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1. Introduction and objective

Cereal straw, a by-product of agricultural crops, is considered a potentially large source of energy supply with an estimated value of $47x10^{18}$ J worldwide (Benoit and Gagnaire, 2008). Concerns about fossil fuel use, along with advances in biomass conversion technology, stimulated the interest in using crop residues as feedstock for bioenergy purposes (Cherubini and Ulgiati, 2010).

Although cereal straw is an abundant source of biomass, its use as feedstock for energy purposes is still scarce. In general, cereal straw currently has on-farm end-uses such as animal bedding and feeding, while for the fraction of straw that is not used, alternative end-practices can be applied. Straw can be removed from the field and sold on local markets, chopped and incorporated into the soil, and burnt on field. These practices are not mutually exclusive but may be differently combined according to specific contexts and farmer's choices.

The aim of this research is to contribute to the literature by assessing the environmental impact of wheat straw end-practices. Three wheat straw end-practices are considered in the study, namely straw baling, incorporation into the soil as fertilizer, and open field burning. In the light of the ever-growing demand of straw as feedstock for energy production, the study deals with two scenarios, namely the STATUS QUO and the DEMAND PULLED scenarios, each one with different combinations of on-farm cereal straw end-practices. Survey results of cereal growers located in Apulia Region (Italy) were used. The ultimate goal is the enhancement of environmental sustainability of each scenario.

The environmental impact of on-farm straw end-practices in the aforementioned scenarios was assessed through the implementation of an Attributional Life Cycle Assessment (ALCA).

2. A short literature review

In general, the literature reports several studies that assessed the impact of single straw end-practice, such as crop residue burning, straw incorporation as well as the impact of residues removal from field; on the other hand, there are few studies that compared impacts among multiple practices. In this section a short literature review is reported.

The open-field burning practice has been widely studied. Open-field burning is a commonly used practice to dispose the straw and to prepare the soil for farming. Straw is burnt *in situ* to facilitate a quick planting of the next crop. This practice has phytosanitary effects which may have a positive influence on yields (Prochazkova et al., 2003). However, straw burning has a deleterious effect on the local air quality (Li et al., 2008; Lai et al., 2009;) and on the soil organic carbon (SOC) content (Cherubini and Ulgiati, 2010), while it causes the waste of a valuable resource. Furthermore, the on-field burning of crop residues might affect human health (Chang et al., 2013; Satyendra et al., 2013; Jain et al., 2014).

One of the key environmental benefits of straw incorporation is the avoidance of the effects of *in situ* straw burning. Furthermore, through straw residues incorporation into the soil, and the increased amount of organic matter attained in this way, farmers aim at enhancing long-term soil fertility. Anyway, although a priori thinking would suggest that a low fertilization intensity is environmentally favourable, Charles et al. (2006) assessed the environmental impacts of wheat production in relation with wheat yields and quality parameters, and showed that increased fertilisation and additional emissions may be justified in case of a sufficient increase in grain yield and quality. Straw incorporation may also have environmental impacts, mainly in terms of greenhouse gas emissions (Gan et al., 2011; Abril et al., 2012; Yao et al., 2013; Yang et al., 2014).

The practice of removing straw from the field and its related environmental burden was considered in several studies. Eutrophication, global warming, and aquatic eco-toxicity were among the most studied environmental impacts (Brentrup et al., 2004; Nguyen et al., 2013; Shafie et al., 2013; Wang et al., 2013; Ingrao et al., 2015).

Besides the literature assessing the environmental impacts of single end-practices, further studies focused on comparing the environmental burden of multiple straw end-practices.

Benoit and Gagnaire (2008) simulated the impact of straw incorporation and straw removal under various sets of soil, climate and crop management conditions in North-eastern France; their results showed that straw removal had little influence on environmental emissions in the field, while straw incorporation in the soil caused a sequestration of only 5–10% of C in the long term (30 years). Assessing the environmental impact of four rice straw end-practices, Silalertruksa and Gheewala (2013) concluded that straw incorporation as fertilizer brought several environmental benefits. Chen et al. (2013) compared the annual CO_2 emissions of straw end-practices in Australia, measuring in 3.45 Mg C ha^{-1} y^{-1} and in 2.13 Mg C ha^{-1} y^{-1} the emissions from maize straw burning and straw incorporation, respectively.

Fusi et al. (2014) compared two different scenarios of rice straw management, i. e. burial into the soil *versus* harvesting in the District of Vercelli (Italy) and affirmed that the collection of the straw improves the environmental performance of rice production.

Monteleone et al. (2015) studied some straw management strategies (straw retention into the soil *versus* straw removal) related to the wheat cultivation system in Italy, focusing on soil organic carbon and N_2O emissions. According to their assessment, straw retention into the soil contributed to a significant increase in soil organic carbon, while straw removal reduced SOC remarkably. Moreover, straw retention caused higher N_2O soil emissions (0.965 kg ha^{-1} yr^{-1}) due to soil denitrification potential, while straw removal showed lower N_2O emissions (0.536 kg ha^{-1} yr^{-1}). Cherubini and Ulgiati (2010) also concluded that the removal of agricultural residues from the fields may arise some concerns about soil quality deterioration, decrease in SOC, and soil erosion phenomena.

In this study, the environmental assessment of wheat and straw production was assessed considering three end-practices, namely burning, incorporation and baling.

Despite such a bulk of literature, a comparison among the environmental impacts of different straw end-practices is hardly ever possible without any consideration on the types of cereal and straw, on the pedoclimatic condition and on the agronomic techniques applied. Wheat grows in a wide variety of environments with a broad range of water availability and ambient temperatures that are critical factors affecting the productivity of cereals (Renzulli et al., 2015). Moreover, agricultural practices are strongly site-specific. Hence, the environmental impacts deriving from crop cultivation and from straw residues management practices are largely dependent on multiple factors. Among others, the specific natural conditions and the characteristics of the production area, the types of straw, and agronomic practices, should be carefully considered. In this study, the environmental assessment of wheat and straw production is carried out within a Mediterranean region, with characteristics and climate conditions typically exhibited in these areas. On the whole, the study area has a flat-drained ground while soils are often loamy with a percentage of sand.

3. Materials

3.1. Study area

The study area is located in the Province of Foggia, within Apulia Region (Southern Italy). Foggia Province (41° 27' Lat. N; 15° 04' Long. E) is located in Southern Italy, 90 m above the sea level. The soil is a vertisol of alluvial origin, typic calcixererts of silty clay texture (12.9 % sand, 43.7 % clay, 43.4 % silt), 1.35 m of depth, with a bulk density of 1.24 Mg m-320, pH 8.5, field capacity at 42% (v/v) and permanent wilting point at 24% (v/v) (Monteleone et al., 2015). The average precipitation rate of the hydrologic summer and winter in Foggia is 208 mm and 289 mm, respectively (Foggia-Amendola Weather Station).

Foggia Province has an agricultural area of about 322 thousand ha (Istat, 2010) and arable land accounts for 71% of total farmland. Winter cereals, mainly durum wheat (95% of cereals crop area), is prevailing. The Province produces one-third of Italy’s annual durum wheat output, on a total area of almost 200,000 ha (Istat, 2010).

Basically, there are no official statistics on straw quantities, on-farm uses or supply to local market. Straw as by-product may have on-farm uses as animal bedding and feed. On the other hand, on those farms where not all straw is used, a combination of end-practices may be applied.

Under Good Agricultural and Environmental Condition (i.e. cross-compliance of EU CAP - Common Agricultural Policy), incorporation into the soil has been enforced with the aim of improving soil organic matter. Additionally, within the EU Agro-Environmental Scheme (Measure 214), farmers who incorporate wheat straw receive an additional payment of 100 EUR ha^{-1}, per 300 unit of d.m. year $^{-1}$. On the other hand, even though on-field burning practice is generally banned, actually under some circumstances of pest, disease or fire risk, on-field straw burning can be carried out, and therefore no straw remains for energy purposes.

A combustion power plant (25 MWe) using straw as its main fuel is being built in the municipality of *Sant'Agata di Puglia* in Foggia Province (Apulia region - Italy). This implies that 130 Gg d.m., the equivalent of approximately 30% of the area's total annual cereal straw output, will be used to fuel the plant; in other words, it amounts to 110,000 hectares of cereal area around the plant.

However, the amount of straw disposed according to each end-practice and the amount of straw that farmers would be willing to sell on the feedstock market for energy production are missing.

3.2 Farm sample and survey

The main data source for this analysis was a survey of farmers in Foggia Province.

