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Technical Inspections of Agricultural Machinery and Their Influence on Environmental Impact

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Abstract: On 20 May 2018, Royal Decree 920/2017, establishing the minimum requirements for the regime of the vehicle technical inspection (ITV in Spanish) to circulate on public roads, entered into force. The new regulations are aimed at ensuring that vehicles in general, and agricultural vehicles in particular, are in proper condition from the point of view of safety and environment. In La Rioja, detailed data are available on the technical inspections performed on agricultural machinery for the last 15 years (2005–2020). The aim of this paper is to analyze the possible effects of technical inspections of agricultural vehicles on their environmental impact. Emissions regulations for this type of vehicle have evolved over the last few years, and as a result, new tractors have better environmental performance. Considering that serious defects detected in vehicle technical inspections can lead the owner to replace the vehicle with a new one, there is a potential reduction in the environmental impact associated with ITVs, as studied in this paper.

Keywords: vehicle technical inspection; agricultural machinery; environmental impact; life cycle assessment

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1. Introduction

European Directive 2014/45/EU indicates the legal framework for the member states regarding vehicle technical inspections (ITV in Spanish) [1]. In the case of Spain, Article 8 of Royal Decree 920/2017, from 23 October [2], regulating the ITV in Spain, determines that for such purposes the technical criteria described in the Inspection Procedure Manual for ITV stations [3] is to be followed. This manual develops the technical criteria to be applied to vehicle technical inspections provided in the current regulations, and is periodically reviewed and updated.

Throughout the years, the manual has advanced in the interest of greater safety and has provided or modified criteria according to the technological progress that society requires. Only when the inspection is deemed favorable is the vehicle's ITV card issued by the ITV station. For this purpose, the manual establishes a classification of defects based on the points and systems inspected and where they are related to the regulatory requirement. Different aspects related to vehicle technical inspections have been widely studied in the scientific literature. For example, Taneerananon et al. analyzed traffic accidents in Thailand and their relationship with defects detected in the vehicles. They concluded that a proper vehicle inspection can be an effective measure to reduce road accidents [4].

However, Hoagland and Woolley suggested that improvement in the reliability and technology of modern vehicles reduces the need for an effective vehicle inspection. To reach to this conclusion, they analyzed the effect of eliminating vehicle inspection in the state of New Jersey and found no significant increase in accidents due to detected vehicle defects [5].

Martín-delosReyes et al. [6] reviewed the existing literature on the effect of vehicle roadworthiness inspections in road accidents. They highlighted the wide variety of results; nevertheless, it was concluded that periodic vehicle inspections are associated with a slight reduction in road accidents.

On the other hand, Hudec et al. analyzed the relationship between vehicle technical inspections and the average age of the vehicle fleet in 10 European Union countries. The conclusions drawn differed greatly depending on the country analyzed. Although for each state the premise remains that the older the vehicle fleet, the higher the number of technical defects found in the inspection, this does not hold similar between countries. In other words, the country with the oldest vehicle fleet is not necessarily the one with the highest number of defects found in inspections [7].

Narváez-Villa et al. developed three artificial intelligence models to analyze and predict the kilometers traveled by a vehicle based on vehicle inspection data. This information that can be useful to propose and revise different policies and regulations in the area of road safety [8].

Alonso et al. analyzed the level of compliance with vehicle technical inspections in Spain and drivers' attitude with respect to this inspection. Although 99.18% of those surveyed complied with vehicle technical inspections, the main reason for it is to avoid possible fines or sanctions. This highlights the need to better convey the importance of the good condition of vehicles to reduce road accidents among the population [9].

Khan et al. highlighted the fact that certain countries do not have the necessary public resources to implement the kind of vehicle regulation and inspection measures that could improve the agricultural vehicle fleet in operation and thus improve the productivity and performance of the agricultural system as a whole [10].

Different studies related to ITV have focused on aspects such as road accidents, age of the vehicle fleet, or drivers' attitude, but none of them have assessed the possible reduction of the environmental impact associated with these vehicle technical inspections.

This article proposes studying the possible relationship between technical inspections of agricultural vehicles and the reduction of environmental impacts.

In the case of agricultural vehicles, there are different emissions standards regulated by the European Union:

- Phase I/II: The regulation of agricultural diesel vehicles took place from 1999 in Phase I and from 2001 to 2004 in Phase II [11].
- Phase III/IV: Phase III for agricultural tractors was adopted in 2005 [12] and entered into force from 2006 to 2013. Phase IV entered into force in 2014.
- Phase V: Phase V was proposed in 2016 and entered into force in 2019 for engines below 56kW and above 130 kW. In 2020 it was enforced for engines between 56 and 130 kW.

