Comparative Analysis of Exhaust Emissions caused by Chainsaws with Soft Computing and Statistical Approaches

Abstract. This research compares the nitrogen (NO) and methane (CH_4) exhaust emissions produced by the engines of two conventional chainsaws (a professional and an amateur one) to those produced by a catalytic. For all the three types of chainsaws, measurements were carried out under the following three different functional modes: a) Normal conditions with respect to infrequent acceleration b) Normal conditions, c) Use of high quality motor oil with a clean filter. The experiment was extended much further by considering measurements of NO and CH_4 concentrations for all the three types of chainsaws, in respect to four additional operation forms. More specifically, the emissions were measured a) under normal conditions b) under the application of frequent acceleration c) with the use of poor quality motor oil and d) with chainsaws using impure filters. The experiments and data collection were performed in the forest under "*real conditions*". Measurements conducted under real conditions were named 'control' measurements and were used for future comparisons. The authors used a portable analyzer (*Dräger X-am 5000* a *Dräger Sensor XXSNO* and a *CatEx 125 PRCH4*) for the measurement of exhaust emissions. The said analyzer can measure the concentrations of exhaust gas components on-line, while the engine is running under field conditions. We have employed fuzzy sets and fuzzy chi square tests in order to model air pollution produced by each type of chainsaw under each type of operation condition. The overall conclusion is that the catalytic chainsaw is the most environmentally friendly.

Keywords: Catalytic Chainsaw, Professional Chainsaw, Amateur Chainsaw, Nitrogen Monoxide, Methane, Fuzzy Chi-Square Test

1. Introduction and Literature review

The concentration of greenhouse gases (GHGs) in the atmosphere has increased substantially since the pre-industrial era, partly as a result of massive use of fossil fuels Karjalainen and Asikainen (1996). The negative impact of exhaust emissions on human health and the environment is beyond doubt (Lijewski et. al. 2013). Anthropogenic emissions of greenhouse gases are expected to influence the global climate so much that the change already poses a threat to the world's environment and economic development (Houghton et al. 1990, 1992).
Forest operations constitute a substantial part of environmental impact. They use inputs of external energy, which should be considered when environmental impact in the forest sector is of concern Berg and Karjalainen (2003).

Despite the obvious influence of exhaust emissions on the environment (atmosphere, flora) caused by mechanized timber harvesting operations, in the case of motor-manual harvesting, chainsaw operators are faced with an immediate hazard since they are exposed to exhaust emissions and frequently work in an environment with a high concentration of hazardous exhaust components (Lijewski et al. 2013). Chainsaw operators are exposed to the emission of PAHs (Polycyclic Aromatic Hydrocarbons) and nanoparticles (Czerwinski et al. 2001; Laanti et al. 2001; Jacke et al. 1996).

There are numerous research projects focusing on the implementation of technological solutions in order to reduce exhaust emissions and fuel consumption. Solutions that have been proposed include the use of catalytic aftertreatment (Schlossarczyk et al. 2004), the application of the stratified scavenging method Ohtsuji and Kobayashi (2002), or the improvement of the charge exchange (Rodenbeck et al. 2006). A wide variety of technical solutions for chainsaw engines was presented by (Zahn 2000), who investigated fuel injection, engine lubrication, stratified scavenging and catalytic after treatment. (Nordfjell et al. 2003; Klav et al. 2012) also studied fuel consumption in relation to exhaust emissions. There is also a considerable amount of literature on the issue of lubricant oils which end up on the ground during harvesting operations and as a result constitute an equally significant aspect of the environmental impact. According to Hartweg and Keilen (1988), during harvesting activities, the soil may absorb up to 0.2 dm^3 (cubic decimeter, a volume unit equivalent to a litre) of oil per 1 cubic meter of harvested timber. Similar values have also been recorded by (Sonnleitner 1992). One of the proposals to solve the problem is the application of biodegradable oils and hydraulic fluids (Ahola 1998; Wightman et al. 1998). A comparison of the emission levels and the operating parameters of the chainsaw engines using mineral and vegetable oils has been presented by (Skoupy et al. 2010).

Generally speaking, literature investigating the problem of exhaust emissions generated during harvesting operations is primarily based on tests and research performed in laboratories and estimates under actual operating conditions. (Lijewski et al. 2013). Tests under actual operating conditions are one of the latest methods in exhaust emission measurement (Merkisz et al. 2010). The measurements of exhaust emissions under actual operating conditions are valuable as they enable the determination of the emission depending on the existing engine operating conditions (a machine or a vehicle) (Lijewski et al. 2013).

Incomplete combustion occurring in fuels, household appliances and other external sources, such as vehicles and industrial activities leads to the creation of air pollutants and particles. CH_4 belongs to those gases that constitute the most significant representatives of the so-called greenhouse gases and are responsible for the greenhouse effect. Its concentration in the 20th century, as a result of technological growth, has increased by almost 100%, whereas its contribution to the greenhouse effect compared with other greenhouse gases (CO_2, CFC_S, N_2O, O_3) is 17% (Gentekakis 2003).

When nitrogen is released, during fuel combustion, it combines with oxygen atoms to create nitric oxide (NO). NOx is produced from the reaction of nitrogen and oxygen gases in the air during combustion, especially at high temperatures (higher than 1000^oC). Out of the seven nitrogen oxides (NO_x), three (N_2O, NO, NO_2) are the most abundant nitrogen oxides in the air. http://www.icopal-noxite.co.uk/nox-problem/nox-pollution.aspx

NO is part of the major pollutants produced by two-stroke internal combustion engines such as chainsaw motors (other pollutants of two-stroke engines include HC, CO, CO_2 and particles) (Gentekakis 2003). NO is a precursor to tropospheric ozone O_3 and nitric acid, namely the secondary gases that contribute to the formation of acid rain (Kraft et al. 2005).

