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Title: **Definition of best harvesting logistics for agricultural residues, and for specialist annual and perennial lignocellulosic crops**	
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1. Introduction

The European Union Directive on the promotion of the use of energy from renewable sources (RED), includes a binding target of a 20 % share of renewable energy in energy consumption by 2020 (Boldrini and Aldrup, 2015, Buratti et al., 2012; Scarlat et al., 2013) in order to reduce the emissions of greenhouse gasses and bring down energy import dependency. Bioenergy production systems, as a part of the solution to this problem, have attracted much attention in recent years because they can be appropriate substitutes for the traditional energy production systems which are finite, non-renewable, and cause of environmental problems (Sathre, 2014).

Currently, around 4 % of the total primary energy consumption of the European Union is met from biomass, and it will become 13 %. This makes biomass the most important renewable energy source, providing two thirds of the total energy produced from renewable (Wiesenthal et al., 2006). In the short to medium run, agricultural residues and annual and perennial lignocellulosic crops could provide a remarkable amount of cellulosic biomass currently untapped, that might contribute to the achievement of the renewable energy targets.

However, unlike other renewable energies, the bioenergy production necessitates the flow of the biomass feedstock from the supply sites to the demand centres. Along this route, the biomass passes through some facilities and undergoes various pre-treatments called the biomass supply chain. Each part of the supply chain (including growing, harvesting, transporting, integrating, storing and distributing) needs specific knowledge, technology and activities. The rising demand for biomass and the increased complexity of the often-multi-level involved supply systems outline the need for comprehensive biomass supply chain management approaches. The optimal design of this supply chain is an important factor in the enhancement of the economic, environmental, and social performance and efficiency of the biomass supply chain (Ghaderi et al., 2016).

In this context BECOOL project aims at evaluating innovative value chains from key resources that will be most likely considered in future biomass plans. More concretely, BECOOL project focused on maize and wheat residues, olive prunings, arundo donax, fiber sorghum and eucalyptus. The most critical aspects of the supply chain of these resources were identified and evaluated within WP1 with the aim of filling the gap whether the problem were technical or the dissemination of the technology/chain model.

The project has placed special attention to the harvesting operation, since it represents one of the most critical bottlenecks in the sustainability of the supply chain. In fact, over the last fifteen years several enterprises have identified cost-effective technologies for harvesting agricultural residues and energy crops. CREA-IT had performed harvesting tests of maize cobs, wheat chaff and olive tree prunings with innovative systems in order to understand their advantages and restrictions in comparison with traditional ones. Innovation is intended here as prototypes, new commercial systems available in the market or new harvesting practices not normally carried out in an area.

Storage is another essential step of the supply chain. Storage can be an opportunity to decrease the moisture content and therefore increase the quality of the product to be efficiently converted. Moreover, storage can be considered one of the rare processes where no costly operations are carried out during the active phase, but where correct preventive measures can improve the quality of the fuel even an increase of the energy content respect to the starting conditions as demonstrated by authors. Scientists showed that biomass fuel

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quality is determined in specific cases by the storage process and important fuel quality characteristics such as calorific value, moisture content and ash content are influenced by storage dynamics. For that reason the project carried out storage trials on eucalyptus (MRC) while on Arundo donax is still on-going.

Given the interest of the consortium of the project on the fiber sorghum, the CREA-IT within the project and in collaboration with COPROB sugar beet cooperative, who has undertaken a productive strategy towards the energy production from biomass, has studied the value chain of fiber sorghum. The objective was to describe the fiber sorghum harvesting machineries and the supply chain built-up by COPROB for an energy purpose.

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2. Biomass resources of interest

This report is the first deliverable elaborated by CREA-IT for WP1 'Definition of best harvesting logistics for agricultural residues, and for specialist annual and perennial lignocellulosic crops' of the BECOOL project. It presents a description of the essential aspect of the resources considered by the project, highlighting their interest as new biomass for energy production.

Based on the feedstocks and cropping systems selected in WP1 and the advanced biofuels conversion technologies selected in WP3 and WP4, a number of harvesting and storage test will be presented in this report as well as value chain description.

2.1 Agricultural residues:

The European policy for energy encourages the utilization of agro-forestry residues, limiting the energy crops plantations (European Parliament, Directive 2009/28/EC; EU 2015/1513, ILUC Directive). In this scenario, it is crucial to exploit the potential of biomass resources that are currently unexploited (Paiano and Lagioia, 2016). In fact, significant amounts of agricultural residues are generated from agricultural crop production.

2.1.1. Wheat chaff

Among the agricultural residues, cereal chaff has gained interest due to its availability and properties both for energy purposes and for animal feeding (Hutton 2008, Saidur 2011). Chaff is made up of seed glumes, seed husk and rachis. This material can be estimated in about 7 % of the threshed product (40 % are seeds, 48 % straw, 5 % stubble). According to EUROSTAT, more than 300 Mt grain is harvested yearly in EU28 (EC, 2007) and considering a mean chaff to grain ratio of 0.17, more than 52 Mt yr^{-1} could be available to be collected in Europe (McCartney et al., 2006). During cereal harvesting, the chaff is normally dispersed in the field together with straw and other fine residues retained by the combine sieves, such as un-threshed heads, short straw, leaf material, weed seeds and whole or cracked kernels from the harvested crop. Moreover, from agronomic point of view, the collection of the chaff reduces the weed seed stock in the soil avoiding the herbicide treatments (Shirtliffe and Entz, 2005). However, such resource is generally left on the ground after cereal harvesting, in fact is simply left on the ground, and covered by the straw. Therefore, being in direct contact with the ground cannot be collected with the pick-up in the following baling operation. However, the growing interest in the exploitation of these residues both for energy (combustion, biogas) and for animal husbandry (fodder, litter), and also the need to reduce the load of seeds of resistant weeds (in the case of organic farming), has pushed some constructors to develop systems for the recovery of the chaff, separately or together with the straw. The main chaff collection technologies available on the market that, basically, implement the following mechanical chains:

- Chaff discharged on the top or inside of the straw swath for baling all together in a second time.
- Chaff discharged to an integrated back container, while straw can be both baled or spread on the ground.
- Chaff discharged to a towed trailer or no-stop baler.

The first method of collection can be preferred when biomass is used for energy production. In fact, baling the straw and chaff together, increases the amount of total biomass collected per hectare and the bales density

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(Lundin and Rönnbäck, 2010). On the other hand, collecting chaff separately from straw allows to obtain a product with a higher nutritive value than straw, suitable for husbandry feeding.

From all the system commercially available, BECOOL tests focused on a device that spreads the chaff on the windrow of straw that is afterwards baled. This system was selected because, after reviewing the already existing technologies, it was considered of special interest due to the cost, harvesting systems and scope of the project.

2.1.2 Maize cobs

Among the un-tapped resources and the agricultural residues, the maize cobs have risen the interest due to its abundance, low cost and favorable properties (Jansen and Lübberstedt, 2011). According to EUROSTAT, more than 9 Mha in EU28 are cultivated yearly with grain maize. Considering an average yield of 1 t ha^{-1} of cob this would mean that more than 9 Mt yr^{-1} of maize cob could be available to be collected in Europe (Pollex and Zeng, 2012; Khawaja and Janssen, 2015) Maize cob is the central core of an ear of maize (*Zea mays* ssp.) and the part of the corn ear on which the kernels grow. Its interesting properties enable a wide array of applications such as: 1) biomass for energy 2) absorbent for animal bedding or substrate in hydroponic cultivation 3) adsorbent for production of active carbon for water treatment, among other applications 4) abrasive material for metal or wood surface conditioning.

Turning cobs into a valuable and cost-effective feedstock greatly depends on the harvest technology. Currently, the maize cobs are rarely used, being normally left on the soil uncollected or collected with the stover (Shinners et al., 2007). In Italy, the company AGRICINQUE Gruppo Racca srl has designed and patented a system to be applied in some of CASE commercial harvester, for that reason this machine was selected to be studied during cob harvesting. The system consists of a device to separate maize cob from the other residues (leaves, stem, culm, etc.) and collect it in an additional tank (9 m^3).

BECOOL carried out harvesting tests in order to study the innovative harvesting systems, the only one patented in Europe, and to acquire reliable data on machine performance and biomass quality.

2.1.3 Olive tree prunings

Prunings from permanent crops in Europe are a substantial reservoir of renewable biomass for energy and industrial use (Pari et al., 2017). The 10.6 Mha currently covered by permanent crops generate 13 Tg. (oven-dry basis) of pruning. However, the rational use of this biomass source is being hindered (Garcìa-Galindo et al., 2016a and 2016b). Firstly, by an increase in surfaces, and a conversion from traditional to intensive systems is forecast as well as a growing demand for fuel biomass (Garcìa-Galindo et al., 2016a, Magar et al., 2011, Spinelli et al., 2012) Secondly, there are various barriers tied to the use of prunings and the development of a sustainable logistic chain to produce energy from it (Dyjakon et al., 2014, Romanski et al., 2014). Pruning (branches and shoots of fruit trees) is considered a problem rather than an opportunity and, hence, it is not used or incorrectly disposed of (Spinelli et al., 2010)

BECOOL project performed harvesting test were carried out on olive tree prunings with the goal to study the harvesting systems at present and the quality of the biomass. This resource was selected because some successful examples of well-designed pruning supply chains for energy production are already available in Europe. In fact, although is just one aspect of the overall process, harvesting prunings plays a pivotal role in building a sustainable and profitable collateral production and hence it needs to be defined correctly. For

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instance, Fiusis s. r.l. (Calimera, LE, Apulia) use olive prunings produced by nine municipalities around the 1 MWe cogeneration plant which produces electricity (which is then sold on to the national grid) and heat. Fiusis's well-established harvesting solution entails the use of three shredders for use on farms that have up to 400 olive trees. For farms with a higher number of olive trees, prunings are collected at the edges of the fields and chipped with a stationary shredder, with a production capacity of 10 t h^{-1}. Chipping in both cases is carried out after a 25 - 30 day period in which the prunings are left in the field to ensure drying and leaf shedding

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2.2 Dedicated annual and perennial crops

In recent decades, some annual and perennial crops became very interesting sources for the production of lignocellulosic biomass aimed at the production of heat, electricity, and second-generation biofuels. In Europe some herbaceous crops and Eucalyptus have been indicated as promising for energy production. Due to the considerable amount of biomass produced the harvesting and the storage presents several drawbacks that weigh on the supply chain.

