LCA screening analysis for a robotic treatment alternative to antifungal products in viticulture

ICARO X4 project

Rev_January 2021

Summary

Introduction

The objective of this summary report is to describe the main assumptions and methods adopted for the quantification of the environmental performance indicators relating to the Icaro project. The presented results did not purpose to support comparative assertions and should be considered valid within the scope of the evaluation of the project in question.

In the analysis, reference was made to the requirements and the setting described in the following standards for life cycle analysis:

- ISO 14040:2006 Environmental management – Life Cycle Assessment – Principles and Framework;

- ISO 14044:2006 Environmental management – Life Cycle Assessment – Requirements and guidelines.

The Project was drawn up by Alessandro Manzardo and Elisa Cecchetto of the University of Padua in collaboration with the company Ammagamma S.r.l. (www ammagamma com)

Target

The objective of the study is to quantify the potential reductions in environmental impacts related to the adoption of an innovative treatment system for the protection of vine plants compared to those of traditional techniques based on the distribution of pesticides. We therefore consider the impacts of two processes with the same purposes, but with different consumption and methods.

The traditional treatment consists in the distribution of pesticides diluted in water on the leaf surface of the vine plants; operations are conducted with the help of a diesel-powered tractor, which performs a certain number of steps per hectare of vine according to need. Pesticides are used to stop some diseases caused by fungi - downy mildew, powdery mildew and botrytis - which proliferate in certain climatic conditions (temperature, humidity, wind, etc.) damaging the plants and compromising the harvest. Traditional treatments they are carried out according to intuition or following the indications of the consortia.

UVC treatment (hereinafter: UVC treatment) is the innovative technique that aims to replace the traditional chemical treatments described above. The vehicle used is a hybrid robot - powered by a petrol engine and lithium battery - equipped with two motorized arms with a total of 8 UV emitters. Passing between the rows, the lamps emit UVC rays which hit the leaf surface. The technology is based on the fact that this type of rays (wavelength between 200 and 280 nm) is able to create thymine dimers in DNA, thus damaging the microorganisms underlying the diseases. The frequency of the processing operations is established from a station located in the center of the field, equipped with sensors supported by an energy-powered battery solar.

These sensors collect climate data and, when favorable conditions are identified for the proliferation of microorganisms, they send the treatment start signal to the robot.

The study refers to the seasonal cycles of wine production and the average number of treatments carried out a season for each methodology.

The results are then presented as a comparison of the two methods and answer the question: "What would they be the differences in terms of potential environmental impacts if traditional antifungal treatments were replaced with UVC treatment, considering a single production season? "

The study considers both the treatment phases (traditional and UVC) and maintenance during the time of the various parts of the tractor and the robot.

The study includes the following phases of the life cycle of the processes under consideration:

1. Identification of materials and sources of incoming energy;
2. Identification of the processes related to the treatments;
3. Identification of maintenance and end of life operations.

The study therefore takes into account the system boundaries shown in Figure 1 and Figure 2.

