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The Environmental Footprint of Scientific Research: Proposals and Actions to Increase Sustainability and Traceability

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Abstract: In their work, scientists are responsible for stating a purpose, defining experimental conditions, producing data, describing and analyzing these data by statistical means, arguing by comparison with the literature, and drawing conclusions. When a manuscript is submitted for publication, no assessment of the direct and indirect environmental impacts of producing the work is reported. In this context, the aim of our study is to suggest schematic methods to assess, reduce, and mitigate the impact of greenhouse gas (GHG) emissions generated by three different papers (two scientific articles and a conference proceeding) previously published by the same authors. The results reported here show proposals and actions to contribute to the reduction of environmental impacts: a preliminary assessment of the inputs and outputs was initially converted into CO_2 equivalents (CO_2 eq.) and, subsequently, into partial mitigation action through the allocation of the planting of additional plants. Furthermore, real traceability and an opportunity to verify the close connection between initial works (papers and conference book) causing the environmental impact and new green life are suggested. Finally, we propose a new label (*S-Paper to T-Plant*) for eco-friendly guidelines.

Keywords: environmental footprint; scientific research; CO_2 equivalent; mitigate impact; social costs of carbon; traceability

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1. Introduction

1.1. Foreword

As a scientific researcher that works daily ... “I live, I consume, I am, I am a worker; if I am a worker involved in research on climate change, I consume myself.” Therefore, I ask myself the following: “Is everything allowed to me if I work in research on climate change issues as well?” Climate change is a global phenomenon; working as a scientist in a laboratory also contributes to (negative) impacts on a global level through the use of natural resources such as water, energy, and materials, and the production of entropy heat, waste, CO_2, etc. As a scientific researcher working in this field, is everything allowed? Further, are all activities allowable without any prior reflection or analysis of the possible environmental impacts of my actions? For example, is any evaluation between different laboratory analytical methods required? Is all of this markedly imbued with ambiguity and hypocrisy disguised as true and scientific aims? Just because I am a researcher, is everything permissible?

Limitations and restrictions are present today in the ethical field on the use of animal and human organisms. The environmental impacts and downstream implications of scientific research work are not addressed, even when the results are made public (publications, conferences, patents, etc.). Any analysis upstream, during, or downstream of the related environmental impact is omitted. Even more limited are any calculations or quantifications of potential, desirable, necessary, and due environmental relief as forms of mitigation [1].

Although scientists recognize the importance of being more efficient in the use of resources and avoiding the negative impact of the overall research effort [2,3], their work is concerned with outlining the scope, defining experimental conditions, producing data, describing and analyzing these data by statistical means, arguing against the literature, and drawing conclusions. At the time of publication, ethical requirements must be stated and met. Nevertheless, when a manuscript is submitted for publishing, no assessment of the direct and indirect environmental impacts of carrying out the work is reported.

As a rule, in the Section 2, we describe in detail the reagents required, the supporting equipment, and the references. However, at first, there is no critical analysis of the choice between different methods from the point of view of environmental sustainability, consideration of the upstream effects of reagents (production, toxicity, etc.), or consideration of downstream effects in the disposal phase after use. In addition, attention is not given to the consumption of exhaustible environmental resources, such as energy and water, litter (from paper, glass, plastic, etc.), toxic waste, and wastewater. In a globalized world, every human action contributes to the impact on the environment in terms of energy consumption, CO_2 emissions, the use of natural resources, potentially dangerous substances, and waste, so even research works are not excluded, and their effects on sustainable development and climate change should be highly regarded.

Here, we express our position on this matter, and we report proposals that include evaluations of the environmental fingerprint following scientific work (ready to publish) and conference papers. These are not considered as a way to "make peace with it, make penance," but instead are a way to "pay" with activities that are designed to mitigate the negative environmental impact of our previous work damage.

An environmental footprint can be a scientific academic term. Evidence of the impact that a business's activities have on the environment include its resource environment and pollution emissions. Examples include (i) the depletion of natural resources; (ii) noise and aesthetic impacts; (iii) residual air and water emissions; (iv) long-term waste disposal; (v) uncompensated health effects; and (vi) changes in the local quality of life. The environmental footprint cited here by the authors of this paper, although starting from a complex scientific concept, is treated in the existing research as a common environmental footprint and includes the water footprint, carbon footprint, etc.