Experiments on animals that were exposed to high concentrations of nitrogen oxides, showed both reversible and irreversible injury to lungs as well as biochemical changes. Lower concentrations, but more prolonged durations of exposure, led to tissue damage, obstruction of bronchioles and great susceptibility to microbial inflammations of the respiratory system. In conclusion, higher oxide concentrations are more detrimental to human and animal health compared with prolonged exposure to lower concentrations (World Bank Group 1998).

Permissible exposure limit for NO is set at 25 ppm. Permissible exposure limit is determined by two Presidential Decrees in Greece (338/2001 and 339/2001) which define it as the limit of an employee's exposure to a chemical agent, measured in the air of his/her breathing zone, that should not be exceeded during any kind of eight-hour daily work and forty-hour weekly work Daikou and Dontas (2013). However, there is no definition of a permissible exposure limit for methane, since this gas is not considered harmful to man.

In previous research efforts of our team (Anezakis 2016; Bougoudis 2014, 2015, 2016a,b; Iliadis 2014) we have tried to model the problem of air pollution using soft computing techniques. We have focused in the hazards caused by extreme values of pollutants in urban centers and in the future projection of air pollutants concentrations, under various climate change models.

1.1 Aim of this research

The present study is the first part of a research project focusing on gases that are detrimental mainly to the environment. Measurements concern the concentrations of methane CH_4 and nitrogen monoxide NO in the environment. Data collection was performed in the countryside with the use of an emissions analyzer (DrägerX-am 5000). In the second part of the project the emphasis will be laid on those gases produced by chainsaw fuels that are harmful to the chainsaw operator. We have combined fuzzy sets and chi square test for the correlation of air pollution for each type of chainsaw and for each type of use. Especially, we tried to find the dependence among each of the four operating conditions of the three chainsaws to the three air pollutants' Risk Linguistics "Low", "Medium" and "High". Additionally, we have estimated the dependence of each one of the three fuzzy CH_4-NO concentration Linguistics, to each one of the four operation types in the case of each chainsaw type independently. The innovation of the proposed research relies on studying of these operating conditions which determine high rates of pollutant emissions. Finally, we have revealed these chainsaws and their operating conditions which estimate the high rates of pollutant emissions. This study helps το find out the chainsaws and their operating conditions which are more environmentally friendly or affect the health of their users. Given that the Chi-Square test offers a bivalent logic estimate regarding Independence or Dependence (InD/Dep) between the examined variables and it is unable to give the exact degree of dependence or independence, we propose a novel method to cover this gap and go one step further. As it has already been mentioned the proposed *Fuzzy ChiSquare test* (FChiSq) fuzzifies the p-values of the test, by producing proper *Linguistics* which express *Low, Medium* or *High* degrees of InD/Dep. In this way we go much further than binary results in a wider spectrum of outcomes. This is a big improvement in the approach which becomes more flexible and rational.

2. Materials and Methods

All measurements have been made under actual conditions prevailing in timber harvesting with the help of an analyzer for the measurement of exhaust emissions produced by three chainsaws. The technological solution of after treatment was investigated in order to reduce NO and CH_4 harmful emissions. Chainsaw emissions were related to three operating parameters, namely use of impure filter, use of poor quality of oils and frequent use of chainsaw accelerator. The three chainsaws that were used in the study were a) a professional Stihl 361 MS, b) an amateur Stihl 170 MS and c) a catalytic MakitaCCS-4301.
Measurements were made with all three chainsaws (professional, amateur and catalytic) under normal conditions, namely with clean filters and good quality oils (recommended and produced by a well-known company) and with regular – infrequent accelerator use. These were benchmark measurements, used for future comparisons, and were named *control measurements*. Subsequently, for each of the three chainsaws separate measurements were performed, namely measurements of NO and CH_4 emissions, with X'_2= frequent accelerator use, X'_3 = use of poor quality oils and X'_4 = impure filter, while the other conditions were normal (for X'_2 use of good quality oils and clean filter, for X'_3 clean filter and infrequent use of accelerator and for X'_4 good quality oils and infrequent use of accelerator). Table 1 shows the chainsaw types that have been used: X_1= catalytic chainsaw, X_2= professional chainsaw and X_3= amateur chainsaw as well the operating parameters: *X'_1= normal conditions*, *X'_2 =frequent accelerator use, X'_3 = poor quality oils, X'_4 = impure filter.*
These conditions were repeated once for measurements Z_1= NO, and a second time for measurements Z_2=CH_4. In total 2082 measurements were carried out, of which 1041 were for NO and another 1041 for CH_4 emissions. Measurements were made in ppm (one part per million by volume in air - ml/m^3).

Table1. Measurement conditions of nitrogen (Z_1= NO) and methane (Z_2=CH_4) emissions produced by a professional, an amateur and a catalytic chainsaw.

	Type of chainsaw		
Operating parameters	**X_1= Catalytic**	**X_2= Professional**	**X_3= Amateur**
X'_1 = Normal conditions	$XX'_{1,1}$ = Catalytic under normal conditions	$XX'_{2,1}$ = Professional under normal conditions	$XX'_{3,1}$ = Amateur under normal conditions

X'₂=Frequent accelerator	XX'$_{1,2}$ = Catalytic with frequent accelerator	XX'$_{2,2}$ = Professional with frequent accelerator	XX'$_{3,2}$ = Amateur with frequent accelerator
X'$_3$=Poor quality oils	XX'$_{1,3}$ = Catalytic with poor quality oil	XX'$_{2,3}$ = Professional with poor quality oil	XX'$_{3,3}$ = Amateur with poor quality oil
X'$_4$=Impure filter	XX'$_{1,4}$= Catalytic with impure filter	XX'$_{2,4}$ = Professional with impure filter	XX'$_{3,4}$ = Amateur with impure filter

Total measurements Y_1= NO: 1041
Total measurements Y_2=CH_4: 1041

2.1 Data mining techniques

After the experiments, data mining was performed by employing a hybrid methodology of soft computing and statistics. Soft computing is an umbrella that covers Fuzzy Logic, Artificial Neural Networks Support Vector Machines and Genetic Algorithms. In this research, Fuzzy Logic was the tool chosen to elicit knowledge through data mining. More specifically, fuzzy classification of the measurements was initiated in order to assign proper Linguistics "labels" to each one. All primitive data vectors were assigned the tags "Low concentration" "Medium" and "High". Thus data mining can offer a rational view and it can take into consideration the extent of air pollution for each type of chainsaw and for each type of use. On the other hand, the Chi-square statistical test was used to reveal the existence of relations between the obtained cases.