Figure 1 Traditional treatment diagram

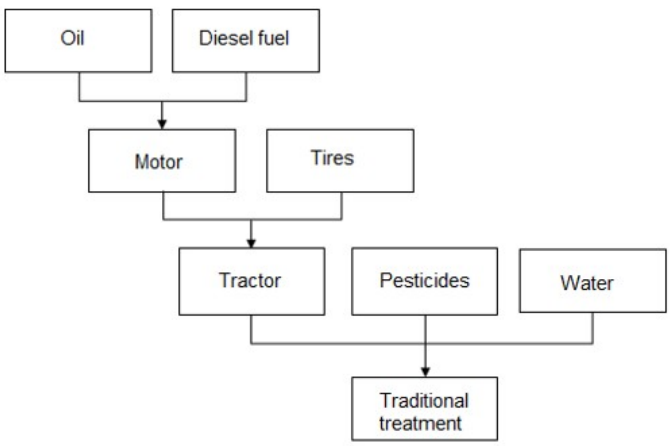
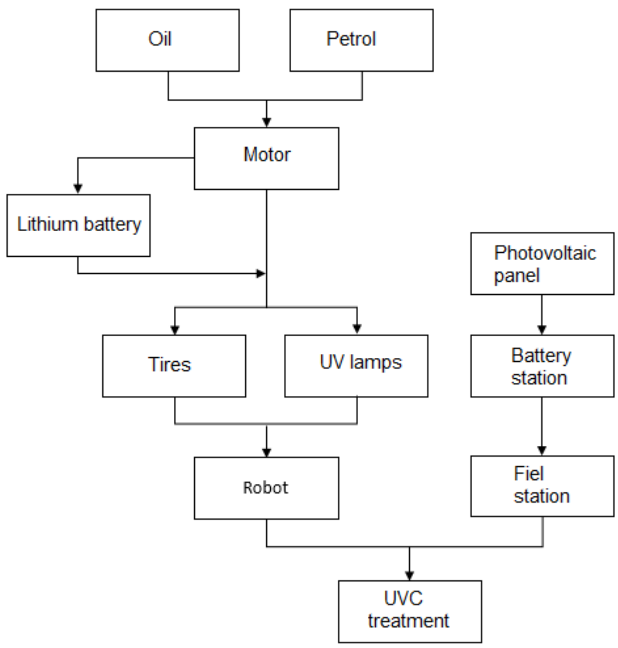


Figure 2 UVC treatment diagram



The system produced is equivalent in both cases and defined as the set of activities useful to complete the total of treatments carried out in a production season of 5 months.

Materials and methods

For the conduct of this study, reference was made, where available, to primary data. Should access to this type of data was not possible, datasets from the Ecoinvent v3 database were taken as a reference and / or other studies published in the scientific bibliography which will be detailed where appropriate.

The study analyzes different categories of environmental impact, listed below:

Category	U.d.m.	Description
Climate change	kg CO2 eq	Climate change can cause negative effects on ecosystem health, human health and well-being material. Climate change is linked to gas emissions greenhouse in the air, for example derived from the consumption of fuels and from agricultural activities.
Ozone depletion	kg CFC 11 eq	This category concerns the depletion of stratospheric ozone, which can have harmful effects on human health, on the health of animals, terrestrial and aquatic ecosystems, biochemical cycles and on materials. The geographical scope of this indicator is on a scale global.
Photochemical ozone formation	kg NMVOC eq	Photo-oxidant formation is the formation of reactive substances (mainly ozone) which are harmful to human health and ecosystems and which can also damage crops. This problem is also referred to as "summer smog". Winter smog does not fall within this category.
Ionizing radiation, human health	kgBq U235 eq	The characterization model used is the one reported in Frischknecht et al, 2000, and represents the potential impact of ionizing radiation on the population, in relation to Uranium 235[1]
Acidification	mol H+ eq	It concerns the acidifying substances that cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems and materials (buildings). A typical source of impact is the emissions associated with the combustion of coal.
Eutrophication Freshwater	kg PO43- eq	Consider the phenomenon of eutrophication, then it includes everyone the impacts due to excessive levels of macronutrients in the environment caused by emissions of nutrients into water and soil (ex. use of fertilizers).
Eutrophication Marine	kg N eq	
Eutrophication terrestrial	mol N eq	
Ecotoxicity Freshwater	CTUe	It includes all the impacts due to emissions into the waters surface of toxic substances for ecosystems. One source typical impact is linked to the use of pesticides in agriculture.
Water use	m3 world eq. deprived	The indicator measures the amount of water remaining in a basin, after the demand for water resources for human and human activities ecosystems was satisfied. Assess the potential for deprivation of the water resource, both for humans and ecosystems, starting from the assumption that the less water is available, the more it is probable that a further user (human or ecosystem) of it be deprived.
Resource Use, energy carriers	MJ	It is a measure of the consumption of non-renewable energy resources. The sources of impact are to be found in the use of fossil fuels and mineral resources.
Resource Use, minerals and metals	Kg Sb eq	

[1] This impact category deals mainly with the eventual impact of low dose ionizing radiation on human health of the nuclear fuel cycle. It does not consider effects due to possible nuclear accidents, occupational exposure nor due to radioactive waste disposal in underground facilities. Potential ionizing radiation from the soil, from radon and from some construction materials is also not measured by this indicator.