The evolution of these emissions standards (see Figure 1) implies that new tractors replacing the ones that do not pass the vehicle technical inspections will have lower emissions and therefore lead to a lower environmental impact.

One of the most widespread methodologies used to assess the environmental impact of any product, process, or service is life cycle assessment [13–15]. Life cycle assessment has been used to study everything from products in the agricultural sector [16–24] to generation systems in the energy sector [25–28], including products in the construction sector [29–32].

The aim of this article is to analyze the possible effect of technical inspections of agricultural vehicles on the environmental impact they generate. Emissions regulations for this type of vehicle have evolved over the last few years, and as a result, new tractors have better environmental performance. Considering that serious defects detected in vehicle technical inspections can lead the owner to replace the vehicle with a new one, there is a potential reduction in the environmental impact associated with ITVs, which is studied in this article.

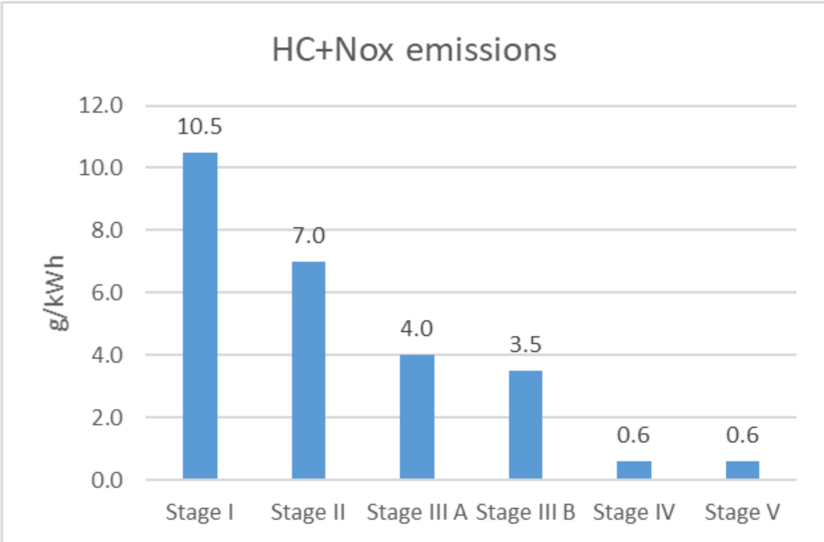

Figure 1. Evolution of NOx + HC emissions standards.

2. Materials and Methods

2.1. Data Collection

Firstly, a collection of the data, provided by the government of La Rioja through the industry service, was carried out. The data collected belong to the 12 ITV stations of the Community, which were provided monthly from January 2017 to December 2020. The data provided establish the type and category of vehicle to be inspected, and according to the classification established by the regulations and the manual (9 typologies of vehicles) and to the defects, were divided into 10 categories.

The vehicle typologies are motorcycles, private passenger cars, other passenger cars, goods vehicles with a maximum authorized mass lower than 3500 kg, goods vehicles with a maximum authorized mass higher than 3500 kg, buses, trailers and semi-trailers, agricultural, and others.

The categories of defects are identification, exterior fittings, bodywork and chassis, interior fittings, lighting and signaling, pollutant emissions, brakes, steering, axles, wheels, tires, suspension, engine and transmission, and others (each category is in turn divided into slight defect (DL in Spanish) and serious defect (DG in Spanish)). Although not all the defect categories have a direct environmental impact, all of them may affect it in different ways. Some have a direct impact (e.g., defects in pollutant emissions) and others have a deferred impact, causing higher fuel consumption and reducing the vehicles' energy efficiency or generating the need to replace the used vehicle with a new one. Therefore, classifying the defects found into categories is relevant.

Based on the aforementioned data, and selecting the type of agricultural vehicles, it was possible to analyze the months and years in which most inspections were conducted, the percentage of rejections as a whole, and years of occurrence. It was also possible to analyze the most common defects and in which category, as well as the percentage of rejections. The data were taken directly from the inspection bulletins filled by the inspectors during the compulsory periodic inspections of agricultural machinery.

On the other hand, data on new registrations for the same periods were also collected.

2.2. Life Cycle Assessment

The IMPACT2002+ [33–35] Life Cycle Impact Assessment (LCIA) methodology was used to assess the environmental impact of the different tractors' emissions. This methodology combines several life cycle assessment methodologies, leading to results in the damage endpoint categories. It facilitates the interpretation of final results in point values (Pt). These points represent the average impact of a European citizen in one year.