2.1.1 The Fuzzy Chi-Square Test

The Chi-Squared hypothesis-testing is a non-parametric statistical test in which the sampling distribution of the test statistic is a chi-square distribution when the null hypothesis is true. The null hypothesis H_0 usually refers to a general statement or default position that there is no relationship between two measured phenomena, or no difference among groups. The H_0 is assumed to be true until evidence suggests otherwise (Corder and Foreman 2014; Greenwood and Nikulin 1996). The statistical control index used for this assessment is the test statistic X^2 (function1).

$$X^2 = \sum \frac{(f_o - f_e)^2}{f_e} \qquad (1)$$

Function 1: The test statistic X^2

Where f_e is the expected frequency and f_o the observed one. The degrees of freedom are estimated as follows (based on the rXc table of labeled categories):

$$df = (r-1)(c-1) \qquad (2)$$

Function 2: The degrees of freedom for the test statistic X^2

For the Null hypothesis (H_0) the critical values for the test statistic X^2 are estimated by the X^2 distribution after considering the degrees of freedom. If the result of the test statistic is less than the value of the Chi-Square distribution then we accept $H_{0,}$ otherwise we reject it.

The produced p-values include the potential error magnitude in the range [0-1]. Each error value is multiplied by 10, raised to the negative sixth power (p-value ⟦10⟧ ^ (-6)). The p-value equal to a is considered as boundary and it cannot determine the dependence or independence between the variables. The dependence is defined with p-values<a, whereas the independence with p-values>a.

In the next step the p-values are fuzzified by the use of Fuzzy Chi-Square test, according to the specified confidence interval and to the significance level. This process can be enhanced with the use of proper Fuzzy Membership functions (FMF) developed to capture the level of dependence (when p-value<a) in the closed interval [0-0.049999] and the degree of independence (when p-value>a) in the closed interval [0.050001-1]. Then proper Linguistics such as High dependence, independence Medium or Low are easily defined.

The following MATLAB commands were used to enhance the above for the Linguistics Low, Medium and High.

$$HighDependence = trimf(dependence, [-0.020000\ 0.000000\ 0.020000])$$
$$MediumDependence = trimf(dependence, [0.005000\ 0.025000\ 0.045000])$$
$$LowDependence = trimf(dependence, [0.030000\ 0.049999\ 0.070000])$$

$$\mathrm{LowIndependence} = \mathrm{trimf}(\mathrm{independence}, [-0.329900\ 0.050001\ 0.430001])$$
$$\mathrm{MediumIndependence} = \mathrm{trimf}(\mathrm{independence}, [0.145100\ 0.525100\ 0.905000])$$
$$\mathrm{HighIndependence} = \mathrm{trimf}(\mathrm{independence}, [0.620000\ 1.000000\ 1.380000])$$

Table 2. Indicative degrees of membership of the dependence Linguistics (Interval [0-0.049999]

P-Value	Linguistics	High	Medium	Low
0	High	1	0	0
0.00001	High	0.99945	0	0
0.012499	High	0.37505	0.37495	0
0.0125	High/Medium	0.375	0.375	0
0.012501	Medium	0.37495	0.37505	0
0.03	Medium	0	0.75	0
0.035	Medium	0	0.5	0.2500125
0.037499	Medium	0	0.37505	0.374968
0.0375	Low	0	0.375	0.3750187
0.049999	Low	0	0	1

Table 3. Indicative degrees of membership of the independence Linguistics (Interval [0.050001-1]

P-Value	Linguistics	Low	Medium	High
0.050001	Low	1	0	0
0.05001	Low	0.99997	0	0
0.287550	Low	0.374871	0.374868	0
0.287551	Medium	0.374868	0.374871	0
0.4301	Medium	0	0.75	0
0.71505	Medium	0	0.5	0.25013157
0.762518	Medium	0	0.375051	0.375047

0.762519	High	0	0.375048	0.375050
1	High	0	0	1

2.2 The proposed hybrid fuzzy-statistics approach

A rational data analysis requires labeling-classification of the obtained crisp air pollution values to “Low”, “Medium” and “High”. This process is the actual core of the analysis. The measured raw values need to pass through fuzzy logic labeling that can reveal the magnitude of air pollution. In this way, important conclusions can be drawn.

Table 4. Triangular Membership Functions (T-FMF) boundaries of three chainsaws with the four operating conditions.