1.2. Background: The Environmental Impact of Scientific Research (the Context)

The environmental and social implications of climate change depend not only on the Earth's systemic responses but also on impacts generated by human activities [4]. The impacts of such activities influence the planetary boundaries that define the safe operating space for humanity with respect to Earth's system. In particular, the concentration of carbon dioxide is negatively affecting climate change; it increased from a pre-industrial value of 280 ppm to 398.5 ppm in 2015, with a proposed threshold limit of 350 ppm [5].

In fact, the IPCC (*Intergovernmental Panel on Climate Change*) emphasizes the aim of decarbonization of economic processes, and more recently (in 2019), the European Commission adopted the Green Deal with the ambitious goal of achieving climate neutrality by 2050 [6].

While scientific research, which encompasses numerous disciplines, has the task of advancing society, it also causes high environmental costs due to laboratory activities. Indeed, research and the activities of researchers also contribute to greenhouse gas (GHG) emissions and resource consumption [7]. A laboratory, for example, requires a large amount of energy as its consumption per square meter is 5 to 10 times that of office buildings [8]. Some of the most common laboratory equipment in use in scientific research (e.g., fume hoods, ultra-low-temperature freezers, and autoclaves) are, in fact, among the largest consumers of energy [9].

Biological, medical, and agricultural research activities also have an impact on the environment: in 2014, 20,500 institutions engaged in this field produced around 5.5 million tons of plastic waste annually [10]. Regarding research conducted in a university context, Achten et al. in 2013 estimated the carbon footprint of a PhD project to be 21.5 tons of CO_2 equivalents (tCO_2 eq.), of which emissions caused by transport accounted for 75%, conference attendance for 20%, and finally, infrastructure for 5% [3].

The pharmaceutical industry globally generates 55% more carbon than the automotive industry [11]. Healthcare sector research (which includes both hospitals and laboratories) generated a climate footprint of 2 giga tCO_2 emissions in 2019, accounting for 4.4% of emissions globally [12]. A literature study not only highlighted the importance of estimating the C eq. footprint generated by clinical laboratory activities, but it also suggested methods to improve environmental performance [13].

Globally, there are several voluntary (nonprofit) initiatives that encourage the adoption of low-environmental-impact measures in laboratories, such as the International Institute for Sustainable Laboratories (I2SL), S-Labs, and My Green Lab (the latter pathway was undertaken in 2020 by the pharmaceutical company Astrazeneca) [2]. The transition to sustainability by laboratories should include a more responsible approach to science by adopting measures that limit negative externalities on the environment in terms of consumption and pollution. Sharing space and equipment, for example, can save energy (fewer building utilities, less ventilation equipment, etc.), as well as the production, disposal, and transportation of multiple types of equipment and waste at the end of their lives [13].

Research conducted in laboratories that have embarked on low-environmental-impact paths may, therefore, also be more efficient at optimizing the financial resources on which research is based. Optimizing energy and equipment costs means not only having less impact on the environment but also investing in human resources (scientists and researchers) and increasing the quality of scientific production. Funding lines could be directed toward those laboratories that implement ecological standards and, thus, optimize the use of different resources (environmental, human, and financial).

In the context of applied research in the field of biorestoration, sustainable restoration and conservation practices are becoming increasingly popular, not only to contain the effect of climate change on the environment but also to ensure greater operator safety with fewer hazardous products and greater respect for works of art [14,15]. In this sense, the use of more sustainable strategies in the field of restoration stems from the Cultural Heritage reflections inspired by the Venice Charter in 1964. The Strategic Innovation and Research Agenda (SIRA) of the Bio-Based Industry Consortium (2017) also emphasizes the transition toward products and practices that consider environmental, social, and economic aspects [16].

The use of more sustainable experimental approaches is now widely shared by restorers around the world. In a survey conducted in the United States, it was found that more than 60% of restorers believed their working practices were potentially harmful to the environment, with the greatest concern being the use and disposal of solvents, chemicals, and hazardous materials [17].

Today, there are a few studies that use different methodologies for assessing the carbon footprint of research activities. For example, a team of researchers in France developed a tool (open source) to allow laboratories to determine their carbon footprint [18]. A frequently used method is LCA (life cycle assessment) for assessing the life cycle of processes [19]. The scale of analysis also differs. For example, some research has assessed the impacts of departments [20,21], with others assessing those related to conferences [22–24] or individual research projects [3]. In addition, there are a few studies proposing instruments to mitigate the impact of research activities and the technology sector in general [25,26].