The methodology chosen to evaluate the potential environmental impacts of the two technologies object of this study is EF Method (adapted).

Data inventory

Data collection

In order to compile the inventory of the system in question, we started with the collection of data relating to the two methods of treatment. For both, the items relating to consumption and maintenance have been identified and separated (replacements) of the two machines.
The study took into consideration 1 hectare of vineyard which, on average, has 36 rows of 100 m in length each, so in 1 hectare there are 3.6 km of rows.
Both the tractor and the robot take about 1 hour to carry out the treatment of 1 ha and both methods require a single pass per treatment.
For the comparison, the number of treatments foreseen in a single production season, equal to 5, was taken into account months.

Traditional treatment

In the case of traditional treatment, the consumptions related to pesticides and water used for were identified their dilution. Pesticides consist of antifungals, used to fight mildew, powdery mildew and botrytis. This method provides a variable number of treatments per season, from a minimum of 12 up to 40, with a single passed to treatment. In this study, 12 treatments were considered as a precautionary approach; for it for the same reason, a use of water equal to 400 L / season was considered, compared to an estimate of 400-500 L / season.
As for the tractor itself, the periodic change of engine oil and the amount of diesel fuel consumed per hour, therefore per hectare treated. The average life of the tractor and its parts has been estimated at 10 years, based on literature data[2,3].
Finally, maintenance involves the engine, the tires (both of the tractor and the barrel) and the battery. It should be noted that the tractor is used for numerous operations throughout the year, so the data has been reported the number of working hours of the vehicle dedicated to the chemical treatment of the vines (12 h / season).

[2] MOUSAZADEH, Hossein, et al. Life-cycle assessment of a Solar Assist Plug-in Hybrid electric Tractor (SAPHT) in comparison with a conventional tractor. *Energy conversion and Management*, 2011, 52.3: 1700-1710.

[3] LEE, Jaewon, et al. Life cycle assessment of tractors. *The International Journal of Life Cycle Assessment*, 2000, 5.4: 205-208.

Table 1 List of consumptions related to traditional treatment, used in the modeling phase.

Traditional treatment - consumption				
Voices	**value**	**u.m.**	**Note**	**Source**
diesel fuel	6	L/ha	The tractor consumes 6 L / hour	agency
water	400	L/ha	per season,	agency
pesticide	50	Kg/ha	per season, with an average of 4.16 kg / treatment	agency
oli	1	L/season		agency
Total treatments per season: 12				

Table 2 List of units subject to maintenance / replacement in traditional treatment.

Traditional treatment - maintenance					
Voices	**amount**	**average life [years]**	**Note**	**Source amount**	**Source years of life**
motor	1	10		agency	literature
battery	1	10		agency	literature

Treatment UVC

Regarding UVC treatment, data on petrol consumption and oil change were collected. The robot Icaro is a hybrid and uses an internal combustion engine to charge a 6.8 kW lithium battery; while the battery is on charge, the energy produced by the alternator is used to make the vehicle move: therefore, initially, the robot the robot moves thanks to the motor, after which it will have a certain battery life. The battery reaches full it loads after a 5 ha journey and has an estimated autonomy of 2 ha, for a total of 7 ha traveled.

The engine has a consumption of 1.2 L / h at full power, so - assuming, in a realistic scenario, consumption proportional and linear - we have that under normal conditions of use equal to 63.5% of the power (0.420 kW) the consumption is 0.760 L / h. In 5 ha, that is the distance traveled with the engine, there is therefore a consumption of 3.8 L; distributing this consumption over the total distance traveled, which also considers the 2 performed on battery alone, the total gasoline consumption is 0.543 L / ha.

The robot has two vertical motorized arms with 4 UVC emitters each. Each emitter is formed with 8 UVC tubes adjustable in intensity, from a minimum of 6 W to a maximum of 21 W.

Furthermore, the energy used by the battery of the station positioned in the field, which is powered by a solar panel.

The maintenance of the robot includes various items: the lithium battery, the motor and oil, the 4 tires, the emitters, to which are added the station battery and the photovoltaic panel. For each of these parts, as in the case of the tractor, the useful life is considered and that is how many years it is necessary to make replacements due to the normal wear and tear due to use.

