consumption in agriculture. The survey included collecting data on agricultural machinery based on machine type, fuel used, type of business and arable land type. There were more than 9,000 participants in the survey, of which more than 6,000 family farms. Results are shown on a national level for four land types: arable land, meadows and pastures, olive plantations and vineyards, as well as for three groups of participants: enterprises, family farms, and eco-producers. The last was found to have the lowest energy consumption and emissions on most land types, except on arable land, where all three groups have similar results. Vineyards had the highest emissions per hectare, while meadows and pastures had the lowest.*

Keywords*: MOBILE MACHINERY, AGRICULTURAL MACHINERY, EMISSIONS, LAND TYPE*

1. Introduction

Since global emissions are continually growing, there is a need for additional policies and measures which will help in their decrease [1]. For this to be achieved, all sources of emissions must be further researched. Among these emissions, non-road mobile machinery (NRMM) has not been researched adequately, and much less is known about their emissions in comparison to emissions from road vehicles [2]. This is partly due to a lack of a designated institution that would collect his data, as well as a lack of infrastructure and procedures for this data collecting process [3].

In Europe, the Regulation (EU) 2016/1628 introduced more stringent restrictions on emissions from NRMM [4]. It is expected to help in further decreasing of NRMM emissions by installing emission reduction technologies on new NRMM or retrofitting older models [5]. Unfortunately, there is little research regarding NRMM emission inventories and most countries do not research NRMM emissions. Without those inventories, little is known about the proportion of NRMM emissions in overall emissions and how this proportion compares with regard to overall NRMM energy consumption. Due to large differences between various models of internal combustion engine installed in NRMM, and large differences concerning NRMM working conditions, even the latest legal restrictions do not follow the ones for road vehicles [6].

There has been little research on agricultural machinery emissions. Since construction machinery and agriculture machinery have the largest proportions in overall NRMM emissions [7, 8], it is important to emphasize their emissions, considering that their emission reduction would result in the largest overall NRMM emission reduction. Unfortunately, there is no data on emission from agricultural machinery based on different arable land types. This information would enable the regulatory bodies to implement optimal measures, which would target machinery that operates on arable land types with the largest emissions per area unit. Furthermore, it would enable them to provide incentives for agricultural work, which results in the lowest emissions.

When researching emissions, the proven method of collecting data is to conduct a survey. It gives a good insight into real work conditions and fuel consumption of different machinery, which is a precondition to estimate emissions [9, 10]. Such approach provide results which accurately represent emissions per type of arable land.

2. Methods

Data on fuel consumption of agricultural machinery was collected as a part of a larger survey on energy consumption in agriculture. Data collection was conducted through a web application and field surveys. Administrative data was provided by the Croatian Bureau of Statistics (CBS), and data collection was conducted from December 2017 to April 2018. A total of 9710 participants were included in the survey, and data on fuel consumption based on fuel type, machine type and agricultural land type were collected.

Concerning land types, data collection was divided into four land types: arable land, meadows and pastures, olive plantations and vineyards. Concerning the type of business, the participants were divided into one of the following three groups: enterprises, family farms, and eco-producers. Data on fuel consumption was collected for diesel and gasoline fuel. Machinery was divided by type, which is shown in Table 1.

Each participant was assigned a unique identification number from the CBS database in order for the results to be linked with the existing CBS data. Results were controlled for their plausibility using certain identifiers. For example, average fuel consumption for tractors was determined in order to single out the outlying answers (e.g., using the wrong fuel based on machinery type or wrong order of magnitude). Following this control, the results were shown on national levels using weight factors provided by the CBS. When calculating weight factor, the CBS took into account individual properties for each survey participant, e.g. type of machinery used, geographic properties, end-use of machinery as per national occupational classification etc.