Based on the list of farmers in the official state census (Istat, 2010), a stratified sample was designed on the basis of median values of farmland used to grow cereals within each municipality in the Province. The municipalities were selected throughout the Province at a distance of up to 70 km from the energy plant site, in line with the Apulia Regional Law n. 31/2008 ruling that the average distance of feedstock transportation should not exceed 70 km. A sample of 203 farms across 24 municipalities was obtained. Table 1 compares the sample and the overall population.

Table 1 Comparison between the case study area and the sample

	Study area[a]	**Sample**
No. of farms classified by median		
< 10 ha	5,813 (53%)	98 (48%)

>= 10 ha	5,215 (47%)	105 (52%)
Total	11,028	203
Cereal area classified by median		
< 10 ha	31,294 (18%)	554.5 (18%)
>= 10 ha	141,699 (82%)	2,559 (82%)
Total	172,993	3,113.5

Source: adapted from ISTAT (2010); [a] <= 1.99 ha is excluded

Farms with less than 2 ha of cereal land were excluded, because the largest proportion of cereal land is actually cultivated by larger farms, therefore the influence of smaller farms on the final assessment can be disregarded. Indeed, data from the 2010 Agricultural Census (Istat, 2010) show that 20% of the total number of specialized cereal farms has less than 2 ha of cereal land, although these farms cover a very small proportion of the area's total cereal land (9%). On the contrary, 18% of farms have an area of over 20 ha, and these account for the largest share of cereal land (42%). The average age of sampled farmers is 55; 45% of respondents also have off-farm jobs, and 91% of farms rely on family labor. The average farm size is 22.91 ha, with an average on-farm cereal area of 15.33 ha. Straw yield (Mg ha^{-1}) ranges from 1 to 5, with an average of 3.11 Mg ha^{-1}. Overall, the sample is satisfactorily representative, considering the large variability within the study area.

As argued by Glithero et al. (2013), for second generation feedstock such as straw there are no official statistics on quantities at the national or local level. Differently from other studies, where alternative end-practices are arbitrary chosen by researchers, a feature of this studio is that scenarios were built according to current end-practices and to the farmer's willingness to change them as elicited through a direct survey.

A questionnaire was designed in order to collect data from farmers on a range of topics including farming practices, grain and straw yield, farm profile, current straw on-farm uses and end-practices (data are available on request). The questionnaire covered farmers' willingness to enter the energy market and their stated intentions about straw end-practices in the presence of a nearby biomass plant for energy production (see the Appendix). The questionnaire was administered by a team of trained recorders in spring 2014. The question on willingness to enter the feedstock market was set out as a binary choice (Yes *versus* No), asking farmers if they expected to switch from current straw use/end-practice to supplying the energy market. Farmers were also asked to indicate their level of commitment (percentage of biomass they would be willing-to-supply) and of participation (length of supply contract). A delivery modality of straw baled with bales left on the field was established.

Farmer's stated behaviours and preferences for straw end-practices allowed us to accurately assess the amount of straw burnt, incorporated into the soil and baled for sale, under both scenarios. The approach applied by Glithero et al. (2013), who carried out an estimation of straw uses along with potential availability for second generation biofuels by surveying 249 farmers across England, was followed. On the basis of the survey returns, sampled cereals land was 3,113.5 ha with average straw yield of 3.11 Mg ha^{-1}. Straw can have on-farm use mostly in livestock. Livestock farms (10% of the sampled farms) use almost all of the straw they produce for animal bedding and feeding; in doing so, any straw end-practices is implemented inside these farms. On the other hand, almost half the farms (46%) are already active on the straw market. Of the 203 farms, 94 sell straw (baled) on established local market. Alternative end-practices include soil incorporation (26% of farms) and on-field burning (18% of farms).

According to the sample data, 56% of respondents would be willing to supply cereal straw for energy purposes. The main change in current end-practices would involve straw incorporated in the soil, and to a lesser extent straw currently burnt, while straw used for feeding and bedding by livestock farmers would not be available for sale. Taking into account this result, the straw used in livestock was excluded from the environmental analysis.

On the basis of farmers' response and taking into account the approach applied by Glithero et al. (2013), two scenarios with a different mix of the three straw end-practices were built (Table 2):

a. the STATUS QUO is the snapshot of current on-farm straw end-practices, with a mix of 50% straw baled, 32% straw incorporated, and 18% straw burnt;

b. the DEMAND PULLED scenario presents the on-farm straw end-practices which would result if straw could be sold on a hypothetical feedstock market for bio-energy production, with a mix of 82% straw baled, 6% straw incorporated, and 12% straw burnt.

Table 2 Comparison between STATUS QUO and DEMAND PULLED scenarios

	% of straw by end-practices (Mg)		
Scenarios	Incorporation	Burning	Baling
STATUS QUO	32%	18%	50%
DEMAND PULLED	6%	12%	82%

Source: direct sample survey

4. LCA Method for Environmental Assessment

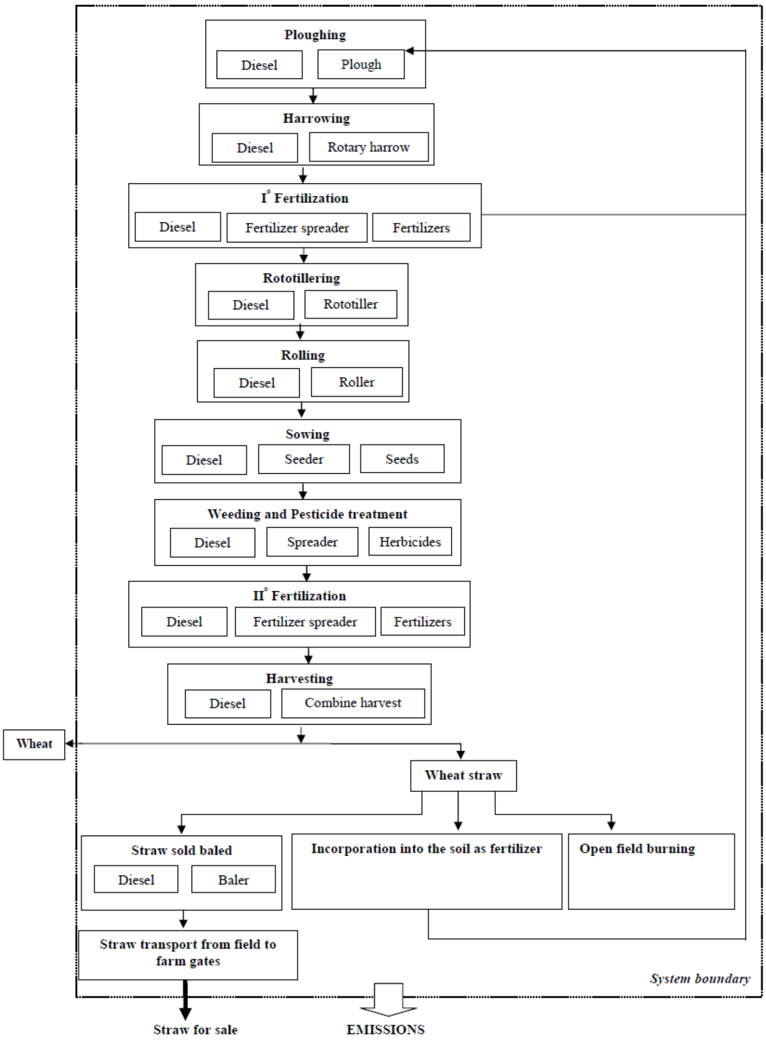
4.1 Goal definition and scoping

The LCA method was used to carry out an environmental impact analysis of each different straw end-practice and scenario.

The analysed system includes all the agricultural processes occurring during the wheat straw life cycle and it is referred to the crop management system applied in the study area. Wheat cultivation has a long tradition in the study area and follows similar characteristics in terms of the type of cereal (mostly durum wheat) and of farming practices.

The system boundaries (Fig.1) included in the LCA are given by the life cycle stages of the wheat cultivation and by on-site straw end-practices.

Figure 1 LCA System boundaries comprise all the processes performed within the farm gate. These boundaries are similar for both studied scenarios



Firstly, the environmental impact of each single practice was separately analysed; then, practices were combined within each scenario to assess and compare the whole environmental burden of two scenarios. This is another feature of this research, which, instead of assessing the environmental impact of a single end-practice, it focuses on the 'real world' complexity, where straw end-practices are actually combined.

As stated above, we focused on the farm gate, while environmental impacts (e.g. transportation, storage, stoking) that are not related to farmer's decision fell out of scope.

