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Review

Agri-Environmental Indicators: A Selected Review to Support Impact Assessment of New EU Green Deal Policies

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Abstract: Every intervention of planning, implementation, and monitoring of agricultural and agri-environmental policies requires assessment tools that should have the characteristics of relevance, completeness, interpretability, data quality, efficiency, and overlapping. Despite the extensive selection of bibliographies and numerous projects designed to develop agri-environmental indicators necessary for assessing the sustainability of new policies, it is difficult to have an integrated and updated set of indicators available, which can be an effective and practical application tool to assists policymakers, researchers, and actors in policy design, monitoring and impact assessment. Particularly, such a need is pressing to face the new environmental challenges imposed by the upcoming European Union Green Deal on the Common Agricultural Policy (CAP) post 2023. This study, therefore, aims to fill this gap by proposing a selection methodology and different pools of agri-environmental indicators differentiated based on a scale approach (crop-farm-district-region). Furthermore, we have attempted to apply our approach by quantifying selected indicators for a specific evaluation necessity, represented in this case by an assessment of the environmental impact of land use change induced by CAP greening requirements in the Northern Italy context. Results of this validation show original crops' impacts comparison, but also highlight great knowledge gaps in the available literature.

Keywords: policy assessment; Green Deal; EU Common Agricultural Policy; scaled indicators; greening

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1. Introduction

Over the last decades, the Common Agricultural Policy (CAP) has moved towards the integration of environmental sustainability goals. This process has led in time to several innovations in the toolset of such policy. Introduction of first agri-environmental measures in 1992, decoupling of direct payments and their conditionality to environmental cross-compliance, after 2003 Fischler Reform, and, more recently, implementation of the greening payment in 2015 represent the most striking examples of how the CAP has been directed toward the inclusion of environmental issues. However, despite many 'green tools' put in place by the recent CAP reforms, the debate around the genuineness of environmental policy integration into the CAP is very lively. Many authors claim that behind the ongoing process of CAP greening lies an attempt to justify the large budgetary allocation of this policy toward a more and more environmentally concerned public opinion, but actually confirming the usual productivist paradigm through the back door [1]. Some authors even go so far as to speak of 'greenwashing' in reference to this process [2]. Doubts also arise regarding the real effectiveness of specific CAP green instruments. For instance, voluntary agri-environmental measures could be affected by adverse selection bias, leading to overcompensation of beneficiaries and limited additional environmental effects [3–5]. The environmental potentiality of the recent greening direct payment was also widely debated [6–11].

Questions and uncertainties about the real effectiveness of the CAP instruments from an environmental perspective claim for a rigorous evaluation process. This is most needed especially at this stage, in the imminence of the new ambitious CAP programming period after 2023, enhancing for greater flexibility and more tailored solutions for farmers' support, but also demanding for policy performances' measurement. Moreover, the new EU Climate Action and European Green Deal will align in a common framework all EU policies concerned with climate and environment, including CAP post 2023, according to a stronger results-based approach. In fact, the Farm to Fork Strategy, which is the agricultural dimension of the European Green Deal, sets precise quantitative environmental targets related to soil and water pollution, GHG emissions from farming activities, and rural biodiversity to which the future CAP must contribute [12–16].

As a consequence, future agricultural and agro-climatic-environmental policy interventions will need more effective indicators' toolsets for an efficient monitoring and assessment, crossing already known evaluation frameworks [17–24].

However, the current CAP assessment remains at stake, being based on a limited scale approach, and poorly connected to future climatic challenges [25–30]. With reference to the first issue, the scale approach means starting from a small context analysis, as a field-crop system, and progressively enlarging the perspective to wider levels, such as farm, district and regional ones, as commonly applied on territorial studies and planning [31–34]. Scale-approach is crucial to: (i) enhance quantitative data' information content and integrate different data sources; (ii) analyse specific governance and policy interactions and dose-response; (iii) connect agri-environmental indicators to their most suitable dimension, overcoming background-related bias.

Agri-environmental indicators can be useful tools to assess and monitor agrosystems' "health state" and related changes induced by policy measures. These indicators should be designed for a quick ex-ante and ex-post evaluation of the environmental effects of agricultural policies in the EU members' regions. Such kind of policy monitoring requires indicators having, at the same time, enough territorial coverage (not exclusively site-specific), and a certain degree of disaggregation. Commonly available agri-environmental indicators are usually unfit for effective policy monitoring, being sometimes customized for a single research site, or conversely, they are "aggregated" and not functional in terms of data requirements and univocal use [35–43]. Moreover, context-specific approaches are functional on monitoring and result checking perspective for single case studies analysis, but they are less useful in terms of policy planning and implementation at a wider territorial level [28,44–49].