Being an experimental technology, it was considered appropriate to carry out impact assessments considering three different possible usage scenarios: one better, one realistic and one worse. The variables related to these scenarios are summarized in Table 3

Table 3 List of consumptions related to UVC treatment and scenarios considered, used in the modeling phase.

UVC treatment - consumption			
Activity items	**value**	**u.m.**	**Note**
petrol	0,543	L/ha	It takes into account the total hectares treated (motorized at 63.5% power + battery only)
Oil change	1,5	L / season	

UVC treatment - usage scenarios		
Scenario	**Number of outputs**	**Power**
Best	25	50%
Realistic	60	65%
Worse	100	100%

Table 4 List of units subject to maintenance / replacement in UVC treatment.

UVC treatment - maintenance			
Voices	**amount**	**average life [years]**	**Note**
photovoltaic panel	1	30	175W, 24V panel; average life: given Ecoinvent
battery station	1	10	
lithium battery	1	12	
motor	1	12	
UVC emitters	8	8,5	Average life from 7 to 10 years, based on use

For the collection of other inventory data, i.e. those relating to the flows of matter and energy as well as to the emissions of the various processes, reference has always been made to the Ecoinvent database.

Modeling

In this phase, a model was created using Ecoinvent databases, updated and recognized at the level international, in order to calculate the impacts relating to the two types of treatment. The databases were appropriately modified in such a way as to reflect as closely as possible the reality described by the company using the data provided.

The main assumptions adopted are reported below.

Table 5 Assumptions adopted in the modeling of traditional treatment..

Traditional treatment	
Phases	**Recruitments**
tractor production	A dataset was used that considers consumption and emissions related to production of a tractor with an average life of 7,000 hours and a weight of 3,000 kg
water	The impacts of well water extraction in Italy were considered

pesticides	A dataset was used that calculates emissions and impacts due to the production of pesticides
impacts of tractor with trailer	A dataset was used to calculate the emissions into the air and into the soil and the production of heat resulting from the work of a tractor with a trailer. Do not consider the transportation of goods. The diesel consumption data provided was used by the company.
processing operation	Simulates the treatment using the data entered on the tractor, water, pesticides and the distance traveled per hectare. The emissions consider those of the tractor with trailer (see above) plus those of pesticides, which have been estimated considering a fictitious pesticide containing 3 antifungal active ingredients against downy mildew, powdery mildew e botrytis (metiram, sulfur and cyprodinil respectively).

Table 6 Assumptions adopted in the modeling of the UVC treatment.

UVC treatment	
Phases	**Main assumptions**
Robot movement	A dataset was used on the impacts of an electric car with a lithium battery
Engine combustion	A dataset on emissions and impacts due to the combustion of a was considered petrol engine. The power and consumption data provided by the company were used.
Field station	Two datasets were used: one for the lithium battery that powers the sensors and one for the photovoltaic panel. Both return the impacts due to production and use of the two elements and have been modified to be aligned with the data provided by the company
Processing operation	Combine the two datasets described above

In the modeling phase of the UVC treatment, the three different scenarios described above were evaluated.

Results

The results of the treatment methodology are reported below for the various impact categories selected traditional (Table 7).

Table 7 Results of the impacts of the traditional methodology relating to 1 hectare for an entire production season.

Impact category	U.d.m.	Tractor use scenario [1ha, 1 season]
Climate change	kg CO2 eq	1003
Ozone depletion	kg CFC11 eq	9.96E-04
Ionising radiation, HH	kBq U-235 eq	106
Photochemical ozone formation, HH	kg NMVOC eq	6
Acidification terrestrial and freshwater	mol H+ eq	9
Eutrophication freshwater	kg P eq	4.81E-01
Eutrophication marine	kg N eq	2
Eutrophication terrestrial	mol N eq	20
Ecotoxicity freshwater	CTUe	7635
Water use	m3 eq. depriv.	90
Resource use, energy carriers	MJ	14657
Resource use, mineral and metals	kg Sb eq	6.73E-03