The functional unit used to quantify all inputs and outputs included within the boundaries of the system is defined as 1 Mg ha^{-1} of total wheat residue produced with a moisture content of 15% (Monteleone et al., 2015).

Allocation describes how ‘input’ and ‘output’ are shared between the main product and co-products (de Boer, 2003). Wheat grain is the main product, while straw is the co-product. The co-product handling is a crucial issue because it could impact on the final LCA results (Brankatschk and Finkbeiner, 2014; Notarnicola et al., 2015). Agricultural products are particularly sensitive to allocation methods because of the different share that their co-products can have. An economic allocation is based on market prices. A mass allocation gives a quantitative view of the co-products and ignores their inherent qualities, i.e. the chemical properties for specific uses, the nutritive components for food or feed purposes. ISO 14044 (2006) describes a hierarchy of allocation approaches, which are preferably based on mass allocation rather than on economic allocation. PAS 2050 standard (2011) recommends the use of economic allocation, while the BP X 30-323-0 standard suggests a physical allocation (ADEME, 2011). Such different recommendations within the LCA-based standards complicate the allocation choices. For these reasons, some Authors (Brankatschk and Finkbeiner, 2014) proposed a cereal unit (CU) allocation method to reduce the variability of LCA results due to different allocation methods. The cereal unit is based on the nutritional value for livestock as a common denominator that allows to consider agricultural products and co-products with different uses. The nutritional value for livestock is influenced by metabolizable energy content of product and co-product for feed purpose (Brankatschk and Finkbeiner, 2014). We compared the effect of three different allocation methods on LCA results, i.e. economic allocation, allocation by biomass, and allocation by cereal unit. Economic allocation was used as basis for sharing all impacts measured into the analysis; then, these results were compared to those with both mass and cereal unit allocation methods. Allocation factors were taken from Li et al. (2012) for both the economic allocation approach (87% is allocated to wheat and 13% to straw) and the mass allocation approach (47% is assigned to wheat and 53% to straw); the percentages of cereal unit allocation came from Brankatschk and Finkbeiner, 2014 (75% and 25% for wheat and straw, respectively).

4.2 Life cycle inventory analysis

Average data from the direct survey to farmers were used for the life cycle inventory analysis. Alongside the questionnaire, a technical sheet was also administrated in order to collect technical-related data and information on farming practices. Primary data (Table 2) refer to wheat and straw yields, to technical characteristics of tractors and agricultural equipment, to diesel and lubricating oil consumption, to type and amount of herbicides and fertilizers. In particular, urea was used for the first N-fertilization. The herbicides for weeding were also obtained through the survey. The cultivation of wheat follows the crop management system usually applied in Foggia Province, with respect to both mechanical operations and agro-chemicals applications (Monteleone et al., 2013).

On the basis of survey results, wheat cultivation cycle resulted in a very similar pattern for the three straw end-practices, with the exception of ploughing and of the first fertilization in case of straw incorporation. Agricultural residues incorporation affects the biological, chemical and physical properties of the soil. Incorporation is the major source of energy and nutrients for the heterotrophic micro-organisms in agro-ecosystems that play a critical role in the organic matter cycle (Voroney et al., 1989). The main advantage of a straw-based fertilizing system is the reduction of urea consumption (Silalertruksa and Gheewala, 2013). During the process of wheat residue incorporation, when straw and stubble return to the soil, wheat grain is the only biomass removed. For this reason, a lower amount of N-fertilizer is applied in the case of incorporation practice when compared to straw burning and baling end-practices, in order to restore the N removed with the biomass. Thus, in case of straw incorporation the quantity of urea (with N-content of 46%) for the first fertilization was lower (i.e. 106.98 Kg ha^{-1}) than the quantity used in the other straw end-practices (i.e. 120 Kg ha^{-1}).

Table 3 Processes involved in the study of both scenarios

		Tractor			Tractor consumption			Input		
Farming operation	Operative machine	Power (kW)	Mass (kg)	Transfer to field* (km)	Fuel (kg ha^{-1})	Lubricating oil (kg ha^{-1})	Fuel and oil transport	Products	Amount (kg ha^{-1})	Products transport to farm (km)

							to farm (km)			
Ploughing	Plough	147	7,700	1.5	33.06	1.42	10	-	-	-
Harrowing	Rotary harrow	147	7,700	1.5	33.06	1.42	10	-	-	-
I° Fertilization	Fertilizer spreader	26	1,500	1.5	0.68	0.03	10	Urea 46% (CH_4, N_2O)	120 (not incorporated straw) 106.98 (incorporated straw)	10
Rototillering	Rototiller	147	7,700	1.5	33.06	1.42	10	-	-	-
Rolling	Roller	147	7,700	1.5	33.06	1.42	10	-	-	-
Sowing	Seeder	66	3,500	1.5	7.55	0.33	10	Seeds	120	10
Weeding treatment	Spreader	26	1,500	1.5	0.90	0.04	10	Herbicide (Metazachlor)	1.2	10
								Water	444	-
II° Fertilization	Fertilizer spreader	26	1,500	1.5	0.68	0.03	10	Ammonium nitrate 24% (NH_4NO_3,)	150	10
Harvesting	Combine harvester	140	9,500	1.5	26.0	0.91	10	-	-	-
Straw baling (where applicable)**	Baler	65	3,900	1.5	2.67	0.16	10	-	-	1.5

Source: direct survey to farmers (sample's average values)

*Transport distance of machinery inside farm was set according to Ecoinvent database (v 3.0).

** Straw was incorporated into soil during ploughing phase; operative machines and products are not used in the open field burning practice.

Data referred to the upstream processes (i.e. tractor and machinery production, maintenance and disposal of tractor and machinery, fertilizers and herbicides production) came from the Ecoinvent database (v 3.0).

A small-sized dry straw bale of 427 kg was the standard size stated by local farmers; secondary data from the Ecoinvent database (v 3.0) were referred accordingly to that size.

Emissions generated by fertilizers and herbicides use were calculated based on literature data and scientific software. EFE-So software (v 2.0.0.6; Fusi and Fusi) was used to calculate the emissions due to the application of fertilizers according to Brentrup et al.'s (2004) model (Table 4). The CO_2 emissions from urea fertilization were calculated according to De Klein et al. (2006) (Table 4).

Table 4 Emissions caused by fertilizers for each straw end-practice

Straw baled for sale

Emissions	I° Fertilization 120 kg Urea (CH_4, N_2O)	II° Fertilization 150 kg Ammonium nitrate (NH_4NO_3,)	Total emissions (kg ha^{-1})	Environment
	(kg ha^{-1})	(kg ha^{-1})		
N_3O leaching*	-5.34	5.10	-0.24	Water
NH_3 volatilization mineral*	8.25	1.02	9.27	Air
NH_3 volatilization organic*	0.00	0.00	0.00	Air
N_2O emissions*	0.58	0.62	1.20	Air
N_2 emissions*	4.21	4.50	8.71	Air
CO_2 from urea fertilization**	44.00	0.00	44.00	Air

Open field burning

Emissions	I° Fertilization 120 kg Urea (CH_4, N_2O)	II° Fertilization 150 kg Ammonium nitrate (NH_4NO_3,)	Total emissions (kg ha^{-1})	Environment
	(kg ha$^{-1)}$	(kg ha$^{-1)}$		
N_3O leaching*	-5.12	5.10	-0.02	Water
NH_3 volatilization mineral*	8.25	1.02	9.27	Air
NH_3 volatilization organic*	0.00	0.00	0.00	Air
N_2O emissions*	0.58	0.62	1.20	Air
N_2 emissions*	4.21	4.50	8.71	Air
CO_2 from urea fertilization **	44.00	0.00	44.00	Air

Straw incorporation in the soil

Emissions	I° Fertilization 106.98 kg Urea (CH_4, N_2O)	II° Fertilization 150 kg Ammonium nitrate (NH_4NO_3,)	Total emissions (kg ha^{-1})	Environment
	(kg ha^{-1})	(kg ha^{-1})		
N_3O leaching*	-5.12	5.10	-0.02	Water
NH_3 volatilization mineral*	7.35	1.02	8.37	Air
NH_3 volatilization organic*	0.00	0.00	0.00	Air
N_2O emissions*	0.52	0.62	1.14	Air
N_2 emissions*	3.75	4.50	8.25	Air
CO_2 from urea fertilization**	39.23	0.00	39.23	Air

*Calculated by EFE-So software (v 2.0.0.6; Fusi and Fusi) according to Brentrup et al.`s (2004) model. A negative value of the N_3O leaching means no leaching and an applied amount of N fertilizer that is lower compared to the N removed (grain, wheat residue, emissions). According to the software architecture, the emissions of the first fertilization are influenced by the amount of biomass removed (not requested for calculating emissions in the second fertilization). A different amount of biomass incorporated into the soil influences the emission generated by the fertilizers applied. For this reason, the column "Total emissions" must be considered for the impact of the N fertilization phase in order to compare the three practices..