The scale approach is different from the currently in place context-specific approach because it is not linked to a specific farm specialisation and/or to particular specific CAP measures [50–54]. In this respect, our research shows a focused scale approach that can be implemented at different levels: crop, farm, district, and region [55–57].

Furthermore, we included a quantitative aspect in indicators' selection, as traditional EU CAP environmental assessment is mainly based on qualitative indicators and is lacking a broad quantitative evaluation framework; this common lack of quantitative data implies serious constraints to future Green Deal result-based policies [42,44,45,58–61].

Quantitative and scale approaches are indissolubly connected: quantitative impacts assessment is poorly relevant if it is not scaled up to more vast areas compared to context-specific studies, and at the same time it is quite hard to estimate real crop or supply chain environmental impacts if quantitative surveys are just dispersed in several small case studies, not being progressively scaled-up along different territorial levels (crop-field, farm, district, region).

A qualitative-quantitative and scale-crop-ecosystem integrated approach can be even more easily connected with the landscape and territorial approach [28,31,34,62,63]. In this regard, for instance, Life Cycle Approach offers a coherent perspective with its typical own indicators, being focused on a mass input-output approach, offering an important hint to introduce a new crop approach and environmental evaluation [64–76].

To resume, future indicators' set must be a relatively simple tool with particular regard to an integrated approach linking agricultural activities impacts with overall ecosystemic conditions. For indicators, selection should be advisable, compact, univocal, comprehensive, and not excessively context specific.

Given these requirements, in our study, we selected a pool of integrated and multi-scaled agri-environmental indicators to evaluate the environmental impact of CAP instruments on a wide range. The selection process was carried out by screening available and well-accepted scientific literature studies concerning environmental indicators and integrating them in a coherent unique pool. Such pool was organised in sub-items and crop-scale subsections, suitable for a wide-range impact assessment.

Lastly, we applied our approach by quantifying selected indicators to a policy evaluation case study: the assessment of agro-ecological impact of land use change induced by CAP greening requirements in the Northern Italy context.

Against this background, the aim of this paper is threefold: (i) to analyse the current state of the art for selecting a set of agri-environmental indicators useful for bridging the gap in current policies assessment; (ii) to provide the stakeholders (policymakers, researchers, etc.) for a harmonised set of indicators, currently not available, for ex-ante and ex-post assessment of CAP instruments; and (iii) using our set of indicators in a site-specific policy assessment exercise at crop scale level.

2. Materials and Methods

The purpose of providing a harmonised set of agri-environmental indicators to assist policy impact evaluation has considered the multi-scale nature of such assessment exercises. For this reason, the collection of relevant sources of agri-environmental indicators has followed a scale approach, looking firstly for those providing information to a more aggregated level (region) and then to downscaled levels (district, farm and field/crop). The different levels of aggregation to which indicators are provided made it necessary to adopt and integrate different search criteria. In particular, for indicators provided to a more aggregated scale (regional) a combination of open-access databases and selected literature review has been adopted.

This framework is coherent to the paper's final aim to create a unique indicator pool that can be up-scaled or down-scaled for the same geographical context, and we, as a result, applied to Northern Italy farming and land cover context, influenced by CAP policies.

Agri-environmental indicators' datasets considered were:

- Standard Eurostat indicators: they are easy to be detected and they are georeferenced, even if at a large scale. However, they are not always updated, functional for deep analysis, being usually related to the large-scale pollution impact on farmland, water and air [12];
- FAO—Sustainable Assessment on Food and Agriculture Systems (SAFA) indicators: these series miss important issues, not clarifying connections among different indicators' pools, and being macro-aggregated at a large scale and poorly functional, so we put them apart [42];
- Context-specific environmental impact assessment papers, providing impacts' estimation at different scale levels (regional, district, farm-crop).