Table 1 shows the emissions allowed according to the standards of each of the different phases defined by the European directives. The different vehicle categories are those listed in Article 9 of Directive 97/68/EC, according to the engine installation date:

Table 1. Summary of emissions limits set by the different emissions standards in the European Union.

Category	Net Power	CO	HC	NOx	PM
	kW	g/kWh	g/kWh	g/kWh	g/kWh
Stage I					
A	130 ≤ P ≤ 560	5.0	1.3	9.2	0.54
B	75 ≤ P < 130	5.0	1.3	9.2	0.70
C	37 ≤ P < 75	6.5	1.3	9.2	0.85
Stage II					
E	13 ≤ P ≤ 560	3.5	1.0	6.0	0.2
F	75 ≤ P < 130	5.0	1.0	6.0	0.3
G	37 ≤ P < 75	5.0	1.3	7.0	0.4
D	18 ≤ P < 37	5.5	1.5	8.0	0.8
Stage III A					
H	13 ≤ P ≤ 560	3.5	4.0	0.2	
I	75 ≤ P < 130	5.0	4.0	0.3	
J	37 ≤ P < 75	5.0	4.7	0.4	
K	19 ≤ P < 37	5.5	7.5	0.6	
Stage III B					
L	13 ≤ P ≤ 560	3.5	0.19	2.0	0.025
M	75 ≤ P < 130	5.0	0.19	3.3	0.025
N	56 ≤ P < 75	5.0	0.19	3.3	0.025
P	37 ≤ P < 56	5.0	4.7	0.025	
Stage IV					
Q	130 ≤ P ≤ 560	3.5	0.19	0.4	0.025
R	56 ≤ P < 130	5.0	0.19	0.4	0.025

After 30 June 1998:

- A: 130 kW ≤ P ≤ 560 kW,
- B: 75 kW ≤ P < 130 kW,
- C: 37 kW ≤ P < 75 kW

After 31 December 1999:

- D: 18 kW ≤ P < 37 kW

After 31 December 2000:

- E: 130 kW ≤ P ≤ 560 kW

After 31 December 2001:

- F: 75 kW ≤ P < 130 kW

After 31 December 2002:

- G: 37 kW ≤ P < 75 kW

After 31 December 2005:

- H: 13 kW ≤ P ≤ 560 kW
- I: 75 kW ≤ P < 130 kW

- K: 19 kW ≤ P < 37 kW

After 31 December 2006:

- J: 37 kW ≤ P < 75 kW

After 31 December 2009:

- L: 13 kW ≤ P ≤ 560 kW

After 31 December 2010:

- M: 75 kW ≤ P < 130 kW
- N: 56 kW ≤ P < 75 kW

After 31 December 2011:

- P: 37 kW ≤ P < 56 kW

After 31 December 2012:

- Q: 130 kW ≤ P ≤ 560 kW

After 30 September 2013:

- R: 56 kW ≤ P < 130 kW

Based on the IMPACT2002+ methodology and studying each of the emissions regulated in the different phases of the European directives, the following impacts per gram of emissions were obtained (see Table 2).

Table 2. Environmental impact per gram of emissions according to the IMPACT2002+ methodology.

Impact Categories	Unit	g CO	g HC	g NOX	g PM
Total	mPt	2.62×10^{-4}	1.40×10^{0}	1.30×10^{-2}	5.29×10^{-2}
Human health	mPt	1.03×10^{-4}	1.40×10^{0}	1.26×10^{-2}	5.29×10^{-2}
Ecosystem quality	mPt	0.00×10^{0}	1.05×10^{-5}	4.17×10^{-4}	0.00×10^{0}
Climate change	mPt	1.59×10^{-4}	0.00×10^{0}	0.00×10^{0}	0.00×10^{0}
Resources	mPt	0.00×10^{0}	0.00×10^{0}	0.00×10^{0}	0.00×10^{0}

The IMPACT2002+ methodology considers four damage categories:

- Human health: In the category of damage to human health, the following possible effects are considered from the impact categories: respiratory effects, both organic and inorganic; human toxicity, both for carcinogenic and non-carcinogenic effects; and ozone layer depletion and ionizing radiation.
- Ecosystem quality: In the category of damage to ecosystem quality, the following impact categories are assessed: terrestrial ecotoxicity, aquatic ecotoxicity, aquatic acidification, aquatic eutrophication, terrestrial acidification, terrestrial nitrification, and land occupation.
- Climate change: In this category, only global warming is considered independently.
- Resources: The resource damage category considers impact categories associated with mineral extraction and non-renewable energy consumption.