Based on this context, we propose an experimental and innovative model to quantify CO_2 emissions and compensate for impacts through the planting of trees with a traceability system (QR code).

1.3. Objective of this Paper

The objective of this paper is to propose a methodological path to carry out a critical analysis of the environmental impacts resulting from both laboratory activities (the results of which are the subject of a scientific publication) and conference proceedings.

This analysis accounts for impacts expressed in CO_2 eq. emissions resulting from the comparison of different laboratory analytical methodologies, instrumentation, the use (or non-use) of chemicals (e.g., reagents), resources (e.g., water), waste production, and energy consumption.

At the conclusion of the assessment, the analysis involves a method for compensating for environmental damage by calculating a conversion calculation for the number of trees to be planted to sequester the quantities of CO_2 eq. emitted into the atmosphere. Knowing the amount of CO_2 eq. emitted is also useful for estimating both the damage and related social costs caused by pollutant emissions and the compensation in terms of carbon credits.

We develop and apply this to real cases with two methodological frameworks for assessing CO_2 eq. emissions in two contexts: laboratory activities (Section 2.1) and a conference proceeding (Section 2.2). Moreover, we propose how to assess, reduce, and mitigate the impacts of the works. We indicate actions to increase the full sustainability of the works carried out using examples of real mitigation tracking and the creation of QR codes linked to planting interventions. Finally, we propose a new label to illustrate the actions described above.

2. Materials and Methods

2.1. Methodological Framework for Assessing Impacts: Scientific Research

We proposed a methodological framework for assessing the impacts of experimental laboratory activities that could be replicated and adapted to different research fields. A step-by-step scheme applicable to laboratory research is shown in Figure 1.

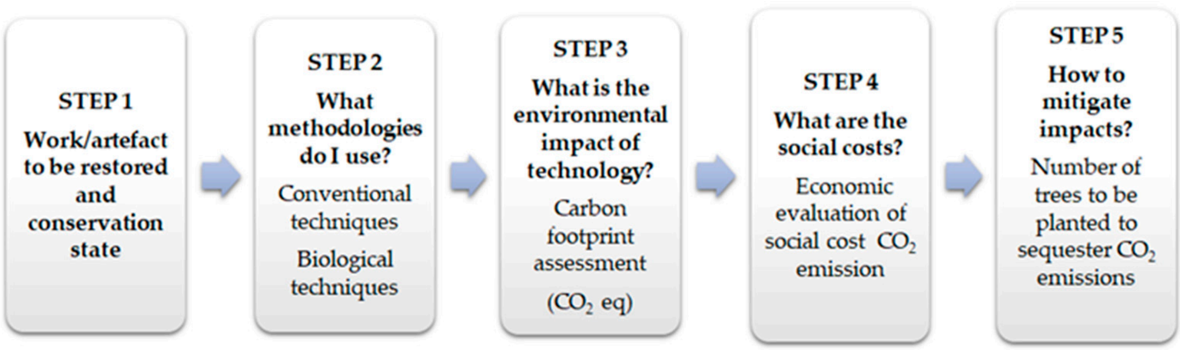

Figure 1. Methodological framework for the evaluation of CO_2 emissions applied to scientific research.

Step 1 was to clarify the objective of the investigation and, in this specific case, the type of work or artifact to be restored and its state of conservation (step 1).

This made it possible to identify the most appropriate restoration and conservation interventions based on the characteristics and problems related to the artifact (step 2).

Step 3 involved assessing the environmental impact of each type of intervention in terms of CO_2 emissions from the consumption of goods and resources and the production of waste (step 3). We considered waste from scientific laboratories (chemical, biological, etc.), which is generally classified as hazardous waste (according to safety standards) and is not suitable for recycling.