With regard to the last point, we conducted bibliographical research on agri-environmental indicators' pools referring to the EU farming contexts, into academic databases (CAB, Web of Science, and Scopus). The time span of the bibliographical research was chosen as a compromise between two different needs: (i) to provide up to date indicators for future policy impact assessment; (ii) to ensure a wide coverage of indicators at different scales. As a compromise, we chose to include articles published from 2013 onward. Search criteria was a combination of the following keywords: "CAP policy assessment", "agri-environmental indicators", "agri-food system assessment", "scaled assessment". The bibliographical research, carried out between May 2020 and February 2021, yielded a total number of 299 articles. From this initial pool, 199 articles were referred to regional-level agri-environmental indicators, while 100 to other levels (district, farm-crop). Being the focus of our study on finding indicators that can be scaled-up along different territorial levels (crop, farm, district, region), we limited the selection of exclusively regional-level agri-environmental indicators, not scalable to more detailed levels, solely to 19 indicators retrievable from Eurostat. With regards to indicators at the district and farm-crop scales, we initially took into account overall other 100 studies, particularly focusing on those regarding crops-related environmental impacts of 23 possible farmland uses referred to [77]. Each article has been screened for content appropriateness and selected or excluded, according to various criteria that will be listed in the remainder of this section. As pointed out, studies have been excluded being older than 2013, so out of the 2014–2020 Greening implementation period. Of 75 remaining studies, we lastly selected 13 studies based on the 2014–2020 reference time, with mass-based indicators and a relation with the Po Plain farming context.

As the first criterion in the selection process, we selected indicators of the environmental impact of agricultural activity measured as pollutant emissions, focusing on quantitative mass-based and area-based agri-environmental indicators. For "mass-based" are meant to be all those indicators expressed as the amount of pollutant per unit of production. For "area-based" are meant to be all those indicators expressed as the amount of pollutant per hectare. The two categories of indicators are well suited for different policy impact assessment needs. Mass-based are able to account for heterogeneity in crop yield across regions and agricultural systems and are more suitable for a balanced assessment of environmental and food security outcomes of EU Green Deal policies. Area-based indicators are instead more suitable to assess the environmental impact of agricultural policies inducing direct and indirect land use change. The latter case will be better explained with a specific application at the end of this section. A major focus was posed on multidisciplinary environmental impact evaluations, in particular considering direct and related agricultural activities impacts. Further criteria adopted during the process of selection of the articles, based on their indicators, were the following:

- Relevance: whether the article's indicators measure the impact on the farm's sustainability;
- comprehensiveness: to be relevant to all systems combining food and non-food production;
- interpretability: indicators must be easily and clearly attributed to one or more scales;
- data quality: to be relevant in describing the considered phenomena;
- efficiency: indicators must be collected quickly and easily;
- overlap: to avoid redundancies with other indicators already selected for the pool.

In fact, the selection process prioritised clear, measurable and data-available indicators. The purpose was to develop an integrated pool of indicators based on the territorial and functional scale of the agricultural activities. Such collection is meant to be different from current CAP evaluation indicators, in three ways: (i) transversality in terms of farm specialisation; (ii) complexity and wilderness in terms of agro-systems characteristics, (iii) easy to be used as input data by policy impact evaluators, in order to provide evidence understandable by stakeholders and policymakers. The indicators considered address several key issues of the EU Green Deal, and of the complementary Farm to Fork Strategy, first of all, the well-known EU climate ambitions, aiming for climate neutrality by 2050, to which the agricultural sector is called upon to contribute. In addition to the issue of GHG emissions from the agricultural sector, the indicators tackle other Green Deal-related questions. For instance, the pollution reduction objectives set out in the EU Action Plan "Towards Zero Pollution for Air, Water and Soil", recently adopted by the EU Commission, and those delineated in the Farm to Fork Strategy on reducing agro-chemicals and fertilisers in agriculture. As a result of the selection, we considered the following 9 agri-environmental indicators at the district and farm-crop level:

- Global Warming Potential (GWP, expressed as kg CO_2 eq/ha)
- Global Warming Potential (GWP, expressed as kg CO_2 eq/Mg)
- Particulate Matter Formation (PM, expressed as kg PM2.5 eq/Mg)
- Pesticide and herbicide use (kg\ha)
- Human Toxicity (kg 1,4-DB eq/Mg DM)
- Photochemical Ozone Formation (POF, expressed as kg NMVOC eq/Mg DM)

- Terrestrial ecotoxicity (1,4-dichlorobenzene equivalents kg/Mg)
- Acidification (kg SO_2 equivalents/Mg)
- Eutrophication (kg PO_4 equivalents/Mg)

After the screening process, 28 agri-environmental indicators have been selected, 19 exclusively referred to the regional level, while 9 referred to the other levels (district, farm-crop). All described indicators and related sources are presented in Appendix A Table A1. It should be specified that, when district and farm-crop indicators can be scaled up, they are also mentioned among those of the higher levels.

