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ANALYSIS OF THE CARBON FOOTPRINT FOR THE MILLING PROCESS

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Abstract: *This paper aims to compute the carbon footprint in a milling process. The research behind it consists in carrying out four experimental tests. Each test analyses how the carbon footprint is influenced by some of the parameters of the milling process and whether they have a positive or negative impact on both the process and the carbon footprint. In experimental tests, the material used is steel which is milled by a CNC machine, and the* CO_2 *emissions released from the process are measured by a* CO_2 *detector.*

Key words: *carbon footprint, milling, steel, process, experiment, measurements*

1. INTRODUCTION

Nowadays there are more and more constraints regarding the reduction of the carbon footprint. From a global perspective, all efforts are focused on realizing a low-carbon economy and the main objective is to achieve a neutral CO_2 economy [1]. A low carbon economy means that the nations must produce so that the CO_2 emissions level to be as low as possible. Even if most actions are oriented towards other sectors, such as energy and transport, production is also an important sector that emits carbon emissions at a high level [2]. Following the above, the present work focuses on determining the carbon footprint in the milling process and regarding the achievement of this aspect, the work is divided into 4 tests in which the carbon footprint released form the process is analysed. The purpose of this paper is to find out if changing some milling process parameters has an impact on the carbon footprint and also to determine if the parameters present negative or positive impacts on the process.

2. LITERATURE REVIEW

The approach presented is part of a doctoral project targeted at products and processes improvements to reduce CO_2 emissions. In order to study the carbon footprint released from the milling process, there are few papers that drown the research in this way which were found in databases and journals like Science Direct, Technium Social Science, Google Scholar and others.

Paper [3] reveals that the smart choices in the economic systems may increase the economic growth without affecting environmental sustainability. Also, this research highlights the themes which are not so much promoted in the public space, as resilient production, optimal allocation and distribution, reverse technological innovations, and so on.

The following article that provides interesting insights for the elaboration of this paper, is [3]. This paper reveals a strong need of Romania to adapt to all the strategies, which are ongoing. Also, knowing the impact that has a process in an industry on the carbon footprint will help companies to make little improvements in this way.

Another article that led the work in this direction is [4]. In this paper, the authors designed a mathematical model for carbon footprint in a milling process, which tries to extend the results obtained in the experiments from the process level to the industry and nation level.

In the article [5], the authors propose a SPM scheme which collect data about the CO_2 emissions in the industry facilities. So, setting optimal parameters for the scheme they proposed, the costs of producing can be reduced.

Also, in the paper [6] the authors highlights that the green process innovation has a high importance for achieving the global objective to become neutral in terms of carbon footprint.

The novelty of this research is bringing a new perspective about the processes impacting carbon emissions and finding a manner to bring value to this situation in order to reduce the negative impact on the environment.

3. METHODOLOGY

In order to define the carbon footprint of the milling process analyzed in this paper, the authors highlighted several important parameters that should be taken into consideration. The parameters refer to the raw material used in the processing (carbon content of the processed steel), the presence or absence of the coolant emulsion, cutting depth, cutting speed, feed rate, etc., but in this paper, the expert considered to take into account the raw material, feed rate and the presence or absence of the coolant emulsion in the process, the rest of the parameters considered to be secondary. The value of the secondary parameters will be kept constant in this research.

Therefore, the raw material used in the milling process is OLC45 steel and the coolant fluid is Ravenol Bohroel-Konzentrat SH. In order to perform the milling process, the CNC machine named Challenger Microcut MCV-2418, was the machine on which all the research was based. The instrument used for milling was 16 mm front-cylinder milling tool from Guhring.

To measure the contribution of carbon dioxide in the milling process we used a data detector of content, called Air CO_2ntrol 5000 produced by TFA, shown in Figure 1.

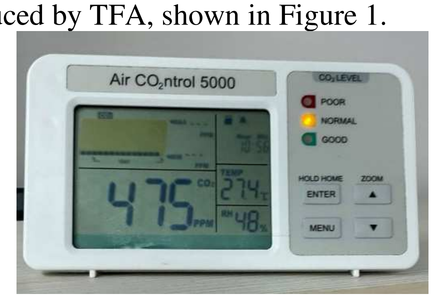

Fig. 1. CO_2 detector

The structure of the research is split in 4 tests, named T0, T1, T2 and T3. In T0, the reference value of carbon dioxide in the laboratory space and the position of the detector were determined, both being essential for the accurate recording of the carbon dioxide values emitted from the milling process. In T1, the research continues with the impact of the feed rate in the milling process of a steel part. In T2, the authors analyzed the impact of the cooler emulsion in the milling process. The final test, T3 reveals the carbon footprint released during a working day in the laboratory space according to the mathematical model of reference value.