Table 1. *Total number of NRMM used in agriculture in Croatia in 2016 by ownership and machinery type*

	Number of machines-owned	**Number of machines-rented**
Single-axle tractors	56 039	682
Two-axle tractors	111 113	2 602
up to 40 kW	57 184	1 755
from 41 to 60 kW	31 579	292
from 61 to 100 kW	16 598	401
more than 100 kW	5 752	153
Combine harvesters	8 604	537
Machinery for potatoes and sugar beet	654	4
Machinery for fodder plants	5 203	127
Other harvesting machinery	258 745	875
Balers	51 515	1 090
Other	73 232	1 231
TOTAL	**565 105**	**7 147**

In order to calculate energy consumption from the fuel consumption data collected in the survey, fuel consumption was converted to megajoules to represent the results in megajoules per hectare (MJ/ha). The conversion factors used were obtained from the national energy report, “Energy in Croatia”, which is published annually by the Ministry of Economy and Sustainable Development. For diesel, a density of 0.832 kg/L and an energy density of 42.71 MJ/kg was used. For gasoline fuel, a density of 0.737 kg/L and an energy density of 44.59 MJ/kg was used [11].

Since only data on fuel consumption could be collected, Tier 1 method as specified in the EMEP/EEA air pollutant emission inventory guidebook for 2019 was used for calculating the emissions [12]:

$$E_{pollu} = \sum_{fuel\ type} FC_{fuel\ type} \times EF_{pollu\ ,fuel\ type}$$

where E_{pollu} is the emission of the specified pollutant; $FC_{fuel\ type}$ is the fuel consumption of each fuel for the source category; $EF_{pollu,\ fuel\ type}$ is the emission factor for a specific pollutant for each fuel type. The emission factors for forestry machinery based on fuel type and pollutant type in g/tonnes of fuels are shown in Table 2. In agriculture in Croatia, diesel and gasoline fuel are used, and emission factors are shown for CO_2, CO, NO_X, HC and PM.

Table 2. *Emission factors for different pollutants and fuel types for NRMM used in agriculture*

	Emission factors [g/tonnes of fuel]	
Pollutant	**Diesel**	**Gasoline**
CO_2	3 160 000	3 197 000
CO	11 469	770 368
NO_X	34 457	7 117
HC	87	665
PM	1 913	157

3. Results

Based on data from the survey and from the EMEP/EEA air pollutant emission inventory guidebook for 2019, energy consumption and emissions were calculated for different types of business and arable land types. Energy consumption for all types of businesses, types of fuel and arable land types are shown in Table 3 and Figure 1.

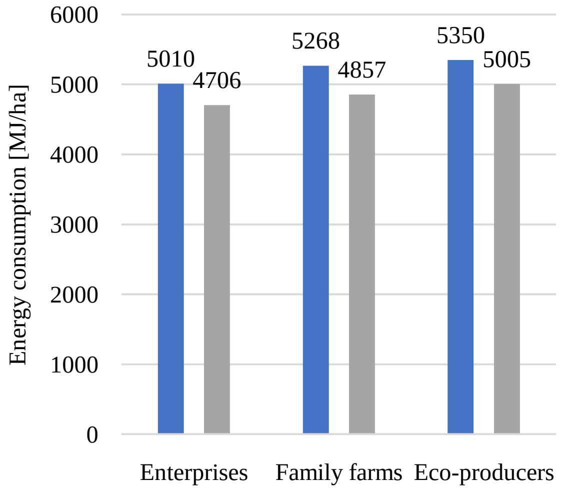
Table 3. *Energy consumption per hectare for types of businesses, types of fuel and arable land types*

	Average consumption (MJ/ha)	
	Diesel	**Gasoline**
Arable land		
Enterprises	5 010	4 706
Family farms	5 268	4 857
EKO producers	5 350	5 005
Average arable land	5 104	4 738
Meadows and pastures		
Enterprises	470	430
Family farms	1 381	1 206
EKO producers	657	637
Average meadows and pastures	956	858
Olive plantations		
Enterprises	5 112	4 771
Family farms	6 543	6 135
EKO producers	2 647	2 471
Average olive plantations	4 941	4 610
Vineyards		
Enterprises	8 280	7 794
Family farms	7 954	7 748
EKO producers	6 686	6 490
Average vineyards	8 213	7 762