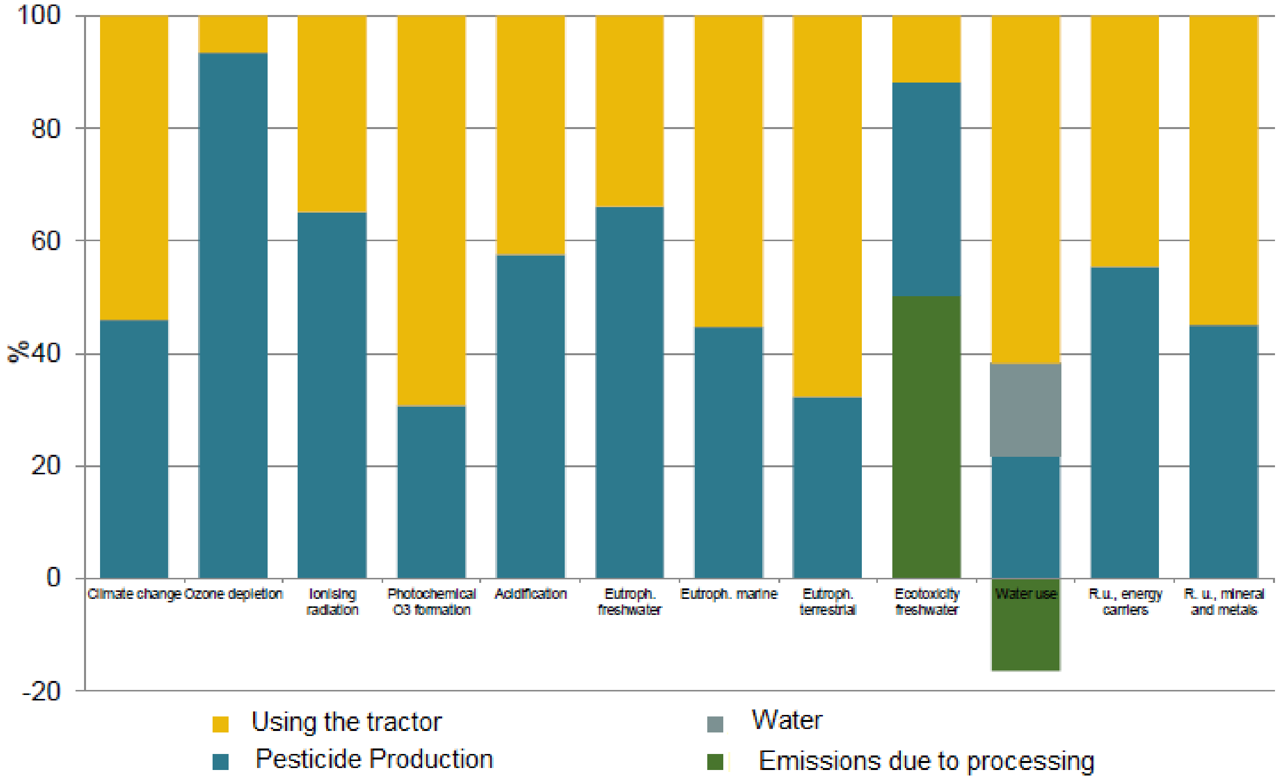


Figure 3 Contribution of the different phases of traditional treatment to the impact categories considered.

As can be deduced, the most impacting phases are those of "use of the tractor" (maximum 69.4% in Photochemical Ozone formation) and "pesticide production" (maximum 93.4% in Ozone depletion), which together represent the major causes of impact on the environment.

The "Emissions due to treatment" phase considers the impacts of the treatment operation, which includes the distribution of pesticides diluted in water on the crop. Precisely because of the products used, this stage has a strong impact on the Ecotoxicity, freshwater category (50%).

It can also be noted that the Water Use category shows a negative value: this is due to the fact that, during the treatment operation, the water taken and used for the dilution of chemicals ("water" phase) comes reintroduced reintroduced into the environment, making the impact on water resources almost nil.

The data relating to the innovative technology based on UVC rays, with the variations, are shown below relating to the three scenarios considered.

Table 1 Results of the impacts of UVC treatment relating to 1 hectare for an entire production season, divided into the three usage scenarios.