1. Catalytic

Fuzzy Sets corresponding to CH4 and NO	T-FMF Boundaries Normal Conditions	T-FMF boundaries Accelerator	T-FMF boundaries Oil	T-FMF boundaries Filter
LowCH4	[-18.2 5 28.2]	[-3.6 14 31.6]	[3.4 17 30.6]	[-15.8 3 21.8]
MediumCH4	[10.8 34 57.2]	[18.4 36 53.6]	[20.4 34 47.6]	[7.7 26.5 45.3]
HighCH4	[39.8 63 86.2]	[40.4 58 75.6]	[37.4 51 64.6]	[31.2 50 68.8]
LowNO	[-5.52 0.6 6.72]	[-10.26 1.3 12.86]	[-0.1 2.7 5.5]	[2.26 4.1 5.94]
MediumNO	[2.13 8.25 14.37]	[4.19 15.75 27.31]	[3.4 6.2 9]	[4.56 6.4 8.24]
HighNO	[9.78 15.9 22.02]	[18.64 30.2 41.76]	[6.9 9.7 12.5]	[6.86 8.7 10.54]

2. Professional

Fuzzy Sets Corresponding to CH4 and NO	T-FMF Boundaries Normal Conditions	T-FMF boundaries Accelerator	T-FMF boundaries Oil	T-FMF boundaries Filter
LowCH4	[-14.8 2 18.8]	[-23.4 7 37.4]	[-11.6 20 51.6]	[-8.8 22 52.8]
MediumCH4	[6.2 23 39.8]	[14.6 45 75.4]	[27.9 59.5 91.1]	[29.7 60.5 91.3]
HighCH4	[27.2 44 60.8]	[52.6 83 113.4]	[67.4 99 130.6]	[68.2 99 129.8]
LowNO	[-4.92 2 8.92]	[-5.6 1.2 8]	[-0.26 2.9 6.06]	[-3.54 2.9 9.34]
MediumNO	[3.73 10.65 17.57]	[2.9 9.7 16.5]	[3.69 6.85 10.01]	[4.51 10.95 17.39]
HighNO	[12.38 19.3 26.22]	[11.4 18.2 25]	[7.64 10.8 13.96]	[12.56 19 25.44]

3. Amateur

Fuzzy Sets Corresponding to CH4 and NO	T-FMF Boundaries Normal Conditions	T-FMF boundaries Accelerator	T-FMF Boundaries Oil	T-FMF boundaries Filter
LowCH4	[-13.6 2 17.6]	[-19.6 4 27.6]	[-12.8 10 32.8]	[-24.4 6 36.4]
MediumCH4	[5.9 21.5 37.1]	[9.9 33.5 57.1]	[15.7 38.5 61.3]	[13.6 44 74.4]
HighCH4	[25.4 41 56.6]	[39.4 63 86.6]	[44.2 67 89.8]	[51.6 82 112.4]
LowNO	[-13.34 0.5 14.34]	[-5.6 4.8 15.2]	[-9.26 5.1 19.46]	[-18.52 2.6 23.72]
MediumNO	[3.96 17.8 31.64]	[7.4 17.8 28.2]	[8.69 23.05 37.41]	[7.88 29 50.12]
HighNO	[21.26 35.1 48.94]	[20.4 30.8 41.2]	[26.64 41 55.36]	[34.28 55.4 76.52]

The analysis of the two pollutants' values with soft computing methods and statistical techniques was employed for all three chainsaws (catalyst, professional and amateur) to the four test operating conditions namely: ***normal conditions*, *frequent accelerator use, poor quality oils, impure filter*.**

The entire algorithmic process involves **three** distinct steps, which are discussed below:

Step 1: Three fuzzy sets (FS) were used for the classification of the (NO, CH_4) values in three respective Risk Linguistics "Low", "Medium", "High". The fuzzy algebraic model developed herein, includes three Triangular Fuzzy Membership functions (FMF) for the fuzzification of the raw values.

According to Zadeh (Kecman 2001; Iliadis 2007; Iliadis and Papaleonidas 2016) every element "x" of the Universe of discourse "X" belongs to a Fuzzy Set (FS) with a degree of membership in the closed interval [0,1]. Thus the following function 3 is the mathematical foundation of a FS.

$$S = \{(x, \mu s(x)/\mu s : X\{[0,1]: x\}\, \mu s(x)\} \quad (3)$$

Function 3: Mathematical foundation of a FS

The following function 4 is an example of a typical Triangular FMF. It must be clarified that the "a" and "b" parameters have the values of the lower and upper bounds of the raw data respectively.

$$\mu_s(X) = \begin{cases} 0\ if\ X < \alpha \\ (X-a)/(c-a) if\ X \in\ [a,c) \\ (b-X)/(b-c)\ if\ X \in [c,b) \\ 0\ if\ X > b \end{cases} \quad (4)$$

Function 4: Triangular fuzzy membership function

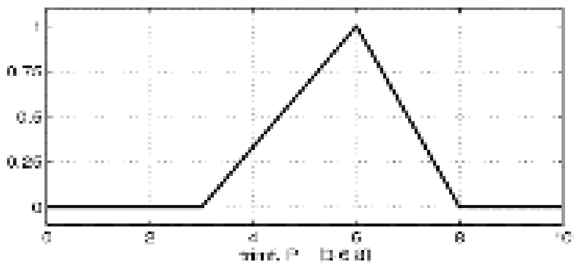

Fig 1. An example of a Triangular FMF. It is clear that the highest membership value that is equal to one corresponds only to one raw value.

Step 2: Using the Chi-Square Test for finding the dependency between the four operating conditions of 3 chainsaws with 3 verbal risk of each pollutant separately CH_4, NO (see Table 3a, 3b). Building 2 Tables 3 * 3 dimensional degrees of freedom df=4 at the confidence interval c=0.95 (see Table 8).

Step 3: After the classification, the statistical Chi-Square Test was employed at significance level a = 0.05 in order to find the dependence between each of the four operating conditions of the three chainsaws to the three air pollutants' Risk Linguistics "Low", "Medium" and "High" (see Table 6,7).
Every chainsaw and each pollutant was examined separately and six tables were developed (three chainsaws * 2 pollutants). These tables had 4 rows and 3 columns, whereas the degrees of freedom (df=6) were calculated from the X^2 distribution to a confidence level c = 0.95 in order to accept or reject the H_0 hypothesis (see Table 9).
Step 4: The Chi-Square Test approach to a significance level of a=0.05 was performed in order to estimate the dependence of each one of the three fuzzy CH_4-NO concentration Linguistics, to each one of the four operation types in the case of each chainsaw type independently. Thus, totally 12 tables were developed (4 operation types * 3 chainsaw categories) with 3X3 dimension (df=4), for a confidence interval γ=0.95 (see Table 10).
The hybrid fuzzy chi square statistical approach was employed in the steps 2,3,4, aiming to determine the actual degree of dependence or degree of independence of the features, by fuzzifying the p-values in the closed interval [0,1]. The fuzzification of the p-Values was performed after the statistical test (Test Statistic) was finished. The hybrid fuzzy chi square test indicates the degree of membership of the p-values to the Linguistics *Low, Medium, High*. In this flexible way we can obtain a more accurate judgment of the degree of dependence or independence.

