# Non-Road Mobile Machinery Emission Inventory in forestry – first results for Croatia

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**Abstract:** Most countries do not have an emission inventory for non-road mobile machinery. Existing inventories are usually based on assumptions, with little available data, due to various factors: a large number of machinery type, a large variety of internal combustion engines installed in non-road mobile machinery, lack of activity data etc. In this paper, an emission inventory for machinery used in forestry in Croatia is developed. Since there is no available data on the machinery, a survey was conducted. Data on fuel consumption based on fuel type and machinery type were gathered. The data were processed and, using weight factors provided by the Croatian Bureau of Statistics, shown on a national level. The results are shown for two main fuel types, gasoline and diesel fuel. The resulting emission inventory is compared to emissions from road vehicles in Croatia by emission type per giga joule of energy spent. Results show that most emissions come from tractors, forwarders and construction work machines and indicate that the proportion of emissions of non-road mobile machinery used in forestry, compared to road transport, is considerably larger than their respective proportion of energy consumption (up to 41 times).

**Keywords:** non-road mobile machinery, emission inventory, forestry, Croatia

## 1. Introduction

The continuous growth of global emissions (United Nations Environment Programme, 2020) is an important scientific research subject. It requires that the countries implement measures that would lead to emissions' decrease. In order to decrease them, the first step is to research their sources. Concerning emissions from internal combustion engines, there is a substantial amount of research concerning road transport. Unfortunately, not much has been done in the area of non-road mobile machinery (NRMM). Most often the problem is a lack of a procedure for collecting the data, as well as designating an institution which could collect it (Tomas Sander Poulsen, 2017). This problem could be mitigated by using the national statistical offices to collect the data needed for an NRMM inventory (Frey H. Christopher and Bammi Sachin, 2003).

Despite more stringent legal restrictions for engines used in NRMM, especially in China (Huanxing et al., 2020), the United States of America (US EPA, 2016) and the EU (Walus et al., 2018), there is little research concerning emission inventories of NRMM and their proportion in overall emissions. Furthermore, even the new legal restrictions are less stringent than those for road vehicles (Szymlet et al., 2018). This can be partially attributed to the large variety of NRMM engine models and intended usage, as well as significant differences in their working conditions. The Regulation (EU) 2016/1628 of the European Parliament and of the Council, which concerns NRMM, includes, among other machinery, agricultural and forestry machinery, garden care appliances, other household machinery, inland water boats, locomotives, construction machines, street cleaners and mobile industrial and commercial appliances.

Concerning machinery used in forestry, little research has been done to measure or estimate their overall emissions, since most research in the field of NRMM machinery is focused on emissions from construction and agricultural machinery, due to these two sectors having the largest proportions in total NRMM emissions (Notter et al., 2016) (Winther, 2020).

If possible, it is best to collect the data based on real work conditions in order to accurately determine the emissions of machinery used in forestry (Lijewski et al., 2017). A survey is best suited to obtain a large quantity of data directly from the users of the machinery used in forestry.

## 2. Methods

### *2.1. Survey*

As a part of a larger survey on energy consumption in agriculture, a survey on machinery used in forestry was conducted. Data collection was conducted via field surveys and a web application based on the administrative data provided by the Croatian Bureau of Statistics (CBS). The collection of data was conducted in the period between December 2017 and April 2018, and the total number of completed questionnaires was 9710. Data on fuel

consumption based on fuel type and machinery type were gathered.

*2.2 Data processing*

Collected data were processed in order to link it to the existing data from the CBS, which was done by assigning a unique reference number, which correlated to the number in the CBS database, to every completed questionnaire. Plausibility control of the answers was conducted using specific identifiers. For example, average fuel consumption was determined for chain saws used in cutting by using total fuel consumption and the total number of chain saws. This enabled to single out the outlying answers (e. g. someone using the wrong order of magnitude, or wrong fuel). Data was collected for multiple end-uses of machinery, as well as for multiple machinery types (Table 1).

Following the control of the data, weight factors provided by the CBS enabled the data to be shown on a national level, which includes fuel consumption, number of machines used, and the total emissions. The CBS's method for determining weight factors takes into account individual properties of each respondent, such as demographic data, geographic properties, type of machinery used, end-use of machinery as per national occupational classification etc. Weight factors were provided for each survey respondent.