For the economic evaluation of CO_2 emissions (step 4), there were two approaches: one was based on the social cost of carbon (SCC), and the other on the market value of emission permits. Specifically, SCC is defined as the marginal cost caused by the emission of one ton of greenhouse gas (carbon dioxide) in one year. This cost also represents the value of damages avoided by reducing or compensating for emissions, i.e., the benefit of reducing atmospheric CO_2 emissions [27]. Ricke et al. estimated that the SCC globally was between United States Dollar (USD) 177 and 805 per ton of CO_2 (tCO_2) (average value of USD 417) [28]. The market value is the price established by the market for emission permits, and, according to the European Climate Exchange, the price ranged from USD 153 per tCO_2 in 2008 to USD 84.01 per tCO_2 in 2022 (January 2022). In this paper, we estimated the social cost of carbon considering EPA estimates (2020) [27] as equal to USD 42 (EUR 40.05 discounted to 2022). This value was multiplied by the CO_2 eq. tons emitted from laboratory activities and from conferences.

Finally, an estimate was made of the number of trees to be planted in compensation for the CO_2 emissions produced by the experimental laboratory activities (step 5).

To make this framework applicable, we proposed a survey sheet (Table 1) useful for the inventory of each identified methodology and the different parameters of laboratory activities, which could be traced to energy consumption, chemicals, equipment, and waste. For each parameter, the unit of measurement and the value taken should be indicated, as this was information that could be translated into CO_2 eq. emissions and was useful for estimating the social costs and the mitigation of impacts in terms of tree planting.

Table 1. Survey sheet for data collection.

Type Consumptions	Evaluation of CO_2 eq. Emission				
	Parameter	Unit	Amount	K Conversion to CO_2	CO_2 Yield (kg)

2.2. Methodological Framework for Assessing Impacts: A Conference

To assess CO_2 eq. conference emissions, a GHG protocol was used in the bibliography [29,30], which differentiated three scopes: GHG emissions from sources controlled by the facility or organization (scope 1); indirect emissions related to energy that was not produced within the structure (scope 2); and finally, other indirect emissions, including travel, catering, and waste generation (scope 3).

From this context, to evaluate the emissions of a conference, we developed a methodological framework divided into four steps (Figure 2).

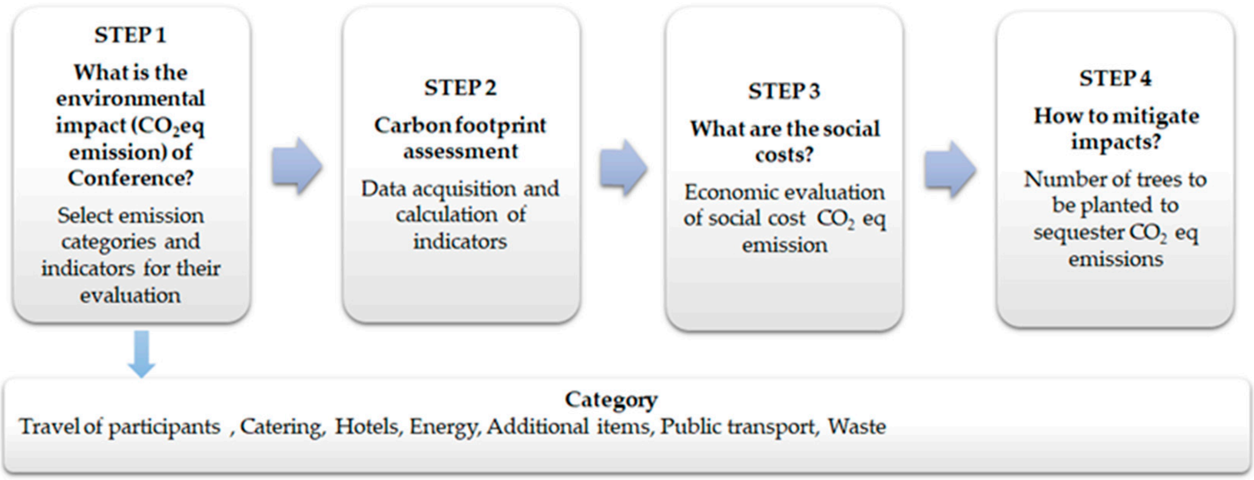

Figure 2. Methodological framework suggested for the evaluation of CO_2 emissions applied to a conference.

Step 1 provided for the selection of impact categories identified by the GHG protocol and related indicators. The selection of these categories depended on the availability of the data underlying the calculation of the indicators.

Step 2 involved quantifying the carbon footprint based on available data. Specifically, according to Table 1, emissions were calculated by multiplying activity data (e.g., passenger travel kilometers, electricity consumption, fuel consumption, etc.) by the appropriate emission factors. The last two steps followed the same methodological procedure described in Figure 1 (Section 2.1). In particular, after estimating the SCC by multiplying CO_2 emissions by the economic coefficient [27] (step 3), we quantified the number of trees to be planted to sequester the CO_2 emitted by the conference (step 4).