N_2 does not generate an environmental impact but it is reported as an indirect measure of denitrification.

**CO_2 emission from urea fertilization was calculated according to De Klein et al. (2006).

Herbicide emissions to air, surface water, and groundwater were assessed by PestLCI 2.0 model (Dijkman et al., 2012). Emissions vales are reported in the Table 5.

Table 5 Emission to air, surface water and ground water due to herbicide*

Emissions	Weeding treatment – Emission allocation of 1.2 kg Metazaclor (kg ha^{-1})
Emissions to air	1.6E-02
Emissions to surface water	1.2E-04
Emissions to groundwater	1.8E-03

*PestLCI 2.0 model (Dijkman et al., 2012) was used to calculate emissions from herbicides to the environment.

Different amount of wheat residue biomass returned to the soil were considered in the three end-practices (Table 6). The above-ground biomass was calculated following Meriggi and Ruggeri (2015), according to which the above-ground biomass is composed by 26.8% of straw, 9.4% of leaves, 12.8% of chaff, and 51% of grain. A root-shoot ratio of 0.25 (USDA-ARS, 1995) was considered to calculate the below-ground biomass.

Table 6 Wheat residue biomass (Mg ha^{-1} on a fresh weight basis) per agricultural end-practice.

Agricultural end-practice	Unit	Above-ground biomass §		Below-ground biomass (root) •	Total biomass returned to the soil
		Biomass removed by the soil	Biomass returned to the soil		
Straw baled for sale	Mg ha$^{-1\ r}$	3.11*	2.58**	1.42	4.00
Incorporation in soil as fertilizer	Mg ha^{-1}	0.00	5.69***	1.42	7.11
Open field burning	Mg ha^{-1}	5.69	0.00	1.42	1.42

§ wheat above-ground biomass composition was calculated considering the 26.8% of straw, 9.4% of leaves, 12.8% of chaff, and 51% of grain (Meriggi and Ruggeri, 2015).
* the amount of straw baled per hectare comes from the survey results.
** the biomass residue returned to the soil includes 9.4% of leaves and 12.8% of chaff (Meriggi and Ruggeri, 2015).
*** the biomass residue incorporated into the soil as fertilizer includes 26.8% of straw (survey result), 9.4% of leaves and 12.8% of chaff (Meriggi and Ruggeri, 2015).
• wheat root biomass assessment based on root-shoot ratio of 0.25 (USDA-ARS, 1995).

Although soil C sequestration contributes for about 89% to the global mitigation potential from agriculture (Smith et al., 2007), the importance of soil C sequestration is insufficiently investigated in current LCA studies (Koerber et al., 2009) due to methodological limitations (Brandao et al., 2011). Currently, in LCA analysis there is no consensus or a standard procedure on how to account for carbon removals from and releases to the atmosphere (Brandao et al., 2013; Petersen et al., 2013).

This LCA study considered a short-term effect of the organic carbon mineralization and stabilization into the soil within the analysed time frame (i.e., one year). Emissions by slow mineralization of the stabilized organic carbon into the soil that occur in long-term were not taken into account.

Based on the amount of wheat residue biomass into the soil (Table 6), the soil organic carbon was calculated according to literature data.

The carbon content in the biomass that returns into the soil was calculated considering a carbon percentage in wheat residue of 46% (Angers et al., 1997).

Residues in soil follow a decomposition process that can be described in two parts: a first rapid mineralization of added biomass followed by a slower mineralization of stabilized microbial products (soil humus) and no decomposed material. Various studies reported that about 60 to 85% of most crop residue carbons evolved as CO_2 into the soil during a one year period (Smith et al., 1971; Haider et al., 1975; Jenkinson, 1971; Oades et al., 1971; Stott et al., 1983; Voroney et al., 1989; Kriauciunienè et al., 2012; Gao et al., 2016).

In particular, during the first year and under different climate and soil conditions, wheat residues into the soil follow a mineralization of added biomass that was measured between 67-74% by Stott et al. (1983), and between 60-80% of the added C by Voroney et al. (1989).

Smith et al. (1971) observed a decomposition of the wheat straw in dry land soil condition after 13 months of 71% with and 81% without added N. A similar straw decomposition was reported by Brown and Dickey (1970) in cooler climate, no cropped plots and no N added (Smith et al., 1971). Kriauciuniene et al. (2012) observed a wheat straw decomposition in Cambisol soil of 65% within the first 2.5 months (September–November). Recent wheat straw decomposition trials has been carried out by Gao et al. (2016) in subtropical climate and Inceptisol soil in aerobic and anaerobic conditions. Carbon lost from wheat straw in the first 6 months accounted for 69.9% and 71.4% of the original carbon mass in the anaerobic and aerobic condition, respectively; about 73% of carbon was lost from the wheat straw in both the anaerobic and aerobic conditions during the 12-month incubation. The slowly degradable plant components, such as lignin, accumulated in the crop residues and the decomposition rates decline. According to Gao et al. (2016), results indicate that the decomposition rates declined as the ratios of lignin-to-carbohydrate increased because of the loss of cellulose and hemicelluloses (90% of hemicelluloses was lost from wheat straw during the first year). As reported by Olk et al. (2006), the decomposition of crop residues promotes accumulation of lignin residues in soils, consistent with the fact that crop residues are likely one of the main parent materials of new soil organic matter (Olk et al., 2006).

According to the “attributional LCA” method carried out in this study, and based on the average decomposition value reported in the cited literature, a 70% of the added C in soil was considered lost for a period of one year.

The CO_2 balance into the soil resulted from the difference between the CO_2 mineralized and the CO_2 stabilized into the soil.

The fraction of mineralized carbon was converted to CO_2 according to Equation 1.

$$CO_{2\,min}(kg \cdot ha^{-1}) = RES(kg \cdot ha^{-1}) \cdot \alpha \cdot \beta \cdot \frac{44}{12} \qquad (1)$$

Where:

$CO_{2\ \mathrm{min}}$ = CO_2 emitted due to wheat residue mineralization (kg CO_2 ha^{-1})

RES = wheat residue returned to the soil (kg ha^{-1})

α = C content in wheat residue (%)

β = C mineralised during the first year in soil (%)

44/12 = CO_2 reduction factor, based on the molecular weight of CO_2 to C

Part of the wheat residual biomass is stabilized into the soil as humus. The calculation of the CO_2-C stored as soil humus was based on parameters drawn from the literature. The isohumic coefficient was used in order to obtain the weight of stable humus formed in a year (Canarache et al., 2006). The amount of biomass converted in soil humus was calculated by multiplying the amount of the organic matter added to the soil with an isohumic coefficient of 0.22 (γ) (Garcia-Torres et al., 2003). The amount of C content in humus was based on a percentage of 55% (δ) of humus soil, according to Trinsoutrot et al. (2000).

The CO_2-C stored as soil humus was calculated as follows (Equation 2):

$$CO_{2\,hum}(kg \cdot ha^{-1}) = RES(kg \cdot ha^{-1}) \cdot \gamma \cdot \delta \cdot \frac{44}{12} \qquad (2)$$

Where:

$CO_{2\ hum}$ = CO_2 equivalent to the carbon stabilized in soil as humus (kg CO_2 ha^{-1})

RES = wheat residue returned to the soil (kg ha^{-1})

γ = isohumic coefficient (%)

δ = average C content in humus (%)

44/12 = CO_2 reduction factor, based on the molecular weight of CO_2 to C

Finally, the change in atmospheric CO_2 due to the modification of the carbon added to the soil was calculated as follows:

$$CO_{2\,bal}(kg \cdot ha^{-1}) = CO_{2\,min}(kg \cdot ha^{-1}) - CO_{2\,hum}(kg \cdot ha^{-1}) \qquad (3)$$

Where:

$CO_{2\ bal}$ = CO_2 balance (kg CO_2 ha^{-1})

$CO_{2\ min}$ = CO_2 emitted due to wheat residue mineralization (kg CO_2 ha^{-1})

$CO_{2\ hum}$ = CO_2 equivalent to the carbon stabilized in soil as humus (kg CO_2 ha^{-1})