Once provided the pool of sources and articles reporting agri-environmental indicators at different scales (Appendix A Table A1), we extracted a selection of such indicators suitable to assist a specific CAP impact assessment case. Such cases fall in the broad category of analyses yielding, as a first evaluation result, the land use change caused by agricultural policy interventions. In particular, the study considered [77,78] has assessed land use transition and crop mix change induced by the obligations associated with the so-called "greening payment" established within the 2015–2020 CAP reform. Such payments (representing the main part of CAP support) were conditioned to farm-level diversification of arable crops and to devoting part of arable land to ecological focus areas (see EU Regulation n. 1307/2013). The analysis taken as a case study has estimated the crop-mix change induced by the greening in a Northern Italian region, characterised by the wide presence of maize monoculture. As the policy impact assessment output is the crop-mix change, crop-level agri-environmental indicators have been selected, in order to evaluate environmental impact due to such land use change. As Northern Italy is one of the EU regions where greening has had the greatest impact in terms of land use change (as esteemed by [77–79], we preferably extracted values referred to this geographical context. In particular, we considered the main cultivated crops and farmland uses, in that area, such as maize, green maize, wheat, ryegrass, sorghum, triticale, rye, barley, rice, tomato, rapeseed, sunflower, alfalfa, permanent grassland, horticulture crops, and poplar. For each combination of indicator and crop, we have attempted, where possible, to find a quantification useful for a hypothetical impact assessment process (see Appendix A Table A2). Not all indicator-crop combinations were covered due to a lack of detailed data. In a few cases, we found the same quantification by two different studies [64–76].

3. Discussion: Suitability of Selected Indicators for Policy Impact Assessment

The present contribution has been conceived to collect agri-environmental indicators suitable to assist and support the impact assessment of EU Green Deal Policies. In collecting and selecting appropriate indicators for this purpose, we had to deal with: (i) the muli-scale nature of agri-environmental assessment exercises; (ii) the need to provide a wide territorial coverage of various indicators; (iii) the trade-off between territorial coverage and accuracy of each indicator. As a result, the pool of selected indicators should serve both in a perspective of territorial wide-range analysis and when a specific focus on crop/farm level is more appropriate. The search and selection process of indicators has dealt with two main categories of environmental assessment studies: those focused on a farm scale, and those conceived to wider scales. Therefore, this contribution has tried to reunify in a single framework all those agri-environmental indicators belonging to different groups and scales of analysis. Combining indicators from different sources and scales allows merging relevance and comprehensiveness of different environmental impacts. Some weaknesses and criticalities emerge both during the selection and harmonisation of indicators and from the observation of the whole pool (Appendix A Table A1) as well as in the attempt of extracting a subset of indicators to be applied to a case study (Appendix A Table A2):

1. The lack and disproportion of available data at different scale levels. Farm-level is easily representable, mainly with site-specific studies, which are usually crop-related, underestimating ecosystem-wide matrix impacts (e.g., biodiversity). In any case, they are precious as the first source of data and direct crops' impacts. The regional level is represented by national or regional databases. Regional scaled indicators are not designed

to be lowered into local contexts, while they are useful only for general overviews, being mainly linked to a broader statistical perspective. The district level is a middle ground between the other scale levels, being an intermediate body between farms and regions. Usually available indicators at that level are computed for certain types of farming. This level is crucial, but it is missing in statistical surveys on environmental impacts assessment.

2. Lack of micro-level indicators. Crop-level environmental impacts are mainly computed in case-specific analysis, difficult to be scaled up. On the contrary, they are rather missing in public regional statistics, where they would have more potential in terms of general impact assessment. The large majority of crop-level agri-environmental indicators refer to arable crops and cereals, while other productions tend to be neglected and not represented at the same scale. The lack of crop-level indicators for some crops emerges clearly from the attempt of applying our data to a specific case study (Appendix A Table A2). This represents a major limitation to ensure full territorial coverage of policy impact assessments.