2.3. Scenario Definition

In order to assess the effect of serious defects on emissions associated with the use of agricultural tractors, different scenarios were established.

2.3.1. Base Case

As a starting point, it was established that 5% of the serious defects detected in technical vehicle inspections eventually lead to the ultimate withdrawal of the tractor and the purchase of a more modern one. This may result in the acquisition of a new tractor (under the latest emissions standard in force) or a used tractor. On average, around 70% of users buy used tractors, whereas 30% would buy a brand-new tractor. This criterion was based on the number of changes of ownership in comparison to the new registrations of this type of vehicle in Spain.

2.3.2. Scenario 1: Increase in Replacement of Vehicles Due to Serious Defects

This scenario considers the possible effect that an increase in the percentage of tractors with serious defects that are replaced by new ones would have on emissions reduction. In this case, 10% is considered, compared to 5% in the base case.

2.3.3. Scenario 2: Increased Purchase of New Versus Used Vehicles

For this last scenario, the 10% replacement of tractors with serious defects is maintained and the distribution of used versus new vehicles is modified. In this case, a distribution of 50% is considered, compared to 70% of used tractors and 30% of new ones in the base case.

3. Results

3.1. Vehicle Technical Inspection

The first analysis was made of a thorough data collection, for the period 2005–2020, to obtain global results and a visualization of all the data from the study period. Table 3 shows the serious (DG) and minor (DL) defects found during the inspections performed on agricultural vehicles.

Table 3. Number of defects classified by category in the period 2005–2020.

Defect Category	No. of Defects
Identification (DL)	14,056
Identification (DG)	7261
Exterior fittings, bodies, chassis (DL)	20,327
Exterior fittings, bodies, chassis (DG)	7619
Interior outfitting (DL)	6
Interior outfitting (DG)	28
Lighting and signaling (DL)	28,599
Lighting and signaling (DG)	21,130
Pollutant emissions (DL)	1
Pollutant emissions (DG)	0
Brakes (DL)	431
Brakes (DG)	892
Steering (DL)	1474
Steering (DG)	803
Axles, wheels, tires, suspension (DL)	3281
Axles, wheels, tires, suspension (DG)	1398
Engine and transmission (DL)	1216
Engine and transmission (DG)	99
Others (DL)	2

The total number of inspections performed on agricultural vehicles in this period was 230,114. The total number of serious defects, leading to a rejection of the inspection, was 40,093. Therefore, the rejection of inspections represented 17.42%.

Minor defects did not in themselves represent a rejection of the inspection; however, they needed to be corrected before re-inspection, otherwise they would be considered serious. The number of minor defects detected during the inspections was 69,393.

A disaggregation of the rejections by type of defect (see Figure 2) shows that more than half of them (52.7%) were related to lighting and signaling, followed by defects in interior fittings, bodywork, and chassis (19.0%) and identification (18%).