The equation can also be written as:

$$CO_{2\,bal}(kg \cdot ha^{-1}) = RES \cdot (\alpha \cdot \beta - \gamma \cdot \delta) \cdot \frac{44}{12}$$

Where:

$CO_{2\ bal}$ = CO_2 balance (kg CO_2 ha^{-1})

RES = wheat residue returned to the soil (kg ha^{-1})

α = C content in wheat residue (%)

β = C mineralised during the first year in soil (%)

γ = isohumic coefficient (%)

δ = average C content in humus (%)

44/12 = CO_2 reduction factor, based on the molecular weight of CO_2 to C

The above formulas were applied to calculate CO_2 emissions in the three agricultural end-practices and results were as follows:

- Straw baled for sale. By applying Equations (1) and (2), CO_2 emissions due to carbon mineralization (CO_2 min) and carbon stabilization (CO_2 hum) into the soil resulted, respectively, 3476 kg ha^{-1} and 1772 kg ha^{-1} (Table 7). The CO_2-C stored in collected straw bales resulted 5245 kg ha^{-1} and it was treated as avoided emission of CO_2. For each Mg^{-1} of straw baled, a soil depletion of 1 kg of phosphorous and of 19 kg of potassium was considered (Silalertruksa and Gheewala, 2013). Estimated diesel consumption for the bailing stage was 1.2 l Mg^{-1} of straw (Silalertruksa and Gheewala, 2013); on-farm bale transfer by tractor across the field to the farm gate was included in the system boundaries.

Table 7 Straw baled for sale emissions

Nutrients and emissions	Emission factor (kg Mg^{-1})	Total emission (kg ha^{-1})
Soil nutrients depletion		
P	1*	3.11
K	19*	59.09
CO_2 stored as bales §		-5245
CO_2 mineralized into the soil ($CO_{2\ min}$) •		+3476
CO_2 stabilized into soil ($CO_{2\ hum}$)• •		-1772
CO_2 balance into the soil•••		**+1703**

* Silalertruksa and Gheewala, 2013

§ straw baled amount was multiplied by the carbon content in wheat straw (46%) and the CO_2 reduction factor (44/12)

• result of Equation 1

•• result of Equation 2

••• result of Equation 3

- Open field burning. When farmers applied on-farm open field burning, all of the above-ground biomass was burnt, while the below-ground biomass (root), evolved in part as CO_2 due to carbon mineralization, and in part was stabilized as humus for a total amount of 1236 kg ha^{-1} and 630 kg ha^{-1}, respectively. Emissions to air from open field burning (Table 8) were considered using emission factors reported by Chang et al. (2013). Phosphorus and potassium lost to air during burning were from Heard et al. (2006).

Table 8 Open field burning emissions

Depletion nutrients and emissions	Emission factor (g kg$_{dm}^{-1}$)	Total emissions (kg ha^{-1})
P*	2.90E-4	1.65E-03
K*	4.60E-3	2.62E-02
CO_2**	1515.00	8620.35
CO**	92.00	523.48
CH_4**	2.70	15.36
N_2O**	0.07	0.40
NOx**	2.50	14.23
SO_2**	0.18	1.02
NMHC**	4.00	22.76
EC**	0.51	2.90
OC**	2.99	17.01
PM_2**	8.30	47.23
PM_{10}**	9.10	51.78
$PCDD/F_S$**	4.86E-8	2.77E-07
PAH_S**	5.26E-3	2.99E-02
CO_2 mineralized into the soil ($CO_{2\ min}$) •		+1236.41
CO_2 stabilized into soil ($CO_{2\ hum}$)• •		-630.45
CO_2 balance into the soil•••		**+605.96**

* Heard et al., 2006
**Chang et al., 2013
• result of Equation 1
•• result of Equation 2
••• result of Equation 3

- Straw incorporation in the soil. As stated by farmers, following the practice of incorporation all straw residues (above and below-ground biomass) were buried. CO_2 emissions due to carbon mineralization and the CO_2-C stabilized in soil as humus resulted 6182 kg ha^{-1} and 3152 kg ha^{-1}, respectively (Table 9).

Table 9 Biomass residue incorporation emissions

Emissions from biomass residue incorporation	Total emission

	(kg ha^{-1})
CO_2 mineralized into the soil ($CO_{2\ min}$) •	+6182
CO_2 stabilized into soil ($CO_{2\ hum}$)• •	-3152
CO_2 balance into the soil•••	**+3029**

• result of Equation 1

•• result of Equation 2

••• result of Equation 3

Finally, to summarize the most relevant differences among the three end-practices Table 10 reports CO_2 eq emissions and inputs per each practice.

Table 10 CO_2 eq emissions and inputs among the three end-practices.

Agricultural phase		**Wheat straw end-practices**		
Fertilization	**Unit**	**Baling**	**Burning**	**Incorporation**
Urea+Amm. Nitr.	kg ha^{-1}	120+150	120+150	106.98+150
CO_2eq*	kg ha^{-1}	401.60	401.60	378.95
Diesel	kg ha^{-1} (MJ ha^{-1})	2.67 (120.15)	-	-
Wheat residue management				
Biomass buried (removed)	t ha^{-1}	4.00 (3.11)	1.42 (5.69)	7.11 (0.00)
CO_2eq*	kg ha^{-1}	-3542.00	9730.62	3029.00

* Carbon dioxide equivalent obtained considering N_2O, CO_2 and CH_4 produced during the fertilization and the wheat residues management practice (conversion factors CML-IA Baseline v.3.01).

For other emissions that are not possible to convert in CO_2eq, please see tabs. 7-9.

4.3 Life cycle impact assessment

In order to assess the environmental impact of 1 Mg ha^{-1} of total straw biomass, the method CML–IA baseline (v 3.01) was used. This method considers the following environmental impacts: abiotic depletion (AD), abiotic depletion (fossil fuels) (ADf), global warming potential (GWP), ozone layer depletion (ODP), human toxicity (HT), fresh water and marine aquatic eco-toxicity (FW, ME), terrestrial eco-toxicity (TE), photochemical oxidation (PO), acidification (AC) and eutrophication (EU).

5. Results and discussion

The environmental impact of each single end-practice was the first step considered in our analysis. In a second step, the combination of the three end-practices within each scenario allowed us to compare the environmental burden of different scenarios.

5.1. The environmental impact of wheat straw end-practices

A first finding of the study concerns the highest impact of fertilizer's production (for first and second fertilizing operations that weigh on average for 50% of the global impact; Figs. 2.a-2.c) whatever the straw end-practice analyzed. The ammonium nitrate production required for cropland farming had a higher impact than urea production. The environmental burden of fertilization in the straw cultivation cycle is in line with other studies. Ingrao et al. (2015) assessed the carbon footprint of an agro-biogas supply chain in Southern Italy, and observed that the global warming emissions were almost entirely due to cropland farming and, in particular, to the production of ammonium nitrate in the amount required for fertilisation. The study of Li et al. (2012) calculated the environmental impact of wheat straw pellets and showed that fertilizer use and harvesting contributed respectively by 15% and 6% to total GWP; by 14.5% and 11.7% to acidification; by 10.2% and 14.3% to human toxicity; moreover, fertilizer had an impact of about 25.7% on the eutrophication category. Finally, Wang et al. (2013) showed that fertilizer application in the wheat cultivation accounts for between 30%-60% of total GHG emissions generated inside the studied system boundaries; moreover, wheat cultivation impacts for over 60% on eutrophication (due to N_2O emissions) and on ozone layer depletion potential (due to pesticide and fertilizer production).

Our findings showed that straw decomposition into the soil was the most relevant source of impact on global warming (GWP) category, both in the straw baling (for the remaining biomass) and in the incorporation practices, with a relative weight of 52% and 67% respectively (Figs. 2.a, 2.b). The high impact of baling and incorporation on GWP emerged in other studies even if a direct comparison of results is not possible, due to different approaches and contexts. Focusing on baling practice, Nguyen et al. (2013) showed that straw removal causes major impacts on global warming, aquatic eutrophication, , and aquatic eco-toxicity. Focusing on straw incorporation, Gan et al. (2011) determined the carbon footprint of wheat produced in different cropping systems in Canada and showed that, on average, emissions from the decomposition of crop straw and roots accounted for 25% of the total greenhouse gas emissions from crop cultivation. According to Abril et al. (2012), the straw burial in the soil, although avoiding the problems caused by burning, generates between 2.5 and 4.5 times more methane. Yao et al. (2013) evaluated the nitrous oxide and methane fluxes from a rice-wheat crop rotation under wheat residue incorporation and no-tillage practices. According to their findings, the impacts of wheat straw incorporation in terms of N_2O and CH_4 emissions (10.7 Mg CO_2eq ha^{-1} yr^{-1} or 725 kg CO_2eq Mg^{-1} grain yield) were usually higher than those with no residue incorporation (7.6 Mg CO_2eq ha^{-1} yr^{-1} or 545 kg CO_2eq Mg^{-1} grain yield). On the contrary, Yang et al. (2014) showed that replacement of fertilizers application by maize straw incorporation did not have a positive effect on mitigating N_2O emissions into atmosphere.