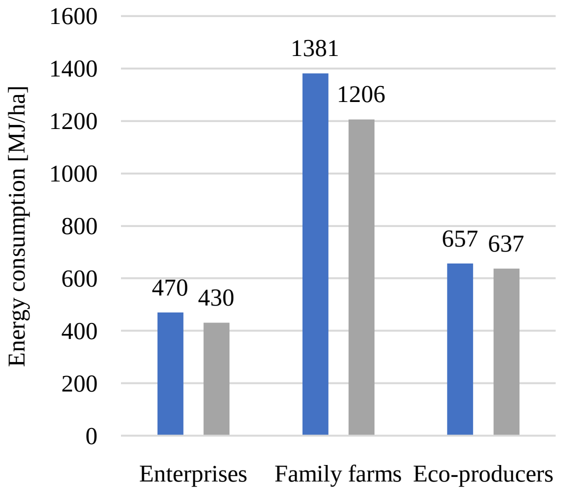
Since there is significantly more machinery that uses diesel fuel than machinery which uses gasoline fuel, the total energy consumption in Croatia is much larger for machinery which uses diesel fuel. Therefore, comparing total energy consumption would make it difficult to compare data between different types of businesses and different arable land types. For the purpose of better comparison of data, the results are shown not for total energy consumption, but in average energy consumption per hectare in megajoules per hectare. This enables data to be adequately compared between different types of businesses and different arable land types.

Concerning energy consumption, results show that vineyards had the highest energy consumption and emissions per hectare of land for both diesel and gasoline fuels. For diesel fuel, energy consumption was 8280 MJ/ha for enterprises, 7954 MJ/ha for family farms, and 6685 MJ/ha for eco-producers. For gasoline fuel, energy consumption was 7794 MJ/ha for enterprises, 7748 MJ/ha for family farms, and 6489 MJ/ha for eco-producers.

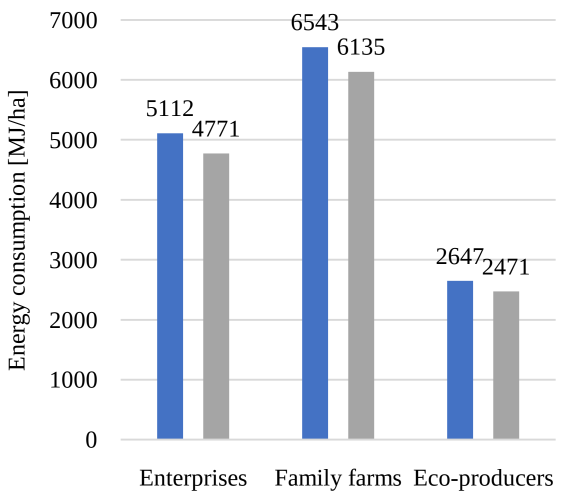
The lowest fuel consumption was on meadows and pastures for both fuels. For diesel fuel, energy consumption was 469 MJ/ha for enterprises, 1381 MJ/ha for family farms, and 656 MJ/ha for eco-producers. For gasoline fuel, energy consumption was 430 MJ/ha for enterprises, 1205 MJ/ha for family farms, and 637 MJ/ha for eco-producers.



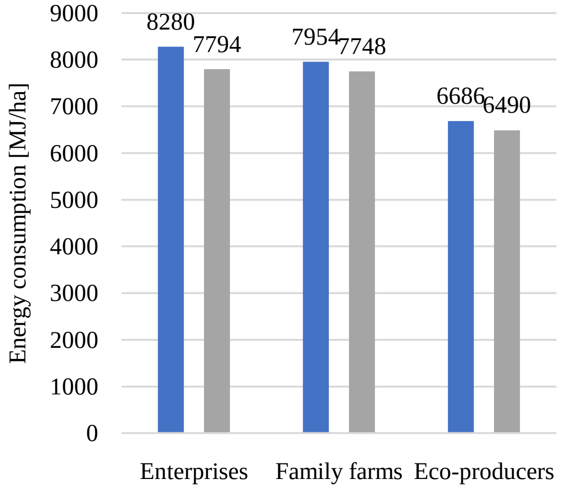
a) Arable land



b) Meadows and pastures



c) Olive plantations



d) Vineyards

Diesel Gasoline

Fig. 1 *Energy consumption of agricultural machinery per hectare based on types of businesses, fuel types and arable land types*