Impact category	U.d.m.	Realistic	Best	Worse
Climate change	kg CO2 eq	70	32	157
Ozone depletion	kg CFC11 eq	1.36E-05	5.29E-06	3.28E-05
Ionising radiation, HH	kBq U-235 eq	5	3	11
Photochemical ozone formation, HH	kg NMVOC eq	1.52E-01	8.91E-02	2.96E-01
Acidification terrestrial and freshwater	mol H+ eq	2.46E-01	1.64E-01	4.35E-01

Eutrophication freshwater	kg P eq	1.88E-02	1.79E-02	2.09E-02
Eutrophication marine	kg N eq	3.39E-02	2.39E-02	5.68E-02
Eutrophication terrestrial	mol N eq	3.61E-01	2.45E-01	6.27E-01
Ecotoxicity freshwater	CTUe	26	21	38
Water use	m3 eq. depriv.	17	14	22
Resource use, energy carriers	MJ	960	429	2183
Resource use, mineral and metals	kg Sb eq	6.88E-04	6.82E-04	6.99E-04

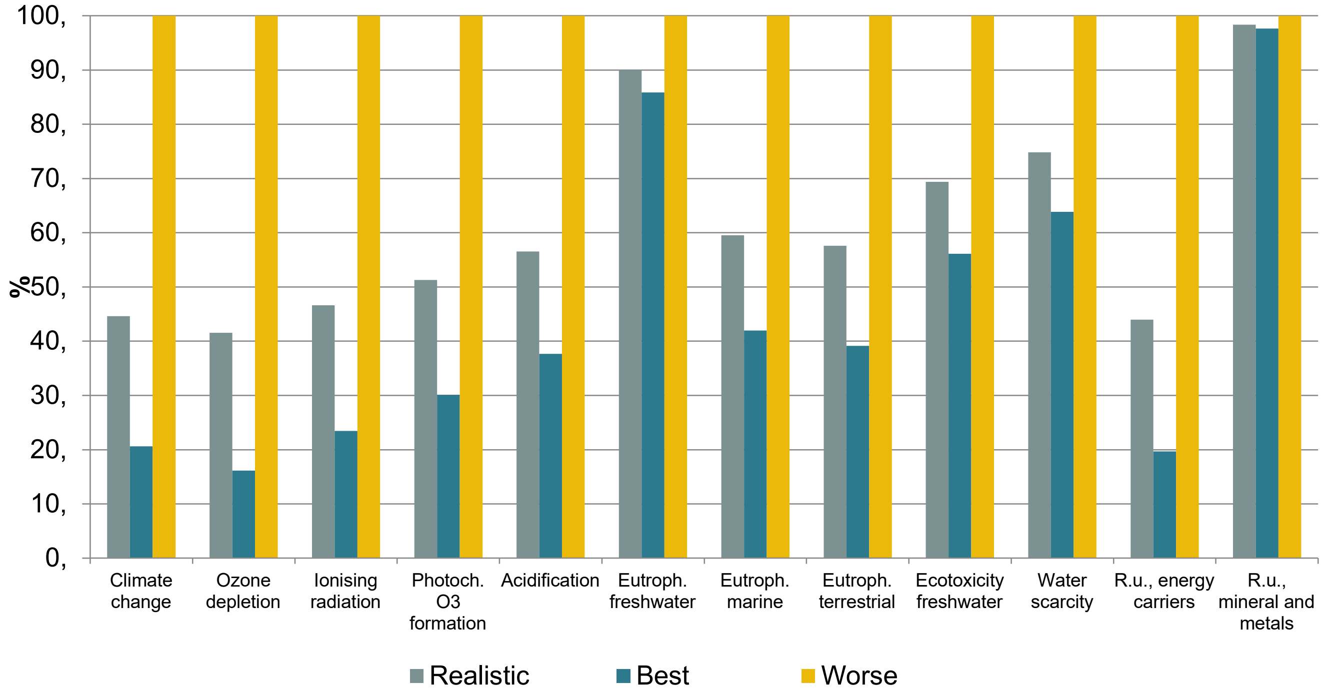


Figure 1 Changes in the impacts in the different categories considered, divided into the three use scenarios..