In the straw burning practice, the highest impact on GWP category was due to the burning process (Fig. 2.c). This finding was in line with other studies. Li et al. (2008) showed that in Beijing (China) straw burning produces large amounts of atmospheric pollutants, especially CO and NO_2; this practice is also the main source of atmospheric particulate and polycyclic aromatic hydrocarbons in both rural and town sites (Lai et al., 2009). Jain et al. (2014) estimated the total greenhouse gases emissions (GHG) and the loss of nutrients from crop-residue burning in India and reported that burning is a serious threat to human health.

Figure 2a Straw baling practice. Agricultural operations and mid-point impacts (economic allocation; percentage values)

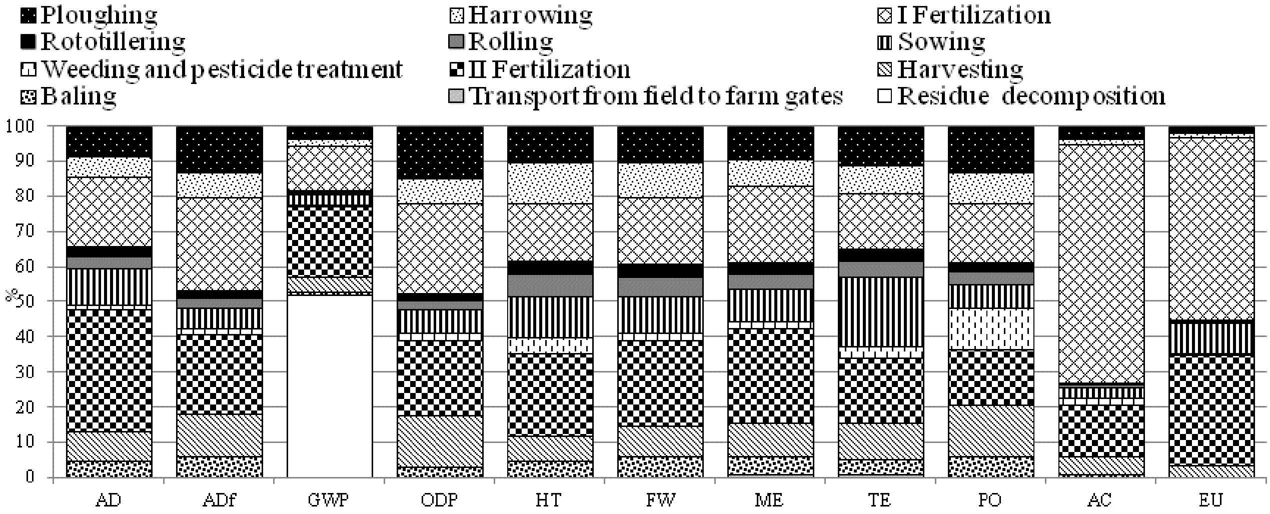


Figure 2b Straw incorporation practice. Agricultural operations and mid-point impacts (economic allocation; percentage values)

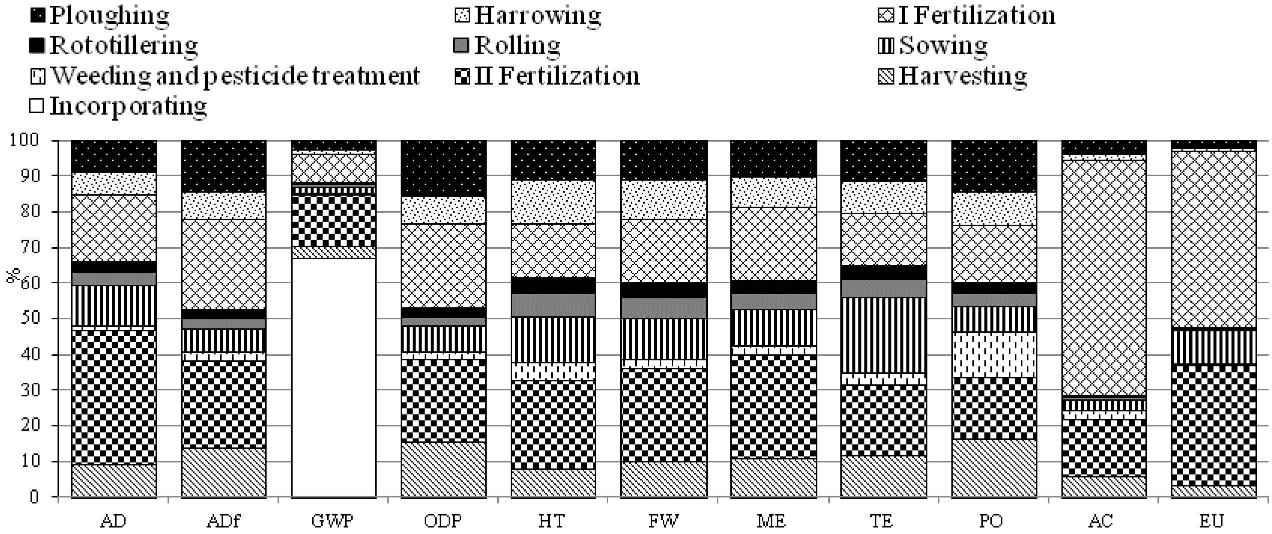
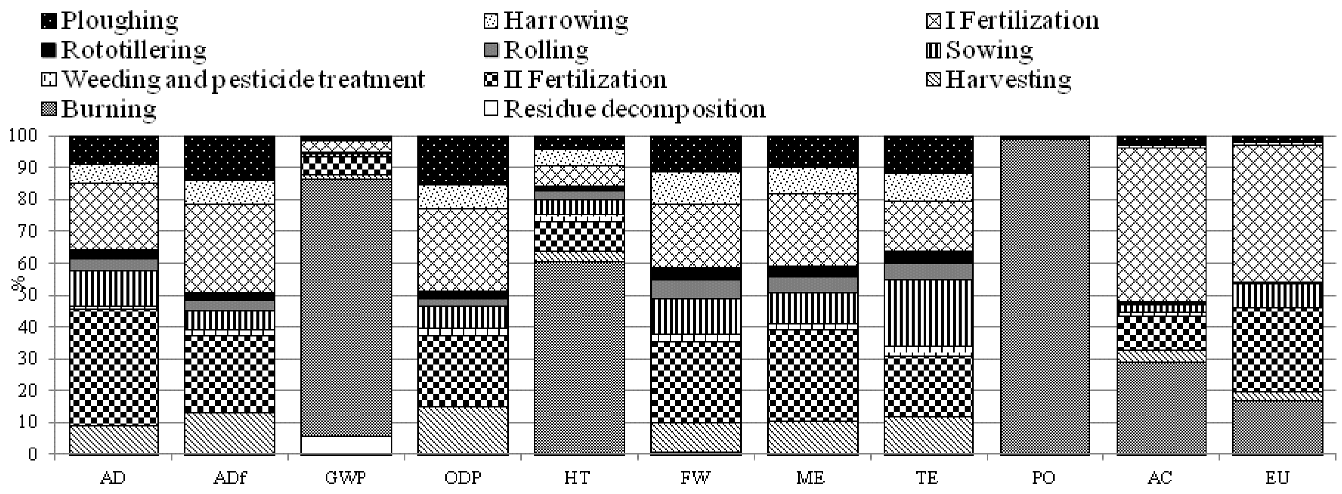


Figure 2c Straw burning practice. Agricultural operations and mid-point impacts (economic allocation; percentage values)



Comparing environmental impacts among practices, results showed that the straw baling for sale had the highest environmental impact for 6 out of 11 impact categories, immediately followed by the open field burning and the incorporation into the soil practices (Fig. 3). The straw baling and the open field burning practice showed a rather similar environmental burden on abiotic depletion (AD), abiotic depletion (fossil fuels) (ADf), ozone layer depletion (ODP), fresh water and marine aquatic eco-toxicity (FW, ME), and terrestrial eco-toxicity (TE) categories. The photochemical oxidation (PO) impact was evident only in the case of straw burning and it was due to carbon monoxide emissions.