3. Results and Discussion

3.1. Results obtained by the Soft Computing analysis

In terms of the overall performance (without considering the type of use-operation) the Professional chainsaw has the highest absolute number and percentage of Low CH_4 emissions, whereas the catalytic has the highest percent of Medium CH_4 gasses and the amateur appears to have the highest Low cases. On the basis of this analysis, no firm conclusion can be drawn about the optimal chainsaw in the overall scenario.
For the case of NO emissions, the catalytic has the highest percent of Low concentrations by far and also the lowest percentage of High cases, whereas the amateur seems to have the most Medium NO pollution measurements. The Professional has the highest percent of "High emissions" and the lowest of "Low". This means that the overall performance of the catalytic chainsaw is certainly the best regarding NO emissions.
However, the overall performance is not the most efficient approach to show the best case. More details are presented in the following Tables 5(a), 5(b) and 6.

Table 5(a). Overall CH4 pollution risk results, based on each pollutant's Linguistics, for the three chainsaws.

ALL TYPES OF OPERATION	Low CH_4	Medium CH_4	High CH_4	Sum of All Linguistics for each chainsaw

Catalytic	87	25.07%	226	65.12%	34	9.79%	347
Professional	101	28.85%	219	62.59%	30	8.57%	350
Amateur	98	28.48%	223	64.82%	23	6.68%	344
Sum of all chainsaws for each Linguistic	286		668		87		1041

Table 5(b). Overall NO pollution risk results based on the risk Linguistics for each pollutant.

ALL TYPES OF OPERATION	**Low CH_4**		**Medium CH_4**		**High CH_4**		**Sum of All Linguistics for each chainsaw**
					9	2.59%	347
Professional	148	42.28%	168	48%	34	9.71%	350
Amateur	149	43.31%	182	52.90%	13	3.77%	344
Sum of all chainsaws for each Linguistic	471		514		56		1041

The conclusions made by considering the mode of use are offering stronger evidence, firmly supported by the obtained results. This form of analysis shows a more clear view of the situation. A detailed presentation of the results is shown in the following Table 6.

In the catalytic chainsaw, when the use is Normal, we have Low CH_4 emissions in 51% of the measurements and Medium ones in 47% (which offers a tolerable working frame), whereas the High concentrations of methane are insignificant. In the same saw, the methane gasses are Medium in 78% of the cases when we accelerate frequently, whereas the poor oil quality plays a significant role and drops this percentage in much favor of the High values. In the case of the impure filter the important result is that the percent of High CH_4 emissions rises to 21% from the initial 2% of the Normal mode.

As it is shown in Table 6, the Professional saw performs much worse than the Catalytic under Normal conditions for CH4 (38% of Low values compared to 51% of the Catalytic) and also in the case of Poor Quality Oil (2% Low versus 14%). The impressive finding is that the Professional acts much better than the Catalytic in the acceleration mode (46% versus 16% Low emissions). For the Impure filter the Professional has fewer High values and it seems to perform better.

Table 6. Presentation of the methane pollution Linguistic results, based on each of the four operation types of three chainsaw.

			1.Catalytic				
TYPE OF USE	Low CH_4		Medium CH_4		High CH_4		Total
Normal	51	51%	47	47%	2	2%	100

Conditions							
Frequent Accelerator	16	16%	78	78%	6	6%	100
Poor Quality Oil	14	23.33%	39	65%	7	11.66%	60
Impure Filter	6	6.89%	62	71.26%	19	21.83%	87
Sum of all use types	87		226		34		347

2.Professional

TYPE OF USE	Low CH_4		Medium CH_4		High CH_4		Total
Normal Conditions	38	38%	56	56%	6	6%	100
Frequent Accelerator	46	46%	52	52%	2	2%	100
Poor Quality Oil	2	3.33%	49	81.66%	9	15%	60
Impure Filter	15	16.66%	62	68.88%	13	14.44%	90
Sum of all use types	101		219		30		350

3.Amateur

TYPE OF USE	Low CH_4		Medium CH_4		High CH_4		Total
Normal Conditions	41	41.00%	52	52.00%	7	7.00%	100
Frequent Accelerator	26	26%	69	69%	5	5%	100
Poor Quality Oil	11	18.33%	42	70%	7	11.66%	60
Impure Filter	20	23.80%	60	71.42%	4	4.76%	84
Sum of all use types	98		223		23		344

For CH_4 compared to the other saws, the Amateur has the highest percentage of High values under Normal conditions and at the same time the lowest percent of Low measurements. However, it is remarkable that the Amateur has a much better behavior than the others for the case of the Impure filter where it favors Low methane values (23.8%). For the acceleration mode it seems to perform better than the Catalytic and worse than the Professional, whereas for the Poor Oil no safe conclusions can be made.

The Amateur chainsaw behaves worse under Normal conditions and it becomes even more harmful during acceleration (the Low values drop, whereas the Moderate and High increase significantly). However, the Amateur behaves unexpectedly well, for the case of the Impure filter and Poor Oil quality.

Table 7. Presentation of the NO pollution Linguistic results, based on each of the four operation types of three chainsaw.