Among perennial grasses, *Arundo donax L*. (Poaceae family) presents several attractive characteristics as dedicated biomass crop. This species is a hydrophyte that grows spontaneously and abundantly in southern Europe and in many subtropical temperate regions of the world (Pilu et al., 2013, 2012). Since the 80s, in Europe, several studies regarding the *Arundo donax L*. biomass potential for energy production have been carried out (Cosentino et al., 2006; Nassi o Di Nasso et al., 2007; Angelini et al., 2009; Lewandowski et al., 2003). *Arundo donax* L. has received much attention from researchers for its vigorous growth, high productivity, low agronomic inputs (fertilizers, pesticides), high tolerance to environmental stress, and suitability to be cultivated in unproductive soils or marginal lands. Furthermore, in 2011, an Italian company constructed a commercial-scale for cellulosic ethanol production facility that use also giant reed, so a strong demand increased for this crop as feedstock. Some other herbaceous species have been receiving increasing attention recently, such as fiber sorghum (*Sorghum bicolor L*. Moench), which has a growing cycle similar to that of traditional food crops and demonstrates a high potential energy related both to anaerobic digestion and second-generation bioethanol production (Amaducci et al., 2000). The characteristics of sorghum for electricity production have also been evaluated in different Italian areas, showing interesting potential (Trebbi, 1993). In recent decades, fiber sorghum (*Sorghum bicolor* L. Moench.) has become one of the most interesting species for the production of lignocellulosic biomass aimed at the production of heat, electricity, and second-generation biofuels (Murray, 2005; Ban et al., 2008; Sipos et al., 2009; Ratnavathi et al., 2010; Davila-Gomez et al., 2011). The ample genetic variability in terms of morphological and physiological traits has allowed the selection of genotypes to be more productive with a sensible improvement of energy yield.

The giant reed and sorghum value chain aroused a great interest for the BECOOL project. The special interest is due to the availability of this biomass all around the Europe and the world and to its specific yield and quality for further processing. Nevertheless, some bottlenecks still exist for these two energy crops. For that reason, CREA-IT focused the attention on the harvesting of sorghum and on the storage of giant reed. Considering the fiber sorghum, this further activity was not carried out as field test but studying and describing an already existing and developed value chain

Short and medium rotation coppice (SRC and MRC) appear to be an interesting strategy for supplying bioenergy plants at global level. The fast-growing capacity and the low agronomic input requirements offer the opportunity to produce high quantities of biomass in low-productive soils, without competing with food crops for fertile arable land (Lenz et al., 2017). Such crops are recognized to work as mechanism for decentralising energy supplies and promoting the local use of bioenergy (Boll et al., 2015), contributing also to improve local biodiversity and playing an important role in the sustainable intensification of agriculture (Haughton et al., 2016). According to production strategy, woody biomass can be obtained exploiting fast-growing hardwood species to be harvested at biennial or quinquennial cycles (Faasch and Patenaude, 2012). Large eucalypt plantations have been established in Europe, South America, China and South East Asia, and their importance to global wood supply keeps increasing. The world-wide area of eucalypt plantations amounts to 19 million

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hectares, mostly devoted to pulpwood production. However, to reduce carbon release to the atmosphere and to ensure supply of energy, there is an expanding interest in using the tree biomass energy for fossil fuel substitution. While many companies are exploring the potential of eucalypt plantations for structural wood, more are looking at establishing dedicated short-rotation plantations for producing energy biomass.

The efficiency of the cultivation of dedicated energy crops depends, as well as on a correct energy and environmental evaluation, on farm cost-effectiveness. In relation to this latter aspect, harvesting can represent a critical phase in relation both to the costs and technique used. Indeed, while many studies have been conducted on production techniques, research on the type of equipment for harvesting energy crops is limited. In general, harvesting and handling of annual and perennial lignocellulosic crops have not been sufficiently investigated thus large room exists to reduce yield gaps

BECOOL has assessed in this case the storage of eucalyptus, monitoring the evolution of moisture and dry matter of two type of formats that could be supplied to bioenergy plants: only stems or whole trees.

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3. Data collection methodology

The following common methodology was used during field tests, even if the experimental design and some parameters acquired were defined for each test and will be explained inside the specific section. The storage test followed a specific methodology described inside the section.

3.1 Machine performance

In each treatment and repetition, the performance of the machines will be evaluated through the study of the working times. All the operations were analyzed following the CIOSTA (Comité International d'Organisation Scientifique du Travail en Agriculture) methodology and the recommendations from the Italian Society of Agricultural Engineering (A.I.I.A.) 3A R1. A reference to these methods can be found in Assirelli and Pignedoli, 2005). All the gathered data were used to define the performance of the machine. Down below are explained in detail how these data should be collected.

Field speed: the field speed (FS) is the average rate of machine travel in the field during an uninterrupted period of functional activity (Km h^{-1}).

Average field speed can be easily measured by marking off a fixed distance (at least 100 m) in the field, placing a mark at each end, and counting the seconds it takes to drive between the marks. Average field speed can then be calculated from equation deriving from the physic formula of the velocity:

Velocity (v) = Space/Time

In this case, the space is intended as the linear meters covered by the machine between a mark and the other.

Working times: the study of the working times and the evaluation of the field speed will allow determining parameters such as **Theoretical filed capacity** (ha h^{-1}), **Effective field capacity** (ha h^{-1}), the **Material capacity** (t h^{-1}), and the **Field efficiency** (%). By knowing the yield of the field (t ha^{-1}), it is possible to obtain also another good indicator of the machine performance called **Material capacity** (t ha^{-1}).

Theoretical field capacity **(TFC):** depends only on the full operating width of the machine and the average travel speed in the field. It represents the maximum possible field capacity that can be obtained at the given field speed when the full operating width of the machine is being used. It is calculated multiplying the field speed for the working width of the machine.

Effective field capacity **(EFC)**: The Effective Field Capacity of a farm machine is the rate at which it performs its primary function, i.e., the number of hectares that can be harvested per hour.

EFC = *worked area (ha)* / *OT* (*h*)

Measurements or estimates of machine capacities are used to schedule field operations, power units, labor, and to estimate machine operating costs. The effective field capacity (EFC) of a machine in the field can be easily calculated by dividing the hectares completed by the hours of **Operative Time (OT)**.

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The operative time is the real time necessary to complete the harvest of the surface object of the test, including also turnings, stops, machine regulations, etc.

The formula used for the estimation of the operative time is the following:

Operative Time (OT) = ET + AT

ET = is the effective time, i.e. the time in which the machine is actually harvesting the product.

AT = are the accessory times which includes *accessory time for maintenance* (ATM), that includes the pauses required for filling or unloading the hoppers (seeds, fertilizers, grains, etc.); *accessory time for turning* (ATT), corresponding to the time needed to reverse the direction; *accessory time for regulations* (ATR), corresponding to the times for adjustments in relation to the conditions of the field or the work.

Field efficiency *(FE)*: expressed as percentage, the field efficiency is the ratio of actual or effective field capacity (EFC) to theoretical field capacity (TFC).

FE (%) = EFC (ha h^{-1}) / TFC (ha h^{-1})

Material Capacity (t h^{-1}): The working capacity of harvesting machines can be measured also by the quantity of material harvested per hour. This capacity is called the machine's material capacity (MC), expressed as tons per hour (t h^{-1}). It is the product of the machine's EFC and the average yield of crop per hectare and can be calculated from equation (5).

MC (t h^{-1}) = EFC (ha h^{-1}) x crop yield (t ha^{-1})

3.2 Biomass characterization and quality of the work

Fuel consumption: the fuel consumption is another indication of the machine performance since it is the direct parameter for the evaluation of the harvesting costs. Fuel consumption was determined through machine tank refilling until full level at the end of each experimental unit (plot) using a graduated large cylinder to define the volume of fuel consumed (l ha^{-1} or l t^{-1} of biomass harvested). Each experimental unit (plot or field) was started with the tank completely full. The fuel consumed was proportioned to the exact surface of the experimental unit tested in order to define the fuel consumed per hectare in that trial.

Crop yield was measured by weighting all the biomass produced in each repetition of the specific test separately. Concerning baling test, the last bale collected from each repetition, even if was not completely formed, was expelled before starting the following repetition. The bales obtained during each repetition were weighted separately. Each bale was marked with a univocal code indicating the specific plot to which it belonged.

The bulk density (kg_{fm} m^{-3}) is a key parameter directly related to logistic issues. A higher density, in fact, substantially affects the cost of the biomass handling, decreasing the number of total transports and, therefore, the cost. The bulk density of the biomass harvested was measured using a steel cylinder of known internal volume according to ISO 17828:2015. A cylinder of 0.026 m^3 was filled with the biomass and then

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weighed using a dynamometer. The ratio between the net weight of samples in the cylinder and its internal volume represented the bulk density, expressed in kg m^{-3}.

Samples of different biomasses were randomly collected in each sampling plot, weighed and stored into vacuum-packs to measure **the moisture content**. The moisture content (MC, w-% ar) was determined according to ISO 14774-2:2009.

Biomass losses correspond to the biomass left on the soil during harvesting. For the identification of the biomass losses 3 plots for each repetition, randomly selected, were identified, and the biomass present was collected and weighed. Percentage of losses (%) were then estimated as the ratio of biomass losses to the sum of crop yield and biomass losses, for each experimental field. The sum of net yield and biomass losses represented the total yield potential (t ha^{-1}). The sum of net yield and biomass losses represented the total yield potential.

The Heating Value was performed according to EN ISO 18125. The HV represents the amount of thermal energy generated by the combustion of one kg of dry matter (considering the water in biomass at atmospheric pressure and at a liquid state of 15°C).
The determination of the ash content was carried out according to the EN ISO 14775.
The nitrogen was obtained according to EN ISO 15104.
The chlorine and sulfur content were determined according to EN ISO 16994.

Statistical analysis: After verifying the normality of the distributions, the data statistically significant were analysed by ANOVA (Onofri, 2007). The Tukey test ($P<0.05$) was used as post-hoc test to separate the means.

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4. Results from BECOOL assessment

4.1 Olive pruning harvesting test

During the project BECOOL tests of harvesting of prunings have been carried out in Agios Konstantinos (Fthiotida region, Greece) in order to test the performance and the quality of the work of shredder FACMA in hilly and flat lands. Results were described in the deliverable 1.3.