3. Results

3.1. Case Studies: Two Scientific Manuscripts Recently Published by the Authors

The results of the application of the above approaches on how to assess, reduce, and mitigate the environmental impacts for two case studies are reported in Tables 2 and 3.

Table 2. Main indicators suggested for calculating the environmental footprint originating from a research activity, impacts, and green mitigation acts. Data applied to a paper by Ranalli et al., 2021 [1], Department of Biosciences and Territory (DiBT), University of Molise, Pesche, Italy.

Type Consumptions	Evaluation of CO_2 eq. Emission				
	Parameter	**Unit**	**Amount**	**K Conversion to CO_2**	**CO_2 Yield (kg)**
Energy (electric power by fossil)	Equipment (instruments, sterile hoods, fans, cooling, sterilization, others).	kWh	600	0.224 [31]	134.40
	Tap water	m^3	12.5	0.32 [32]	4.00
Chemical products	Reagents (dried cultural media; antibiotics, acid and basic solutions, others).	kg, liter	35	1.47 [32]	51.40
	Toxic, hazard (solvents).	kg	2	0.62 [32]	1.24
Wastes	Plastic	kg	20	1.74 [32]	34.80
	Glass	kg	4	0.85 [32]	3.40
	Paper	kg	2	2.42 [32]	4.84
	Effluents	m^3	11.0	0.29 [33]	3.20
Transports personnel and samples/ materials [34] (Bus and Car, diesel)		km	850	0.121 [35]	102.85
CO_2 eq. total emissions (kg)		340.13 (0.34 t)			
Social Costs (€)		13.62			
Mitigation Action [36]	N° of plants to be planted: 4 41°60′74.57″ N 14°26′46.43″ E	Which type (*Ilex aquifolium* L.); when (autumn); where (DiBT, Unimol, Pesche, IT); how (manually); who provides (expert gardeners); control and guarantee of the time (Green Service, DiBT).			

The methodology suggested in Table 2 and Figure 3 is applied to scientific research carried out on both laboratory and onsite scales, published by Ranalli et al., 2021 [1].

(**a**) *Ilex aquifolium* tree

(**b**) QR code by Ranalli et al., 2021.

Figure 3. (**a**) Example of an *I. aquifolium* (var. *argentea marginata*) planted; (**b**) QR code traceability between environmental impact of manuscript [1] and mitigation action by *I. aquifolium* plantation.

3.1.1. Plant Mitigation Actions 1

Plants offer great biodiversity. Supported by botanic experts, we selected the following in case 1:

- *Ilex aquifolium* L. (var. *argentea marginata*) species (called Agrifoglio), belonging to the Aquifoliaceae Family. This is an evergreen tree or shrub that grows up to 10 m tall with shiny, dark green, decorative, variegated foliage that does not renew simultaneously. The reddish-colored fruits provide a decorative contrast to the color of the leathery, spiny-margined leaves on the lower branches of young plants. It contains saponins, the xanthine theobromine, and a yellow pigment, ilexanthine [37]. Nowadays, it is rarely used in herbal medicine due to its toxicity; however, it has diuretic, febrifuge, and laxative properties [38].
- K conversion kg CO_2 eq. to the number of plants, 100:1 [36].

Table 3 and Figure 4 reports data from the same methodology when applied to the scientific laboratory research of Aquilano et al., 2022 [39].

(**a**) *Taxus baccata* tree

(**b**) QR code by Aquilano et al., 2022.

Figure 4. (**a**) Example of a *T. baccata* planted; (**b**) QR code for traceability between environmental impact of manuscript [21] and mitigation action by *T. baccata* plantation.

Table 3. Main indicators suggested for calculating the environmental footprint originating from a research activity, impacts, and green mitigation acts. Data applied to paper by Aquilano et al., 2022 [39], DiBT, University of Molise, Pesche, Italy.