1.Catalytic

TYPE OF USE	Low NO		Medium NO		High NO		Total
Normal Conditions	58	58%	40	40%	2	2%	100
Frequent Accelerator	62	62%	37	37%	1	1%	100
Poor Quality	39	65%	20	33.33%	1	1.66%	60

Oil							
Impure Filter	15	17.24%	67	77.01%	5	5.74%	87
Sum of all use types	174		164		9		347

2.Professional

TYPE OF USE	Low NO		Medium NO		High NO		Total
Normal Conditions	95	95%	1	1%	4	4%	100
Frequent Accelerator	37	37%	53	53%	10	10%	100
Poor Quality Oil	8	13.33%	38	63.33%	14	23.33%	60
Impure Filter	8	9.19%	76	87.35%	6	6.66%	90
Sum of all use types	148		168		34		350

3.Amateur

TYPE OF USE	Low NO		Medium NO		High NO		Total
Normal Conditions	32	32%	64	64%	4	4%	100
Frequent Accelerator	22	22%	73	73%	5	5%	100
Poor Quality Oil	23	38.33%	34	56.66%	3	5%	60
Impure Filter	72	85.71%	11	13.09%	1	1.19%	84
Sum of all use types	149		182		13		344

From Table 7, we clearly see that the vast majority of NO emissions in both the Catalytic and the Professional chainsaws are classified as Low and a significant number of them are labeled as Medium. However, the number of Low cases is higher in the Catalytic saw and also the number of High values is significantly lower for the Catalytic compared to the Professional. Another important result is that the Professional performs almost perfectly (95% Low NO values) when the operation is in Normal mode. In all other cases the Catalytic saw has much lower NO emissions than all the other saws. The Professional saw behaves almost perfectly under Normal conditions. The vast majority of NO emissions in Amateur chainsaw are classified as Medium. The amateur performs almost perfectly (85.71% Low NO values) when the operation is Impure Filter while (73% Medium NO values) when the operation is Frequent Accelerator. Summing up, we conclude that the “filter” operation significantly determines the emissions of nitric oxide (NO) and methane (CH_4).

3.2. Statistical analysis Results

Useful conclusions have been made by using the soft computing data mining method described in the previous sections; however, an X square test was chosen to prove the actual influence of the air pollutants emissions by the operation mode for each of the chainsaw types. This influence, which clearly emerges in the previous section, was proven here by a well-established statistical approach.

Table 8. Test Statistic P-Values and Fuzzy P-Values between all modes of operation of the three chainsaws and air pollution risk Linguistics.

All modes of operation for the three chainsaws	Risk Linguistics related to CH_4	Risk Linguistics related to NO
TestStatistic	3.34	22.98
P-Value	0.5019	0.00013
Fuzzy P-Value Linguistics	Medium Independence	High Dependence
Degree of membership	0.938947	0.9935

We see that there is a very high dependence between the Nitrogen oxide emissions and the operation modes for all types of chainsaws whereas there is a moderate independence in the case of the methane emissions (see Table 8).

Table 9. Test Statistic P-Values and Fuzzy P-Values of the three types of chainsaws and air pollution risk Linguistics.

Chainsaw Type	Linguistics of CH_4 pollutant	Linguistics of NO pollutant
1. Catalytic		
TestStatistic	70.4897	52.2
P-Value	<0.00001	<0.00001
Fuzzy P-Value Linguistics	High Dependence	High Dependence
Degree of membership	1	1
2. Professional		
TestStatistic	50.13	192.07
P-Value	<0.00001	<0.00001
Fuzzy P-Value Linguistics	High Dependence	High Dependence
Degree of membership	1	1
3. Amateur		
TestStatistic	15.28	86.06
P-Value	0.018	<0.00001
Fuzzy P-Value Linguistics	Medium Dependence	High Dependence
Degree of membership	0.6594	1

The chainsaw types under all of the developed scenarios were examined using statistical Chi-Square Test (CST) which has proven that there exists a significant dependence between the operating conditions and the Linguistics of the air pollutants. It was established with great accuracy that all four operating conditions significantly determine the level of emissions of the two pollutants (see Table 9).

The CST produced high Test Statistic values against small P-values for a confidence interval γ=0.95, rejecting the null hypothesis that there exists a dependence between the four operating conditions of the three chainsaws and the concentration of each air pollutant. High dependence with degree of membership (DOM) equal to 1 was recorded between each of the four operating conditions of the three chainsaws with the NO emissions. Instead only the catalytic and professional chainsaw showed high dependence equal to 1 with the linguistics representing concentrations of CH_4. (see Table 9).

Table 10. Test Statistic P-Values and Fuzzy P-Values for the three air pollution risk Linguistics for CH_4-NO and for each of the four operation types of each chainsaw separately.

	NO Linguistics 1.Catalytic	NO Linguistics 2.Professional	NO Linguistics 3.Amateur

Linguistics for CH_4	**Normal conditions opetation mode**		
	TestStatistic 7.03	TestStatistic 4.1353	TestStatistic 8.2863
	P-Value 0.1342	P-Value 0.388	P-Value 0.081
	Fuzzy P-Value Linguistics	Fuzzy P-Value Linguistics	Fuzzy P-Value Linguistics
	Low Independence	Medium Independence	Low Independence
	Degree of membership 0.7784237	Degree of membership 0.6392105	Degree of membership 0.9167474
Linguistics for CH_4	**Acceleration operation mode**		
	TestStatistic 19.3295	TestStatistic 9.8063	TestStatistic 14.1436
	P-Value 0.00068	P-Value 0.0438	P-Value 0.0068
	Fuzzy P-Value Linguistics	Fuzzy P-Value Linguistics	Fuzzy P-Value Linguistics
	High Dependence	Low Dependence	High Dependence
	Degree of membership 0.966	Degree of membership 0.691035	Degree of membership 0.6575
Linguistics for CH_4	**Oil operation mode**		
	TestStatistic 5.8428	TestStatistic 7.1508	TestStatistic 6.5444
	P-Value 0.2112	P-Value 0.1281	P-Value 0.1620
	Fuzzy P-Value Linguistics	Fuzzy P-Value Linguistics	Fuzzy P-Value Linguistics
	Low Independence	Low Independence	Low Independence
	Degree of membership 0.5757868	Degree of membership 0.7944763	Degree of membership 0.7052263
Linguistics for CH_4	**Filter operation mode**		
	TestStatistic 5.1981	TestStatistic 15.7591	TestStatistic 4.6808
	P-Value 0.2675	P-Value 0.0033	P-Value 0.3216
	Fuzzy P-Value Linguistics	Fuzzy P-Value Linguistics	Fuzzy P-Value Linguistics
	Low Independence	High Dependence	Medium Independence
	Degree of membership 0.42745	Degree of membership 0.832	Degree of membership 0.464579

