sustainability

MDPI

Article

Hemp Seed Production: Environmental Impacts of *Cannabis sativa* L. Agronomic Practices by Life Cycle Assessment (LCA) and Carbon Footprint Methodologies

Enio Campiglia [1], Laura Gobbi [2], Alvaro Marucci [1], Mattia Rapa [2], Roberto Ruggieri [2] and Giuliana Vinci [2,*]

1 Departament of Agriculture and Forest Sciences, Tuscia University, Via San Camillo de Lellis snc, 01100 Viterbo, Italy; campigli@unitus.it (E.C.); marucci@unitus.it (A.M.)

2 Departament of Management, Sapienza University of Rome, Via del Castro Laurenziano 9, 00161 Rome, Italy; laura.gobbi@uniroma1.it (L.G.); mattia.rapa@uniroma1.it (M.R.); roberto.ruggieri@uniroma1.it (R.R.)

* Correspondence: giuliana.vinci@uniroma1.it

Received: 17 June 2020; Accepted: 6 August 2020; Published: 13 August 2020

check for updates

Abstract: This paper evaluated the environmental impacts of different agronomic practices for a hemp seed crop grown in Mediterranean environment. The following agricultural variables have been considered: seven monoecious hemp varieties(Epsilon68 (E68), Fedora17 (F17), Felina32 (F32), Ferimon (Fe), Futura75 (F75), Santhica27 (S27), Uso31 (U31)), three plant densities (40, 80, and 120 plants m^{-2}), and two levels of nitrogen (N) fertilization (50 and 100 kg ha^{-1} of N). Life cycle assessment (LCA) and carbon footprint (CF) methodologies have been applied to evaluate impacts. In all hemp genotypes, the impacts grew by decreasing both N fertilizer and plants densities. The scenario most impacting was E68/F75/S27 genotypes cultivated with 50 kg ha^{-1} of N fertilizer and 40 plants m^{-2}, while the lowest one was Fe with 100 kg ha^{-1} of N fertilizer and 120 plants m^{-2}. The highest CF was found for E68/F75/S27 cultivated with 50 kg ha^{-1} of N fertilizer and 40 plants m^{-2} (18.720 kg CO_2 eq). This study highlighted the most environmentally sustainable agronomic practices to support farmer and decision maker in *Cannabis sativa* L. cultivation for seed production.

Keywords: industrial hemp; environmental impact; farmer practices; hemp seed cultivation; LCA; carbon footprint

1. Introduction

Cannabis sativa L., also named hemp or industrial hemp, has been cultivated in all continents for centuries for food, textile fibers, and medicine aims [1,2]. However, during the 20th century the increasing use of cotton and synthetic fibers [3] and the prohibition of hemp cultivation in many countries, due to the Δ9-tetrahydrocannabinol (THC) content, which is a psychotropic substance, led to a decline in industrial hemp cultivation. Nowadays there is a renewed interest in hemp growing because the European Union reintroduced the legal cultivation of industrial hemp with a THC content lower than 0.2% [4,5].

Even though the industrial hemp has been traditionally grown in Europe for fiber production [6], there is an increasing interest in hemp cultivation as a multipurpose crop. In fact, hemp products can find application not only in the textile sector, but also in innovative areas such as building, cosmetics, biofuels, and even food [7,8]. In food sector, hemp is usually cultivated to obtain edible seeds that can be consumed as such or from which oil and protein cake are extracted.

Hemp seeds have high nutritional value, due to their protein composition and unsaturated fatty acids presence (ω–3, ω–6) [9]. The large use of hemp seed as food source is very recent, therefore there is a lack of agronomic information to support hemp cultivation, such as genotype choose and cultivation management [10]. In literature, monoecious varieties are reported as the best choice for seed production [11], while a wide range of agronomic techniques are indicated.

Several studies recommend using few inputs during industrial hemp cultivation. In fact, phosphorus and potassium fertilizations seem to have a very limited effect on biomass and seed yields [12], while nitrogen addition shows significant results only in low-medium doses [13,14]. Weed control is usually not necessary due to its fast growth after emergence; moreover, there is the possibility to grow industrial hemp in rained conditions [6]. Starting from these conditions, hemp seems to be classified as a sustainable crop [15].

Despite this, the agri-food sector is one of the most environmental impacting and it is second only to the petrochemical sector. The major negative outputs are related to agricultural practices, such as greenhouse cultivation, irrigation, and fertilization [16]. For this reason, it is necessary that the entire agro-food chain becomes more sustainable, from the responsible choice of raw materials up to the correct disposal of production residues or their reuse in other processes.

The aim of this paper is the evaluation of environmental impacts of different agronomic practices for an industrial hemp seed crop. Several agricultural variables have been considered as: cultivar, sowing density, and fertilizers, according to reference experimental scenarios [13]. In particular, seven hemp varieties (Epsilon 68, Fedora 17, Felina 32, Ferimon, Futura 75, Santhica 27, and Uso 31), three different plant densities (40, 80, and 120 plants m^{-2}) and two different levels of nitrogen fertilization (50 and 100 kg ha^{-1} of N) have been considered. Moreover, the environmental impact of 42 scenarios has been evaluated, coming from the combination of all the variables investigated (varieties, plant density, and nitrogen fertilization).

Therefore, this study has the purpose to identify the best agriculture practices for hemp seed production with the lowest environmental impact. To evaluate the hemp seed environmental impacts, two tools for sustainability evaluation have been chosen: life cycle assessment (LCA) and carbon footprint (CF). The first is referred to two voluntary ISO [17,18] and its application can make the results comparable with other studies. Carbon footprint is also referred to an international standard [19] and it communicates in CO_2 equivalent the total greenhouse gas emissions directly or indirectly associated with a product or service [20].

At the best of our knowledge, there are just a few articles that deal with LCA of hemp products, and not one for hemp seed production as a food source [21–23]. A study has evaluated the impacts related to the industrial hemp cultivation for fiber production [21]. Instead, another study described the impact assessment of industrial hemp for non-wood paper pulp [23]. Moreover, an LCA evaluation of thermal insulator hemp material has been carried out with a "from cradle to gate" approach [22]. Therefore, the environmental sustainability evaluation herein reported can highlight the impact of different farming practices (cultivar choice, plant density, and dose of nitrogen fertilizer) concerning to the industrial hemp cultivation for seed production in the Mediterranean environment. In this study, a cradle-to-factory gate analysis was considered, because hemp seed can be the raw material of many industries. Moreover, this is the most used approach for seed crops [24].

2. Materials and Methods

2.1. Life Cycle Assessment

The standard life cycle assessment methodology was applied to the cultivation of hemp seed for food purposes. The LCA is becoming the standard tool for environmental impact assessment, driving the choices of producers and consumers. The ISO 14040–14044 highlight that an LCA study should comprise four phases [17,18].

Goal and scope definition: in the first phase of the study, the LCA expert formulates and specifies the objective and the field of application of the study based on the motivations and the recipients of the LCA [25]. In this paper, environmental impacts of hemp seed production were analyzed by assessing the agronomic practices used in an experimental field. All data used for the LCA and CF calculation coming from a previous study [13]. For more details concerning the agronomic experiment, such as soil type, weather, location, period, and differences between seed varieties, reference is made to previous work [13]. The experiments have been conducted in a Mediterranean environment in central Italy. The aim of the experimental field was the assessment of hemp yield, in terms of stems, inflorescences, and seeds, by changing genotype, plant density, and N fertilization. Seeds are the only food products of hemp cultivation; therefore, the sustainability evaluation was herein proposed exclusively for hemp seed production.

The functional unit used for LCA was 1 kg of seeds produced. The system boundaries are reported in Figure 1, a cradle-to-gate approach was herein applied. Hemp seed (as other seeds) can be the raw material for other industrial processes, therefore the system boundary was fixed at the factory gate, as reported in other studies [24].