4. RESULTS AND DISCUSSION

4.1. T0: Setting the reference value and positioning the CO_2 detector

The first step in this experiment was to establish the reference value of the CO_2 content in the laboratory space, which is an essential step to be able to relate only the values obtained in the milling process. Therefore, this paper focuses on the differences between the values obtained in the milling process and the reference value. In order to be able to determine the reference value, early in the morning, before starting the working day, we measured the values of carbon dioxide recorded in the laboratory space. Accordingly, Figure 2 shows five measurements of reference value, each of them taken in different days. It should be noted that the CO_2 detector records CO_2 values every 5 seconds, so the data recording time was about 5 minutes each day, so at least 60 records of CO_2 values averaged for each day. As can be seen in the figure, on some days we obtained higher values, such as RV2, and on other days, lower values.

Table 1 shows the average of the reference value for each day we collected data and also an average for all the collecting data we performed on all the days. So, the reference value to which we will report all the data we will obtain in the milling process will be calculated with the average obtained for all the measurements performed in Table 1, meaning 451 ppm CO_2.

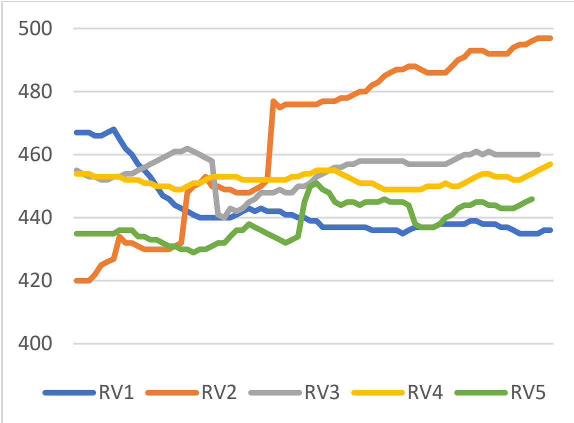

Fig. 2. Reference value

Table 1

Averages of reference values

PARAMETERS	AVERAGE/DAY
RV1	443
RV2	465
RV3	455
RV4	452
RV5	439
AVERAGE	451

Also, in T0, several tests were performed during the milling process in order to define the position of the CO_2 detector. In terms of measuring the CO_2 released in the process, the detector was positioned near the workpiece, as it can be seen in the figure 3. Also, in the figure it can be seen the milling tool from Guhring, which is used in the process.

Fig. 3. First position of the CO_2 detector

Following the milling process of a piece of steel, we noticed a tendency to slow growth of the values of carbon footprint released. Also, the position of the CO_2 detector next to the machined part makes it impossible to measure the carbon footprint when we add the cooling emulsion, given that the CO_2 detector is not resistant in a humid environment.

As a result of these unfavorable aspects, the CO_2 detector was positioned upon the CNC machine. It should be mentioned that to obtain the most accurate values, the CNC machine was covered with a protective film that does not allow carbon dioxide to spread over the entire surface of the laboratory, but only inside the CNC machine. Of course, carbon dioxide is a gas whose spread property is very high, and the team of experts could not isolate the inside of the CNC machine completely.

All things considered, we made a comparison between the values obtained for processing steel without emulsion, depending on the positioning of the CO_2 detector. Figure 4 shows CO_2 data obtained from both processes. So, P1 represents the values recorded in the first test, where the

CO_2 detector was positioned next to the workpiece, and P2 represents the values recorded in the second test, when the CO_2 detector was positioned above the CNC machine. For both situations, the carbon dioxide values recorded exceed the previously calculated reference value.