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4.2 Wheat chaff harvesting test

Harvesting tests of wheat chaff were conducted near the city of Nantes (France) during wheat grain harvesting in July 2018. From all the system commercially available, the tests focused on a device that spreads the chaff on the windrow of straw that is afterwards baled. This system was selected because, after reviewing the already existing technologies, it was considered of special interest due to the cost, harvesting systems and scope of the project. Results of this activity were already reported in the deliverable 1.3.

The analysis of the data collected during the project revealed the possibility of studying in further detail wheat chaff merging the activity carried out on maize cob.

In fact, a substantial impulse to use some agricultural residues for bioenergy can be represented by Harcob, a new harvesting system, developed by the Italian company Agricinque of Racca group (Marene, CN, Italy). The system consists of a device to separate maize cob and from the other residues (leaves, stem, culm, etc.) and an additional tank (9 m^3) for storing collected materials (results on maize cob harvesting were already presented in deliverable 1.3). The system is patented and already commercial, but it is not already well developed on using this machine to harvest wheat chaff. In Europe, there is currently no established practice to collect chaff during harvesting, even if there are already technologies developed for its baling together with straw or separated as a bulk product. However, a collection and removal of chaff represents an herbicide-free weed management technique, as chaff contains most of the harvested weed seeds. Chaff collection can prevent the weed seeds from entering the soil and reduce the spread of weed patches. The purposes of the trial reported here were: (1) to evaluate the operating parameters of the Harcob system, the quality and effectiveness of its work during cob harvesting, (2) to verify the possibility of using the same combine harvester to gather wheat chaff (although it was developed to harvest the maize cob) with a new configuration. Moreover, an economic analysis of the harvesting of the two crop by-products was also performed. This approach will foster the utilization of two untapped biomass sources simplify the harvesting and reducing its cost.

The new study was conducted in July 2019 in the Northern Italy at Revello (44.709920 N and 7.435711 E), Cuneo province, for the harvesting of wheat chaff and results were compared with data collected in 2018 harvesting maize cob with same machine in the same farm. The farm is oriented to dairy farming and has a biogas power plant of 250 kWe fed by cow manure and litter, and maize residues (cob and stalks). The test was carried out using a modified axial-flow combine harvester (Axial-flow 7130; Case IH, Racine, WI, USA), capable of harvesting separately the maize grains and threshed cobs. The combine was equipped with a specific cob harvesting device, comprising a threshing and separation system, a dedicated cob tank and an unloading device. The cob is stored till is unloaded with an innovative auger system ensuring no blocking problems and allowing the discharging of cob (as well as chaff) and grain at the same time. The combine can still be used for only grain harvesting, by manually disconnecting the main drive belt. The test was performed in three blocks (replicates), belonging to the same field, of about 0.5 ha each. The combine harvester during the harvesting of maize and wheat has been set according to Table 1:

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Table 1: Combine harvester CASE IH Axial Flow 7088 setting used during harvesting of maize and wheat.

Crop	**Wheat**	**Maize**
Setting		
rotor speed (rpm)	750	750
gap between rotor and separator (mm)	15	20
cleaning fan speed (rpm)	540	540
spreader speed (rpm)	560	560
openings of upper sieve (mm)	17	12
openings of lower sieve (mm)	14	9

Furthermore, before starting the wheat harvesting test the combine was modified as follow: The maize sieve (41 mm) was changed according to the dimension of the wheat seeds (28 mm). The crushing elements (knife) of the beating cylinder were changed. The modification must be intended as an adaptation of the harvesting system to the different crop.

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Figure 1: Knives for harvesting wheat chaff (left) and maize cob (right)

The biomass remaining in the stubble was assessed by measuring the average cut height that was evaluated by measuring 100 random cut heights transversally to the field for each block. The working time study was performed according to the Comité International d'Organisation Scientifique du Travail en Agriculture (CIOSTA) methodology and the recommendations from the Italian Society of Agricultural Engineering (A.I.I.A.) 3A R1. Harvested areas were measured as well as the machines' operation time, and yield obtained per each experimental field during the harvesting tests in order to calculate the theoretical field capacity (TFC, ha h^{-1}), the effective field capacity (EFC, ha h^{-1}) of the equipment used and their field efficiency (FE, %) and material capacity (MC, Mg h^{-1}). The field capacity corresponds to the number of hectares that can be harvested per hour and its measurement is used to schedule field operations, labour, power units, and to assess machine operating costs. The effective field capacity (EFC) of a machine in the field was calculated by dividing the hectare completed by the hours of actual field time. TFC depends only on the full operating width of the machine and the average travel speed in the field representing the maximum possible FC that can be obtained at the given field speed and full operating width of the machine is being utilized. EFC is less than TFC as a result of the various delays that may occur in the field during the work. The ratio of EFC to TFC represent the

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machine's FE. FE is expressed as the percentage of a machine's TFC actually achieved under real conditions. It accounts for overlapping (failure to utilize the full operating width of the machine) and many other time delays like emptying grain and residues, traveling, turning, refilling the fuel tank, making adjustments, waiting for trucks and stops for the operator to rest. Other idle times due to activities that occur outside the field, such as travel to and from the field, major repairs or daily service, are not included in FE measurement. The MC of harvesting machines is often measured by the quantity of material harvested per hour (t h^{-1}). It is obtained multiplying the machine's EFC and the average yield of crop per hectare. Fuel consumption was recorded by using the measuring system of the combine harvester

Grain and residues of both maize and wheat were harvested per each block and weighed separately in the farm scale by using different trailers. After wheat straw baling, the bales produced from each experimental block were weighed. The biomass losses were assessed differently for wheat chaff and maize cob. Concerning wheat chaff, losses were measured by knowing the total biomass available in the field (assessed during the pre-harvesting stage), the biomass left in the field due to the cut height (assessed during post-harvesting stage) and the grain and by-product harvested and baled, employing the following formula:

Harvesting losses (t ha^{-1}) = Rph − Se − St − B − T (1) where:

Rph = Total amount of biomass assessed in pre-harvesting stage (t ha^{-1}); Se = amount of seeds (t ha^{-1}); St = stubble (t ha^{-1}) (wheat/maize stalks (t ha^{-1}) × cut height (w%)); B = amount of baled residue (t ha^{-1}) and T = amount of chaff collected (t ha^{-1}).

Maize cob harvesting losses were assessed by collecting and weighing the cob biomass left on the ground. Three random 10 m^2 plots were chosen per each block. Then, cobs present in each plot were collected and weighted with a portable dynamometer. Therefore, harvesting losses (%) were estimated as the ratio of residue losses (Mg ha^{-1}) to the sum of biomass yield (Mg ha^{-1}) and residue losses (Mg ha^{-1}) for each block. The total biomass yield potential was calculated summing the net biomass yield and biomass losses (Mg ha^{-1}).

Ownership and operating costs were the focus of the economic analysis. Standard values provided by the CRPA methodology and the data collected during the field tests (primary data) were used during the machine operating cost evaluation. Furthermore, data measured during the field tests was validated by interviews with agroindustry owners and their usual suppliers who provided additional cost items used in the cost analysis. The hourly costs for all the equipment tested during the harvesting were calculated for both cereal crops according to methodology described in the section. Table 2 reports the parameters used during the cost analysis of the harvesting systems tested

Table 2: Economic parameters used for the cost analysis of cereal straw and chaff, and Maize cob collections using Harcob technology.

Parameters	Unit	Wheat chaff collection	Straw baling	Maize cob collection
Machine		Combine harvester CASE IH	Deutz-Fahr Agrotron M620	Combine harvester CASE IH Axial

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		Axial Flow 7088				Flow 7088	
Power	kW	269		115,6		269	
Operating machine			Harcob		Baler - Deutz-Fahr Varimaster 690		Harcob
Financial cost							
Investment	€	226,380.00	75,000.00	85,000	32,000	226,380.00	75,000.00
Service life	year	10	10	12	8	10	10
Service life	h	3,000	3,000	14,000	2,500	3,000	3,000
Resale	%	19	18	28	23	19	18
Resale	€	43,260.00	13,263.00	28,200	7,225	43,260.00	13,263.00
Depreciation	€	183,120.00	61,737.00	56,800	24,775	183,120.00	61,737.00
Annual usage	h y^{-1}	480	480	294	294	480	480
Interest rate	%	3	3	3	3	3	3
Labour cost	€ h^{-1}	11.5		11.5		11.5	
Workers	n°	1		1		1	
Fixed costs							
Ownership costs	€ y^{-1}	18,312.00	6,173.69	7,080.99	3,096.86	18,312.00	6,173.69
Interests	€ y^{-1}	4,044.60	1,323.95	1,275.42	588.38	4,044.60	1,323.95
machine shelter	m^{-2}	26.88		9.12	9.89	26.88	
Value of the shelter	€ m^{-2}	100.00		100.00	100.00	100.00	
Value of the shelter	€ y^{-1}	53.76	0.00	27.36	29.67	53.76	0.00
insurance (0.25%)	€ y^{-1}	565.95	0.00	212.50	80.00	565.95	0.00
Variable costs							
repair factor	%	40.00	45.00	80.00	90.00	40.00	45.00
repairs and maintenance	€ h^{-1}	48.29	18.00	1.22	10.83	48.29	18.00
fuel cost	€ l^{-1}	0.57		0.57		0.57	
fuel consumption	l h^{-1}	35.45		9.68		36.86	
fuel cost	€ h^{-1}	20.35		5.56		21.16	
lubrificant cost	€ l^{-1}	3.03		3.03		3.03	
lubrificant consumption	l h^{-1}	0.18		0.09		0.18	
lubrificant consumption	€ h^{-1}	0.55		0.27		0.55	
salary	€ h^{-1}	11.50		11.50		11.50	

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cost of baling string	€ h^{-1}	32.32	

The calculation of the operating costs was per hour of work carried out, per unit area and per ton of product harvested. The share of harvesting costs was carried out through the market value (Chamber of Commerce of Modena) of each product and co-product produced according to Table 3. The economic allocation, per harvesting phase (combine harvesting and baling), comes from the ratio between each product revenue on the total revenues obtained, according to the following formula:

$$Ea = \frac{Mp * Y_i}{\sum_{i=1}^{3} R_i}$$

where Ea = Economic allocation of each product or co-product (i.e., grain, straw, chaff and cob) per harvesting phase (combine harvesting or baling); Mp = Market price of each product or co-product; Yi = Yield of each product or co-product and Ri = Revenue obtained by multiplying Mp × Yi .

Table 3. Economic allocation used for the cost analysis of products and by-products collected during both tests and each harvesting phase, with Harcob technology.