Type Consumptions	Evaluation of CO_2 eq. Emission				
	Parameter	**Unit**	**Amount**	**K Conversion to CO_2**	**CO_2 Yield (kg)**
Energy (electric power by fossil)	Equipment (instruments, sterile hoods, fans, cooling, sterilization, others)	kWh	800	0.224 [31]	179.20
	Tap water	m^3	22.0	0.32 [32]	7.04
Chemical products	Reagents (dried cultural media; antibiotics, acid and basic solutions, others)	kg, liter	50	1.47 [32]	73.00
	Toxic, hazard (solvents)	kg	1	0.62 [32]	0.62
Wastes	Plastic (Petri dishes)	kg	30	1.74 [32]	52.20
	Glass	kg	2	0.85 [32]	1.70
	Paper	kg	2	2.42 [32]	4.84
	Effluents	m^3	20.0	0.29 [33]	5.80
Transports personnel and samples/materials (Car, gasoline) [34]		km	800	0.12 [35]	96.80
CO_2 eq. total emissions (kg)		421.20 (0.421 t)			
Social Costs (€)		17.00			
Mitigation Action [36]	N° of plants to be planted: 4 41°60′75.90″ N 14°26′49.46″ E	Which type (*Taxus baccata* L.); when (autumn); where (DiBT, Unimol, IT); how (manually); who provides (expert gardeners); control and guarantee of the time (Green Service, DiBT).			

3.1.2. Plant Mitigation Actions 2

Plants offer great biodiversity. Supported by botanic experts, we selected the following in case 2:

- *Taxus baccata* L. is a tree of the conifer order, widely used as an ornamental hedge or isolated plant. It is also known as the "tree of death." The active ingredient responsible for the toxicity of branches, leaves, and seeds, where it is present in percentages varying between 0.5 and 2%, is an alkaloid taxin. It has a narcotic and paralyzing effect on humans and many domestic animals. The organs that contain the most of it are the old leaves.
- K conversion kg CO_2 eq. to the number of plants, 100:1 [36].

3.2. Case Study: A Conference

The selected case is a conference titled "Lo Stato dell'Arte 20" (The State of Art20) of the Italian Group of International Institute for Conservation (IGIIC), 13–15 October 2022, at Campobasso, Italy (Table 4 and Figure 5) [40]. The scientific committee decided to collect the extended scientific contributions of the authors in traditional forms, such as an abstract book printed on A4 size paper (24 × 32 cm), all in black/white ink, and only the cover of the book in color. Each volume contains 472 pages, weighs 1.8 kg, and 200 copies were printed [41]. A copy of the book was inserted into a natural textile bag for each participant registered at the conference (more than 100 attended). Flyers on conference communications were printed in color, in A3 format.

Table 4. Main indicators suggested for calculating the environmental footprint originating from the conference titled "Lo Stato dell'Arte20" (The State of Art20), IGIIC, 13–15 October 2022, Campobasso, Italy [40]. DiBT, Università del Molise, Pesche, Italy.

Type Consumptions	**Evaluation of CO_2 eq. Emission**				
	Parameter	**Unit**	**Amount**	**K Conversion to CO_2**	**CO_2 Yield (kg)**
Energy (electric power by fossil)	Equipment (services)	kWh	40	0.22 [31]	8.80
	Toxic, hazard	kg	0	0.62 [32]	0
Wastes	Plastic	kg	5	1.74 [32]	8.70
	Paper b/w (abstract book: 200 copies, 1.8 kg each)	kg	360	2.42 [32]	871.20
	Colored paper (flyer, cover of books)	kg	10	13.60 [32]	136.00
	Effluents	m^3	2	0.29 [33]	0.58
CO_2 eq. total emissions (kg)		1009 (1.01 t)			
Social Costs (€)		40.50			
Mitigation Action [36]	N° of plants to be planted: 11 DiBT, Unimol, IT. 41°60′71.82″ N 14°26′46.28″ E	Which type (*Ostrya carpinifolia* Scop.); when (early winter); how (manually); who provides (expert gardeners); control and guarantee of the time (Green Service, DiBT).			

(**a**) USB key only for Poster Session IGIIC

(**b**) *O. carpinifolia* and QR code Book Conference

Figure 5. (**a**) USB key including only posters presented at the conference *Lo Stato dell'Arte20* (IGIIC, 13–15 October 2022, Campobasso, Italy) [40]; (**b**) QR code traceability between environmental impact of abstract book (conference IGIIC) and mitigation action by *O. carpinifolia* plantation.