Figure 4 shows how the modification of the number of treatments and the power used entail considerable impact variations. In particular, the greatest differences are highlighted for the Climate Change, Ozone categories depletion, Ionising radiation and Resource use, energy carriers, mainly due to the different quantities of fuel consumed. Some categories - such as Resource use, minerals and metals – show however, less marked differences between the three scenarios: this is due to the fact that these impacts are not related to operations processing itself, as for the manufacturing operations of the robot components and the field station.

Finally, a table is proposed below which allows you to compare the impacts of the traditional methodology with the realistic scenario of UVC-based technology.

Table 9 Comparison between the impacts of traditional treatment and the realistic scenario of UVC treatment (1ha, 1 season)

Impact category	Unit	Tractor	Realistic UVC scenario	Variation %
Climate change	kg CO2 eq	1003	70	**-93.0**
Ozone depletion	kg CFC11 eq	9.96E-04	1.36E-05	**-98.6**
Ionising radiation, HH	kBq U-235 eq	106	5	**-95.2**
Photochemical Ozone formation	kg NMVOC eq	6	1.52E-01	**-97.5**
Acidification	mol H+ eq	9.47	2.46E-01	**-97.4**
Eutrophication freshwater	kg P eq	4.81E-01	1.88E-02	**-96.1**
Eutrophication marine	kg N eq	2.29	3.39E-02	**-98.5**
Eutrophication terrestrial	mol N eq	20	3.61E-01	**-98.2**
Ecotoxicity freshwater	CTUe	7635	26	**-99.7**
Water use	m3 depriv.	90	17	**-81.6**
Resource use, energy carriers	MJ	14657	960	**-93.4**
Resource use, mineral and metals	kg Sb eq	6.73E-03	6.88E-04	**-89.8**

From Table 9 it is possible to observe how, with UVC technology, impact reductions are achieved by at least 80% in all categories, with a peak of 99% in the Ecotoxicity freshwater category.

One of the main causes of these differences is to be found in the use of fuel: the robot, in fact, being hybrid, has the ability to exploit the energy of combustion longer thanks to the autonomy given by the battery; in addition, the robot does not need energy to transport a trailer, which it does in the case of the tractor with the barrel. This explains much of the differences in impacts due to the use of resources and in those relating to climate change. The second cause is linked to the production and use of pesticides, phases that are totally eliminated in the UVC treatment, with consequent advantages from the point of view of impacts on the environment.

If we instead considered the worst case scenario, then with a number of seasonal releases equal to 100 and one power used by 100%, the variations (shown in Table 10) would still remain above 84% in all categories, apart from Water use.

Table 10 Comparison between the impacts of traditional treatment and the worst case scenario of UVC treatment (1ha, 1 season).

Impact category	Unit	Tractor	Worst scenario UVC	Variation %
Climate change	kg CO2 eq	1003	157	**-84.4**
Ozone depletion	kg CFC11 eq	9.96E-04	3.28E-05	**-96.7**
Ionising radiation, HH	kBq U-235 eq	106	11	**-89.8**
Photochemical O3 formation	kg NMVOC eq	6	2.96E-01	**-95.1**
Acidification	mol H+ eq	9.47	4.35E-01	**-95.4**
Eutroph. freshwater	kg P eq	4.81E-01	2.09E-02	**-95.6**
Eutroph. marine	kg N eq	2.29	5.68E-02	**-97.5**

Eutroph. terrestrial	mol N eq	20	1	**-96.9**
Ecotoxicity freshwater	CTUe	7635	38	**-99.5**
Water use	m3 depriv.	90	22	**-75.4**
RU, energy carriers	MJ	14657	2183	**-85.1**
RU, mineral and metals	kg Sb eq	6.73E-03	6.99E-04	**-89.6**

Analysis of new ICARO variants

During the presentation of the results to the client, the need emerged to evaluate the impacts of 2 other possible ones variants, developed to increase the surface covered by the single machine.