Emissions per hectare for each business and land type were also calculated and shown in Table 4 for diesel and gasoline fuel. The highest emissions were from machinery working in vineyards. Different types of emissions were highest for different fuels. Concerning diesel fuel, the highest emissions were 616.38 kg CO_2/ha, 6.72 kg NO_X/ha and 0.37 kg PM/ha for enterprises. The highest CO and HC emissions were from machinery in enterprises using gasoline fuel, with 135.95 kg CO/ha and 0.12 kg HC/ha. As with fuel consumption, the lowest emissions per hectare were from machinery working in meadows and pastures. The lowest emissions for gasoline fuel were in enterprises and were 31.16 kg CO_2/ha, 0.07 kg NO_X/ha and 0.002 kg PM/ha. For diesel fuel, emissions were lowest in enterprises and were 0.13 kg CO/ha and 0.001 kg HC/ha.

As expected, when comparing the same business types and land types, CO_2, NO_X and PM emissions were higher from machinery using diesel fuel than those using gasoline fuel. For machinery using gasoline fuel, it was vice versa, with CO and HC emissions being higher compared to emissions from machinery using diesel fuel. Furthermore, eco-producers had the least emissions on every type of land, except on arable land, where they had similar emissions to family farms and enterprises.

Table 4. *Emissions per hectare for types of businesses, types of fuel and arable land types*

	Diesel emissions [kg/ha]					Gasoline emissions [kg/ha]				
	CO_2	CO	NO_X	HC	PM	CO_2	CO	NO_X	HC	PM
Arable land										
Enterprises	372.93	1.35	4.07	0.01	0.23	340.61	82.08	0.76	0.07	0.02
Family farms	392.15	1.42	4.28	0.01	0.24	351.55	84.71	0.78	0.07	0.02
Eco-producers	398.28	1.45	4.34	0.01	0.24	362.26	87.29	0.81	0.08	0.02
TOTAL	379.96	1.38	4.14	0.01	0.23	342.99	82.65	0.76	0.07	0.02
Meadows and pastures										
Enterprises	34.96	0.13	0.38	0.001	0.02	31.16	7.51	0.07	0.01	0.002
Family farms	102.82	0.37	1.12	0.001	0.06	87.29	21.03	0.19	0.02	0.004
Eco-producers	48.89	0.18	0.53	0.001	0.03	46.14	11.12	0.10	0.01	0.002
TOTAL	71.16	0.26	0.78	0.001	0.04	62.08	14.96	0.14	0.01	0.003
Olive plantations										

	Diesel emissions [kg/ha]					Gasoline emissions [kg/ha]				
	CO_2	CO	NO_X	HC	PM	CO_2	CO	NO_X	HC	PM
Enterprises	380.52	1.38	4.15	0.01	0.23	345.37	83.22	0.77	0.07	0.02
Family farms	487.07	1.77	5.31	0.01	0.29	444.08	107.01	0.99	0.09	0.02
Eco-producers	197.02	0.72	2.15	0.01	0.12	178.87	43.10	0.40	0.04	0.01
TOTAL	367.84	1.34	4.01	0.01	0.22	333.71	80.41	0.74	0.07	0.02
Vineyards										
Enterprises	616.38	2.24	6.72	0.02	0.37	564.20	135.95	1.26	0.12	0.03
Family farms	592.14	2.15	6.46	0.02	0.36	560.87	135.15	1.25	0.12	0.03
Eco-producers	497.70	1.81	5.43	0.01	0.30	469.77	113.20	1.05	0.10	0.02
TOTAL	611.37	2.22	6.67	0.02	0.37	561.82	135.38	1.25	0.12	0.03

4. Conclusion and recommendations

Unlike emissions from road transport, which are extensively researched and in the focus of public debate and policies, much less is known about emissions from non-road mobile machinery. Although they significantly contribute to overall emissions, they are often neglected in emission reduction policies and rarely peak research interest. In addition to contributing to overall emissions, agricultural machinery emission more directly affects both the workers operating this machinery and the final product, i.e., the food which the final consumers eat. Like any other emission from internal combustion engines, agricultural machinery emission affects the environment, especially the workers operating this machinery and the final product, i.e., the food which the final consumers eat.