Product	**Market price** (€ t^{-1})	**Yield** (t ha^{-1})	**Revenue** (€ ha^{-1})	**Economic allocation for combine harvester** (%)	**Economic allocation for baling** (%)
Wheat seed	198.50	10.93	2,169.60	88 %	0 %
Straw	50.00	5.48	274.00	11 %	100 %
Chaff	50.00	0.67	33.5	1 %	0 %
Total		**17.08**	**2,477.11**	**100 %**	**100 %**

Product	**Market price** (€ t^{-1})	**Yield** (t ha^{-1})	**Revenue** (€ ha^{-1})	**Economic allocation for combine harvester** (%)
Maize seed	185.00	13.12	2,427.20	96 %
Cob	65.00	1.72	111.80	4 %
Total		**14.84**	**2,539.00**	**100 %**

4.2.1 Avoided CO2 Emission from Fossil Fuel

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In order to evaluate the CO_2 emissions from fossil fuel combustion avoided per unit area (t CO_2 ha^{-1}) using cobs and chaff for bio-energies, the equivalent energy production per residue was calculated as follows:

$$ER = Yi \times NC$$

where: ER = Energy content in residue per unit area (MJ ha^{-1}); Yi = Yield of each residue collected (kg ha^{-1}) and NC = net calorific value of the residue (MJ kg^{-1}). Considering a net calorific value of diesel of 38.6 MJ l^{-1}, the diesel equivalent per unit area (l ha^{-1}) to residue collected was calculated as follows:

$$DE = ER/DD$$

where DE = diesel equivalent per unit area (l ha^{-1}); ER = energy content in residue per unit area (MJ ha^{-1}); DD = net calorific value of diesel (MJ l^{-1}). Considering that 2.65 Kg CO_2 are emitted per liter of Diesel consumed (kg CO_2 l^{-1}), the avoided emission of CO_2 due to bioenergy produced per residue collected was calculated according to the following formula:

$$AC = D \times EC$$

where AC = avoided emission of CO_2 due to bioenergy produced per residue collected (kg CO_2 ha^{-1}); DE = Diesel equivalent per unit area (l ha^{-1}); EC = emission of CO_2 per liter of diesel (2.65 Kg CO_2 l^{-1}).

The average value of the stem diameter was 2.3 (±1.5) cm with a maximum value of 3.3 cm. The plant height showed a great variability ranging between 155 and 420 cm with an average value of 325.8 (±31.9) cm. The average weight of the total biomass was 50.7 (±6.4) t ha^{-1}, showing a great variability ranging between 42.8 to 55.1 t ha^{-1}. The ears yield was 19.5 (±2.2) t ha^{-1} in average with 17.0 and 20.9 t ha^{-1} of minimum and maximum values respectively. The average value of the ears/biomass ratio was 44.0%. The average value of the leaf moisture content (MC) was 32.5 (±2.9) %, while the stalks registered value of 72.2 (±2.8) %. Grain MC showed an average value of 18.9 (±2.2) %, while cob MC was 32.1(±3.4) %. The average bulk density of the cob resulted 132.36 (±11.58) kg m^{-3}.

The combine harvester machine equipped with the Harcob system, allowed the collection of 13.12 t ha^{-1} of grain and 1.72 t ha^{-1} of maize cobs. The unharvested maize cobs that remained in the field were assessed to be equal to 0.58 t ha^{-1} (25% of the total potentially harvestable cob biomass). The material capacity was 18.58 t h^{-1} and 2.31 t h^{-1} for grain and cob, respectively. The unloading of the maize grain and the cobs takes place at the same time because the cobs' tank has been dimensioned in order to be filled at the same time as the grain tank. This technical feature allows one to keep the unproductive times due to the unloading of the maize seed unchanged even after the introduction of a parallel production process to collect the cobs (Figure 2). The fuel consumption was equal to 27.1 l ha^{-1}. A summary of the results of the performance test are reported in Table 4.

Table 4. Results of the maize and cob harvesting test with combine harvester (CASE IH 7140, Racine, WI, USA) and Harcob system.

Parameters	**Mean**	**Dev. St.**
Theoretical Field Capacity (ha h^{-1})	1.89	±0.29
Effective Field Capacity (ha h^{-1})	1.36	±0.18
Yield (t grain ha^{-1})	13.12	±0.28
Material Capacity (t grain h^{-1})	18.58	±0.13

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Yield (t_{dw} cobs ha^{-1})	1.72	±0.23
Material Capacity (t cobs h^{-1})	2.31	±0.09
Fuel Consumption (l ha^{-1})	27.1	±4.02
Cob Losses (t ha^{-1})	0.58	±0.23

Figure 2. Simultaneous unloading phase of Maize kernel and cob tanks using Harcob system.

The cost analysis of maize harvesting highlighted that the cob collection with the Harcob device is 26% more expensive compared to the traditional maize seed harvesting in terms of both hourly and per unit area costs (Table 5).

Table 5. Operating costs of maize seeds and cob harvesting. Comparison between traditional and Harcob systems.

Maize Seeds and Cob Harvesting Costs with Harcob Technology				
	Unit	**Corn**	**Cob**	**Total Harvesting Cost**
Market price	€ t^{-1}	185	65	
Yield	t ha^{-1}	13.12	1.72	
Cost Allocation	%	96%	4%	100%
Combine Harvester + Harcob	€ h^{-1}	155.95	7.18	163.13
	€ ha^{-1}	114.67	5.28	119.95

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	€ t^{-1}	8.74	3.07

Traditional Maize Seeds Harvesting Costs Without Cob Collection		
	Unit	**Corn**
Market Price	€ t^{-1}	185
Yield	t ha^{-1}	13.12
Cost Allocation	%	100%
	€ h^{-1}	129.51
Combine Harvester	€ ha^{-1}	95.23
	€ t^{-1}	7.26

The higher investment required to purchase the Harcob system also has an impact on the cost of corn (€ t^{-1}) which resulted 20% higher than harvesting without Harcob. However, the Harcob system produced a revenue of 111.80 € ha^{-1} higher than the traditional harvesting system permitting the collection of about 1.7 t cob per hectare (Table 2). Furthermore, subtracting the only harvesting costs to the total revenues obtained with each harvesting system, with Harcob the profit was 2,419.05 € ha^{-1} while with the traditional harvesting system the difference was 2,331.97 € ha^{-1}. With Harcob it was possible to obtain an income of 87.08 € ha^{-1} (4%) higher than using the traditional harvesting system without Harcob.

Pre-harvesting test permitted to assess a total amount of biomass per hectare of 25.9 (±0.34) tons, of which 11.5 (±1.01) tons of grain and 2.48 (±0.11) tons of chaff. The amount of straw was estimated in 8.58 (±1.08) tons per hectare of which 3.38 (±0.48) tons of stubble that remained in the soil due to the cutting height of the machine. The average value of the straw moisture content was 23.0 (±1.4) %. Grain and chaff moisture content were 12.4 (±0.4) %. The average bulk density of the chaff resulted 42.88 kg m^{-3}.

The Harcob system was developed for harvesting corn cobs. Given the growing interest of the agricultural, industrial and research sectors in unused wheat residues, once the necessary modifications to be made to the combine already described had been identified, specific harvesting tests were conducted to verify the possibility of also using the Harcob system for the separate harvesting of cereal husks. During the wheat harvesting tests the grain and chaff collected were 10.93 and 0.67 t ha^{-1}, respectively. The material capacity was 12.98 t h^{-1} and 0.79 t h^{-1} for grain and chaff, respectively. Performance test results are summarized in Table 6.

Table 6. Results of the wheat grain and chaff harvesting test with combine harvester CASE IH 7140 and Harcob system.

Parameters	**Mean**	**Dev. St.**
Theor. Field Capacity (ha h^{-1})	1.42	±0.05
Eff. Field Capacity (ha h^{-1})	1.19	±0.01
Yield (t seeds ha^{-1})	10.93	±0.43
Material Capacity (t seeds h^{-1})	12.98	±0.66

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Yield (t chaff ha^{-1})	0.67	±0.02
Material Capacity (t chaff h^{-1})	0.79	±0.02
Fuel Consumption (l ha^{-1})	29.86	±0.31

Results of pre-harvesting and harvesting tests were elaborated in order to define the mass balance and to assess the biomass losses. Harvesting tests carried out on wheat have shown the Harcob system's incapability of effectively separating the wheat chaff from the straw. In particular, the Harcob tank contained about 10% of straw mixed with chaff. Furthermore, the windrow of residues generated by the combine was made by 50% of chaff and 50% of straw.

Due to the results of the harvesting and the impossibility to distinguish chaff from straw, these two biomasses were considered together for the mass balance definition reported in Table 7. Results highlighted 4.87% of grain losses and 47.06% of chaff and straw losses (excluding the stubble part that remained uncollected in the soil).

Table 7. Wheat grain and residues losses assessment.

Wheat Fractions	**Potential Biomass*** (tdw ha^{-1})	**Harvested Products** (tdw ha^{-1})	**Biomass Losses** (%)
Grain	10.2	9.7	4.87
Chaff	2.2	0.6	47.06
Straw	5.2	3.3	
Stubble	2.1	2.1	-
Total Residues	9.5	6.0	47.06

* Fractions of the biomass available per unit area assessed with pre and post-harvesting analysis

The wheat chaff harvesting cost resulted higher than the cob harvesting using the same system (Table 8). The higher investment required to purchase the Harcob system has an impact also on the cost of wheat (€ t^{-1}) which is 24% higher than harvesting without Harcob. Furthermore, Harcob device developed for maize cob harvesting resulted able to collect part of the wheat chaff separately by the straw, but with some chaff losses of about 47%. Comparing the total costs to harvest wheat with and without the Harcob system, it can be observed that the use of Harcob implied an extra cost of 14%. In the absence of a chaff market, assuming the market price of chaff comparable to that of straw (50 € t^{-1}), the harvesting of chaff with the Harcob system allowed to obtain a revenue of 33.5 € ha^{-1} (Table 3) While, according to the economic allocation used for cost sharing among wheat products reported in Table 3, the profit obtainable by chaff collection with Harcob system resulted 31.4 € ha^{-1}.

Table 8. Operating costs of wheat grain and residues harvesting. Comparison between traditional and Harcob systems.