Authors that contributed a scientific poster to the conference were invited to send a digital version in advance; the poster discussion was carried out on a digital totem where authors were invited to summarize the aims and the results obtained to date.

In addition, information on local transport, what to see, what to eat, and where to sleep was furnished on separate sheets of paper.

Plant Mitigation Actions 3

Plants offer great biodiversity. Supported by botanic experts, we selected the following in case 3:

- *Ostrya carpinifolia* Scop. is a tree in the family Betulaceae. It is the only species of the genus *Ostrya* native to Europe. It is a medium-sized deciduous tree, which can reach up to 20–25 m tall, with a conical or irregular crown and scaly, rough bark. The wood is very heavy and hard and was historically used to fashion plane soles.
- K conversion kg CO_2 eq. to the number of plants, 100:1 [36].

3.3. Impact of This Manuscript

At the end of the writing of this manuscript, the method described above for how to assess, reduce, and mitigate environmental impacts was applied. Therefore, considering the notes in Tables 1 and 2, we estimated a value of less than 100 kg of CO_2 eq. emissions. An additional *T. baccata* tree was planted in an area adjacent to the previous plants (Section 3.1.2).

3.4. New Label

In Figure 6, a new label that schematizes the *S-Paper to T-Plant* action is reported.

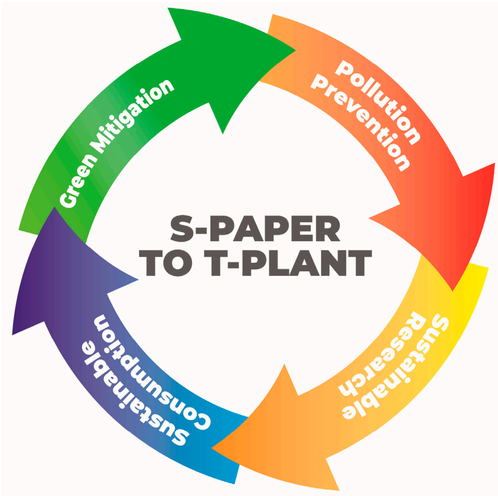

Figure 6. A new label that schematizes the Scientific Paper to Traceability Plant (*S-Paper to T-Plant*) action proposed.

The *S-Paper to T-Plant* action is a proposal to reduce the negative impacts and global greenhouse gas emissions caused by research activities in green, healthy, and environmentally friendly systems.

By putting our research activities on a sustainable path, the *S-Paper to T-Plant* action aims to involve new stakeholders and contribute to accelerating the global transition to a much-needed sustainable new lifestyle. We can contribute to having a neutral or positive environmental impact, helping to mitigate climate change, and adapting to its impacts. This can reverse the loss of biodiversity and preserve the natural ecosystem to ensure natural resources (soil and water) for food security, nutrition, and public health are protected.

Communication is currently an aspect of great importance; communicating clearly and correctly is an added value to communication. We believe that proposing an intuitive logo with text and keywords is a way to reinforce the value of the objectives set.

We hope that the proposed logo can meet at least part of the initial aspirations, and therefore, we believe it is realistic to start a patenting phase.

4. Discussion

In this paper, three examples of the application of the methodological frameworks are described. Two of these are the results of research published by the authors of this paper and relate to laboratory and in situ microbiological techniques applied to a case of dry biocleaning of artworks [1] and to the effect of EOs versus *E. coli* in natural water [39].

The third case was an evaluation of CO_2 emissions and mitigation actions after a conference on scientific activities (printed book) in cultural heritage sectors. This decision was made by a majority vote of the Scientific Committee of the conference, although it was objected to by one of the authors of this paper, who was a member of the same committee.

The results showed that, depending on the techniques used, emissions could vary greatly between sectors. However, in both cases of the research reported [1,31], energy consumption and the transportation of personnel and materials had the largest impacts (Tables 2 and 3). The presence of equipment in laboratories was among the predominant causes of electrical and thermal energy consumption and waste. Such consumption could be reduced by using equipment that is more efficient and by optimizing its use.

Regarding transportation, this referred mainly to field activities in which researchers collected useful information to calibrate, test, and validate methods developed in research.

For the conference, however, what impacted it the most was waste originating mainly from the printing of papers (Table 4). These emissions could be greatly reduced by publishing the conference proceedings online or on digital memory devices (USB keys). Reducing paper consumption could lead not only to a reduction in CO_2 emissions but also in NO_x, CO, and SO_x emissions (responsible for global warming), as well as lower water consumption.