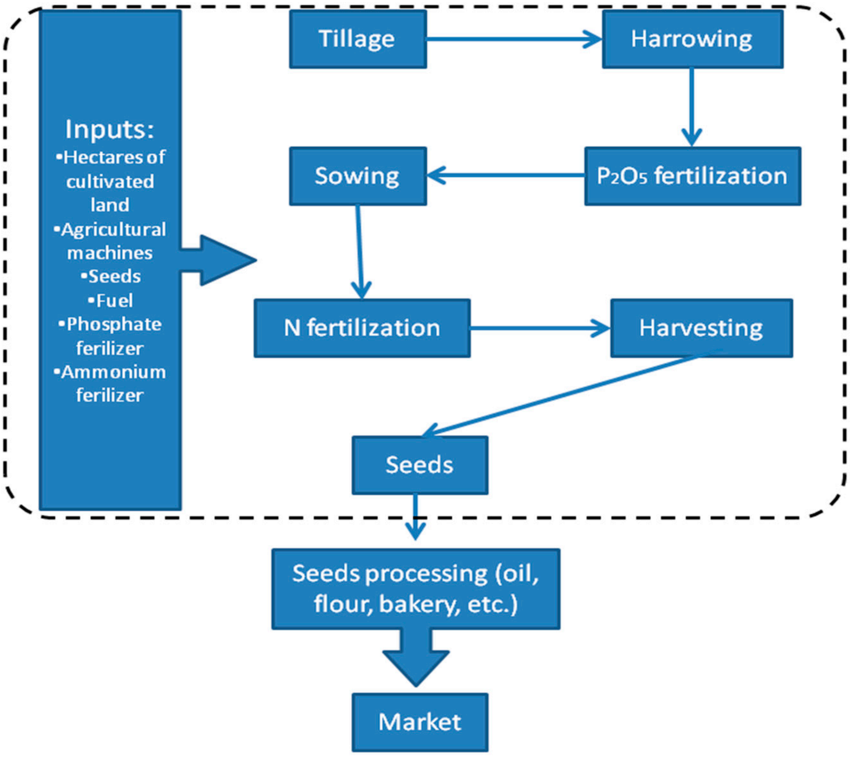

Figure 1. System boundaries for Cannabis Sativa L. cultivation for hemp seed production.

Life cycle inventory (LCI): the second phase involves the modeling of the product system, data collection, as well as the description and verification of data [25]. In the agriculture practices evaluation, herein proposed, the following practices have been considered:

(i) seven industrial hemp varieties [Epsilon 68 (E68), Fedora 17 (F17), Felina 32 (F32), Ferimon (Fe), Futura 75 (F75), Santhica 27 (S27), and Uso 31 (U31)];
(ii) three different plant densities (40, 80, and 120 plants m^{-2});
(iii) two different level of nitrogen fertilization (50 and 100 kg ha^{-1} of N) [13].

Life cycle impact assessment (LCIA): the third phase is aimed at assessing the contribution that the product makes to the individual categories of impact, such as global warming, acidification, etc. [26]. In the impact's calculations, the categories, according to Re.Ci.Pe. 2016 method, were: Global Warning

Human Health (GWHH), Global Warming Terrestrial Ecosystems (GWTE), Global Warming Freshwater Ecosystems (GWFE), Stratospheric Ozone Depletion (SOD), Ionizing Radiation (IR), Ozone Formation Human Health (OFHH), Fine Particulate Matter Formation (FPMF), Ozone Formation Terrestrial Ecosystems (OFTE), Terrestrial Acidification (TA), Freshwater Eutrophication (FEU), Marine Eutrophication (MEU), Terrestrial Ecotixicity (TET), Freshwater Ecotoxicity (FET), Marine Ecotoxicity (MET), Human Carcinogenic Toxicity (HCT), Human Non Carcinogenic Toxicity (HNCT), Land Use (LU), Mineral Resource Scarcity (MRS), Fossil Resource Scarcity (FRS), Water Consumption Human Health (WCHH), Water Consumption Terrestrial Ecosystems (WCTE), and Water Consumption Aquatic Ecosystems (WCAE). These categories are considered midpoint indicators that highlight a single environmental problem and they are usually summarized into three endpoint indicators. These endpoint indicators show the environmental impact on three higher aggregation levels: human health, environment, and resource scarcity.

Interpretation of the results: this phase is the most important. Through the analysis of the main contributions, the sensitivity analysis, and the uncertainty analysis, it is possible to determine if the goals, previously defined, have been reached. All the conclusions are drawn up during this phase. Sometimes, a critical revision is necessary, especially when a comparative study is carried out [27].

2.2. Carbon Footprint

The carbon footprint is a measure that expresses in CO_2 equivalent the total greenhouse gas emissions directly or indirectly associated with a product, an organization, or a service. In accordance with the Kyoto Protocol, the greenhouse gases included are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6), and perfluorocarbons (PFCs) [28]. The tons of CO_2 equivalent (t CO_2 eq) allows to express the greenhouse effect produced by these gases with reference to the greenhouse effect produced by CO_2, considered equal to 1 (for example, methane has a greenhouse potential 25 times higher than CO_2, therefore a ton of methane is accounted for as 25 t CO_2 eq). The measurement of the CF of a product or process requires the identification and quantification of raw material and energy consumed in the selected phases of its life cycle and, therefore, it is consequent to an LCA study [20].

Not all the compounds emitted are greenhouse gasses (GHGs), so only the species reported in the IPPC report of 2006 [28] were considered, i.e., carbon dioxide, methane, nitrous oxide, hydrocarbons, hydrofluorocarbons, chlorofluorocarbons, hydrochlorofluorocarbons, perfluorocarbons, halon, fluorinated ethers, and Sulphur hexafluoride. Each GHGs have a different greenhouse effect, therefore the CO_2 equivalents were calculated according to Forster et al. [29] as follows:

$$\mathrm{CF} = \sum \mathrm{G.G.}_{\mathrm{i}} \ldots \mathrm{K}_{\mathrm{i}}$$

where $\mathrm{G.G.}_{\mathrm{i}}$ is the greenhouse gas quantity produced and K_i is the CO_2 equivalents coefficient for that gas. In this study, the GHGs sequestered by this crop have not been taken into consideration, being an experimental field. Therefore, the benefits coming from several agriculture aspects (use of rotations, cover crops, permanent pastures, etc.) have not been included. It is noteworthy that the carbon footprint label is perceived by consumers as an index of quality and sustainability of companies. It is possible to use the recent ISO 14067 [19] standard—"greenhouse gases—carbon footprint of products—requirements and guidelines for quantification and communication", which refers to the previous ISO 14040–14044 [17,18]. The CF and the inventory of greenhouse gas emissions are essentially designed for companies, production chains, or complex services: in the case of the CF, the evaluation can be integrated with an LCA also for the purpose of the realization of an environmental product declaration (EPD) which can then be advertised through the carbon label to the various stakeholders and customers of the company (national and foreign) [30].

3. Results

3.1. Life Cycle Inventory

The combination of all the variables investigated determined 42 possible scenarios of impact. In Table 1, the hemp seed yield for all the combinations is reported. The statistical analysis of data (reported in Table 1) highlights that E68, F75, and S27 genotypes had no significant differences in seed yield for all the plant densities and N fertilization levels. The same trend was found for F17 and F32.

Table 1. Hemp seed yield for the 42 impact scenarios. Values belonging to the same characteristic with different letters in rows for plant density (within N fertilization level) and in columns for hemp genotype (lower case letter) are statistically different according to LSD (0.05) (Source: Campiglia et al., 2017 [13]). E68 = Epsilon 68; F17 = Fedora 17; F32 = Felina 32; F75 = Futura 75; Fe = Ferimon; S27 = Santhica 27; U31 = Uso 31; D1, D2, and D3 = 40, 80, and 120 plants m^{-2}; N100 and N50 = 100 and 50 kg of N ha^{-1}.

	Seed Yield (t ha^{-1})											
	N50						N100					
Varieties	**D1**		**D2**		**D3**		**D1**		**D2**		**D3**	
E68	0.02	cA	0.02	cA	0.03	dA	0.12	cA	0.11	cA	0.12	cA
F17	1.06	bC	1.61	aB	2.02	abA	1.04	bB	1.68	bA	1.93	abA
F32	1.01	bC	1.36	abB	1.92	bA	1.13	bB	1.69	bA	2.00	abA
F75	0.03	cA	0.04	cA	0.04	dA	0.13	cA	0.15	cA	0.14	cA
Fe	1.20	aC	1.75	aB	2.44	aA	1.60	aB	2.26	Aa	2.27	aA
S27	0.01	cA	0.02	cA	0.02	dA	0.12	cA	0.13	cA	0.12	cA
U31	1.02	bB	1.14	bAB	1.39	cA	0.81	bB	1.44	bA	1.82	bA

Therefore, these varieties can be regarded as only one and the possible scenarios have been reduced to 24 ones.