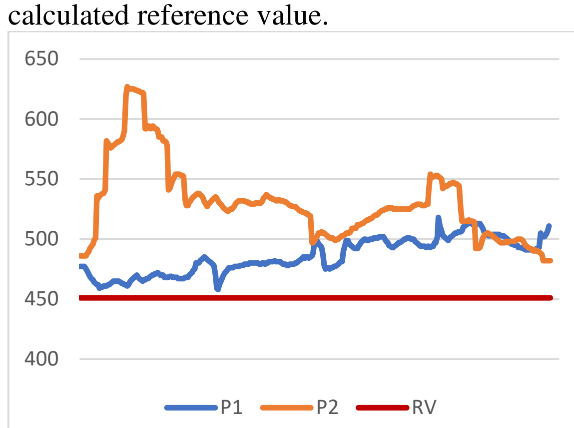

Fig. 4. Both measurements for determining the position of the CO_2 detector

In order to make a better analysis based on the recorded values, we computed an average for all the data obtained for both P`s. According to Table 2, the average values obtained in P1 are

485 ppm CO_2, and in P2 are 529 ppm CO_2. Therefore, the conclusion that emerges from these calculations is that we must take into consideration the position of the detector in order to compare the results we obtain. As the position of the detector result to be a parameter in our study, it has to be the same in future tests. The experts consider that there are two strong reasons for choosing P2 for future tests.

Table 2

Measurements of CO_2 emissions regarding the position of CO_2 detector

POSITION	P`S AVERAGE	REFERENCE VALUE	DIFFERENCE BETWEEN P`S AND RV
P1	485	451	34
P2	529	451	78
DIFFERENCE BETWEEN P`S			44

The first reason is related to the spread of carbon dioxide. As we said previously, the CNC machine does not have a clearly defined surface because is not closed at the top. During the tests, in order to obtain the most accurate carbon dioxide data, the machine was covered with a film, so that the spread of the CO_2 to be in a well-defined space, even if the bottom of the machine is not covered. At the same time, covering the CNC machine, the values recorded by the CO_2 detector cannot be disturbed by other processes that take place in the laboratory. Also, the values obtained in P1 show a linear increase of the values recorded by the CO_2 detector, while in P2 there are large variations of the CO_2 values recorded in the process. In the experts' opinion, this is a fact related to the spread of the gas which is released from top to bottom. While in P1, the CO_2 values are recorded after the gas has been spread inside the CNC machine, in P2, the CO_2 values are recorded instantaneously.

The second reason why the values recorded in P2 are more appropriate in current research is due to the possibilities of using the cooling emulsion in the milling process, thus not affecting the functionality of the CO_2 detector. As I said before, in P1 the cooling emulsion is difficult to use, because the detector must be protected from the liquid so that the recorded data is accurate.

Also, table 2 also reveals the difference obtained between the average of the data recorded in the two processes and the reference value. In P1, the difference of CO_2 released in the process is 34 ppm CO_2 , meanwhile in P2 is 78 ppm CO_2 , more than the doubled value obtained in P1.

In future tests, the experts will analyse the data recorded by the CO_2 detector in P2 and the result will be compared with the reference value 451 ppm CO_2 .

4.2. T1: The impact of the feed rate in the milling process of a steel part

The first analysis performed in this research after establishing the reference value and the position of the detector was to determine the impact of the feed rate on the carbon footprint in the milling process when we use or do not cooler emulsion.

Figure 5 shows four measurements performed in T1 where the first two of them (P1, P2E) maintain the same feed rate and the last two (P3, P4E) are increasing the speed by 50%. As it can be seen, when we increase the speed, the process tends to be shorter. This is the reason why the fourth processes are not equal. Also, the data recorded by the detector when the feed rate was increased, are higher than the others.

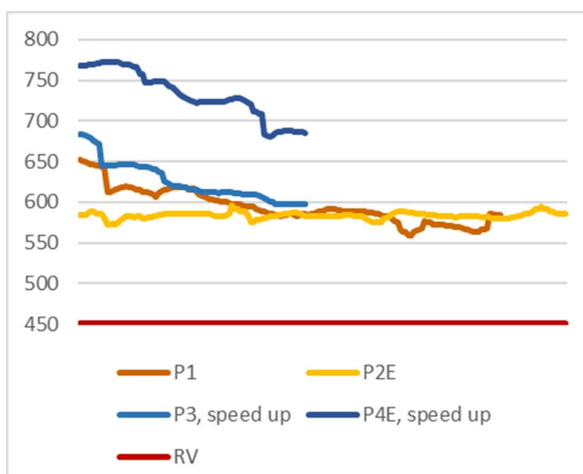

Fig. 5. The impact of the feed rate for carbon footprint

Also, in these four processes, two of them are processes where the cooler emulsion was added in the process, like P2E and V4E. The other two (P1 and P3) are simple processes that do not use cooling emulsion. To be able to compare the data obtained, the authors compute the average value for each process. The result obtained are presented in Table 3.