Differences in the environmental burden of the three practices were remarkable on human toxicity (HT), global warming (GWP), and photochemical oxidation (PO) impact categories. On these impacts, the straw burning was undoubtedly the most impactful practice, due to dioxins, nitrogen oxides, and nitrogen emissions respectively. Furthermore, the open field burning had significant impacts on other mid-point impacts, namely on acidification (AC) and on eutrophication (EU) impact categories. These findings are in line with previous literature (Li et al., 2008; Chang et al., 2013; Chen et al., 2013; Satyendra et al., 2013; Jain et al., 2014;).

Switching from open field burning to baling practice (Δ_1 in Table 11) the environmental impact on PO and GWP categories decrease by 98.6%, and 71.9%, respectively; the impact on human toxicity category decreased by 54%. Similar results for PO and GWP categories come out by swapping the open field burning practice with the incorporation into the soil (Δ_2 in Table 11) with the exception of the GWP category which impact showed a lower decrease in Δ_2 (49.4%) than in Δ_1 (71.9%). This result was due to the CO_2 stored in the bales and not to CO_2 coming from bales burned; in fact the environmental impacts at combustion power plant level were not included in the system boundaries.

Finally, the differential impact between baling and incorporation (**Δ_3)** was very high only on GWP and revealed a better performance of the baling practice; differences in other impacts, while in favour of incorporation, appeared quite negligible.

Figure 3 Characterization. Comparison among practices (economic allocation; percentage values)

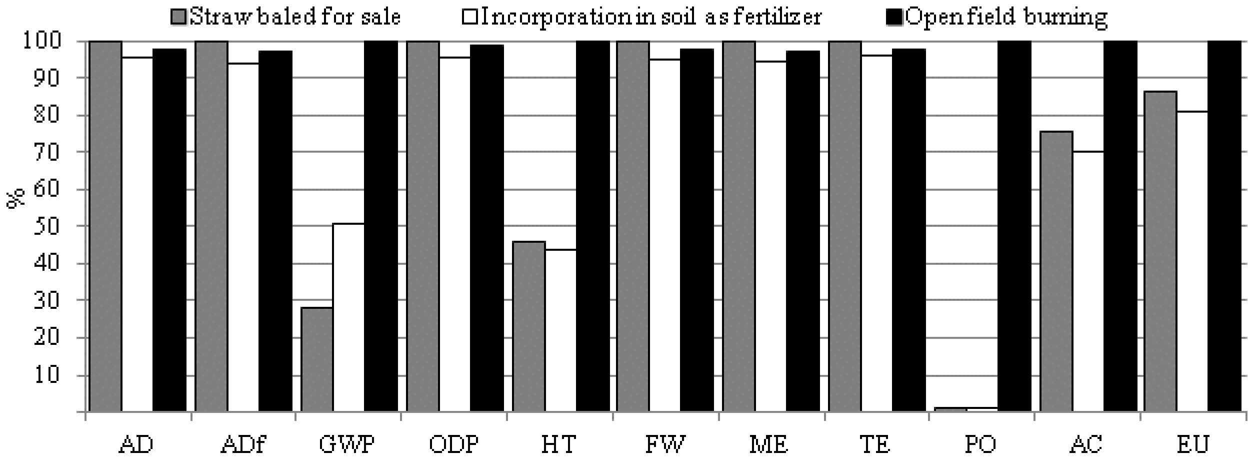


Table 11 Differential of environmental impacts among straw practices (economic allocation)

Impact categories	**Δ_1 (%)**	**Δ_2 (%)**	**Δ_3 (%)**
AD (kg Sb eq)	2.2	-2.6	4.9
ADf (MJ)	2.7	-3.5	6.4
GWP (kg CO_2 eq)	-71.9	-49.4	-44.4
ODP (kg CFC-11 eq)	1.5	-3.2	4.9
HT (kg 1,4-DB eq)	-54.0	-56.0	4.4
FW (kg 1,4-DB eq)	2.4	-2.8	5.4
ME (kg 1,4-DB eq)	2.7	-2.9	5.8
TE (kg 1,4-DB eq)	2.2	-2.0	4.3
PO (kg C2H4 eq)	-98.6	-98.7	5.1
AC (kg SO2 eq)	-24.2	-30.1	8.4
EU (kg PO4-eq)	-13.7	-18.8	6.3

Δ_1 (%): differential between Baling and Open field burning practices
Δ_2 (%): differential between Incorporation into the soil and Open field burning practices
Δ_3 (%): differential between Baling and Incorporation into the soil

5.2 The environmental impact of alternative scenarios

The environmental assessment of scenarios was performed according to the economic allocation method.

Results showed that the DEMAND PULLED scenario was the most impactful for 8 out of 11 mid-point categories (Fig. 4). The unfavourable performance of the DEMAND PULLED scenario was attributable to the different mix of straw end-practices compared to the STATUS QUO scenario, i.e. a reduction in the amount of straw incorporated into the soil (-26%) and burnt (-6%) and an increase in the baled straw (+32%). In particular, the removal of straw from the field led to an increase in the fertiliser used for wheat cultivation, which in turn caused a higher environmental impact on all mentioned eight impact categories. However, in relation to these categories, the gap in the relative burden of two scenarios was negligible.

On the remaining three mid-point impacts, namely the global warming, human toxicity, and photochemical oxidation categories, the environmental impact of DEMAND PULLED scenario was significantly lower than the STATUS QUO scenario (on average for about 19% on the three impact categories). In particular, switching from STATUS QUO scenario to DEMAND PULLED the environmental impact on photochemical oxidation and global warming categories decreases by 30.9% and 21.1% respectively; while the impact on human toxicity category decreased by 5% (Table 12).

The higher environmental impact of STATUS QUO scenario on photochemical oxidation (PO), global warming (GWP), and human toxicity (HT) categories can be explained as follows. Impacts on PO were caused by carbon monoxide emitted during the straw burning process; impacts on GWP were due to the carbon dioxide produced during straw burning and straw incorporation into the soil; finally, impacts on HT were caused by dioxins. These results are due to the fact that in the STATUS QUO scenario the quantities of straw burnt (18%) and incorporated into the soil (32%) are higher than those in the DEMAND PULLED scenario (12% and 6% respectively).

Finally, considering the similar burden of both scenarios on some impact categories and the best profile of the DEMAND PULLED scenario on other impact categories, study findings showed that overall the scenario with the straw market for bio-energy production may be preferable to the current situation.

The two assessed scenarios were defined based on the current straw end-practices and on farmers' disposition to change these practices. Another scenario in which the straw burning practice was fully banned would have environmental benefits. In order for this scenario to become a reality, proper interventions and tools are needed to influence farmer's behaviour. As this regard, Giannoccaro et al. (2016) have investigated the farmer's motivation of on-field burning and found the timeliness of farming activities at the end of cereal cropping as the most frequent reason given for on-field burning.

Figure 4: Comparison between STATUS QUO and DEMAND PULLED scenarios (economic allocation)

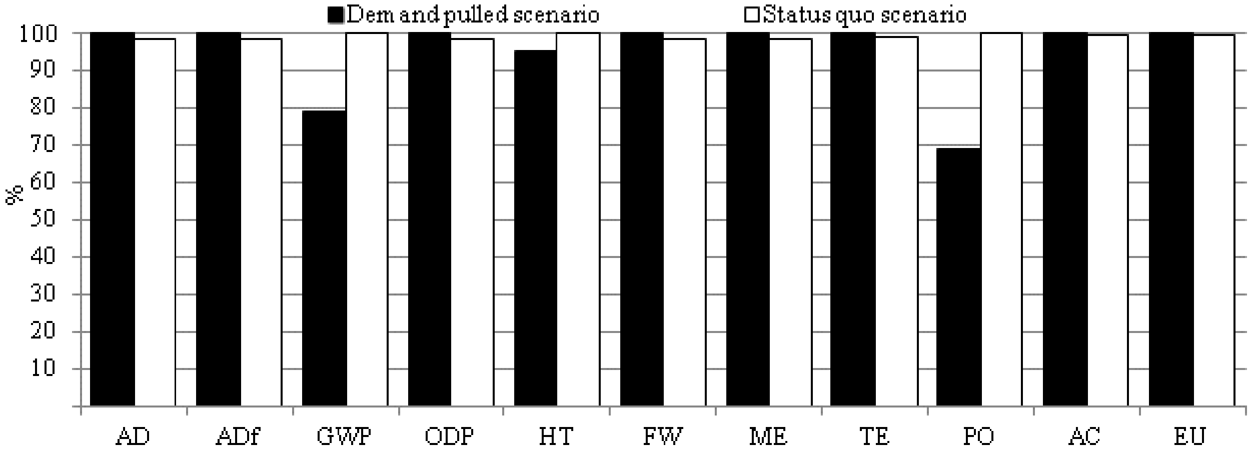


Table 12: Differential of environmental impacts between STATUS QUO and DEMAND PULLED scenarios (economic allocation)