In the evaluation, the following inputs have been considered:

- hectares of land used,
- N fertilizer,
- P_2O_5 fertilizer,
- seeds (for sowing),
- agriculture machines involved,
- fuels.

The data above reported have been expressed in t ha^{-1}, therefore, to refer at the functional unit chose, all data have been recalculated and expressed in kg of hemp seed produced. This unit was generally used in LCA dealing with agricultural products, e.g., for rice and coffee production [31,32]. The inventory is reported in Table 2. Data related to used land, N fertilizer, P_2O_5 fertilizer, and seeds have been originated according to the referred study [13]. Indeed, the Good Agriculture Practices (GAP) for industrial hemp cultivation have been utilized to obtain the data of agriculture machines and fuels involved. Pesticides are not registered for use on industrial hemp in Italy and in many other countries all over the world, therefore they have not been evaluated. Furthermore, irrigation was not herein included, since there is the possibility to grow industrial hemp in rained conditions [6] and the years considered in this study were quite rainy, so the irrigation was not necessary.

Table 2. Life cycle inventory for hemp seed cultivation. All data are expressed for 1 kg of seed produced. E68 = Epsilon 68; F17 = Fedora 17; F32 = Felina 32; F75 = Futura 75; Fe = Ferimon; S27 = Santhica 27; U31 = Uso 31; D1, D2, and D3 = 40, 80, and 120 plants m^{-2}; N100 and N50 = 100 and 50 kg of N ha^{-1}.

	N50			**N100**		
	D1	**D2**	**D3**	**D1**	**D2**	**D3**
Land (ha)						
E68/F75/S27	0.05000	0.03750	0.03333	0.00811	0.00769	0.00750
F17/F32	0.00097	0.00067	0.00051	0.00092	0.00059	0.00051
Fe	0.00083	0.00057	0.00041	0.00063	0.00044	0.00044
U31	0.00098	0.00088	0.00072	0.00123	0.00069	0.00055
N fertilizer (kg)						
E68/F75/S27	2.50000	1.87500	1.66667	0.81081	0.76923	0.75000
F17/F32	0.04831	0.03367	0.02538	0.09217	0.05935	0.05089
Fe	0.04167	0.02857	0.02049	0.06250	0.04425	0.04405
U31	0.04902	0.04386	0.03597	0.12346	0.06944	0.05495
P_2O_5 fertilizer (kg)						
E68/F75/S27	5.00000	3.75000	3.33333	0.81081	0.76923	0.75000
F17/F32	0.09662	0.06734	0.05076	0.09217	0.05935	0.05089
Fe	0.08333	0.05714	0.04098	0.06250	0.04425	0.04405
U31	0.09804	0.08772	0.07194	0.12346	0.06944	0.05495
Seed for sowing (kg)						
E68/F75/S27	0.35000	0.52500	0.93333	0.05676	0.10769	0.21000
F17/F32	0.00676	0.00943	0.01421	0.00645	0.00831	0.01425
Fe	0.00583	0.00800	0.01148	0.00438	0.00619	0.01233
U31	0.00686	0.01228	0.02014	0.00864	0.00972	0.01538
Diesel (kg)						
E68/F75/S27	3.25000	2.43750	2.16667	0.52703	0.50000	0.48750
F17/F32	0.06280	0.04377	0.03299	0.05991	0.03858	0.03308
Fe	0.05417	0.03714	0.02664	0.04063	0.02876	0.02863
U31	0.06373	0.05702	0.04676	0.08025	0.04514	0.03571
Agriculture machines (kg)						
E68/F75/S27	0.82000	0.61500	0.54667	0.13297	0.12615	0.12300
F17/F32	0.01585	0.01104	0.00832	0.01512	0.00973	0.00835
Fe	0.01367	0.00937	0.00672	0.01025	0.00726	0.00722
U31	0.01608	0.01439	0.01180	0.02025	0.01139	0.00901

3.2. Life Cycle Impact Assessment

After the definition of functional unit, system boundaries and the inventory the impact of the 24 combinations was evaluated by means of SimaPro software, version 9.0 (PRé Sustainability, Amersfoort, The Netherlands). Re.Ci.Pe. 2016 was the method used for the impacts calculation by 22 midpoint impact categories (GWHH, GWTE, GWFE, SOD, IR, OFHH, FPMF, OFTE, TA, FEU, MEU, TET, FET, MET, HCT, HNCT, LU, MRS, FRS, WCHH, WCTE, WCAE) and 3 endpoint compartments (ecosystems, human health, and economic resources) [33]. The 22 impact categories are expressed in 3 measurement units, each one reflecting the 3 endpoint areas. The environment is evaluated by the loss of biodiversity; indeed, the categories impacting on this subject are expressed in living species loss per year. The human health is assessed with the disability-adjusted life year (DALY) unity, despite the categories impacting on the resources being expressed in United States Dollar (USD) [34,35]. Several databases (Agri-footprint, ELCD, Ecoinvent) have been used for the scenarios impact evaluation. All the inputs reported in Par 3.2 have been found in the databases, the only exception were the seeds used for sowing. Therefore, the hemp seed item was created by using the GAP information. For 1 kg of seed, the following materials have been used: 0.1025 Kg of N fertilizers, 0.05206 Kg of P_2O_5 fertilizer, 0.15481 of K_2O, 0.45621 of CaO, 0.08905 kg of diesel, and 0.022468 kg of agriculture machines. The results of the impacts calculation of the 22 categories are reported in Table 3 for Uso31 genotype, in Table 4 for Ferimon, in Table 5 for Fedora 17 and Felina 32, and Table 6 for Epsilon 68, Futura 75, and Santhica 27.

Table 3. Impact assessment of Uso 31 genotype at different N fertilizer and plant density levels. D1, D2, and D3 = 40, 80, and 120 plants m^{-2}; N100 and N50 = 100 and 50 kg of N ha^{-1}. Global Warning Human Health (GWHH), Global Warming Terrestrial Ecosystems (GWTE), Global Warming Freshwater Ecosystems (GWFE), Stratospheric Ozone Depletion (SOD), Ionizing Radiation (IR), Ozone Formation Human Health (OFHH), Fine Particulate Matter Formation (FPMF), Ozone Formation Terrestrial Ecosystems (OFTE), Terrestrial Acidification (TA), Freshwater Eutrophication (FEU), Marine Eutrophication (MEU), Terrestrial Ecotixicity (TET), Freshwater Ecotoxicity (FET), Marine Ecotoxicity (MET), Human Carcinogenic Toxicity (HCT), Human Non Carcinogenic Toxicity (HNCT), Land Use (LU), Mineral Resource Scarcity (MRS), Fossil Resource Scarcity (FRS), Water Consumption Human Health (WCHH), Water Consumption Terrestrial Ecosystems (WCTE), and Water Consumption Aquatic Ecosystems (WCAE).