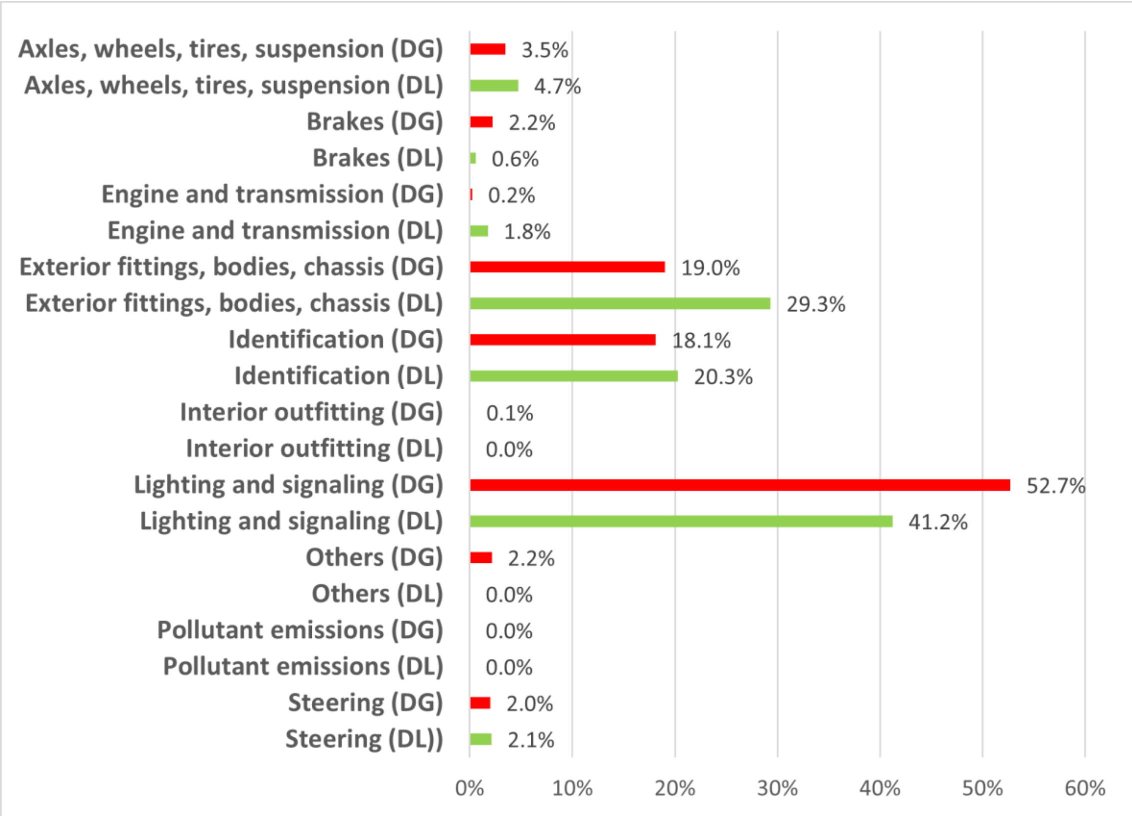

Figure 2. Percentage of serious defects (DG) and minor defects (DL) in 2005–2020.

In regard to the percentage of minor defects (69,393) and the types of defects (see Figure 2), it can be seen that most of them were in the category of lighting and signaling (41.2%), followed by interior fittings, bodywork, and chassis (29.3%) and identification (20.3%).

If these three categories are compared, which accounted for 90% of the defects over the years within the study period (with the exception of 2012 and 2013 for lack of the full data of the period), it can be seen there was an increase after 2005 in the categories of lighting and signaling in both minor and serious defects, with a peak in 2008 and 2009, followed by a decline until 2014 and a subsequent peak in 2018 and 2019 (see Figure 3).

In the exterior body and chassis fittings category, there was also an evolution over the years similar to that of lighting and signaling, with an initial peak in 2008 and 2009, which then declined until 2014, peaking again in 2018 and 2019 (see Figure 3).

With respect to the identification category, the evolution over the years followed a different path, with an upward trend in the first years until 2011 and a stability in serious defects for the last four years of the period (see Figure 3).