The results of this paper, which show emissions based on land type and business type, provide data that can help policymakers develop policies to create optimal measures for emission reduction. Vineyards, with the largest emissions per hectare, are most suitable for policies aiming at emission reduction. A policy of incentivizing eco-production would result in emission reduction in vineyards and olive plantations and meadows and pastures. For arable land, additional policies could further reduce emissions and protect both the workers operating agricultural machinery and the end consumers.

3. References

[1] U. N. Environment, “Emissions Gap Report 2019,” *UNEP - UN Environment Programme* (2019). Available: http://www.unenvironment.org/resources/emissions-gap-report-2019.

[2] J. Brodny and M. Tutak, “Analysis of the diversity in emissions of selected gaseous and particulate pollutants in the European Union countries,” *Journal of Environmental Management*, **vol. 231**, pp. 582–595 (2019), doi: 10.1016/j.jenvman.2018.10.045.

[3] T. S. Poulsen, “Market Analysis for Non-road Mobile Machinery Sector,” Scandinavian GPP Alliance (2017). Available: https://www.gate21.dk/wp-content/uploads/2017/06/Market-Analysis-for-Non-Road-Mobile-Machinery-Sector_FINAL.pdf.

[4] Regulation 2016/1628, “On requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery, amending Regulations (EU) No 1024/2012 and (EU) No 167/2013, and amending and repealing Directive 97/68/EC (Text with EEA relevance).” European Parliament (2016),Available: http://data.europa.eu/eli/reg/2016/1628/oj/eng.

[5] K. J. Walus, L. Wargula, P. Krawiec, and J. M. Adamiec, “Legal regulations of restrictions of air pollution made by non-road mobile machinery-the case study for Europe: a review,” Environ. Sci. Pollut. Res., **vol. 25**, no. 4, pp. 3243–3259 (2018), doi: 10.1007/s11356-017-0847-8.

[6] N. Szymlet, P. Lijewski, P. Fuć, B. Sokolnicka, and M. Siedlecki, “Comparative analysis of passenger car and non-road machinery specific emission in real operating conditions,” in *2018 International Interdisciplinary PhD Workshop (IIPhDW)* (2018), pp. 226–230, doi: 10.1109/IIPHDW.2018.8388362.

[7] B. Notter, P. Wüthrich, and J. Heldstab, “An emissions inventory for non-road mobile machinery (NRMM) in Switzerland,” Journal of Earth Sciences and Geotechnical Engineering, **vol. 6**, no. 4, pp. 273–292 (2016).

[8] M. Winther, “Danish emission inventories for road transport and other mobile sources,” p. 136 (2020).

[9] P. Lijewski, J. Merkisz, P. Fuć, A. Ziółkowski, Ł. Rymaniak, and W. Kusiak, “Fuel consumption and exhaust emissions in the process of mechanized timber extraction and transport,” Eur J Forest Res, **vol. 136**, no. 1, pp. 153–160 (2017), doi: 10.1007/s10342-016-1015-2.

[10] J. Lang *et al.*, “A high temporal-spatial resolution air pollutant emission inventory for agricultural machinery in China,” J. Clean Prod., **vol. 183**, pp. 1110–1121 (2018), doi: 10.1016/j.jclepro.2018.02.120.

[11] “Energy in Croatia,” Ministry of Economy and Sustainable Development, Zagreb (2020). Available: http://www.eihp.hr/wp-content/uploads/2021/01/1_Energija_u_Hrvatskoj_2019-2_compressed-1.pdf.

[12] EEA, “EMEP/EEA air pollutant emission inventory guidebook 2019.” European Environment Agency (2019). Available: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019.