Categories	Unit	N50, D1	N50, D2	N50, D3	N100, D1	N100, D2	N100, D3
GWHH	DALY	3.48×10^{-6}	3.17×10^{-6}	2.70×10^{-6}	5.99×10^{-6}	2.99×10^{-6}	2.44×10^{-6}
GWTE	species/yr	6.96×10^{-9}	6.34×10^{-9}	5.40×10^{-9}	1.20×10^{-8}	5.99×10^{-9}	4.88×10^{-9}
GWFE	species/yr	1.90×10^{-13}	1.73×10^{-13}	1.47×10^{-13}	3.27×10^{-13}	1.63×10^{-13}	1.33×10^{-13}
SOD	DALY	6.57×10^{-9}	5.96×10^{-9}	5.02×10^{-9}	1.66×10^{-8}	8.83×10^{-9}	7.09×10^{-9}
IR	DALY	7.75×10^{-10}	6.99×10^{-10}	5.81×10^{-10}	1.05×10^{-9}	5.59×10^{-10}	4.49×10^{-10}
OFHH	DALY	6.71×10^{-10}	6.03×10^{-10}	4.99×10^{-10}	8.82×10^{-10}	4.78×10^{-10}	3.82×10^{-10}
FPMF	DALY	6.01×10^{-7}	5.41×10^{-7}	4.49×10^{-7}	8.65×10^{-7}	4.66×10^{-7}	3.73×10^{-7}
OFTE	species/yr	9.73×10^{-11}	8.75×10^{-11}	7.25×10^{-11}	1.28×10^{-10}	6.94×10^{-11}	5.54×10^{-11}
TA	species/yr	5.89×10^{-10}	5.31×10^{-10}	4.42×10^{-10}	9.68×10^{-10}	5.19×10^{-10}	4.15×10^{-10}
FEU	species/yr	1.49×10^{-10}	1.34×10^{-10}	1.10×10^{-10}	1.94×10^{-10}	1.06×10^{-10}	8.44×10^{-11}
MEU	species/yr	9.11×10^{-14}	8.18×10^{-14}	6.76×10^{-14}	1.19×10^{-13}	6.48×10^{-14}	5.17×10^{-14}
TET	species/yr	1.75×10^{-11}	1.58×10^{-11}	1.30×10^{-11}	2.29×10^{-11}	1.25×10^{-11}	9.95×10^{-12}
FET	species/yr	9.93×10^{-12}	8.92×10^{-12}	7.37×10^{-12}	1.29×10^{-11}	7.06×10^{-12}	5.63×10^{-12}
MET	species/yr	1.74×10^{-8}	1.57×10^{-8}	1.29×10^{-8}	2.27×10^{-8}	1.24×10^{-8}	9.88×10^{-9}
HCT	DALY	2.76×10^{-6}	2.48×10^{-6}	2.05×10^{-6}	3.60×10^{-6}	1.96×10^{-6}	1.57×10^{-6}
HNCT	DALY	3.16×10^{-5}	2.84×10^{-5}	2.35×10^{-5}	4.12×10^{-5}	2.25×10^{-5}	1.79×10^{-5}
LU	species/yr	1.22×10^{-9}	1.84×10^{-9}	2.73×10^{-9}	1.10×10^{-8}	1.45×10^{-9}	2.09×10^{-9}
MRS	USD	0.001435	0.001289	0.001065	0.001869	0.001021	0.000814
FRS	USD	0.057579	0.05202	0.043484	0.085886	0.045129	0.036336
WCHH	DALY	1.94×10^{-8}	1.74×10^{-8}	1.44×10^{-8}	2.53×10^{-8}	1.38×10^{-8}	1.10×10^{-8}
WCTE	species/yr	1.18×10^{-10}	1.06×10^{-10}	8.74×10^{-11}	1.54×10^{-10}	8.39×10^{-11}	6.69×10^{-11}
WCAE	species/yr	5.27×10^{-15}	4.73×10^{-15}	3.91×10^{-15}	6.89×10^{-15}	3.75×10^{-15}	2.99×10^{-15}

Table 4. Impact assessment of *Ferimon genotype* at different N fertilizer and plant density levels. D1, D2, and D3 = 40, 80, and 120 plants m^{-2}; N100 and N50 = 100 and 50 kg of N ha^{-1}. Global Warning Human Health (GWHH), Global Warming Terrestrial Ecosystems (GWTE), Global Warming Freshwater Ecosystems (GWFE), Stratospheric Ozone Depletion (SOD), Ionizing Radiation (IR), Ozone Formation Human Health (OFHH), Fine Particulate Matter Formation (FPMF), Ozone Formation Terrestrial Ecosystems (OFTE), Terrestrial Acidification (TA), Freshwater Eutrophication (FEU), Marine Eutrophication (MEU), Terrestrial Ecotixicity (TET), Freshwater Ecotoxicity (FET), Marine Ecotoxicity (MET), Human Carcinogenic Toxicity (HCT), Human Non Carcinogenic Toxicity (HNCT), Land Use (LU), Mineral Resource Scarcity (MRS), Fossil Resource Scarcity (FRS), Water Consumption Human Health (WCHH), Water Consumption Terrestrial Ecosystems (WCTE), and Water Consumption Aquatic Ecosystems (WCAE).

Categories	Unit	N50, D1	N50, D2	N50, D3	N100, D1	N100, D2	N100, D3
GWHH	DALY	2.96×10^{-6}	2.07×10^{-6}	1.54×10^{-6}	2.65×10^{-6}	2.65×10^{-6}	1.96×10^{-6}
GWTE	species/yr	5.91×10^{-9}	4.13×10^{-9}	3.07×10^{-9}	5.30×10^{-9}	5.30×10^{-9}	3.92×10^{-9}
GWFE	species/yr	1.61×10^{-13}	1.13×10^{-13}	8.39×10^{-14}	1.45×10^{-13}	1.45×10^{-13}	1.07×10^{-13}
SOD	DALY	5.58×10^{-9}	3.88×10^{-9}	2.86×10^{-9}	7.89×10^{-9}	7.89×10^{-9}	5.68×10^{-9}

Table 4. *Cont.*

Categories	Unit	N50, D1	N50, D2	N50, D3	N100, D1	N100, D2	N100, D3
IR	DALY	6.59×10^{-10}	4.55×10^{-10}	3.31×10^{-10}	4.99×10^{-10}	4.99×10^{-10}	3.60×10^{-10}
OFHH	DALY	5.70×10^{-10}	3.93×10^{-10}	2.84×10^{-10}	4.28×10^{-10}	4.28×10^{-10}	3.06×10^{-10}
FPMF	DALY	5.11×10^{-7}	3.53×10^{-7}	2.56×10^{-7}	4.17×10^{-7}	4.17×10^{-7}	2.99×10^{-7}
OFTE	species/yr	8.27×10^{-11}	5.70×10^{-11}	4.13×10^{-11}	6.21×10^{-11}	6.21×10^{-11}	4.44×10^{-11}
TA	species/yr	5.00×10^{-10}	3.46×10^{-10}	2.52×10^{-10}	4.64×10^{-10}	4.64×10^{-10}	3.33×10^{-10}
FEU	species/yr	1.27×10^{-10}	8.71×10^{-11}	6.29×10^{-11}	9.49×10^{-11}	9.49×10^{-11}	6.77×10^{-11}
MEU	species/yr	7.74×10^{-14}	5.33×10^{-14}	3.85×10^{-14}	5.81×10^{-14}	5.81×10^{-14}	4.14×10^{-14}
TET	species/yr	1.49×10^{-11}	1.03×10^{-11}	7.42×10^{-12}	1.12×10^{-11}	1.12×10^{-11}	7.98×10^{-12}
FET	species/yr	8.44×10^{-12}	5.81×10^{-12}	4.20×10^{-12}	6.33×10^{-12}	6.33×10^{-12}	4.51×10^{-12}
MET	species/yr	1.48×10^{-8}	1.02×10^{-8}	7.37×10^{-9}	1.11×10^{-8}	1.11×10^{-8}	7.92×10^{-9}
HCT	DALY	2.35×10^{-6}	1.62×10^{-6}	1.17×10^{-6}	1.76×10^{-6}	1.76×10^{-6}	1.26×10^{-6}
HNCT	DALY	2.69×10^{-5}	1.85×10^{-5}	1.34×10^{-5}	2.01×10^{-5}	2.01×10^{-5}	1.44×10^{-5}
LU	species/yr	1.03×10^{-9}	1.20×10^{-9}	1.56×10^{-9}	7.76×10^{-10}	7.76×10^{-10}	1.67×10^{-9}
MRS	USD	0.00122	0.00084	0.000607	0.000915	0.000915	0.000652
FRS	USD	0.048942	0.033884	0.024773	0.040262	0.040262	0.02913
WCHH	DALY	1.65×10^{-8}	1.13×10^{-8}	8.19×10^{-9}	1.24×10^{-8}	1.24×10^{-8}	8.82×10^{-9}
WCTE	species/yr	1.00×10^{-10}	6.89×10^{-11}	4.98×10^{-11}	7.52×10^{-11}	7.52×10^{-11}	5.36×10^{-11}
WCAE	species/yr	4.48×10^{-15}	3.08×10^{-15}	2.23×10^{-15}	3.36×10^{-15}	3.36×10^{-15}	2.40×10^{-15}

Table 5. Impact assessment of *Fedora 17 and Felina 32* genotypes at different N fertilizer and plant density levels. D1, D2, and D3 = 40, 80, and 120 plants m^{-2}; N100 and N50 = 100 and 50 kg of N ha^{-1}. Global Warning Human Health (GWHH), Global Warming Terrestrial Ecosystems (GWTE), Global Warming Freshwater Ecosystems (GWFE), Stratospheric Ozone Depletion (SOD), Ionizing Radiation (IR), Ozone Formation Human Health (OFHH), Fine Particulate Matter Formation (FPMF), Ozone Formation Terrestrial Ecosystems (OFTE), Terrestrial Acidification (TA), Freshwater Eutrophication (FEU), Marine Eutrophication (MEU), Terrestrial Ecotixicity (TET), Freshwater Ecotoxicity (FET), Marine Ecotoxicity (MET), Human Carcinogenic Toxicity (HCT), Human Non Carcinogenic Toxicity (HNCT), Land Use (LU), Mineral Resource Scarcity (MRS), Fossil Resource Scarcity (FRS), Water Consumption Human Health (WCHH), Water Consumption Terrestrial Ecosystems (WCTE), and Water Consumption Aquatic Ecosystems (WCAE).