Impact categories	Δ (%)
AD (kg Sb eq)	1.4
ADf (MJ)	1.8
GWP (kg CO_2 eq)	-21.1
ODP (kg CFC-11 eq)	1.3
HT (kg 1,4-DB eq)	-5.0
FW (kg 1,4-DB eq)	1.5
ME (kg 1,4-DB eq)	1.6
TE (kg 1,4-DB eq)	1.2
PO (kg C2H4 eq)	-30.9
AC (kg SO2 eq)	1.5

EU (kg PO4-eq)	0.6

Finally, in assessing the environmental burden of the three practices and related scenarios, the effects on yield should be carefully evaluated. The sign and the magnitude of yield effects may influence the environmental assessment. In this regard, the current literature on the yield effect of straw incorporation, burning and removal practices is not conclusive. For instance, according to some Authors, the incorporation of straw causes a yield increase (Silalertruksa and Gheewala, 2013), while for other Authors it shows a yield decrease (Prochazkova et al., 2003); according to Verhulst et al. (2011) and Grahmann et al. (2014), straw incorporation and straw removal cause a yield increase, while straw burning causes a yield decrease. Moreover, some Authors discuss the sensitivity of environmental impacts to optimal crop production and fertilization strategies, looking at yield potential and wheat quality (Charles et al., 2006). In relation to these aspects, more conclusive studies are necessary to incorporate the effect of straw practices on yield in LCA procedures and to obtain a more comprehensive assessment of the different environmental burdens. In this study, it was not possible to derive from farmer's responses the effect of the straw practices on the yield. Anyway, their choice about the mix of straw end-practices was related to other drivers and benefits that prevail even in the perspective of selling all available straw to the energy plant.

5.3 Sensitivity analysis on allocation methods

The comparison of results obtained with the three allocation methods (Table 13) showed that, regardless to the practices, impacts with the mass allocation method were higher than impacts with the cereal unit and economic allocation method. These results are in line with Li et al. (2012).

Table 13: Environmental impact of 1 Mg ha-1 wheat straw in DEMAND PULLED and STATUS QUO scenarios:Economic, Mass and CU allocation methods

Impact categories	DEMAND PULLED scenario			STATUS QUO scenario		
	Economic	Mass.	CU	Economic	Mass.	CU
AD (kg Sb eq)	5.62E-05	2.29E-04	1.08E-04	5.54E-05	2.26E-04	1.06E-04
ADf (MJ)	2.02E+02	8.24E+02	3.89E+02	1.99E+02	8.10E+02	3.82E+02
GWP (kg CO_2 eq)	5.75E+01	2.35E+02	1.11E+02	7.29E+01	2.97E+02	1.40E+02
ODP (kg CFC-11 eq)	1.85E-06	7.54E-06	3.56E-06	1.83E-06	7.45E-06	3.51E-06

HT (kg 1,4-DB eq)	7.96E+00	3.24E+01	1.53E+01	8.38E+00	3.41E+01	1.61E+01
FW (kg 1,4-DB eq)	2.30E+00	9.34E+00	4.41E+00	2.26E+00	9.21E+00	4.35E+00
ME (kg 1,4-DB eq)	5.53E+03	2.25E+04	1.06E+04	5.44E+03	2.22E+04	1.04E+04
TE (kg 1,4-DB eq)	2.73E-02	1.11E-01	5.24E-02	2.70E-02	1.10E-01	5.18E-02
PO (kg C2H4 eq)	2.58E-02	1.05E-01	4.96E-02	3.73E-02	1.52E-01	7.17E-02
AC (kg SO2 eq)	3.60E-01	1.47E+00	6.93E-01	3.55E-01	1.46E+00	6.91E-01
EU (kg PO4-eq)	1.66E-01	6.77E-01	3.19E-01	1.65E-01	6.73E-01	3.18E-01

Moreover, previous findings obtained according to the economic allocation did not change in a significant way. Whichever the allocation method, the environmental impacts of the three straw end-practices did not change significantly. Again, the DEMAND PULLED was better than the STATUS QUO scenario based on global warming (GWP), human toxicity (HT), and photochemical oxidation (PO) impact categories. Both scenarios had a quite similar impact on other environmental categories.

6. Conclusions

The environmental impact of alternative straw end-practices management and scenarios has been assessed through an attributional Life Cycle Assessment.

Basically, the findings of this study are in line with the literature reporting the open field burning as the most impacting practice on global warming, human health, photochemical oxidation, acidification, and on eutrophication impact categories.

The burden of straw incorporation in the soil as fertilizer is higher than that of the straw baling practice on global warming category. The lowest impact of straw incorporation practice on other impact categories depends on the reduction of urea consumption in the first fertilization phase. The comparison between the environmental impacts of incorporation and baling at farm gate boundaries highlights the crucial question if the reduction in fertilizer use (incorporation) outweighs the benefits from using the carbon for energy purposes (baling). This question stimulates an extension of the system boundaries in subsequent studies.

Nevertheless the scope of this study was broader than the assessment of single straw end-practices, and tried to compare the environmental impact of the increase in straw demanded as energy feedstock. The DEMAND PULLED scenario was elicited on the basis of farmers' willingness to sell (wholly or partly) their on-farm straw on a feedstock market. In this regard, farmers' response gave us valuable information about potential straw availability and on-farm end-practices for straw. Our environmental assessment referred to the straw management within the cereal farm boundaries, excluding livestock use and energy processes. Inside these boundaries, results highlight that the DEMAND PULLED scenario has a better environmental profile than the STATUS QUO scenario on some impact categories, while scenarios are quite similar on other categories.

These results allowed us to conclude that the perspective of selling the straw on the local energy feedstock market is a better solution compared with the current situation. According to farmer's intentions, in the DEMAND PULLED scenario the straw to be sold will be mainly obtained by reducing straw incorporation. In the best scenario straw burning would be fully avoided. Anyway, farmer's disposition to reduce the most impactful straw practice in the DEMAND PULLED scenario is not as relevant as it would be advised. In fact, some farmers would continue to burn the residues because this practice allows them to prepare the soil for next cultivation in an easily and fast way.

This conclusion calls for further research on factors influencing farmer's preferences about straw end-practices and for policy measures aimed at changing their behaviour towards a more sustainable scenario.

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Appendix

Excerpts from the questionnaire

Crop pattern (average of the last three years**)**

Crop	hectares
Field Crops	
|_| Durum wheat	__________
|_| Other cereals	__________
|_| Fibre and industrial crops (sweet beet, sunflower, rape)	__________
|_| Set aside	__________
|_| Leguminous plants and fodder	
Vegetable	
|_| Tomate	__________
|_| Short farming vegetable (specify)_____________________	__________
|_| Asparagus, artichoke	
|_| Other vegetables (specify)	
Permanent	
|_| Olive tree	__________
|_| Vineyard	__________
|_| Other orchard	
|_| **Greenhouse**	

In your farm, is there livestock reared? |_|Yes |_| No

On average (last three years**) on-farm yield grain (kg/ha) ________**

On average (last three years**) on-farm yield straw (t/ha) ________**

To the on-farm straw produced you apply (many options apply**):**

a |_| baling and selling out (**please report as** % of on-farm cereal land____)
b |_| baling and storing for on-farm livestock (…% of on-farm cereal land ____)
c |_| chopping and incorporation in the soil (…% of on-farm cereal land ____)
d |_| neither baling, nor incorporation, then burning (…% of on-farm cereal land ____)
e |_| other specify________________________(…% of on-farm cereal land ____)

A power plant for energy production shall soon be operative in Sant'Agata di Puglia and straw will be the main fuel. Assuming that market prices, straw yields, Common Agricultural Policy (aid and environmental constraints) applied in the last three years shall remain unchanged in the coming years, please answer the question as follows:

Are you willing to sell your on-farm straw (wholly or partly**) annually produced?**

|_| Yes |_| No |_| Do not know |_| Other (specify)_____________________

If yes, how much straw are you willing to sell on feedstock market for energy purposes? 10…20…30…40…50…60…70…80…90…100% (of your average cereal land - hectares)