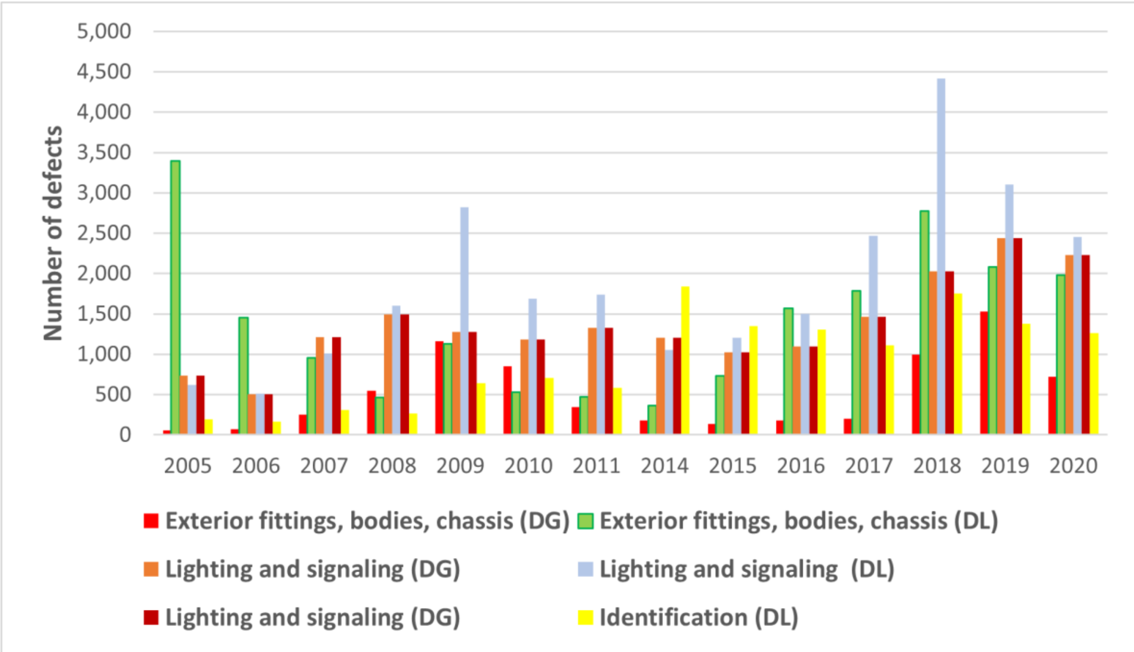

Figure 3. Number of serious (DG) and minor (DL) defects in lighting and signaling, identification and exterior fitting, bodywork, and chassis per year.

In relation to the studies performed monthly, it was found that inspections of this type of vehicle are seasonal—i.e., inspections do not take place every month—and this is due to the fact that the ITV stations are mobile and campaigns are established by municipalities where they move to the municipalities to avoid the displacement of agricultural vehicles as much as possible and make it easier for users to follow the procedure.

Another analysis and its subsequent results was that of the comparison of the categories of serious defects with other types of vehicles. In this case, Figure 4 shows the results obtained and the differences with the categories of private cars and vehicles for goods with a maximum authorized mass higher than 3500 kg.

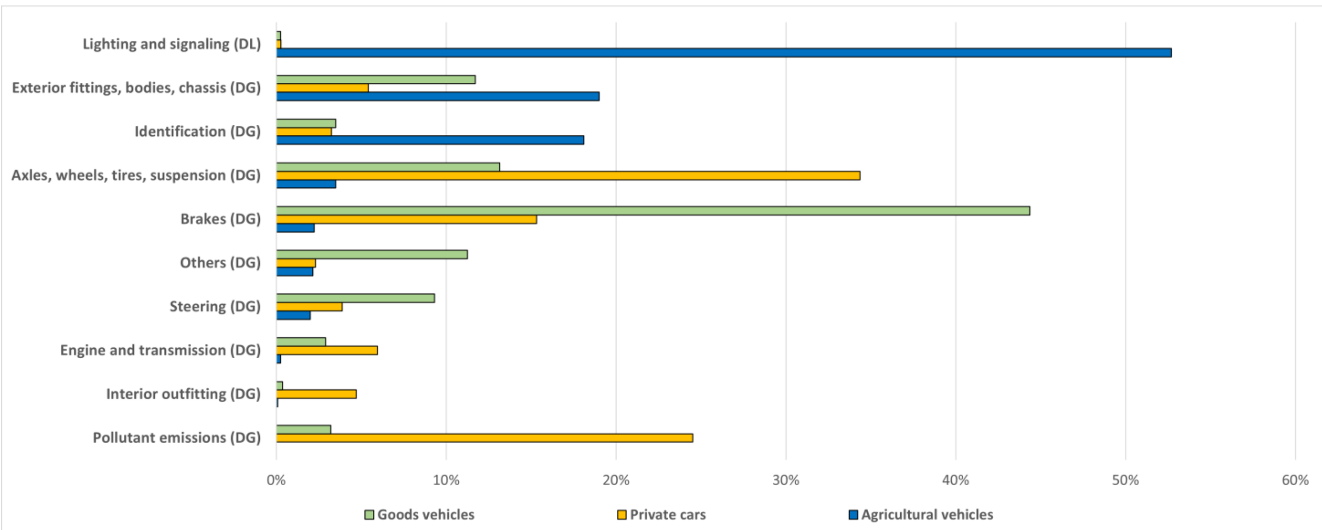

Figure 4. Comparison of serious defects with other types of vehicles.

Figure 4 shows that unlike agricultural vehicles, where most of the serious defects were found in the categories of lighting and signaling; exterior fittings, bodywork, and chassis;

and identification, in other types of vehicles, almost no serious defects were detected in lighting and signaling, very few in identification, and defects in exterior fittings, bodywork, and chassis also had a lower rate.

On the other hand, the maximum number of defects, with 45% of them in goods vehicles with a maximum authorized mass higher than 3500 kg, were found in the brakes category, followed by defects in the categories of axles, wheels, tires, and suspension at 15%, and exterior fittings, bodywork, and chassis at 12%.

In the typology of private cars, most of the defects were found in the categories of axles, wheels, tires, and suspension (35%), followed by defects in pollutant emissions (around 25%) and brakes (15%).