Categories	Unit	N50, D1	N50, D2	N50, D3	N100, D1	N100, D2	N100, D3
GWHH	DALY	3.43×10^{-6}	2.43×10^{-6}	1.90×10^{-6}	3.91×10^{-6}	2.56×10^{-6}	2.26×10^{-6}
GWTE	species/yr	6.86×10^{-9}	4.87×10^{-9}	3.81×10^{-9}	7.82×10^{-9}	5.12×10^{-9}	4.52×10^{-9}
GWFE	species/yr	1.87×10^{-13}	1.33×10^{-13}	1.04×10^{-13}	2.13×10^{-13}	1.40×10^{-13}	1.23×10^{-13}
SOD	DALY	6.47×10^{-9}	4.57×10^{-9}	3.54×10^{-9}	1.16×10^{-8}	7.55×10^{-9}	6.57×10^{-9}
IR	DALY	7.64×10^{-10}	5.36×10^{-10}	4.10×10^{-10}	7.36×10^{-10}	4.78×10^{-10}	4.16×10^{-10}
OFHH	DALY	6.61×10^{-10}	4.63×10^{-10}	3.52×10^{-10}	6.31×10^{-10}	4.08×10^{-10}	3.54×10^{-10}
FPMF	DALY	5.93×10^{-7}	4.15×10^{-7}	3.17×10^{-7}	6.15×10^{-7}	3.98×10^{-7}	3.45×10^{-7}
OFTE	species/yr	9.59×10^{-11}	6.72×10^{-11}	5.11×10^{-11}	9.16×10^{-11}	5.93×10^{-11}	5.13×10^{-11}
TA	species/yr	5.80×10^{-10}	4.08×10^{-10}	3.12×10^{-10}	6.84×10^{-10}	4.43×10^{-10}	3.85×10^{-10}
FEU	species/yr	1.47×10^{-10}	1.03×10^{-10}	7.80×10^{-11}	1.40×10^{-10}	9.05×10^{-11}	7.82×10^{-11}
MEU	species/yr	8.98×10^{-14}	6.28×10^{-14}	4.77×10^{-14}	8.57×10^{-14}	5.54×10^{-14}	4.78×10^{-14}
TET	species/yr	1.73×10^{-11}	1.21×10^{-11}	9.19×10^{-12}	1.65×10^{-11}	1.07×10^{-11}	9.22×10^{-12}
FET	species/yr	9.78×10^{-12}	6.84×10^{-12}	5.20×10^{-12}	9.33×10^{-12}	6.03×10^{-12}	5.21×10^{-12}
MET	species/yr	1.72×10^{-8}	1.20×10^{-8}	9.13×10^{-9}	1.64×10^{-8}	1.06×10^{-8}	9.15×10^{-9}
HCT	DALY	2.72×10^{-6}	1.90×10^{-6}	1.45×10^{-6}	2.60×10^{-6}	1.68×10^{-6}	1.45×10^{-6}
HNCT	DALY	3.11×10^{-5}	2.18×10^{-5}	1.65×10^{-5}	2.97×10^{-5}	1.92×10^{-5}	1.66×10^{-5}
LU	species/yr	1.20×10^{-9}	1.41×10^{-9}	1.93×10^{-9}	1.14×10^{-9}	1.24×10^{-9}	1.93×10^{-9}
MRS	USD	0.001415	0.00099	0.000751	0.00135	0.000873	0.000754
FRS	USD	0.056742	0.039933	0.03068	0.059371	0.038572	0.033656
WCHH	DALY	1.91×10^{-8}	1.34×10^{-8}	1.01×10^{-8}	1.82×10^{-8}	1.18×10^{-8}	1.02×10^{-8}
WCTE	species/yr	1.16×10^{-10}	8.12×10^{-11}	6.17×10^{-11}	1.11×10^{-10}	7.17×10^{-11}	6.20×10^{-11}
WCAE	species/yr	5.19×10^{-15}	3.63×10^{-15}	2.76×10^{-15}	4.96×10^{-15}	3.21×10^{-15}	2.77×10^{-15}

Table 6. Impact assessment of Epsilon 68, Futura 75 and Santhica 27 genotypes at different N fertilizer and plant density levels. D1, D2, and D3 = 40, 80, and 120 plants m^{-2}; N100 and N50 = 100 and 50 kg of N ha^{-1}. Global Warning Human Health (GWHH), Global Warming Terrestrial Ecosystems (GWTE), Global Warming Freshwater Ecosystems (GWFE), Stratospheric Ozone Depletion (SOD), Ionizing Radiation (IR), Ozone Formation Human Health (OFHH), Fine Particulate Matter Formation (FPMF), Ozone Formation Terrestrial Ecosystems (OFTE), Terrestrial Acidification (TA), Freshwater Eutrophication (FEU), Marine Eutrophication (MEU), Terrestrial Ecotixicity (TET), Freshwater Ecotoxicity (FET), Marine Ecotoxicity (MET), Human Carcinogenic Toxicity (HCT), Human Non Carcinogenic Toxicity (HNCT), Land Use (LU), Mineral Resource Scarcity (MRS), Fossil Resource Scarcity (FRS), Water Consumption Human Health (WCHH), Water Consumption Terrestrial Ecosystems (WCTE), and Water Consumption Aquatic Ecosystems (WCAE).