In **variant A** the engine changes as a HATZ 1B50 Diesel engine is installed, but the endothermic engine always works to power the 6.8 kWh battery which acts as storage. The rest of the components remains the same as the base case, i.e. the variant with the petrol engine. In this case the specific fuel consumption was estimated at 807.9 g / ha

The numerical estimates made to calculate the specific fuel consumption are shown below:

- the operation draws on average 80 A for the lamps and 80 A for the traction, while 60 A goes in the 6.8 kWh battery. The overall operation is therefore usually at 220 A.
- In 1 hour, 5.28 kWh are produced, of which 3.84 kWh for lights and movement and 1.44 kWh go to recharge the battery.
- Considering cautiously 0.9 of battery charging and discharging efficiency, of the 1.44 kWh, al vehicle 1.3 kWh are usable again.
- Every hour of operation at 5.28 kW power, the engine has excellent fuel consumption, and consumes 245g / kWh, so in 1h it consumes 1341g of fuel.
- Having stored charge for 20 minutes of autonomy, considering a speed of 4.5 km / h e that 1 hectare of vineyard has 3.6 km of rows, with 1341 g it covers about 1.66 hectares, which corresponds to 807.9 g / hectare

In **variant B**, the petrol engine is always eliminated as a function of a HATZ diesel engine 1B50, but the storage battery is also eliminated. In this case the specific fuel consumption is been estimated at 816 g / ha.

The numerical estimates made to calculate the specific fuel consumption are shown below:

- In this case the operation absorbs on average 80 A for the lamps and 80 A for the traction, while 10 A goes into the service battery.
- The overall operation is therefore normally at 170 A.
- In 1 hour, therefore, 4.08 kWh are produced.
- At that power level the engine consumes 250 g / kWh, so it consumes every hour of operation 1,020 g of fuel.
- Always going at 4.5 km / h, and considering that 1 hectare has 3.6 km of rows, they come in 1 hour treated 1.25 hectares, which lead to a specific consumption of 816 g / hectare.

Both variants were simulated in the worst case, therefore considering 100 passes per season.

Impact category	Unit	Tractor traditional	Worst scenario UVC (hybrid petrol)	Variant A (hybrid diesel)	Variant B (Diesel only)
Climate change	kg CO2 eq	1.00E+03	1.57E+02	3.66E+02	3.70E+02
Ozone depletion	kg CFC11 eq	9.96E-04	3.28E-05	6.73E-05	6.79E-05
Ionising radiation, HH	kBq U-235 eq	1.06E+02	1.08E+01	2.69E+01	2.72E+01
Photochemical O3 formation	kg NMVOC eq	6.02E+00	2.96E-01	1.77E+00	1.79E+00
Acidification	mol H+ eq	9.47E+00	4.35E-01	1.98E+00	2.00E+00
Eutroph. freshwater	kg P eq	4.81E-01	2.09E-02	9.39E-02	9.47E-02
Eutroph. marine	kg N eq	2.29E+00	5.68E-02	5.74E-01	5.80E-01
Eutroph. terrestrial	mol N eq	2.04E+01	6.27E-01	6.26E+00	6.32E+00
Ecotoxicity freshwater	CTUe	7.63E+03	3.82E+01	9.38E+02	9.47E+02
Water use	m3 depriv.	9.03E+01	2.22E+01	6.17E+01	6.22E+01
RU, energy carriers	MJ	1.47E+04	2.18E+03	5.10E+03	5.15E+03
RU, mineral and metals	kg Sb eq	6.73E-03	6.99E-04	5.23E-03	5.28E-03

The traditional treatment remains the most impactful, even when compared with the two new variants considered in the worst case. It should be noted that the transition from a petrol engine to a *diesel leads to an increase in impacts especially in the Climate change and Resource Use - energy categories* carriers, due to the variation in the type of fuel used. Variant B (diesel only) features only slight increases in impact compared to variant A (hybrid diesel).

Conclusions

In the study in question, two methodologies for the defense of vine plants were compared fungal microorganisms: the traditional one, which involves the distribution of chemical products through the use of a tractor, and the innovative one, based on the exposure of the leaf surface to UVC rays by means of a robot with emitters

From the analysis conducted, which took into account the necessary treatment operations in one hectare in the During a single production season, it appears that UVC technology allows to reduce the impacts on the environment compared to the traditional methodology in all the categories considered, above all thanks to different exploitation of fuel and the elimination of chemicals. This is confirmed in all use scenarios considered for UVC treatment, albeit with different impact reductions, or even assuming 100 outings per season at 100% of the useful power.

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