3.2. Environmental Impact

Based on these emissions data defined by the European directives and assuming an average power of agricultural vehicles of 90 kW and about 400 working hours per year [36], the annual impact of the emissions of a tractor was calculated according to the emissions standard to which it complies (see Table 4).

Table 4. Environmental impact of a tractor's emissions according to its emissions standard.

Impact Category	Unit	Stage I	Stage II	Stage IIIA	Stage IIIB	Stage IV	Stage V
Total	Pt	5.37×10^{1}	3.10×10^{1}	1.12×10^{1}	9.84×10^{0}	9.82×10^{0}	7.11×10^{1}
Human health	Pt	5.36×10^{1}	3.09×10^{1}	1.11×10^{1}	9.80×10^{0}	9.78×10^{0}	7.09×10^{1}
Ecosystem quality	Pt	9.04×10^{-2}	5.16×10^{-2}	4.96×10^{-2}	6.07×10^{-3}	6.07×10^{-3}	1.38×10^{-1}
Climate change	Pt	2.85×10^{-2}	2.85×10^{-2}	2.85×10^{-2}	2.85×10^{-2}	2.85×10^{-2}	2.85×10^{-2}
Resources	Pt	0.00×10^{0}	0.00×10^{0}	0.00×10^{0}	0.00×10^{0}	0.00×10^{0}	0.00×10^{0}

Figure 5 shows the progressive reduction of the total environmental impact associated with tractors' emissions according to the emissions standard.

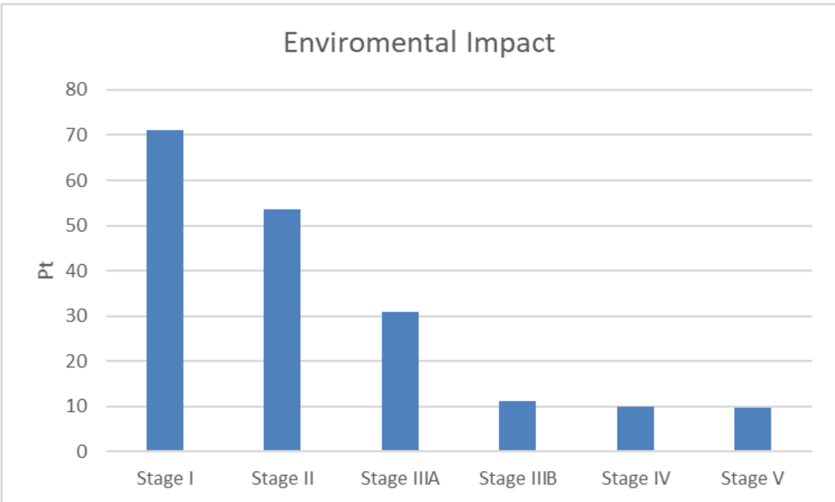

Figure 5. Evolution of the environmental impact of tractor emissions.

The reduction of the environmental impact is clearly noticeable in phases I, II, and IIIA and IIIB, with reductions of 24.41%, 42.36%, and 63.85%, respectively. The following developments resulted in a smaller reduction, with variations of 12.11% and 0.19%.

3.3. Scenarios

Table 5 shows the reduction in the annual environmental impact calculated for each of the three scenarios proposed. The analysis of the base case and the distribution of the different impact categories shows that the Human Health category presented the greatest reduction (-3.88×10^3 Pt, -7.76×10^3 Pt, and -8.89×10^3 Pt in the base case, Scenario 1, and Scenario 2, respectively). This reduction is mainly associated with the reduction in hydrocarbon emissions, at several orders of magnitude higher than the effect of the reduction of NOx or particulate matter.

Table 5. Annual reduction of environmental impact in the three scenarios proposed.

Impact Category	Unit	Base Case	Scenario 1	Scenario 2
Total	Pt	-7.78×10^3	-8.91×10^3	-3.89×10^3
Human health	Pt	-7.76×10^3	-8.89×10^3	-3.88×10^3
Ecosystem quality	Pt	-1.40×10^1	-1.64×10^1	-7.00×10^0
Climate change	Pt	0.00×10^0	0.00×10^0	0.00×10^0
Resources	Pt	0.00×10^0	0.00×10^0	0.00×10^0

In the Ecosystem Quality category, the largest impact reduction (-7.00×10^0 Pt, -1.40×10^1 Pt, and -1.64×10^1 Pt in the base case, Scenario 1, and Scenario 2, respectively) was derived from the reduction in NOx emissions after the HC emissions, with no effect from CO or PM emissions in this category.