Categories	Unit	N50, D1	N50, D2	N50, D3	N100, D3	N100, D1	N100, D2	N100, D3
GWHH	DALY	0.000177	0.000136	0.000125	3.33×10^{-5}	3.44×10^{-5}	3.3×10^{-5}	3.33×10^{-5}
GWTE	species/yr	3.55×10^{-7}	2.71×10^{-7}	2.50×10^{-7}	6.67×10^{-8}	6.88×10^{-8}	6.63×10^{-8}	6.67×10^{-8}
GWFE	species/yr	9.68×10^{-12}	7.40×10^{-12}	6.82×10^{-12}	1.82×10^{-12}	1.88×10^{-12}	1.81×10^{-12}	1.82×10^{-12}
SOD	DALY	3.35×10^{-7}	2.55×10^{-7}	2.32×10^{-7}	9.68×10^{-8}	1.02×10^{-7}	9.78×10^{-8}	9.68×10^{-8}
IR	DALY	3.95×10^{-8}	2.99×10^{-8}	2.69×10^{-8}	6.13×10^{-9}	6.48×10^{-9}	6.19×10^{-9}	6.13×10^{-9}
OFHH	DALY	3.42×10^{-8}	2.58×10^{-8}	2.31×10^{-8}	5.21×10^{-9}	5.55×10^{-9}	5.29×10^{-9}	5.21×10^{-9}
FPMF	DALY	3.07×10^{-5}	2.31×10^{-5}	2.08×10^{-5}	5.09×10^{-6}	5.41×10^{-6}	5.16×10^{-6}	5.09×10^{-6}
OFTE	species/yr	4.96×10^{-9}	3.74×10^{-9}	3.36×10^{-9}	7.57×10^{-10}	8.06×10^{-10}	7.69×10^{-10}	7.57×10^{-10}
TA	species/yr	3.00×10^{-8}	2.27×10^{-8}	2.05×10^{-8}	5.67×10^{-9}	6.02×10^{-9}	5.74×10^{-9}	5.67×10^{-9}
FEU	species/yr	7.59×10^{-9}	5.72×10^{-9}	5.12×10^{-9}	1.15×10^{-9}	1.23×10^{-9}	1.17×10^{-9}	1.15×10^{-9}
MEU	species/yr	4.65×10^{-12}	3.50×10^{-12}	3.13×10^{-12}	77.05×10^{-13}	7.54×10^{-13}	7.18×10^{-13}	7.05×10^{-13}
TET	species/yr	8.94×10^{-10}	6.74×10^{-10}	6.04×10^{-10}	1.36×10^{-10}	1.45×10^{-10}	$.1.38 \times 10^{-10}$	1.36×10^{-10}
FET	species/yr	5.06×10^{-10}	3.81×10^{-10}	3.41×10^{-10}	7.68×10^{-11}	8.21×10^{-11}	7.82×10^{-11}	7.68×10^{-11}
MET	species/yr	8.89×10^{-7}	6.69×10^{-7}	5.99×10^{-7}	1.35×10^{-7}	1.44×10^{-7}	1.37×10^{-7}	1.35×10^{-7}
HCT	DALY	0.000141	0.000106	9.50×10^{-5}	2.14×10^{-5}	2.28×10^{-5}	2.18×10^{-5}	2.14×10^{-5}
HNCT	DALY	0.001612	0.001213	0.001087	0.000245	0.000261	0.000249	0.000245
LU	species/yr	6.20×10^{-8}	7.85×10^{-8}	1.27×10^{-7}	2.85×10^{-8}	1.01×10^{-8}	1.61×10^{-8}	2.85×10^{-8}
MRS	USD	0.073199	0.055103	0.049343	0.011108	0.011876	0.011309	0.011108
FRS	USD	2.936431	2.223787	2.01486	0.495994	0.522288	0.499905	0.495994
WCHH	DALY	9.88×10^{-7}	7.44×10^{-7}	6.66×10^{-7}	1.50×10^{-7}	1.60×10^{-7}	1.53×10^{-7}	1.50×10^{-7}
WCTE	species/yr	6.01×10^{-9}	4.52×10^{-9}	4.05×10^{-9}	9.13×10^{-10}	9.76×10^{-10}	9.29×10^{-10}	9.13×10^{-10}
WCAE	species/yr	2.69×10^{-13}	2.02×10^{-13}	1.81×10^{-13}	4.09×10^{-14}	4.36×10^{-14}	4.16×10^{-14}	4.09×10^{-14}

As above mentioned, the 22 impact categories can be summarized into 3 main areas. Figure 2 shows the overall vision of the impacts coming from the 24 scenarios evaluated. According to the method chosen, the impact in the 3 endpoints has been calculated by summarizing each impact of the categories impacting in that area. Moreover, the highest impact was set at 100% and the others have been accordingly compared.

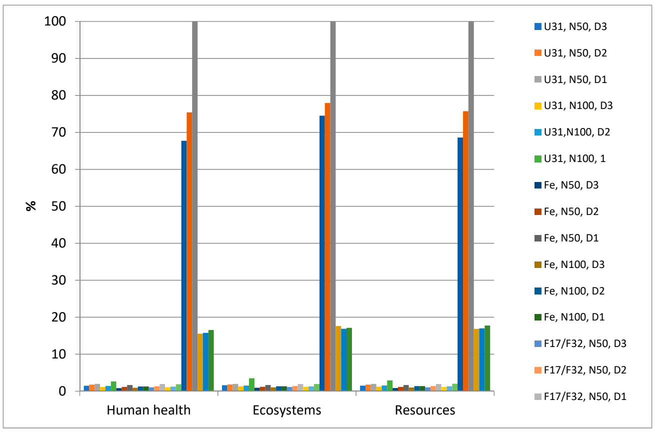

Figure 2. Life cycle impact assessment (LCIA) of the 24 scenarios evaluated, reported in 3 endpoints (expressed as percentage of the highest impact. E68 = Epsilon 68; F17 = Fedora 17; F32 = Felina 32; F75 = Futura 75; Fe = Ferimon; S27 = Santhica 27; U31 = Uso 31; D1, D2, and D3 = 40, 80, and 120 plants m^{-2}; N100 and N50 = 100 and 50 kg of N ha^{-1}.

3.3. Carbon Footprint

The carbon footprint (CF) is an objective evaluation of greenhouse gasses (GHGs) produced by a product, a process, or a service. In this case, the GHGs were evaluated, expressed as kg of CO_2 eq, of the Cannabis Sativa L. cultivation. From the results of LCA conducted, it is possible to highlight the output of the process attributable to the emissions in air, in soil, and in water. Through Simapro 8.5, it was possible to select only the emissions in air, in order to obtain a list with all the chemical species emitted by the system studied. The results of CF for the 24 scenarios evaluated have been reported in Figure 3. In the figure, the CF was reported in descending order along the scenarios.

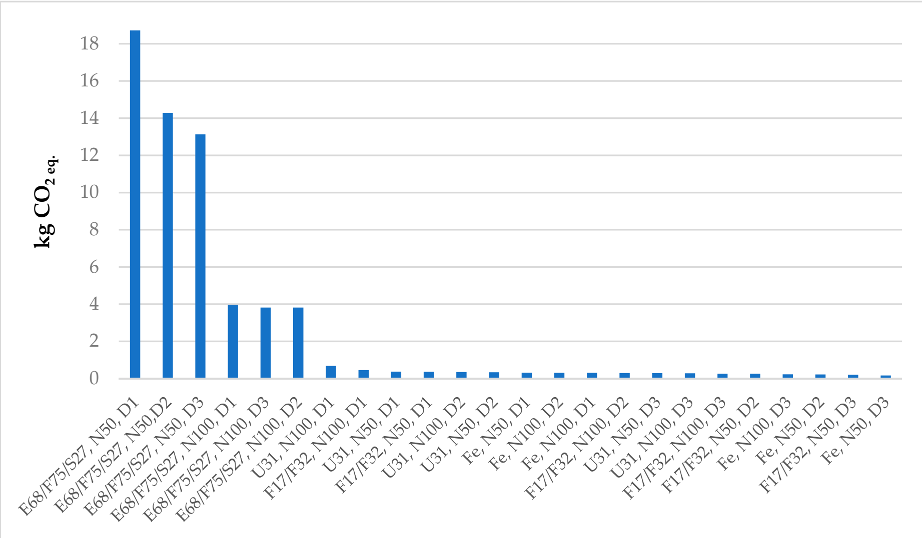

Figure 3. Carbon footprint of the 24 scenarios evaluated, expressed as kg of CO_2. E68 = Epsilon 68; F17 = Fedora 17; F32 = Felina 32; F75 = Futura 75; Fe = Ferimon; S27 = Santhica 27; U31 = Uso 31; D1, D2, and D3 = 40, 80, and 120 plants m^{-2}; N100 and N50 = 100 and 50 kg of N ha^{-1}.

4. Discussion

As reported by the LCIA results, the genotypes with major impact were Epsilon 68, Futura 75, and Santhica 27, while Ferimon had the lowest impact. Moreover, in all the genotypes the impacts grew by decreasing N fertilizer and plants densities. Therefore, the E68/F75/S27 genotypes cultivated with 50 kg ha^{-1} of N fertilizer and 40 plants m^{-2} was the scenario with the highest impact, while Ferimon with 100 kg ha^{-1} of N fertilizer and 120 plants m^{-2} was the lowest one. Overall, the lowest fertilizer level (50 kg ha^{-1}) had a major impact compared to the high level (100 kg ha^{-1}). Among all the genotypes, the lowest fertilizer level had a major impact by decreasing the plant density. The same trend was highlighted in the 100 kg ha^{-1} level, the only exception was pointed out in the ecosystems endpoint for Fe and E68/F75/S27 genotypes.

In the percentage comparison, the E68/F75/S27 genotypes resulted the most impacting in human health (100–15.5%), ecosystems (100–16.8%), and resources (100–16.8%), too. The F17 genotypes had a medium range of 1.9–1.1% in all the 3 endpoints, while U31 of 3–1.2%. Therefore, Ferimon resulted the most sustainable: human health (1.6–0.8%), ecosystems (1.3–0.9%), and resources (1.3–0.8%).