**Table 1.** Total number of NRMM used in forestry in Croatia in 2016 by end-use and machinery type

| End-use and machinery type | Total number of NRMM |
|---|---|
| **Cutting and making wood assortments:** | **4810** |
| Chain saws | 4810 |
| **Skidding and exportation:** | **1073** |
| Adapted tractors | 60 |
| Articulated tractors | 822 |
| Forwarders | 91 |
| Equipage | 82 |
| Tractors equipped with cranes | 19 |
| **Construction machinery:** | **115** |
| Construction work machines | 115 |
| **Other resources of work:** | **539** |
| Agricultural tractor | 143 |
| Other resources on own drive | 396 |

Since more accurate data could not be conducted, Tier 1 method for determining emissions was used, as specified in the EMEP/EEA air pollutant emission inventory guidebook 2019 (EEA, 2019):

$$E_{pollu} = \sum_{fuel\ type} FC_{fuel\ type} \times EF_{pollu,fuel\ type} \quad (1)$$

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 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 forestry, 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 forestry (EEA, 2019),

| | Emission factors [g/tonnes of fuel] | |
|---|---|---|
| **Pollutant** | **Diesel** | **Gasoline** |
| $CO_2$ | 3160000 | 3197000 |
| CO | 11469 | 770368 |
| $NO_X$ | 34457 | 7117 |
| HC | 87 | 665 |
| PM | 1913 | 157 |

## 3. Results

Based on data acquired via survey, an emission inventory for NRMM used in forestry can be calculated. Using weight factors, total fuel consumption was calculated for different end uses and machine types (Table 3). A total of 893 t of gasoline fuel was used. Only chain saws used for cutting and making wood assortments used gasoline fuel. Concerning diesel fuel, a total of 6408 t was used, of which most was used by articulated tractors (2939 t), followed by forwarders (1373 t), and construction work machines (1164 t). In total, 7301 t of fuel was used.

**Table 3.** Total fuel consumption (Diesel and Petrol) of NRMM used in forestry in Croatia in 2016 by end-use and machinery type

| End-use and machinery type | Gasoline [t] | Diesel [t] |
|---|---|---|
| **Cutting and making wood assortments:** | **893** | |
| Chain saws | 893 | |
| **Skidding and exportation:** | | **4710** |
| Adapted tractors | | 117 |
| Articulated tractors | | 2939 |
| Forwarders | | 1373 |
| Equipage | | 258 |
| Tractors equipped with cranes | | 24 |
| **Construction machinery:** | | **1873** |
| Construction work machines | | 1164 |
| **Other resources of work:** | | **534** |
| Agricultural tractor | | 519 |
| Other resources on their own drive | | 15 |
| **Total** | **893** | **6 408** |

Results on total fuel consumption were used to calculate total energy consumption and emissions, which are shown in Table 4. Considering the machinery end use categories, skidding and exportation had the largest proportion of energy consumption, with 201166.03 GJ of energy consumption, followed by construction machinery (in forestry), cutting and making wood assortments, and other resources of work, with 49729.75 GJ, 39831.41 GJ, and 22810.47 GJ, respectively. Concerning machinery types, articulated tractors had the largest proportion of energy consumption, with 125525.74 GJ, followed by forwarders and construction work machines, with 58623.06 GJ and 49729.75 GJ, respectively. Total energy consumption was 543969.93 GJ.

Since emissions were calculated based on fuel consumption, these categories were also the largest emission emitters. Concerning fuel type, a large difference can be seen between gasoline and diesel fuel powered machine in CO emissions. Although chain saws used only 39831.41 GJ of energy or 7.32% of total energy consumption, they emitted 554.54 t of CO, or 88.3% of total CO emissions. This is due to engine properties, i.e. gasoline engines emitting much more CO per a unit of spent energy compared to diesel engines. A difference can also be seen with diesel powered engines concerning $NO_X$ and PM emissions. With a proportion of 92.67% of total energy consumption, they emitted 98.46% of total $NO_X$ emissions, and 99.38% of total PM emissions.

In order to better understand the impact of emissions of forestry machinery, their emissions were compared to emissions from road vehicles ("Croatian National Inventory Report," 2020). The comparison is given in Table 5 and Figure 1. Although having a proportion in energy consumption of 0.35% compared to road vehicles, their emissions have proportions of 0,38% for $CO_2$, 2.11% for CO, 0.93% for $NO_X$, and 0.11% for HC. Unfortunately, there is no available data for PM for road vehicles in Croatia. As shown in Figure 2, NRMM has a much larger proportion of CO and $NO_X$ compared to energy consumption. This is due to less stringent legislation concerning NRMM compared to road vehicles, which results with older or no technology for emission reduction being installed in NRMM.

## 4. Discussion - Conclusion

With focus on the emissions from road transport, emissions from NRMM have been neglected. This emission inventory confirms that NRMM used in forestry have a much larger proportion in certain emissions compared to their proportion in energy consumption. In order to reduce emissions and their harmful impact on overall air quality, as well as the health of the workers which operate this machinery, a proactive legislative action should be taken to retrofit older NRMM with technology for emission reduction. The first step in preparing future legislation for this process, more detailed emission inventories must be made, to understand the optimal areas of NRMM for emission reduction legislation.