In finding the dependence of the three-risk linguistics corresponding to the pollutants (CH_4-NO) for each of the four operating modes of each chainsaw, the "acceleration" mode yielded a significant dependence between the concentration risk linguistics of the two pollutants in the three chainsaws.

High dependence with degree of membership (DOM) equal to 0.966 was recorded between the risk linguistics of CH_4 and NO with the acceleration operation mode when using the catalytic chainsaw.

Moreover high dependence with degree of membership (DOM) equal to 0.832 was achieved between the linguistics of CH_4 and NO with the filter operation mode when using the professional chainsaw. From the other hand medium independence with degree of membership (DOM) equal to 0.6392105 was presented between the linguistics of CH_4 and NO with the normal conditions operation mode when using the professional chainsaw. (see Table 10).

4. Discussion based on raw data values

As it is illustrated in Figure 2, considering the absolute recorded pollutants values, the catalytic chainsaw produced the lowest amount of NO emissions compared with the professional and the amateur saws. Under normal conditions (infrequent accelerator use, good quality oils and clean filter), the control catalytic chainsaw generated the lowest NO emissions followed by the professional chainsaw; on the other hand, the amateur chainsaw caused three times as many emissions as the catalyst. In relation to the operating parameters, the catalytic saw produced the highest emissions when operated with frequent accelerator use; however, when compared with the other two types of chainsaw, it generated the lowest amounts of NO emissions.
In the case of the professional saw, the use of an impure filter considerably affected the increase in the actual raw values of NO concentrations, whereas the amateur saw generally caused the highest NO concentrations, a fact that is closely associated with the use of bad quality oils.

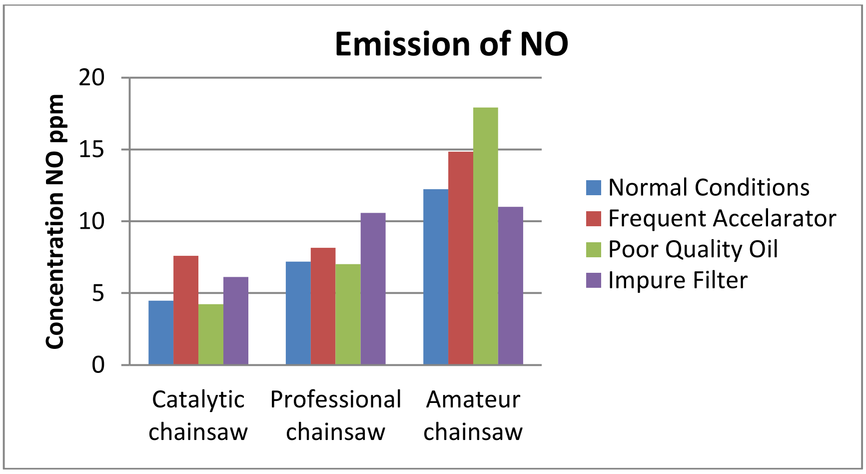

Fig 2. Concentrations of NO in ppm

As it can be seen in figure 2, the raw values of NO emissions are for all three types of saws (catalyst, professional and amateur) and all three operation parameters (frequent accelerator use, poor quality oils and impure filters) below the Permissible Exposure Limit, which equals 25 ppm. Figure 3 shows that, under normal conditions, the professional and the amateur saws produced the lowest methane emissions, but the catalyst saw, under the given operation parameters, generally released the lowest CH_4 pollutants. The highest CH_4 emissions were generated by the professional saw when operated either with poor quality oils or an impure filter.