Starting from the LCA results, it was possible to calculate the carbon footprint of the emitted gases for the different agronomic practices combinations. It's noteworthy that also in this case the genotypes with highest CF were Epsilon 68, Futura 75, and Santhica 27. Moreover, the agronomic practices most impacting (18,720 kg of CO_2 eq. for 1 kg of hemp seed) were the use of 50 kg ha^{-1} of N fertilizer and 40 plants m^{-2}. Ferimon, as above, resulted the genotype most environmentally sustainable. The only difference with LCA results is that, in this genotype, the less use of N fertilizer lead at minor CF (0.161 kg CO_2 eq for 1 kg of hemp seed).

This feature was probably due to the degradation of chemical species containing N into nitrous oxide (N_2O), with a high greenhouse effect (1 N_2O = 298 CO_2 eq.) [36]. In this study, the CF of 18 scenarios evaluated were below 0.675 kg CO_2 eq. These results are comparable with the CF of other crops, e.g., 0.186 kg CO_2 eq for soybeans [37], 0.53 kg CO_2 eq for rice [38], and 0.633 kg CO_2 eq for wheat [39–42]. Furthermore, the majority of the scenarios herein evaluated result lower than other crops, e.g., rapeseed (0.768 kg CO_2 eq), sunflower (0.889 kg CO_2 eq) [43], and coffee (2.355 kg CO_2 eq) [30]. Despite the CF of Epsilon 68, Futura 75, and Santhica 27 genotypes, comprising 6 scenarios evaluated, higher than the above-mentioned crops was found.

In conclusion, the evaluation herein reported has highlighted the environmental impact of several agronomic practices for hemp seed production. Furthermore, this microlevel assessment is related to an experimental field and it might be validated in real farms [44]. Nevertheless, the tools involved for the evaluation were widely used in literature for agro-food sector [45].

5. Conclusions

This study evaluated the environmental sustainability of different agronomic practices for a hemp seed crop by means of life cycle assessment and carbon footprint tools. Several agricultural variables have been considered, such as hemp varieties (Epsilon68 (E68), Fedora17 (F17), Felina32 (F32), Ferimon (Fe), Futura75 (F75), Santhica27 (S27), Uso31 (U31)), plant densities (40, 80, and 120 plants m^{-2}), and levels of nitrogen (N) fertilization (50 and 100 kg ha^{-1} of N). From the LCA and CF results, it was possible to point out that Fe resulted the variety most environmentally sustainable, despite E68/F75/S27 varieties appeared with the highest impact. For the other agriculture practices, the LCA results showed that the negative impacts grew by decreasing N fertilizer and plants densities while the less use of N fertilizer led to a minor CF.

The scenario with the highest impact was E68/F75/S27 genotypes cultivated with 50 kg ha^{-1} of N fertilizer and 40 plants m^{-2} (18.720 kg CO_2 eq), while the lowest one was Ferimon with 50 kg ha^{-1} of N fertilizer and 120 plants m^{-2} (0.161 kg CO_2 eq). Therefore, the environmental evaluation herein proposed can be a useful and significant managerial tool. Moreover, the evaluation of the agronomic practices' sustainability could be used by a legislator in order to regulate and to promote the hemp seed cultivation with specific genotypes and soil practices.

This evaluation is limited to the Mediterranean environment, but this research could be a starting point to highlight the best matching of all the inputs, such as fertilizers or fuels used, for *Cannabis sativa* L. cultivation for seed production. Moreover, this study, coming from an experimental field, could be a preliminary step for the validation and application in real farms.

Author Contributions: Conceptualization, E.C., L.G., A.M., M.R., R.R., G.V.; methodology, E.C., L.G., A.M., M.R., R.R., G.V.; software, E.C., L.G., A.M., M.R., R.R., G.V.; validation, E.C., L.G., A.M., M.R., R.R., G.V.; formal analysis, E.C., L.G., A.M., M.R., R.R., G.V.; data curation, E.C., L.G., A.M., M.R., R.R., G.V.; writing—original draft preparation, E.C., L.G., A.M., M.R., R.R., G.V.; writing—review and editing, E.C., L.G., A.M., M.R., R.R., G.V.; visualization, E.C., L.G., A.M., M.R., R.R., G.V.; supervision, E.C., L.G., A.M., M.R., R.R., G.V. All authors have read and agreed to the published version of the manuscript.

Funding: This work has been realized with funds received from the following agencies: Italian Ministry of Education, Universities and Research—Dipartimenti di Eccellenza—L. 232/2016; "LaCanapa" Project (Regione Lazio LR13/2008—Dipartimento di Chimica e Tecnologie del Farmaco).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Carus, M.; Karst, S.; Kauffmann, A. The European Hemp Industry: Cultivation, processing and applications for fibres, shivs and seeds. *Eiha* **2016**, *2003*, 1–9.
2. Groom, Q.; Clarke, R.C.; Merlin, M.D. Cannabis: Evolution and Ethnobotany. *Plant Ecol. Evol.* **2014**, *147*, 149. [CrossRef]
3. Allegret, S. The history of hemp. In *Hemp: Industrial Production and Uses*; Bouloc, P., Allegret, S., Arnaud, L., Eds.; CAB International: Bar sur Aube, France, 2013; pp. 4–25, ISBN 9781845937928.