3. Disproportion in the availability of indicators. It may be observed how some indicators show greater interest and coverage (e.g., Climate Change and CO_2 eq emissions), while others suffer from limited coverage (e.g., Eutrophication, Acidification, Particulate Matter Formation, Pesticides and Herbicides use, etc), being a limitation for policy impact assessment. These statements are based on the attempt to provide suitable crop-level area-based indicators for the environmental impact assessment of the case study (Appendix A Table A2). In that case (land use change induced by CAP greening crop diversification in Northern Italy), the available combinations of crop-pollutant indicators were limited. Focusing on that case study (Northern Italy), indicators selectable from the whole pool (Appendix A Table A1) assuring, at the same time, enough crop type and territorial coverage, were limited to the most relevant crops in the area [77–81]. In fact, assigning to each crop its related environmental parameter, we would be able to derive an estimation of policy environmental impact starting from the estimated changes in crop allocation. Data show internal coherence, as they converge on a common order size, especially were referred to similar crops. Focusing again on the application to the case study area, some limits and data gaps, referred to many combinations of crops and agri-environmental indicators emerge:

(a) Total lack of data for some categories of farmland uses, such as fallow land, particular types of grassland, landscape features, agroforestry systems, cover crops, and some industrial crops.

(b) Data deficiency for many categories of indicators, including Particulate Matter Formation, Pesticides and Herbicides, Human Toxicity, Photochemical Ozone Formation, and Eutrophication. From this perspective, only main sources of pollution can be quantitatively estimated, even if on a very narrowed base and in a specific context; therefore, great sources of pollution remain not assessed and estimated.

Our approach, even if applied to a single case study, shows all constraints to develop an integrated future CAP evaluation. Lack of data combined with datasets separation prevents a developing integrated evaluation approach. Future data research will need to be more impact-focused and exploring, mapping in detail and improving the quality of different data sources. Clarifying data connection can also be a future aim in the current research context.

4. Conclusions

We tried to develop an integrated pool of indicators, suitable for environmental evaluation for the farming sector along with different scale steps and suitable for different commonly grown EU crops. The final expected result was supposed to be a coherent framework, including data coming from different sources and data banks. Until the present day, agri-environmental indicators for environmental impacts assessment have been just partially available in the European context; in particular, we noticed a common gap in clearly pairing environmental indicators to the spatial-context scale at different levels.

The main need consists of a selected and narrowed pool, functional for the CAP environmental impacts monitoring and assessment. The selection process was carried out in order to set up an advisable compact, univocal, comprehensive, and not excessively particular pool. Bridging policy and agro-ecosystem analysis is increasingly relevant, given the emphasis on environmental goals by the new EU Green Deal strategy. In this sense, our paper constitutes a partial contribution to the ambitious objective of a comprehensive assessment and evaluation of CAP environmental and climate impacts.

Agri-environmental indicators from different databases have been integrated into a unique pool and divided into suitable sub-sections. Unity of measure was a critical point, and working on standardised mass-based unity of measure has been a practical solution to integrate different datasets.

Among the main constraints of current research, we can include: (i) it is an alternative insight on the issue of environmental impacts' assessment; (ii) lack of validation on the field with diversified case studies, which is linked to the issue of having a complete and coherent bibliography; (iii) limited crop-related information availability.

In conclusion, the current paper is intended to be the first proposal for a new series of environmental indicators studies, based on a scale approach. Extending crops and indicators pools should be a purpose for future and more detailed research, including for instance a more explicit and wider integration between LCA's and Eurostat's indicators pool.

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

Appendix A

Table A1. Integrated indicators' list divided by scale and typology.

Scale	Agronomical-Operational	Database\Source
Region	• Agri-environmental: Area under organic farming (Eurostat_sdg_02_40) Agriculture: area under management practices potentially supporting biodiversity (EEA_SEBI020) Harmonised risk indicator for pesticides (HRI1), by groups of active substances (Eurostat_sdg_02_51, source: EC) Ammonia emissions from agriculture (Eurostat_sdg_02_60, source: EEA) Ammonia emissions from agriculture—% of total emissions (Eurostat_tai07, source: EEA) Gross nutrient balance on agricultural land by nutrient (Eurostat_sdg_02_50) Estimated soil erosion by water—area affected by severe erosion rate (source: JRC) (Eurostat_sdg_15_50) Gross nutrient balance in agricultural land (Eurostat_t2020_rn310) Agriculture: nitrogen balance (EEA_SEBI019) Soil organic carbon (EEA_LSI005) Share of forest area (Eurostat_sdg_15_10)	Eurostat
	• Natural areas: Ecosystem coverage (EEA_SEBI004) Fragmentation of natural and semi-natural areas (EEA_SEBI013) Habitats of European interest (EEA_SEBI005)	Eurostat
	• Livestock: Livestock density index (Eurostat_tai09)	Eurostat
	• Water: Crop water demand (EEA_CLIM033) Water exploitation index, plus (WEI+) (Eurostat_sdg_06_60, source: EEA) Water productivity (Eurostat_t2020_rd210) Water resources: long-term annual average (Eurostat_ten00001)	Eurostat