Wheat Harvesting Cost using Harcob Technology					
	Unit	**Grain**	**Straw**	**Chaff**	**Total Cost Per Phase**

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Market Rice	€ t^{-1}	198.50	50.00	50.00	
Yield	t ha^{-1}	10.93	5.48	0.67	
Cost Allocation	%	88%	11%	1%	100%
Combine Harvester + Harcob	€ h^{-1}	142.04	17.94	2.19	162.18
	€ ha^{-1}	139.26	17.59	2.15	159.00
	€ t^{-1}	12.74	3.21	3.21	
Cost Allocation	%	-	100%	-	100%
Tractor + Baler	€ h^{-1}	-	112.71	-	112.71
	€ ha^{-1}	-	36.15	-	36.15
	€ t^{-1}	-	6.60	-	6.60
Total Cost of the Harvesting System	€ h^{-1}	142.04	130.65	2.19	274.88
	€ ha^{-1}	139.26	53.74	2.15	195.14
	€ t^{-1}	12.74	9.81	3.21	
Traditional Wheat Harvesting Cost Without Chaff Collection					
	Unit	**Grain**	**Straw**	**Chaff**	**Total Cost Per Phase**
Market Price	€ t^{-1}	198.50	50.00	0.00	
Yield	t ha^{-1}	10.93	5.48	0.00	
Cost Allocation	%	89%	11%	0%	100%
Combine Harvester	€ h^{-1}	114.15	14.41	0.00	128.56
	€ ha^{-1}	111.91	14.13	0.00	126.04
	€ t^{-1}	10.24	2.58	0.00	
Cost Allocation	%	-	100%	-	100%
Tractor + Baler	€ h^{-1}	-	112.71	-	112.71
	€ ha^{-1}	-	36.15	-	36.15
	€ t^{-1}	-	6.60	-	6.60
Total Cost of the Harvesting System	€ h^{-1}	114.15	127.12	0.00	241.27
	€ ha^{-1}	111.91	50.28	0.00	162.19
	€ t^{-1}	10.24	9.18	0.00	

The collection of agricultural residues such as cobs and chaff for energy purposes implies avoided CO_2 emissions due to reduced use of fossil fuels. In this study, considering a net calorific value of 18.4 MJ kg^{-1} of cob and 15.1 MJ kg^{-1} of chaff (Kis et al., 2017), according to the product collected during the tests, the

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equivalent energy was estimated to be 31,648 and 10,117 MJ ha^{-1} for cobs and chaff, respectively. This leads to an avoided Diesel consumption of 820 and 262 l ha^{-1} due to cob and chaff for energy production, respectively. Maize cobs and wheat chaff for energy purposes would avoid greenhouse gasses emissions (GHG) from fossil fuel equal to 2.2 t CO_2 and 0.7 t CO_2, respectively.

Since the beginning of the nineteenth century, before modern combine harvesters, corn was harvested as a whole ear of corn and shelled afterwards by Stone and Snow. Even if cobs were all collected, harvesting was a labour-intensive job because the grain still had to be threshed. With the increase in harvesting mechanization, the trend had become to leave the cob in the field. It was only in the 1980s that Bargiel et al. developed a first cob collection system based on a mechanical separator that unloaded it onto a towed trailer [30], although, the system still had limits in terms of cob losses that resulted about 31% considering a cob purity of 89%. The low purity of the cob collected, affected also its bulk density that was 100 kg m^{-3}. Since 1980 several studies have analyzed various solutions for the harvesting of corn cobs, sometimes reaching high levels of purity of the harvested product and significantly reducing harvest losses (Jhonson, 2010), but where multiple passes were necessary, or trailers towed by tractors side-by-side the combine.

Moreover, as noted by (Shinners and Entz, 2010) the fraction of available stover harvested by conventional means was rather low, between 37% and 57%. A combined single-pass harvesting system of corn grain and residues in single-pass would further reduce field operations and costs.

Shinners proposed a harvesting system of corn grain and stover in single-pass that resulted 39% less productive than the conventional grain harvest system. In addition, the authors of the study had highlighted clear difficulties for the system to manage both cereals and residues at the same time.

Hence, the Harcob system represents an innovation considering the possibility to perform a single-pass grain and cob harvesting with simultaneous unloading of the products (grain and cob) in two different trailers, without affect the harvesting performance of the combine, and without modifying the harvesting method and costs. The cob harvesting losses of 25% are comparable with the results of tests performed with an experimental corn cob separation system mounted on a John Deere 9750 STS combine in Iowa (USA), where this parameter ranged between 35% and 5%.

Harvesting tests were carried out also to collect wheat chaff even if first results highlighted the need for further improvement and modifications due to high losses and the level of impurities measured. The Harcob system was developed to be mounted in axial combine harvesters that can provide lower grain breakage percentage and higher productivity respect to the traditional harvesters with straw walkers but, on the other hand have stronger mechanical action on the straw. Even if Harcob system allows one to collect 0.6 t ha^{-1} of chaff for bioenergy, the use of Harcob showed 47% of biomass losses. The amount of biomass losses could be explained by the straw crushing caused by the threshing system of the axial harvester. In fact, once the straw is cut in smaller parts, then the cleaning and ventilation system is not able to discriminate and separate the grain from the chaff and from the straw. The result was that part of the chaff went into the straw windrow.

Even if experiences of chaff harvesting are almost absent in the bibliography, there are already machines on the market developed for the separate collection of chaff and straw, mainly to avoid the spread of weed seeds, but also for their use in animal husbandry or for the production of biofuel and energy (Pari et al, 2019; Unger and Glasner, 2019). The experience carried out by Pari during chaff and straw collection by means a residue spreader tested in Sweden for chaff and straw baling, showed a residue harvesting losses between 31% to 47% (Pari et al., 2018). This is to clarify that the harvesting efficiency of the Harcob system was similar to that of a system developed for the spreading of residues and that can partially, by changing the setting, allow a certain

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admixing of the chaff with the straw. For this reason, improvements will be necessary to optimise chaff harvesting with Harcob, reducing both product losses and increasing the separation capacity of the two fractions.

Even if maize harvesting by Harcob was 25% more expensive per unit area than a traditional system, it resulted more convenient than contractor harvesting cost in Italy where the harvesting cost varies from 135 to 150 € ha^{-1}. According to the test results, in case of maize grain and cobs harvesting, the tested device allows farmers to have a higher profit even if both hourly and per unit area costs are higher than those of a traditional system. Concerning the chaff harvesting costs no information were found for the Italian agricultural sector. However, the cost of wheat harvesting (grain and straw) is similar to traditional systems in Central (150–175 € ha^{-1} including straw chopping) and Northern Italy (206–245 € ha^{-1} including straw bailing).

The risk of high bioenergy demand is the impacts of the indirect land use change (ILUC) which may occur when grazing land or farmland previously devoted to food production is turned over to the production of biofuels. This production change may expand agriculture land into areas with high carbon stock (i.e. peatlands, forests and wetlands), causing the release of greenhouse gases (CO_2 stored in soil and trees) and negating the benefits of using biofuels instead of fossil fuels, in terms of emission savings. Hence, the European Renewable Energy Directive (RED II) faces this risk. Consequently, alternative feedstock to produce bioenergy sources, such as cobs and chaff, are fundamental to sustain the agro-energy production chain.

The impact on the atmospheric CO_2 using biomass as fuel is negligible. Biomass utilization on a global scale could contribute to environmental protection, having in mind that biomass sources are CO_2-neutral because all the CO_2 from biomass combustion is absorbed during new biomass growing to be used for the same purpose. The present study demonstrated that using residues the reduction of CO_2 from fossil fuel is ranging from 0.7 to 2.2 t CO_2 ha^{-1}. Even if the amount is low, they are very important because they are derived from renewable material.

Maize cob and wheat chaff are often less expensive untapped residues compared to dedicated energy crops. In fact, both maize cob and cereal chaff are co-products of grain production, and excluding harvest and nutrient replacement, no additional costs are necessary. However, the feasibility of using these feedstocks for bioenergy production is mainly related to the harvest methods used and biomass available and collectable per hectare. The scope of this study was to evaluate the operating parameters of the Harcob system and the quality and effectiveness of its work during cob harvesting and to verify the feasibility of harvesting the wheat chaff through an innovative system (although it was developed to harvest the maize cob). According to the methodology utilized in this study it was possible to harvest 1.72 t ha^{-1} and 0.67 t ha^{-1} of cob and chaff, respectively. This would allow farmers to obtain a revenue of 111 € ha^{-1} from the sale of the cobs corresponding to an increase in profit of 4% compared to the harvesting of only corn seed using the traditional system. As far as the chaff collection through the use of the Harcob system has not shown real advantages from the economic point of view allowing farmers to obtain an increase in profit close to zero. This result is obviously influenced by the market price of the chaff which in this article has been assumed to be the same as that of straw. Although, the separate collection of the product, the increase in collection efficiency, and the presence of a specific market (for agricultural or industrial use) could make the use of by-product collection systems such as Harcob increasingly economically attractive.

In conclusion, the Harcob system could be considered suitable to harvest such different and high potential crop by-products and may represent a solution for farmers investing in the bioenergy production chain. Furthermore, the possibility of using the same combine harvester for two different cash crops in two different

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seasons will increase the profitability of the machinery. Aspects related to the improvement of the system for chaff harvesting should be investigated and included in future studies.

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4.3 Maize cob harvesting test

The maize cob has become a material of high interest since the most common practice is to leave the cobs on the soil during the harvesting of maize grains, but it could be used as resource for bio-commodities: biomass for energy and others like:

- Absorbent for animal bedding or substrate in hydroponic cultivation (for instance).
- Adsorbent for production of active carbon for water treatment, among other applications.
- Abrasive material for metal or wood surface conditioning.

Some manufacturer companies have developed devices to be implemented in most spread commercial combine harvesters to perform the combined collection of grain and cobs in one step.

In Italy, the company AGRICINQUE Gruppo Racca srl has designed and patented a system to be applied in some of CASE commercial harvester, for that reason this machine was selected to be studied during cob harvesting. The study was conducted in October 2018, results were reported in the deliverable 1.3 and used for the additional comparative study described in section 4.2.

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4.4 Fiber sorghum value chain

The CREA-IT within the project in collaboration with COPROB sugar beet cooperative, who has undertaken a productive strategy towards the energy production from biomass, has studied the value chain of fiber sorghum. The objective was to describe the fiber sorghum harvesting machineries and the supply chain built-up by COPROB for an energy purpose. The value chain was described in deliverable 1.3.