4. European Commission. Common Catalogue of Varieties of Agricultural Plant Species. Available online: https://op.europa.eu/ (accessed on 16 June 2020).
5. European Commission. Delegated Regulation (EU) No 639/2014 of Marhc 11. Available online: https://eur-lex.europa.eu/ (accessed on 16 June 2020).
6. Amaducci, S.; Scordia, D.; Liu, F.H.; Zhang, Q.; Guo, H.; Testa, G.; Cosentino, S.L. Key cultivation techniques for hemp in Europe and China. *Ind. Crops Prod.* **2015**, *68*, 2–16. [CrossRef]
7. Venturi, P.; Amaducci, S.; Amaducci, M.T.; Venturi, G. Interaction between Agronomic and Mechanical Factors for Fiber Crops Harvesting: Italian Results-Note II. Hemp. *J. Nat. Fibers* **2007**, *4*, 83–97. [CrossRef]
8. Linger, P.; Müssig, J.; Fischer, H.; Kobert, J. Industrial hemp (*Cannabis sativa* L.) growing on heavy metal contaminated soil: Fibre quality and phytoremediation potential. *Ind. Crops Prod.* **2002**, *16*, 33–42. [CrossRef]
9. Rodriguez-Leyva, D.; Pierce, G.N. The cardiac and haemostatic effects of dietary hempseed. *Nutr. Metab.* **2010**, *7*, 32. [CrossRef] [PubMed]
10. Tang, K.; Struik, P.C.; Yin, X.; Thouminot, C.; Bjelková, M.; Stramkale, V.; Amaducci, S. Comparing hemp (*Cannabis sativa* L.) cultivars for dual-purpose production under contrasting environments. *Ind. Crops Prod.* **2016**, *87*, 33–44. [CrossRef]
11. Ascrizzi, R.; Ceccarini, L.; Tavarini, S.; Flamini, G.; Angelini, L.G. Valorisation of hemp inflorescence after seed harvest: Cultivation site and harvest time influence agronomic characteristics and essential oil yield and composition. *Ind. Crops Prod.* **2019**, *139*, 111541. [CrossRef]
12. Aubin, M.P.; Seguin, P.; Vanasse, A.; Tremblay, G.F.; Mustafa, A.F.; Charron, J.B. Industrial Hemp Response to Nitrogen, Phosphorus, and Potassium Fertilization. *Crop. Forage Turfgrass Manag.* **2015**, *1*, 1–10. [CrossRef]
13. Campiglia, E.; Radicetti, E.; Mancinelli, R. Plant density and nitrogen fertilization affect agronomic performance of industrial hemp (*Cannabis sativa* L.) in Mediterranean environment. *Ind. Crops Prod.* **2017**, *100*, 246–254. [CrossRef]
14. Tang, K.; Struik, P.C.; Amaducci, S.; Stomph, T.J.; Yin, X. Hemp (*Cannabis sativa* L.) leaf photosynthesis in relation to nitrogen content and temperature: Implications for hemp as a bio-economically sustainable crop. *GCB Bioenergy* **2017**, *9*, 1573–1587. [CrossRef]
15. Piotrowski, B.S.; Carus, M. Ecological benefits of hemp and flax cultivation and products. *Nov. Inst.* **2011**, *68*, 1–6.
16. Ruviaro, C.F.; Gianezini, M.; Brandão, F.S.; Winck, C.A.; Dewes, H. Life cycle assessment in Brazilian agriculture facing worldwide trends. *J. Clean. Prod.* **2012**, *28*, 9–24. [CrossRef]
17. ISO 14040. *Environmental Management—Life Cycle Assessment—Principles and Framework*; International Organization for Standardization: Geneva, Switzerland, 2006.
18. ISO 14044. *Environmental Management—Life Cycle Assessment—Requirements and Guidelines*; International Organization for Standardization: Geneva, Switzerland, 2006.
19. ISO 14067. *Greenhouse Gases—Carbon Footprint of Products—Requirements and Guidelines for Quantification and Communication*; International Organization for Standardization: Geneva, Switzerland, 2013.
20. Vinci, G.; Rapa, M. Hydroponic cultivation: Life cycle assessment of substrate choice. *Br. Food J.* **2019**, *121*, 1801–1812. [CrossRef]
21. Werf, H.M.G. Life Cycle Analysis of field production of fibre hemp, the effect of production practices on environmental impacts. *Euphytica* **2004**, *140*, 13–23. [CrossRef]
22. Zampori, L.; Dotelli, G.; Vernelli, V. Life cycle assessment of hemp cultivation and use of hemp-based thermal insulator materials in buildings. *Environ. Sci. Technol.* **2013**, *47*, 7413–7420. [CrossRef] [PubMed]
23. González-García, S.; Hospido, A.; Feijoo, G.; Moreira, M.T. Life cycle assessment of raw materials for non-wood pulp mills: Hemp and flax. *Resour. Conserv. Recycl.* **2010**, *54*, 923–930. [CrossRef]
24. Dekamin, M.; Barmaki, M.; Kanooni, A.; Meshkini, S.R.M. Cradle to farm gate life cycle assessment of oilseed crops production in Iran. *Eng. Agric. Environ. Food* **2018**, *11*, 178–185. [CrossRef]
25. Rebitzer, G.; Ekvall, T.; Frischknecht, R.; Hunkeler, D.; Norris, G.; Rydberg, T.; Schmidt, W.P.; Suh, S.; Weidema, B.P.; Pennington, D.W. Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environ. Int.* **2004**, *30*, 701–720. [CrossRef]
26. Finnveden, G.; Hauschild, M.Z.; Ekvall, T.; Guinée, J.; Heijungs, R.; Hellweg, S.; Koehler, A.; Pennington, D.; Suh, S. Recent developments in Life Cycle Assessment. *J. Environ. Manag.* **2009**, *91*, 1–21. [CrossRef]
27. Zanghelini, G.M.; Cherubini, E.; Soares, S.R. How Multi-Criteria Decision Analysis (MCDA) is aiding Life Cycle Assessment (LCA) in results interpretation. *J. Clean. Prod.* **2018**, *172*, 609–622. [CrossRef]

28. IPPC. 2006 IPCC Guidelines for National Greenhouse Gas Inventories—Volume 3—Industrial Processes. Available online: https://www.ipcc-nggip.iges.or.jp/ (accessed on 16 June 2020).
29. Forster, P.; Artaxo, P. Changes in Atmospheric Constituents and in Radiative Forcing. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2007.
30. Wimmer, W.; Bey, N.; Malsch, A. An integrated approach for introducing ECODESIGN into an industrial company—From customer demands to an Enviromental Product Declaration. In Proceedings of the 14th International Conference on Engineering Design (ICED), Stockholm, Sweden, 19–21 August 2003; Folkeson, A., Gralen, K., Norell, M., Sellgren, U., Eds.; Design Society: Scotland, UK, 2003.
31. Giraldi-Díaz, M.R.; Medina-Salas, L.; Castillo-González, E.; León-Lira, R. Environmental impact associated with the supply chain and production of grounding and roasting coffee through life cycle analysis. *Sustainability* **2018**, *10*, 4598. [CrossRef]
32. Mungkung, R.; Pengthamkeerati, P.; Chaichana, R.; Watcharothai, S.; Kitpakornsanti, K.; Tapananont, S. Life Cycle Assessment of Thai organic Hom Mali rice to evaluate the climate change, water use and biodiversity impacts. *J. Clean. Prod.* **2019**, *211*, 687–694. [CrossRef]
33. Vinci, G.; D'Ascenzo, F.; Esposito, A.; Musarra, M.; Rapa, M.; Rocchi, A. A sustainable innovation in the Italian glass production: LCA and Eco-Care Matrix evaluation. *J. Clean. Prod.* **2019**, *223*, 587–595. [CrossRef]
34. Rapa, M.; Vinci, G.; Gobbi, L. Life cycle assessment of photovoltaic implementation: An italian case study. *Int. J. Civ. Eng. Technol.* **2019**, *10*, 1657–1663.
35. Vinci, G.; Esposito, A.; Rapa, M.; Rocchi, A.; Ruggieri, R. Sustainability of Technological Innovation Investments: Photovoltaic Panels Case Study. *Int. J. Civ. Eng. Technol.* **2019**, *10*, 2301–2307.
36. Huang, L.; Riggins, C.W.; Rodríguez-Zas, S.; Zabaloy, M.C.; Villamil, M.B. Long-term N fertilization imbalances potential N acquisition and transformations by soil microbes. *Sci. Total Environ.* **2019**, *691*, 562–571. [CrossRef]
37. Raucci, G.S.; Moreira, C.S.; Alves, P.A.; Mello, F.F.C.; Frazão, L.D.A.; Cerri, C.E.P.; Cerri, C.C. Greenhouse gas assessment of Brazilian soybean production: A case study of Mato Grosso State. *J. Clean. Prod.* **2015**, *96*, 418–425. [CrossRef]
38. Yodkhum, S.; Gheewala, S.H.; Sampattagul, S. Life cycle GHG evaluation of organic rice production in northern Thailand. *J. Environ. Manag.* **2017**, *196*, 217–223. [CrossRef]
39. Alhajj Ali, S.; Tedone, L.; Verdini, L.; De Mastro, G. Effect of different crop management systems on rainfed durum wheat greenhouse gas emissions and carbon footprint under Mediterranean conditions. *J. Clean. Prod.* **2017**, *140*, 608–621. [CrossRef]
40. Ankathi, S.K.; Long, D.S.; Gollany, H.T.; Das, P.; Shonnard, D. Life cycle assessment of oilseed crops produced in rotation with dryland cereals in the inland Pacific Northwest. *Int. J. Life Cycle Assess.* **2019**, *24*, 627–641. [CrossRef]
41. Esmaeilzadeh, S.; Asgharipour, M.R.; Bazrgar, A.B.; Soufizadeh, S.; Karandish, F. Assessing the carbon footprint of irrigated and dryland wheat with a life cycle approach in bojnourd. *Environ. Prog. Sustain. Energy* **2019**, *38*, 13134. [CrossRef]
42. Tahmasebi, M.; Feike, T.; Soltani, A.; Ramroudi, M.; Ha, N. Trade-off between productivity and environmental sustainability in irrigated vs. rainfed wheat production in Iran. *J. Clean. Prod.* **2018**, *174*, 367–376. [CrossRef]
43. Forleo, M.B.; Palmieri, N.; Suardi, A.; Coaloa, D.; Pari, L. The eco-efficiency of rapeseed and sunflower cultivation in Italy. Joining environmental and economic assessment. *J. Clean. Prod.* **2018**, *172*, 3138–3153. [CrossRef]
44. Lindgreen, E.R.; Salomone, R.; Reyes, T. A Critical Review of Academic Approaches, Methods and Tools to Assess Circular Economy at the Micro Level. *Sustainability* **2020**, *12*, 4973. [CrossRef]
45. Arzoumanidis, I.; Salomone, R.; Petti, L.; Mondello, G.; Raggi, A. Is there a simplified LCA tool suitable for the agri-food industry? An assessment of selected tools. *J. Clean. Prod.* **2017**, *149*, 406–425. [CrossRef]