Table A1. *Cont.*

Scale	Agronomical-Operational	Database\Source
	• Agri-environmental (LCA\ Quantitative environmental evaluation):	Web of Science and Scopus
	Global Warming Potential (a) GWP, kg CO_2-eq/ha; (b) GWP, kg CO_2-eq/Mg: Human Livestock Tillage Fertilizers Pesticides Irrigation (Bacenetti et al., 2014; Naudin et al., 2014; Manfredi et al., 2014; Noya et al., 2015; Bacenetti et al., 2018; Forleo et al., 2018; Lovarelli et al., 2018; Noya et al., 2018; Zucali et al., 2018; Vailante et al., 2019; Bacenetti et al., 2020; Lehmann et al., 2020; Lovarelli et al., 2020	Web of Science and Scopus
	• Acidification (kg SO_2-eq/year)—(Bacenetti et al., 2014; Lehmann et al., 2020; Lovarelli et al., 2020; Naudin et al., 2014; Noya et al., 2015; Zucali et al., 2018)	Web of Science and Scopus
	• Eutrophication (kg PO_4-eq/year)—(Bacenetti et al., 2014; Lehmann et al., 2020; Lovarelli et al., 2020; Naudin et al., 2014; Noya et al., 2015; Zucali et al., 2018)	Web of Science and Scopus
District	(LCA\Quantitative environmental evaluation): Agri-environmental:	Web of Science and Scopus
	Global Warming Potential (a) GWP kg CO_2-eq/ha; (b) GWP, kg CO_2-eq/Mg: Human Livestock Tillage Fertilizers Pesticides Irrigation (Bacenetti et al., 2014; Naudin et al., 2014; Manfredi et al., 2014; Noya et al., 2015; Bacenetti et al., 2018; Forleo et al., 2018; Lovarelli et al., 2018; Noya et al., 2018; Zucali et al., 2018; Vailante et al., 2019; Bacenetti et al., 2020; Lehmann et al., 2020; Lovarelli et al., 2020).	Web of Science and Scopus
	• Acidification (kg SO_2-eq/year)—(Bacenetti et al., 2014; Lehmann et al., 2020; Lovarelli et al., 2020; Naudin et al., 2014; Noya et al., 2015; Zucali et al., 2018)	Web of Science and Scopus
	• Eutrophication (kg PO_4-eq/year)—(Bacenetti et al., 2014; Lehmann et al., 2020; Lovarelli et al., 2020; Naudin et al., 2014; Noya et al., 2015; Zucali et al., 2018)	Web of Science and Scopus
Farm-Crop	(LCA\Quantitative environmental evaluation): Agri-environmental: • Global Warming Potential (a) GWP, kg CO_2-eq/ha; (b) GWP, kg CO_2-eq/Mg: Human Livestock Tillage Fertilizers Pesticides Irrigation (Bacenetti et al., 2014; Naudin et al., 2014; Manfredi et al., 2014; Noya et al., 2015; Bacenetti et al., 2018; Forleo et al., 2018; Lovarelli et al., 2018; Noya et al., 2018; Zucali et al., 2018; Vailante et al., 2019; Bacenetti et al., 2020; Lehmann et al., 2020; Lovarelli et al., 2020)	Web of Science and Scopus
	• Particulate Matter Formation (PM, expressed as kg PM2.5 eq Mg^{-1})—(Zucali et al., 2018; Bacenetti et al., 2018; Vailante et al., 2019; Bacenetti et al., 2020; Lovarelli et al., 2020)	Web of Science and Scopus
	• Pesticide and herbicide use (kg ha^{-1})—(Bacenetti et al., 2014; Noya et al., 2015; Forleo et al., 2018; Noya et al., 2018; Zucali et al., 2018; Bacenetti et al., 2018; Bacenetti et al., 2020; Lovarelli et al., 2020)	Web of Science and Scopus
	• Human Toxicity (kg 1,4-DB eq Mg^{-1} DM)—(Bacenetti et al., 2014; Noya et al., 2015; Forleo et al., 2018; Noya et al., 2018; Lovarelli et al., 2018; Zucali et al., 2018)	Web of Science and Scopus
	• Photochemical Ozone Formation (POF, expressed as kg NMVOC eq Mg^{-1} DM)—(Bacenetti et al., 2014; Manfredi et al., 2014; Noya et al., 2015; Bacenetti et al., 2018; Forleo et al., 2018; Noya et al., 2018; Lovarelli et al., 2018, Zucali et al., 2018; Vailante et al., 2019; Lovarelli et al., 2020)	
	• Terrestrial ecotoxicity (1,4-dichlorobenzene eq kg Mg^{-1})—(Bacenetti et al., 2014; Manfredi et al., 2014; Noya et al., 2015; Noya et al., 2018; Lovarelli et al., 2018, Zucali et al., 2018; Vailante et al., 2019)	
	• Acidification (kg SO_2-eq/year)—(Bacenetti et al., 2014; Lehmann et al., 2020; Lovarelli et al., 2020; Naudin et al., 2014; Noya et al., 2015; Zucali et al., 2018)	
	• Eutrophication (kg PO_4-eq/year)—(Bacenetti et al., 2014; Lehmann et al., 2020; Lovarelli et al., 2020; Naudin et al., 2014; Noya et al., 2015; Zucali et al., 2018)	