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4.5 Eucalyptus storage test

The goal of this subtask is to define the best logistic chain of eucalyptus on the basis of the storage performance and of the quality of the biomass according to the final use of the feedstock. For this purpose, CREA carried out storage trials of 5 years old eucalyptus plants in three different biomass formats (whole trees, chips and firewood), testing different treatments: the whole plants were stored with and without branches, the comminuted biomass was stored covered and uncovered, and the firewood was tested in outdoor and indoor conditions. Data were presented in the deliverable 1.3.

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4.6 Arundo storage test

Arundo donax L. belongs to Poaceae family and is a perennial grass. Usually, grows in damp soils, either fresh or moderately saline, and is native to the Greater Middle East. It has been widely planted and naturalised in the mild temperate, subtropical and tropical regions of both hemispheres (Herrera and Dudley, 2003), especially in the Mediterranean and California. Giant reed is one of the most promising crops for energy production in the Mediterranean climate of Europe and Africa, where it has shown advantages as an indigenous crop, with a durable yield and sufficient resistantance to long drought periods. In the last years Arundo donax L. has represented an important attractive as bioenergy source. Several studies have been carried out to improve the destructuration of the lignocellulosic fraction and facilitate the sugar release (De Bari et al., 2013; Scordia et al., 2012) with scope to bioethanol production. On the other hand, few experiences on storage of A. donax biomass have been carried out (Curt et al., 2013; Sanzone and Sortino, 2010). Little is known about the specific environmental factors that regulate A. donax growth, phenological changes and seasonality of storage that may affect its suitability as energetic source. However, Giant reed biomass calorific value can depend to period of storage and also affected by fertilisation and plant density. In order to improve knowledge on giant reed and to favour the diffusion of energy crops in cropping systems, the study based on different types of storage and assessment of biomass behaviour.

The study was conducted between March and September 2019 at Research Centre for Engineering and Agro-Food Processing (CREA-IT) in Monterotondo, near Rome, Central Italy (42°10’19’’N latitude, 12°62’66’’E longitude). The biomass chips utilized derived from an Arundo plantation growing at CREA-IT experimental farm. 10 tonnes of comminuted biomass has been stored in 2 piles 4 m long, 3 m wide and 2 m tall. The material was stored for 7 months in a flat site close to the plantation (Figure 3).

Figure 3: Covered and uncovered pile of comminuted Arundo donax.

To isolate the chips from the soil and avoid contamination, a pvc sheet was layed on the ground working as storage floor. The shape and the orientation of the two piles were maintained as similar as possible, to ensure that climatic factors had the same influence on both treatments. One of the piles was covered using a Toptex

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textile tissue, i.e. a material capable to allow transpiration and avoid the penetration of precipitations. Each pile consisted of two sections (replicates), each one including 3 sampling points; in total 6 sampling points per pile were utilized (Figure 4); a similar scheme was already utilized in previous studies (Barontini et al., 2014).

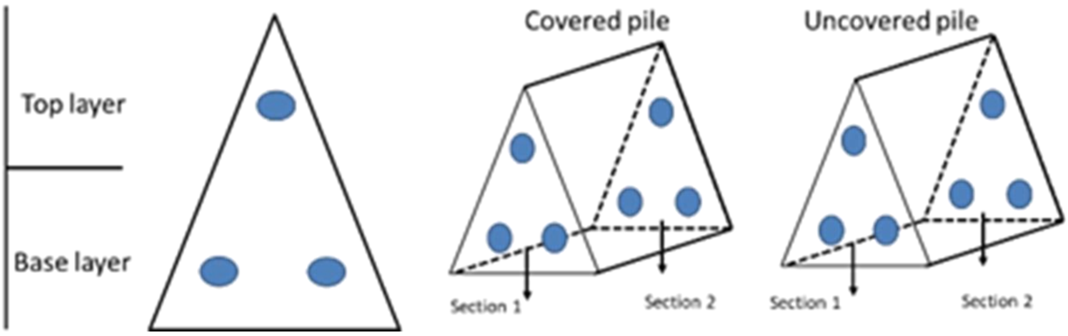

Figure 4. On the left side the single transversal section of the scheme utilized to set the experiment; on the right side the full scheme of the experiment with two sections (replicates) in both treatments.

Internal temperature during storage was monitored placing one pT-100 thermocouple in each sampling point. The probes were connected to a computerized data monitoring cab, connected itself to the web and remotely controlled. Chip storage was carried out outdoor with two different storage systems (covered *vs* uncovered); the material was exposed to the same weather conditions and the climatic parameters such as temperature, precipitation, wind speed and wind direction were recorded during the entire storage period (7 months). These parameters were recorded using a weather cab “DAVIS VANTAGE PRO 2” placed in the proximity of the storage site and connected to wireless net. Near each thermocouple a plastic net filled with about 1 kg chips (pre-weighed) was placed in order to monitor dry matter losses. After storage the bags were removed from the piles and weighed before and after drying in a ventilated oven set at 105±2 °C. The calculation of the dry matter losses, dry bulk density and moisture content was assessed by using the methodology described at section 3.2.

Comparison of two different storage methods of giant reed was tested. Bulk density is one of the important technical properties. It is very easy to determine and can be correlate to many other physical parameters. The experiment showed an initial bulk density (Table 9) of 130 Kg m^{-3}, after the storage period covered and uncovered pile showed a reduction of about 50 %. the reduction of the bulk density was even higher in the uncovered pile.

Table 9: Value of bulk density of *Arundo donax L.* stored in two different ways (covered and uncovered)

Type of storage	**Bulk density (Kg m^{-3})**
Pre-storage	130.6
Post-storage (covered)	62.6
Post-storage (uncovered)	60.1

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Figure 5 showed the trend of principal climatic parameters referred to the whole period of storage of the biomass. The cumulated precipitations were higher in the months of May and September, while higher temperatures were concentrated in Summer, from June to August 2019.

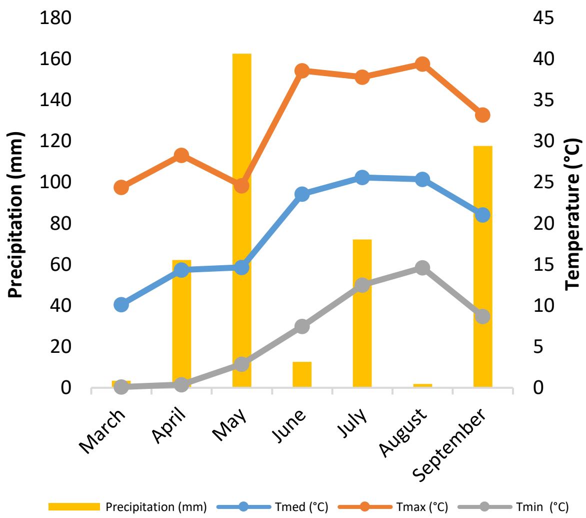

Figure 5: Trend of main climatic parameters, temperature (°C) and precipitation (mm) recorded during the storage of *Arundo donax*.

Comparison between monthly heat development in covered and uncovered (Figure 6) pile of *A. donax* biomass was evaluated. Generally, the inner temperature of the biomass is a reliable indicator of storage performance, since degradation reaction are exothermic and generate a marked temperature rise. After one month from the initial experiment, the temperature in the covered pile (Figure 4) was irregular. Even if the trend was not regular for all the parts of the pile, the temperature recorded at the end of the storage was under 50 °C with a lowest value of 32 °C.

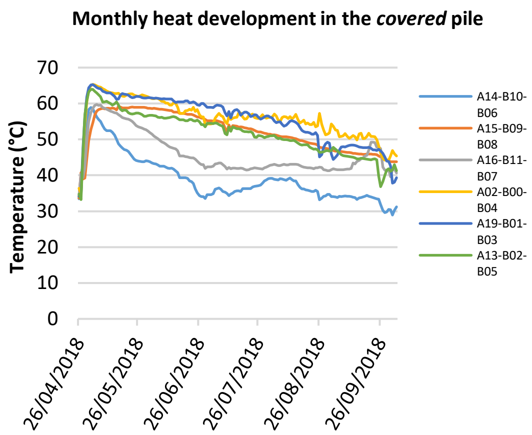

Figure 6: Monthly heat development in *covered* pile, where the numbered letters (e.g. A14, B10, etc.) indicate the thermocouple

The uncovered pile (Figure 7) showed the temperature stabilized at around 60 °C. The temperature rise in stored biomass could be symptom of microbial activity or sufficient condition to start and favourite the

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development of microorganisms grow. At the end of the storage test the temperature was around 50 °C in all parts of the pile. However, could be necessary to extend the research activity to the whole energy chain in order to identify the most sustainable conversion technologies, in combination with the better storage way of *A. donax* biomass.

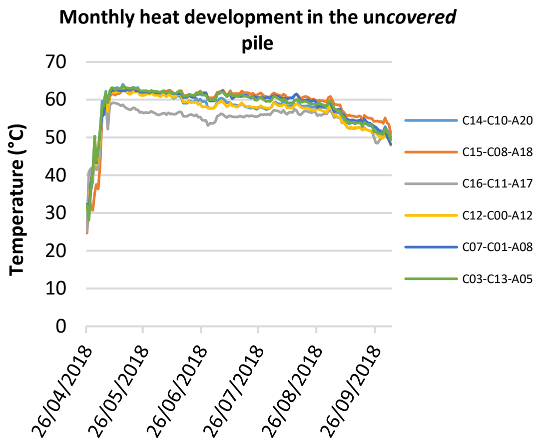

Figure 7: Monthly heat development in *uncovered* pile, where the numbered letters (e.g. C14, C10, etc.) indicate the thermocouple

Comparison of moisture content reduction during the storage test was also evaluated. the results are depicted in table 10.

Table 10. Moisture content (MC) of Arundo donax covered and uncovered piles, expressed in percentage (%), where: MC_i, initial moisture content, MCft is the final content in the Top layer, MFfb is the final content in the Base layer, and MC_f, final average moisture content, that is at the end the storage.

	Covered	**Uncovered**
MCi (%)	49.7±0.93	
MCft (%)	9.7±0.004	19.4±0.05
MCfb (%)	9.2±0.01	15.0±0.03
MCf (%)	9.4±0.003	17.2±0.03

Results highlighted that the reduction of moisture content was higher in the covered pile, as expected, respect to the uncovered pile. Inside each pile, the final moisture content was lower in the base layer respect to the top layer.
Starting from the evaluation of the moisture content reduction during the storage test, the dry matter losses were calculated. Results are shown in table 11.