Table 1

Measurements of carbon footprint in T1

PARAMETERS	AVG	RV	DIFFERENCE BETWEEN AVG AND RV
P1	594	451	143
P2E	583	451	132
P3, speed up	625	451	174
P4E, speed up	732	451	281

As it can be seen, the average values for the first two processes, when the speed is constant, the quantity of CO_2 emitted in the process where the cooler emulsion is added, is lower (P2E<P1). The situation is different when the speed is increased. The process where the cooler emulsion is added in the process emitted more CO_2 than when the emulsion is missing (P4E>P3). The impact of the cooler emulsion will be discussed in the next test. What is interesting to see in these results are the higher differences between values obtained in T1 compared with T0. If in T0, the quantity of CO_2 released, the maxim value was 78 ppm CO_2, in T1 we have values fourth times higher.

This higher difference between tests comes from their complexity. In Figure 6 are presented the workpieces realized in both tests. If in the first test, the process is based only on passing the material with a milling cutter, in the second test the process is more complex and the amount of data the CNC machine has to process is higher.

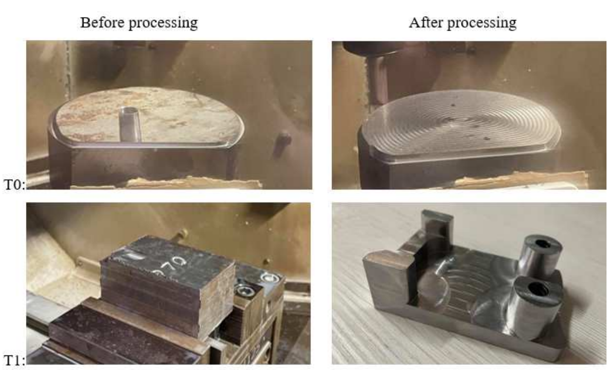

Fig. 6. Both workpieces processed in T0 vs. T1

Some interesting ideas that emerge from these tests are the following: the complexity of the workpiece increases the amount of CO_2 emission and the higher the feed rate is, the higher the quantity of CO_2 emitted in the process is.

Also, in the table 3 it can be seen that the impact of the emulsion in the process becomes more present if the feed rate increases. So, when the feed rate is constant, like in P1 and P2E, the difference between CO_2 emitted is only by 11 ppm CO_2, while the speed is increased by 50%, (P3 and P4E) the difference between CO_2 emitted in the process is 105 ppm CO_2 which is 10 times higher than in the first case.

In order to find out the importance of the cooler emulsion in the milling process, the experts performed the next text, T2.

4.3. T2: The impact of the cooler emulsion in the milling process

Test 2 was performed in order to determine the role of the cooling emulsion in the steel milling process. Therefore, six steel gauges were processed, three of them were processed using cooling emulsion, while for the other three gauges the processing was performed without cooling emulsion.

Figure 7 shows the 3D model of the gauge together with the necessary settings for its processing. To process each gauge, the process took about 15 minutes, whether I used cooling emulsion or not.

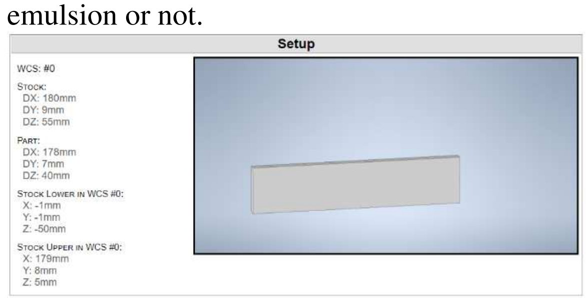

Fig. 7. The 3D model of a gauge

Also, in figure 8 are represented the values of carbon dioxide recorded by the CO_2 detector, during the processing of the gauges. The processing of the gauges was carried out as follows: the first three gauges (gauge1, gauge2, gauge3) were processed with cooling emulsion, and the last three gauges (gauge4, gauge5, gauge6) were processed without cooling emulsion. From the graph, it can be seen that the values recorded for the first three milling processes are higher when the cooling emulsion is used in the processing.