Table A2. Crops-related environmental indicators referred to Northern Italy context.

Crops Category	Paper	Global Warming Potential (a) (GWP, Expressed as kg CO_2 Equivalents ha^{-1})	Global Warming Potential (b) (GWP, Expressed as kg CO_2 eq Mg^{-1})	Particulate Matter Formation (PM, Expressed as kg PM2.5 eq Mg^{-1})	Pesticide and Herbicide Use (kg ha^{-1})	Human Toxicity (kg 1,4-DB eq Mg^{-1} DM)	Photochemical Ozone Formation (POF, Expressed as kg NMVOC eq Mg^{-1} DM)	Terrestrial Ecotoxicity (1,4-Dichlorobenzene eq kg Mg^{-1})	Acidification (kg SO_2 eq Mg^{-1})	Eutrophication (kg PO_4 eq Mg^{-1})
Maize	Bacenetti et al., 2014	1929.00	177.00		6.00	17.33	0.01	0.06	8.25	4.38
Green maize	Zucali et al., 2018	2528.00	131.00		3.00	16.63	0.01	0.04	4.75	2.46
Green maize	Noya et al., 2015		631.00		6.00		1.30	0.08	7.50	
Rotation Maize and RyeGrass	Zucali et al., 2018	3409–3773	142.00			29.87–35.93	0.02–0.01	0.08–0.06	8.3–4.80	3.77–1.96
Triticale	Noya et al., 2018		738–445			37–22	1.02–0.61	0.22–0.13	26.00	
Wheat	Noya et al., 2015		498.49		5.00	27.90	0.63	0.02	3.30	
Barley	Lovarelli et al., 2020		184.89	0.14	0.59		1.02			
Barley	Noya et al., 2018		743.00			38.00	0.91	0.07	22.00	
Rye	Noya et al., 2018		695–571		6.06	27–23		0.19–0.16	23–19	
Triticale	Noya et al., 2015		492.18		5.00	26.04	0.61	0.02	3.15	
Rice	Bacenetti et al., 2020		937.30–832.70	0.44–0.38			2.13–1.86			
Pulses	Forleo et al., 2018		526.00		6.02–0.68	44.70	0.48–0.03	0.32	14.97–4.03	5.26–2.08
Pulses	Forleo et al., 2018		307.00		6.12–1.07	72.81	0.39–0.06	0.36	33.21–2.94	1.48
Other Arable Crops	Manfredi et al., 2014		258.57				0.01		0.50	1.97
Alfa Alfa	Zucali et al., 2018	683.00	58.50			17.33	0.01	0.07	1.97	0.54
Alfa Alfa	Bacenetti et al., 2018		84.54	0.07	2.00		0.79			
Horticulture	Valiante et al., 2019		212.00	0.11			0.58			
Permanent Grassland	Zucali et al., 2018	1224.00	129.00	0.00		33.04	0.01	0.04	8.88	2.18
Permanent Crops	Lovarelli et al., 2018		67.28–63.24			7.9–7.10	0.4–0.32		1.54–1.51	

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