According to the SSC method, the estimated economic costs were EUR 13.60 (USD 14.45) and EUR 17.00 (USD 18.10) for [1,21], respectively; furthermore, the estimated economic cost was EUR 40.50 (USD 43.0) for the IGIIC Conference [40].

To contribute to compensation for environmental damage produced by the emission of CO_2 into the atmosphere as a result of our work, we proposed the planting of new trees.

As cited above (Tables 1–3), the plant mitigation actions were based on the use of a coefficient (K) conversion of 100 kg CO_2 eq. to one plant (i.e., 100:1). This value was fixed, ranging between large interval values, including 80–150, as well as lower and higher values, and was influenced by several factors (type of soil, environmental temperature, rain, etc.), as reported in the literature [26]. In addition, a young (2–3-year-old) broadleaf plant was suggested; this is important because, at ten years, evidence of carbon sequestration equivalent to the amount of CO_2 in woody biomass is confirmed.

Moreover, these trees, which produce oxygen and absorb CO_2 when planted in urban areas, could contribute several further benefits: (i) they remove particulate matter (PM_{10}) emitted by anthropogenic activities; (ii) they regulate the local microclimate and mitigate the heat island effect that occurs on summer days with high temperatures; and (iii) the QR code labels on each tree informs people about the frontiers of knowledge being explored by research activities in several fields at local academic institutions.

A further advantage is contributing to sensitizing people to the environmental impact of our daily activities and increasing respect for environmental resources, nature preservation, and conservation.

This same model and path could then be followed by other public and private entities.

The costs of these mitigation and traceability activities need to be foreseen at an early stage of project drafting and budgeted and accounted for in the financial plan. Therefore, in the final phase, the budget can be accounted for as an expenditure item (expenditures).

The examples described above are not limited cases. In fact, at the request of the paper's authors, a new, structured initiative is being launched at the DiBT, University of Molise, with the identification of a green area (*Green Park*) in the neighboring area for the planting of additional plants to contribute to the mitigation of the impact of scientific works produced annually by researchers belonging to the same organization.

A new model of a departmental forest is being created to which researchers may adhere, initially on a voluntary basis and, subsequently, on a mandatory basis. For this proposal, the Council of the Department of Biosciences and Territory already gave a preliminary favorable opinion at its meeting in December 2022, followed by confirmation in February 2023.

Finally, it is important to remark that these environmental impact assessment activities must involve specialists from many disciplines (chemistry, biology, agronomy, botany, forestry, economics, and others).

5. Conclusions

In conclusion, in this study, we proposed schematic procedures and models for how to assess, reduce, and mitigate the greenhouse gas (GHG) emission impacts generated, for example, by three different previously published works (two scientific papers and one conference), which were well-known by the authors.

In addition, the analysis included a method of compensating for environmental damage through a conversion calculation for the number of trees to be planted to sequester the amount of CO_2 eq. emitted by a scientific work. This point of view should be considered as an initial and partial contribution to compensate for and mitigate the negative environmental impacts caused by conducted work.

The additional innovative content of this work is to help raise awareness of the impacts in terms of CO_2 emissions from the world of research and, in addition, to suggest mitigation actions with traceable plantings, not only locally but also globally. Examples of direct traceability between scientific papers and plants were given, with a new label (*S-Paper to T-Plant*) as sustainable environmental guidelines.

A new Green Park model linked to a department's scientific activities is being created to become a real reference for other communities.

We are aware that a comprehensive assessment of the environmental impacts caused by businesses and economic activities includes the analysis of more environmental parameters and areas.

The limitations of this research may be the quality and quantity of the input data on the types of consumption from research activities and conferences. A systematic collection of different types of consumption could allow a more precise estimation of CO_2 emissions and their mitigation.

We are truly convinced that the results presented here represent a small, new contribution to raising awareness of the need for greater respect for limited environmental resources, even on the part of those involved in research.

We hope that, even in the field of research, for both the upstream and downstream effects of experiments and publications, there will be a greater focus on environmental issues, with the inclusion of a final paragraph in the text of this manuscript regarding these aspects.

The proposal fits fully with the actions of the European Green Deal and Agenda 2030 for Sustainable Development, which suggest actions to reduce anthropogenic impacts on the environment.

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