**Table 4.** Total emissions of NRMM used in forestry in Croatia in 2016 by end use and machinery type

| End use and machinery type | Energy [GJ] | $CO_2$ [t] | CO [t] | $NO_X$ [t] | HC [t] | PM [t] |
|---|---|---|---|---|---|---|
| **Cutting and making wood assortments:** | **39 831.41** | **2 855.82** | **554.54** | **6.36** | **0.59** | **0.14** |
| Chain saws | 39 831.41 | 2 855.82 | 554.54 | 6.36 | 0.59 | 0.14 |
| **Skidding and exportation:** | **201 166.03** | **14 883.74** | **54.02** | **162.29** | **0.41** | **9.01** |
| Adapted tractors | 4978.4 | 368.34 | 1.34 | 4.02 | 0.01 | 0.22 |
| Articulated tractors | 125 525.74 | 9 287.32 | 33.71 | 101.27 | 0.26 | 5.62 |
| Forwarders | 58 623.06 | 4 337.37 | 15.74 | 47.3 | 0.12 | 2.63 |
| Equipage | 11 024.84 | 815.70 | 2.96 | 8.89 | 0.02 | 0.49 |
| Tractors equipped with cranes | 1 013.99 | 75.02 | 0.27 | 0.82 | 0 | 0.05 |
| **Construction machinery:** | **49 729.75** | **3 679.37** | **13.35** | **40.12** | **0.1** | **2.23** |
| Construction work machines | 49 729.75 | 3 679.37 | 13.35 | 40.12 | 0.1 | 2.23 |
| **Other resources of work:** | **22 810.47** | **1 687.69** | **6.13** | **18.4** | **0.05** | **1.02** |
| Agricultural tractor | 22 810.47 | 1 687.69 | 6.13 | 18.4 | 0.05 | 1.02 |
| Other resources on own drive | 648.75 | 48.00 | 0.17 | 0.52 | 0 | 0.03 |
| **Total NRMM** | **543 969.93** | **40 155.7** | **628.04** | **413.08** | **1.62** | **22.72** |
| **Road transport** | **89 442 323** | **6 112 800** | **29 779** | **2 4465** | **1 060** | **/** |

**Table 5.** Total emissions of NRMM used in forestry in Croatia in 2016 by end-use compared to emissions from road vehicles

| End use and machinery type | Energy | $CO_2$ | CO | $NO_X$ | HC |
|---|---|---|---|---|---|
| Cutting and making wood assortments | 0.045% | 0.047% | 1.86% | 0.026% | 0.056% |
| Skidding and exportation | 0.225% | 0.243% | 0.181% | 0.663% | 0.039% |
| Construction machinery | 0.056% | 0.060% | 0.045% | 0.164% | 0.010% |
| Other resources of work | 0.026% | 0.028% | 0.021% | 0.075% | 0.004% |
| **Total** | **0.35%** | **0.38%** | **2.11%** | **0.93%** | **0.11%** |

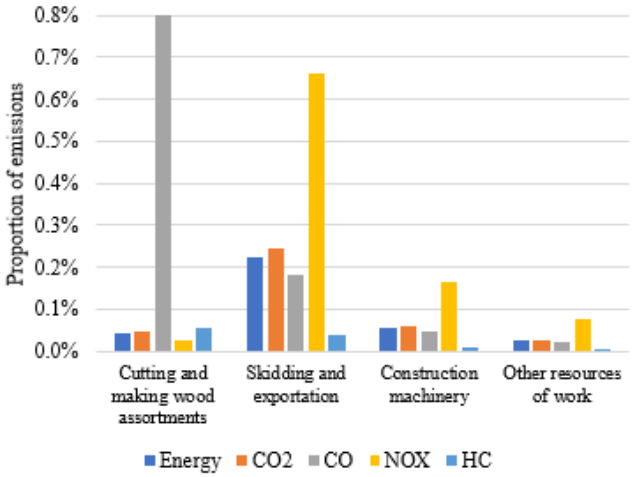


**Figure 1.** Comparison of emissions from NRMM used in forestry to emissions from road transport

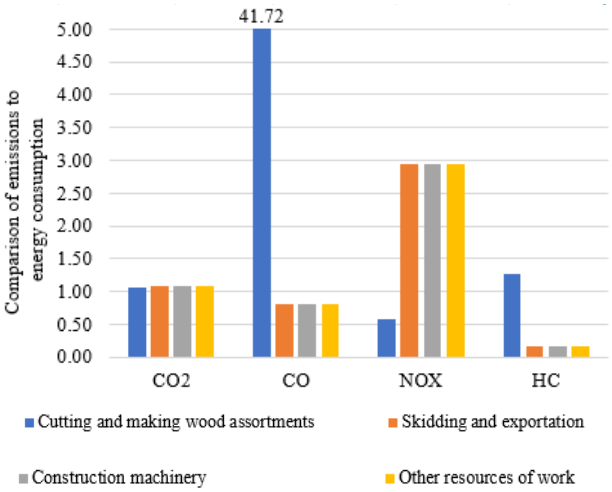


**Figure 2.** Comparison of emissions from NRMM used in forestry to their respective shares in energy consumption

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