Table 11. Dry Matter losses (DM) of Arundo donax covered and uncovered piles, expressed in percentage (%).

Dry Matter losses (%)	**Covered**	**Uncovered**
Top layer	7.3±0.03	15.6±0.11
Base layer	0.4±0.01	13.9±0.06

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Total losses	3.8±0.04	14.7±0.06

Results of dry matter losses follow the trend of the moisture content reduction. The covered pile shown lower losses respect to the uncovered pile. Regarding each pile the losses were higher in the top layer respect to the base layer.

At the present, the harvesting period and the system adopted for giant reed are still under debate. The feasibility of the storage of giant reed as chipped biomass for energy purposes is unknown and represents a lack in the scientific literature. It strongly depends on the season, on the geographical area and on the system utilised. This study clarifies on the potentiality of different storage systems, highlighting the advantages and disadvantages by using the Toptex textile as storage material. The results showed how the storage of the biomass caused a reduction of almost 50 % of the bulk density. Furthermore, at the end of the storage the moisture content, the inner temperature and the dry matter losses were higher in the uncovered pile respect to the covered one. The storage test highlighted as it was possible to reach a moisture content suitable for energy production processes in 7 months using a covering textile and to sharply reduce the bulk density. The covered treatment allows to reduce the dry matter losses that usually affects the storage of comminuted biomass.
This study represents a critical data, useful for further investigation focused on the effect of the storage on the main energy parameters, such as fuel quality, heating value and principal elementary compounds.

5 Sugarcane straw harvesting and synergies with BioValue project

Sugarcane is one of the most important crops in the world and due to its large diffusion in Brazil, this country has become the largest producer of sugar. Sugarcane, even if is cultivated mainly for sugar production generates also other interesting by-products to be considered in line with a circular economy approach.

In fact, Brazil is nowadays the second largest producer of ethanol in the world and bagasse is largely used in the sugar production plants as energy source due to their high primary energy content per Mg of biomass.

Bagasse (the industrial fibrous residue from the juice extraction) is basically all combusted in the boilers to provide energy required for their functioning. Straw (also known as trash) is normally burned in the pre-harvest step. The common practice of burning the sugarcane straw is spread especially in facilities with non-mechanized on-field operations (i.e. manual harvesting) with the aim to facilitate harvest and transport operations and costs.
Nowadays, due to environmental, agronomic and economic reasons, the manual harvest of sugarcane has been gradually replaced by mechanical practices with disposal of straw on the ground, in a system called green cane management that makes straw available for other uses. In industry, straw can be used for second-generation (2G) ethanol production and/or bioelectricity generation, constituting an important part of the energy matrix.
The green management of sugarcane produces large amounts of straw placed on the soil after each harvest, ranging from 10 to 20 Mg of dry matter per ha.
In the field, sugarcane straw promotes soil conservation, preserves moisture and reduces erosion, thus enhancing crop yield. For this reason and in order to preserve soil quality, even if straw could represent an opportunity for bioenergy production an adequate level of this biomass should be maintained on the soil.

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Despite the large energy potential associated with the sugarcane straw, very little efforts have been made so far to establish an appropriate harvesting rate and logistic chain to exploit such potential.

Similarly to corn stover in the US (Atchison and Hettenhaus, 2004), for sugarcane straw to become a real feedstock for large biorefineries, an innovative logic chain covering collection, storage and transportation should be develop to ensure biomass quantity and quality. As the attention has been mostly towards the harvesting of the cane stalks, it is still not clear for the industry the best way to collect the straw for energy applications (Leal et al., 2013). In fact, until the end of the 80's, the only concern of sugar cane growers was the amount of cane stalks produced in the field (Hassuani et al., 2005).

Many authors have studied the technical parameters and economic impacts of different straw recovery systems, being the solutions mostly focused on two different paths: integral harvesting routes and baling. In the integral harvesting route, the straw is harvested and transported together with sugarcane stalks, while in the baling route, the straw is left to dry in the field for about 2 weeks after sugarcane is collected. The straw is then windrowed, collected and compacted into bales, which are subsequently loaded and transported to the mill separately from the stalks.

Each of the two systems have pros and cons. The baling system allows the straw to be recovered with less moisture and in a compacted form, which facilitates transportation and storage and reduces the respective costs; however, possible damage to the ratoon and the soil compaction are important disadvantages as well as the high ash content of the biomass deriving from windrowing. The integral harvesting system is based on reducing the speed of the harvester primary extractor which, in turn, increases the amount of straw transported with the sugarcane and reduces losses. This system also reduces soil compaction, since fewer machines are involved. However, higher straw moisture and lower load density are unfavourable aspects of integral harvesting (Okuno et al., 2019).

While relevant studies on these two recovery systems have been carried out on the importance of maintaining the straw in the soil for environmental reasons, defining the right quantity of biomass to be removed, innovative logistic chains able to supply sugarcane straw of quality at competitive costs are still not defined.

Two technical solutions were studied for the improvement of biomass quality, more concretely for the reduction of ash content in the biomass. Two possibilities have been explored. The first possibility evaluated the change of the windrowing process technique, from the traditional one to the belt windrower, in order to decrease the quantity of soil transported into the bales and therefore biomass ash content. The second possibility studied was the baling of the straw biomass directly from the harvesting machine, directing one fan of the cleaning system into the baler that follows the harvesting machine. The top leaves and the straw discharged from the second fan are directed into the soil, as normally done, to maintain a portion of biomass in it. The first approach allows to reduce the ash content of the bales without changing the current logistic chain as well as ensuring the drying of the biomass in the field before windrowing. The second approach decreases the field traffic by avoiding the windrowing and the baling operations since the loose biomass is baled directly after harvesting.

The research consisted in a preliminary technical study based on field data acquired during the experimental test carried out in Brazil in 2019 in collaboration with BioValue project and mainly on data acquired on previous research activities with the aim to reduce ash content in sugarcane straw. The approach followed was to study the problem of straw harvesting from a holistic point of view, given by the experience of the authors, by the large number of published paper and report studied and from data acquired during straw harvesting. The study of previous research highlighted the problem of defining a harvesting system able to reduce the impact on the soil, maintain the right quantity of biomass in the soil and to reduce the ash content in the straw collected. Two different solutions were defined on the basis of the approach above described and compared with the

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existing one in order to define pros and cons. For each of the two technical solutions identified the new configuration of the value chain was studied and described. For one of these, a simplified technical design was developed in order to describe the harvesting technique since is not present on the market a machine and no experience exist on this solution.
Two technical solutions for the improvement of biomass quality, more concretely for the reduction of ash content in the biomass were identified.

The first possibility consists in the change of the windrowing process technique, from the traditional one to the belt windrower, in order to decrease the quantity of soil transported into the bales and therefore biomass ash content.

Figure 8. Traditional windrower

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Figure 9. Continuous windrower

The main difference compared to traditional rake is represented by the pick-up system: the rake lifts the crop in order then to transport it on a conveyor belt, whereas traditional rakes drag the crop on the ground up to the windrow. This difference leads to:

- **lower product losses**. During crop dragging traditional rakes tend to leave on the ground a part of product. On the opposite, with the continuous merger the biomass is lifted on a belt and it is not dragged on the ground as it usually happens with traditional rakes;
- **less damages to fresh growth of crop**. Under normal conditions, already after some days from harvesting the crop produce fresh growth made up of small stalks. Under these conditions, rotary-rakes tend often to break the small stalks, causing a delay in growth and therefore in harvesting.
- **Less ash content in the biomass.** The raking system allows to avoid collection of ground and stones that goes into the biomass and into the bales.

Adopting this solution, no variation in the actual harvesting value chain will occur but only a modification in the windrowing system, so the drying of the biomass will happen in the field.

The second possibility studied was the baling of the straw biomass directly from the harvesting machine, directing one fan of the cleaning system into the baler that follows the harvesting machine (figure 5). The direct baling is already a commercial system applied to harvest some residual biomass such as the wheat straw (Shields, 2011). The system is very interesting and promising because it speeds up the harvesting process, reduces the field traffic and increase the quality of the biomass by avoiding the contact between straw and soil.

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Figure 10. Mechanical harvesting

Figure 11. Traditional baling

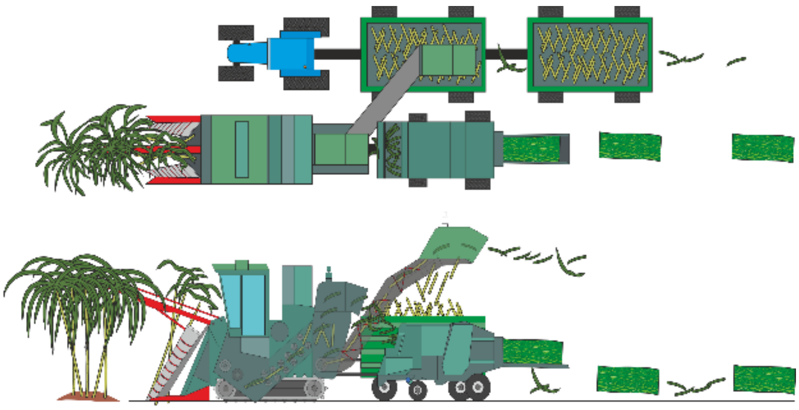

Figure 12. Direct baling

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The top leaves and the straw discharged from the second fan are directed into the soil, as normally done, to maintain a portion of biomass in it. This approach decreases the field traffic by avoiding the windrowing and the baling operations since the loose biomass is baled directly after harvesting. Some experiences of integral harvesting were already carried out, but the straw was collected with the billets of the cane and a mechanical separation of the two biomasses was necessary in the sugar plant. Also, the threshing of the straw was studied in order to decrease the bulk density of the biomass directing the trash with the billet or into the soil (Neves et al., 2016). The solution proposed, differently from the others previously developed, is designed to:

- **lower the ash of the biomass.** The contact between the soil and the straw is avoided**.**
- **maintain the baling system**. The value change will continue by baling the biomass.
- **allowing the storage of the biomass**. Differently for harvesting the loose biomass, the storage will take place normally by piles of bales.
- **reduce the field traffic**. Only the harvesting/baling operation will occur without necessity of windrowing.

The sugarcane straw is a very interesting biomass considering the high availability per hectare, the diffusion of the crop in the world and energy production potential.