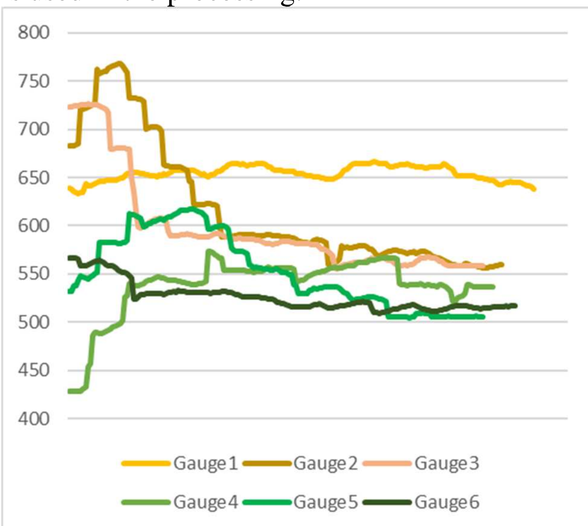

Fig. 8. Recorded data for the steel gauges processing

In order to analyze the previously recorded results, in Table 4 we calculated the average data of CO_2 obtained for the processing of each gauge. Also, to see them in a better perspective, there is computed the difference between the average value obtained and the reference value, in order to obtain the increase of CO_2 that took place in each process.

Table 4

Measurements of CO_2 for the processing gauges

PROCESS	AVERAGE	RV	AVERAGE-RV
Gauge 1	654	451	203
Gauge 2	617	451	166
Gauge 3	597	451	146
Gauge 4	537	451	86
Gauge 5	552	451	101
Gauge 6	526	451	75

The values of the growth of CO_2 in the milling process of the gauge are higher considering that the milling process is not so complex like in T1. As it can be seen, the values are between 75 and 203 ppm CO_2 . In T0, when the experts were proceeding the experiments regarding the position of the CO_2 detector, P2 (the position of the detector was above the CNC machine) has a value of 78 ppm CO_2 . Then, the process was performed without cooling emulsion, like in the T2, for processing the gauges 4, 5 and 6, where the average values are between 75 and 101 ppm CO_2 . So, now it can be seen a pattern in those measurements, that when we measure the CO_2 released for a simple process, without using cooler emulsion, the CO_2 values do not exceed 100 ppm CO_2 . The things change when the cooling emulsion is added in the milling process. So, in T2, when the cooler emulsion is added in the process, the average for CO_2 data obtained in the process are much higher. In this test, the values of CO_2 for processing the gauges 1, 2 and 3, when the cooler emulsion is added in process take values between 146 and 203 ppm CO_2 , greater than at least 50 ppm CO_2 .

Also, another analysis between the first three gauges and the last three gauges can be seen in the following table 5. The authors compute an average between the values obtained in the previous table for the first and the last three gauges. After that, they calculated a difference between the results obtained. The difference is 85 ppm CO_2 , a value which is higher than the lowest value obtaining for the processes where the cooler emulsion is not used. This means that the cooling emulsion in the process has a higher impact for the quantity of the CO_2 emitted in the milling process.

Table 5

Differences between first and last three gauges

PARAMETERS	AVERAGE
Gauges 1, 2, 3	172
Gauges 4, 5, 6	87
DIFFERENCE	85

4.4. T3: Analysis of the carbon footprint after the end of the processes in the laboratory space

In this test, the expert analyzed the amount of CO_2 in the laboratory space at the end of the day, after the processing of materials were done. Therefore, accordingly to the calculation model of the reference values studied in T0, the experts analyzed the increase of reference value in the laboratory space at the end of a working day. Figure 9 shows the five cases studied of the data recorded by the CO_2 detector. The position of the detector was the same as in T0, where the reference values where recorded.