Finally, the Climate Change and Resource categories remained unchanged by emissions reductions and therefore did not result in any reduction of environmental impact in any scenario.

A comparison of the results in the different scenarios shows a clear increase in the reduction of the environmental impact when the percentage of tractors with serious defects replaced by new or used ones increases. On the other hand, if a more even distribution of new versus used tractors is considered, a clear improvement becomes evident with the increase in the number of modern tractors complying with the latest EU emissions standards.

4. Discussion

In light of the results of the study, it can be said, as mentioned in the introduction to this document, that the procedure manual is variable and updated almost annually due to changes in technology and social and environmental changes. This means that the values and criteria to define the defects are modified, and thus, there have been fluctuations over the years in vehicle technical inspections [37]. Furthermore, although vehicle technical inspections standards have been increasing, especially for exhaust emissions, they are not homogeneous between different countries and, therefore, make it difficult to perform comparative studies between countries.

Likewise, it has been verified that for each type of vehicle different criteria and parameters are established and given more importance or value. As an example, it was observed how in agricultural vehicles defects due to polluting emissions have no weight or relevance, since there are hardly any defects in this category, compared to private cars, which are quite relevant, and how brakes in heavy vehicles can be compared to those in agricultural vehicles.

At this point, it is safe to infer that lighting and signaling in agricultural vehicles are given special significance, and this may be due to the fact that their visibility and signaling to other vehicles with which they share the road is vital in order to avoid accidents, which generally have serious consequences [38]. For this reason, increasingly, legislation and standards in different countries are establishing specific requirements in these areas that significantly affect agricultural vehicles. As for identification defects, their reason may be due to the age of the vehicles and the loss of documentation, license plates, etc. The defects found in exterior fittings, bodywork, and chassis are largely due to the work and common use of the vehicles themselves.

In some cases, these serious defects found in vehicle technical inspections may lead the owner to consider replacing it with a new or used one, in any case in better conditions.

Considering that agricultural vehicles usually have a fairly long service life, it is reasonable to assume that the new vehicles to be acquired, whether new or used, will be more modern than the vehicle discarded. This modernization of the agricultural vehicle fleet is associated with an improvement in emissions standards along with the evolution of the emissions regulations in the European Union.

Therefore, a relationship can be established between the possible serious defects found in vehicle technical inspections and a possible reduction in emissions from these vehicles in the coming years [39,40]. Although the relationship between vehicle inspections and the reduction of environmental impact is not thoroughly confirmed in the scientific literature [41], this article attempted to highlight the positive environmental effect that vehicle inspections can have.

5. Conclusions

This article analyzes the possible effect of vehicle roadworthiness tests on the reduction of environmental impacts due to emissions from agricultural vehicles.

Analyzing the data of the vehicle technical inspections from 2005 to 2020 in the Autonomous Community of La Rioja (Spain), it can be concluded that in the typology of agricultural vehicles, which were the basis of the study, the lighting and signaling systems have the most serious defects. Likewise, the exterior fittings, the bodywork, and the chassis are elements in which a significant number of serious defects associated with the damage suffered in the performance of agricultural work are detected. Defects in vehicle lighting and signaling are often the cause of major road accidents, leading to increased maintenance costs and a shortening of the service life. Chassis defects—and other major external defects—ultimately reduce the efficiency of agricultural works, which results in higher energy (fuel) consumption and, therefore, a negative impact on the environment.

In order to assess the possible effect of these serious defects on the environmental impact of agricultural vehicle emissions, the IMPACT2002+ methodology was used. Under this methodology, three possible scenarios were analyzed: a base case, in which 5% of serious defects implies a vehicle replacement with a distribution of 70% of used vehicles and 30% of new vehicles; a scenario with an agricultural vehicle replacement of 10% of the serious defects and the same distribution for used and new vehicles; and a third scenario including this same 10% in the conversion of serious defects into new vehicles and a distribution of 50% used vehicles and 50% new vehicles.

The annual reduction in impact calculated for La Rioja (Spain) was -3.89×10^3 Pt, -7.78×10^3 Pt, and -8.91×10^3 Pt in the base case, Scenario 1, and Scenario 2, respectively. Analyzing the different impact categories, the category that underwent the greatest reduction in all scenarios was Human Health, followed by the Ecosystem Quality category, although at different orders of magnitude. The Climate Change and Resource categories did not change in any scenario.

The analyzed results show that vehicle technical inspections and the evolution of emissions limits over the years in the European Union have a clear effect on the reduction of the environmental impact associated with emissions from agricultural vehicles.

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