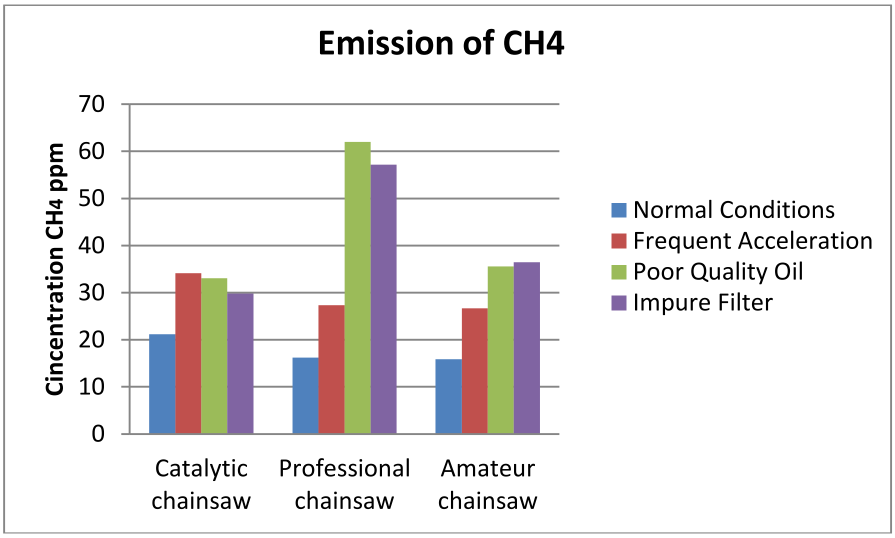

Fig 3. Concentrations of CH_4 in ppm

A catalytic chainsaw produces the lowest NO emissions. These are slightly increased when the saw is operated with frequent accelerator (7.59 ppm) use and impure filter (6.13 ppm), but when compared to the other two saw types, they are lower (the corresponding values for professional saw: 8.15 ppm and 10.57 ppm and for amateur saw are: 14.84ppm and 10.99ppm). However, its performance is not the same as regards CH_4 emissions. These are higher, under normal conditions (21.17 ppm), when compared with the professional (16.22 ppm) and amateur (15.87 ppm) saws. As regards the other operating parameters, in other words when the catalyst saw is operated with frequent accelerator use (34.13 ppm), impure filter (33.03 ppm) or poor quality oils (29.8 ppm), it releases more or less the same methane emissions as a common non-professional saw (26.69 ppm, 35.58 ppm, 36.46 ppm). However, it generates considerably lower emissions than a professional saw when this is used with an impure filter (57.17 ppm) or bad quality oils (62 ppm).

A professional saw, under normal conditions, causes more NO emissions (7.18 ppm) in comparison with a catalytic one (4.48 ppm), but lower emissions when compared with an amateur (12.23). Generally, these results are valid for the other operating parameters, too. As far as methane emissions are concerned, however, the professional saw generates very high concentrations when it is operated with poor quality oils (62 ppm) or an impure filter (57.17 ppm).

A amateur chainsaw produces the highest NO emissions compared to the other two types, both under normal function (12.23 ppm, professional and catalytic saw: 7.18 ppm and 4.48 ppm) or under any operation other mode (frequent acceleration 14.84 ppm (7.58ppm/8.15ppm), poor quality oils 17.91 ppm (4.23 ppm/7ppm) and impure filter 10.99 ppm (6.13 ppm/10.57 ppm). The same is true for CH_4 emissions, with the exception of those cases in which poor quality oils and impure filters are used; in such circumstances the highest emissions are released by the professional saw.-

In particular, the results of the present paper as far as operating parameters are concerned are as follows:
Under normal conditions the catalytic chainsaw produced high CH4 (21,17 ppm) emissions and the amateur saw high NO (12.34 ppm) concentrations. With frequent accelerator use the amateur saw generated high NO (14.84 ppm) emissions and the catalytic saw relatively high CH4 concentrations (34.13 ppm). With poor quality oils there were high CH4 concentrations (62 ppm) released by the professional saw and NO concentrations produced by the amateur saw (17,91 ppm). With impure filter use the results are more or less the same, namely that the professional saw produced high CH4 concentrations (57.18 ppm) while the professional and amateur saws high NO concentrations (10.57 ppm and 10.99 ppm).

5. Conclusions-Future Work

Greece is one of the few European Union countries in which air pollutants emissions are on the rise. NOx levels have increased by approximately 17% while most European countries have managed to reduce their emissions by up to 40% Pelekasi and Skourtos (1992).
NO presence in the atmosphere is generally associated with a great range of respiratory diseases; it is also considered responsible for the production of photochemical oxidation compounds (Gendekakis 2003). Nitrogen monoxide and dioxide can cause severe injury to the tracheobronchial mucosa and respiratory epithelium (Melas et al. 2000).
The methodology that is presented in this paper for the measurement of emissions under actual conditions in the place where the machinery is operated is quite innovative and it could be used in the future as the basis for the development of timber harvesting technologies aiming at reducing the impact both on the environment and man (Lijewski et al. 2013).
All chainsaws showed a significant dependence between the four operating conditions and the Linguistics of air pollutants. High dependence with degree of membership (DOM) equal to 1 was recorded between each of the four operating conditions of the three chainsaws with the NO.
Instead only the catalytic and professional chainsaws showed high dependence equal to 1 with the linguistics of CH_4.
In the case of the “accelerator” there is a strong dependency between the Linguistics of the two air pollutants in all three chainsaws. High dependence with degree of membership (DOM) equal to 0.966 was recorded between the linguistics of CH_4 and NO with the acceleration operation mode when using the catalytic chainsaw. Moreover high dependence with degree of membership (DOM) equal to 0.6575 was achieved between the linguistics of CH_4 and NO with the acceleration operation mode when using the amateur chainsaw. Also low dependence with degree of membership (DOM) equal to 0.691035 was calculated between the linguistics of CH_4 and NO with the acceleration operation mode when using the professional chainsaw. Finally high dependence with degree of membership (DOM) equal to 0.832 was achieved between

the linguistics of CH_4 and NO with the filter operation mode when using the professional chainsaw.

According to the results of the present study, a catalyst chainsaw is recommended as being more environmentally friendly. However, should a conventional saw be used, this ought to be a professional and not an amateur one. Although modern amateur saws have almost the same performance and convenience in terms of operation and maintenance as professional ones, it has been made clear from the measurements conducted in the frame of the present research that they release the highest amount of emissions – mainly NO emissions – both under normal conditions and under the tested operating parameters. However, even today these chainsaws are not considered able to meet the demanding standards of the field of commercial forestry.

When a professional saw is chosen, special emphasis ought to be laid on its operation instructions provided by the manufacturer: its filter should be cleaned frequently and in accordance with the product's specifications and high quality oils should be used.

A future research would involve more air pollutants and more features related to the environmental conditions in the working space. Also additional analysis can be performed by employing supervised Machine Learning (ML) classification (e.g. Artificial Neural Networks, Support Vector Machines) or unsupervised like Self Organized maps or Fuzzy c-means clustering. This would enhance the results and could lead to more rational decisions on how to obtain a better and healthier working space in small- or medium-sized wood processing companies.

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