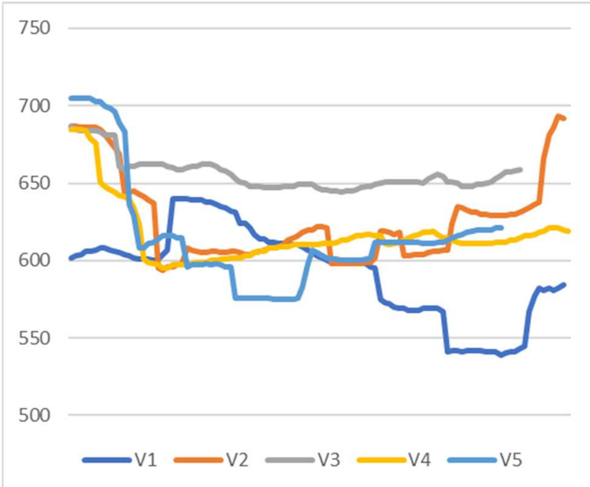

Fig. 9. Recorded data of CO_2 for laboratory space at the end of a working day

In Figure 9, the recorded values are approximately between 500 and 700 ppm CO_2. Also, if we make a comparison between the average reference value obtained at the beginning of a working day and the values obtained at the end of a working day, the amount of CO_2 in the laboratory undergoes very large increases. At the same time, it should be mentioned that when the data recorded took place in this research, the only machine in the laboratory that worked was the CNC machine on which all the experiments were performed. Therefore, the recorded values obtained are quantities of CO_2 recorded only for the processes carried out by our experiment, without suffering errors of other processing processes.

In the table 6 is calculated the average per each measurement performed in T3. The averages obtained in the fifth measurements take values between 592 and 656 ppm CO_2. These values are a lot higher than the reference value of 451 ppm CO_2. In the table is also calculated the increase of CO_2 per each day reported to the reference value. The minimum value obtained from these differences is 141 ppm CO_2, which is higher than other values computed in the milling process. This means, that the CO_2 emissions spread very quickly and easily.

Table 6

Analysis of carbon footprint for the laboratory space at the end of a working day

PARAMETERS	AVERAGE/DAY	RV	FV-RV
V1	592	451	141
V2	625	451	174
V3	656	451	205
V4	616	451	165
V5	615	451	164
AVERAGE	621	451	170

Considering that the recordings during the processes were made in enclosed space (CNC area) and the higher increase was approximately 200 ppm CO_2, the values obtained at the end of the day are considered very large, especially since the area inside the CNC is approximately 7 m2 and the laboratory area is 1800 m2.

5. CONCLUSIONS

In this paper we can emphasize the following conclusion:

- The spread of the CO_2 emissions is released from top to bottom. The position of the CO_2 detector can be count as a parameter for the research given that the impact of it has a large impact for the processed data.
- The feed rate has a strong impact in the quantity of CO_2 released in the process. As the feed rate increases, so do the CO_2 values.
- Also, the complexity of the workpiece has a strong influence on the carbon footprint. So, as the complexity of the workpiece is higher, so does the emissions.
- The cooler emulsion in the process increases the CO_2 emissions released in the milling process. Also, the cooler emulsion doesn't have a linear growth and the results obtained when it used to show large variations in the milling process.
- The capacity of CO_2 emissions to spread are very high and the results obtained doesn't show 100% accuracy.

This paper presents the first trial tests the experts performed for the milling process of the steel. So, the following research directions are as follows:

- Performing another set of tests of carbon footprint analysis to validate the results obtained in this paper.
- Changing the material used in the milling process and tracking its impact on the carbon footprint.

- Developing a mathematical model so that the obtained results can be extrapolated to the level of process, industry, nation.

6. ACKNOWLEDGEMENT

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ANALIZA AMPRENTEI DE CARBON PENTRU PROCESUL DE FREZARE

Rezumat: Această lucrare își propune să calculeze amprenta de carbon într-un proces de frezare. Cercetarea din spatele acesteia constă în efectuarea a patru teste experimentale. Fiecare test analizează modul în care amprenta de carbon este influențată de unii dintre parametrii procesului de frezare și dacă aceștia au un impact pozitiv sau negativ atât asupra procesului, cât și asupra amprentei de carbon. În testele experimentale, materialul folosit este oțelul care este frezat de o mașină CNC, iar emisiile de CO_2 eliberate din proces sunt măsurate de un detector de CO_2.

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