The exploitation of such a biomass will foster the production of bioenergy and mainly of 2G ethanol with a huge impact on greenhouse gases reduction. Actually, the sugarcane straw is still untapped since the change from manual to mechanical harvest is a recent process and is still in progress in many areas of the world. For that reason some bottlenecks are still present in the value chain. The right quantity of straw to be maintained into the soli for soil fertility is not well defined as well as the system to harvest it.

The results of the research highlighted the complexity of the sugarcane harvesting. Different aspects are involved in the task: the environmental aspects of soil fertility and compaction, the quality of the biomass and the storage of the biomass. The two straw harvesting systems proposed tackle the problem providing a solution at the present bottlenecks.

6 Dissemination activities

According to the objective of the project the exchange of knowledge between Brazil and Europe in the framework of BeCool-Biovalue projects evaluating the possibility to introduce effective mechanization systems for sugarcane straw harvesting was developed.

In fact, the aims of twinning Project is to promote exchange of knowledge between the two Continents that had founded two twins proposals. BECOOL, from EU has been conceived for being carried out in close cooperation with BioVALUE, from Brasil, in order to benefit from cross disciplinary experiences in EU and Brasil on advanced biofuels.

Due to different climate conditions, some of the knowledge developed in Brazil can be transferred only to the Overseas European Territories stakeholder, in the tropical area. France, Spain, Portugal, the Netherlands have Overseas territories that can receive benefit from the knowledge developed/acquired in Brazil.

Sugar Cane in Europe is cropped in Spain (Canary Islands), Portugal (Azores Islands), France (La Reunion, Martinica, Guadalupe, Mayotte). La Reunion Island is the most representative areas where 23.000 ha are

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cropped and 1.800.000 tons of cane are produced annually, two sugar factories product 200.000 ton of sugar, of which 15.000 tons are consumed in the Island and 185.000 tons are consumed in Europe.
Beyond the production of sugarcane in La Reunion, is also present a specific research center (eRcane) and a Regional Office of CIRAD research center focused on sugarcane crop development.
For these reasons, La reunion island was identified as a territory where different stakeholders (farmers, researchers, sugar factory) could benefit from the transfer of the knowledge developed and or acquired in Brazil on sugar cane production and mechanization in the framework of the BECOOL/BioVALUE projects.
A specific meeting was organized with eRcane. The eRcane Research Centre has a pivotal role in the sugarcane sector in Réunion while being at the forefront of genetic and technological progress with a view to boosting sugarcane production and ensuring its economic viability and sustainability. Since its inception, eRcane has been producing new high-yielding sugarcane varieties through an experimental breeding programme that prioritizes criteria that will ensure the sustainability of growers' income: upholding high performance during successive crop harvests, focusing on tolerance to diseases, insects, etc.
New expertise has gradually emerged in both the Agronomy and Industry branches.
ERcane is renowned in many other sugarcane producing countries for its core areas of excellence. ERcane provides technical support in these countries and exports Réunion agronomic and industrial know-how.
Elite Réunion varieties are also tested abroad, and some are grown on a commercial scale, including R570 and R579, two local varieties that are currently grown in many countries.
Considering sugarcane production, the situation is very different respect to other areas of the world due to the weather conditions, slop, and soil characteristics. Rainfall is very high in the west coast (5.000 mm/y) respect to the east (50 mm/y), and this implies the need of irrigation in east fields and that the crop yield is very variable in the island. Cloudy conditions are very common in the highlands where the soil is mainly volcanic. eRcane has 7 breeding stations in the islands to select varieties and study new cultivation techniques. Characteristics that are selected for breeding are the yield, disease resistance and ratooning capacity. The crop should be replanted every 7/8 years but normally farmers wait 15 years to replant sugarcane. In order to perform this breeding programme, they ibridize and select varieties starting from around 2500 biparental crossing. Germplasm bank includes 1000 clones of which 600 are local coming from Reunion Island. The selection programme lasts around 15 years to produce 1 variety, including selection and field testing. There is a very strong collaboration with CIRAD in this process, mainly for genetic and disease studies.
To improve breeding activities, 20 varieties from abroad countries are imported and tested, on the contrary from 5 to 10 varieties are exported (mainly to brasil) to be also tested. In other areas where eRcane is involved, mainly central Africa, they support technical course to develop a personal breeding programme instead of sending varieties because they experienced that the local variety is best performing that the imported one.
There is a specific department of eRcane working on cultivation of sugarcane that is divided in four pillars: weed control, fertilization, mechanization, networking. Weeds are the most important problems due to the tropical climate and they can represent a yield reduction of 40 % if are not controlled properly. Farmers usually use herbicides that are the only products registered on sugarcane, no pesticides are used. The herbicides rate per crop is very low respect to other crops, they use 3.4 doses of herbicides per year per crop. In the last few years farmers, with the aim of reducing chemicals, are adopting mechanical weeding, cover crops in the interrow (1.5 meters in sugarcane field), plant cover between cycles, mulching, intercropping. Considering the mulching technique, 12 t/ha of sugarcane straw are maintained to control weeds. They are also testing thermal weeding even if is too expensive to be used. Considering mechanization, the average of farm size is around 8 hectares, so they adopt micro-mechanization systems.

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During the meeting the BECOOL and BioVALUE projects were presented and the willingness to transfer knowledge to the European stakeholder of sugarcane sector. Activities and results of CREA in the framework of the project were also presented as well as the results obtained with the SUCRE project. After this description was presented the specific activity carried out from CREA in Brasil on sugarcane straw harvesting and the proposal of modifying the harvesting value chain in order to harmonize the collection of sugarcane straw to satisfy environmental, edaphic and energetic requirements. A specific visit was organised to the laboratories and experimental farm of eRcane. The final aim of their breeding activity is to maximize sugar content of the crop and reducing the energetic cost required to extract it. Side activities are to develop bioplastic materials from sugarcane biomass and to perform training activities for researchers (exchange of PhD students) and farmers. The experimental farm has a germplasm seed bank and cultivate varieties in order to maintain seeds. Furthermore, is present a complete value chain from seed to seed (seedling, pots, greenhouse, fields, thresher, fridge) for breeding activities.

Tereos Océan Indien is a subsidiary of the Tereos sugar cooperative group which work in the processing of beet, cane, wheat, corn, potato, cassava and alfalfa.
Tereos Océan Indien has more than 620 employees working in the cane-sugar-rum-energy sector.
Located in the north of Reunion Island, in Saint – André, the Bois-Rouge sugar refinery, built in 1817, is one of two active sugar factories on Reunion Island.
With a grinding capacity of 8,000 tonnes per day, the sugar refinery processes around 900,000 tonnes of cane for a production of 100,000 tonnes of sugar during the sugar season, from July to December.
120 permanent employees and 60 seasonal workers ensure the smooth running of the sugar factory and five sugar cane reception centers: Stella, Tamarins, Grand Pourpier, La Mare and Bois-Rouge.
The Bois-Rouge sugar refinery manufactures white, blond and red cane sugar intended for the local market and for export to the European market. It was in Bois-Rouge that the world's first bagasse-coal cogeneration thermal power station was built in 1992. During the sugar season, in exchange for the bagasse from the sugar refinery, the plant produces the steam and electricity that the plant needs, with excess production being sold to EDF. The falling flow technique, used in beet sugar factories, was adapted to cane sugar factories for the first time, in Reunion, by the teams from Bois-Rouge and Le Gol. The falling water body, consisting of a sixth vapor effect, saves energy. The installation of the pre-extractor upstream of the diffusion, a world first, has improved extraction performance. 70% of the sucrose is extracted before the passage of the cane for distribution. This investment significantly increased the processing capacity of the canes. The fluidized bed cooler for special brown sugars has increased drying capacity by around 20%. Lower cooling temperature and longer drying time give more homogeneous sugar which keeps better over time.
The sugar cane industry is a strategic activity for Reunion. It is a sure value: it represents the first export station of the island, it structures and protects 25,000 hectares of land and represents 18,300 direct, indirect and induced jobs.
3,000 producers deliver nearly 1,800,000 tonnes of cane for a production of 200,000 tonnes of sugar: the cane-sugar-rum-energy sector is one of the island's main economic activities.
It creates wealth and jobs: 18,300 direct and indirect and induced jobs, or 13% of commercial employment in Réunion. It represents between 40% and 60% of exports by value of products manufactured in Reunion Island and 80% of Reunion's exports by volume. Reunion has two factories on a European scale, the Gol and Bois-Rouge sugar factories.
The constant modernization of the Réunion industry has made it a technological showcase recognized throughout the cane sugar world. eRcane, the sector's research center, carries out cooperation and technical

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assistance missions in the sugar countries of the tropical belt. In the Indian Ocean, but also in Africa, Asia, the Pacific and the Caribbean, its expertise in varietal selection, the result of 75 years of practice, is regularly requested.
Sugar cane also produces electricity. For Reunion, it is a source of energy autonomy. In 1992, the commissioning of a mixed bagasse-coal thermal power station was a world first. Today, the two power plants, adjacent to the sugar factories, transform 540,000 tonnes of bagasse into energy, which avoids the importation and combustion of 138,000 tonnes of coal each year.
Now there is the need to substitute the coal, used form January to June, with other biomass sources: this is a strong strategic issue for the eRcane Research and Development center, that have to develop other source of biomass for feeding the plant.
Actually, the sugar mill can be considered a biorefinery as it already produces a mix of bio-products from sugar cane and its by-products:

- a food product: sugar
- electricity with bagasse
- fertilizer with scum
- alcohol with molasses.

New outlets, with high added value for the sector, corresponding to the valorization of "whole plant" cane are being studied.
In addition, cane provides products and co-products that are useful for other plant or animal productions.
Sugar cane covers more than 30 % of the island's fodder and litter needs; Sugar scum and bagasse ash are used in the composition of amendments or compost; Molasses is used as a feed supplement for livestock Finally, the cane fields recycle and recover large quantities of locally produced livestock manure.
The needs of sugar cane straw valorisation is a must as also other potential utilization of cane have to be explored. Cane is rich in many other molecules, which will offer it new outlets in perfumery, pharmacopoeia, industry and biochemistry.
The first bagasse/coal hybrid thermal power plant in France was established by Albioma in 1992 at the Bois-Rouge site. It was then the only one installation on the island able to convert bagasse, a fibrous residue from sugar cane, into electricity to supply the Réunion power grid. In 2020, the Group announced the conversion of the plant to 100% biomass. Located in the north of Réunion Island, the Bois-Rouge cogeneration plant has an installed capacity of 108 MW. It is adjacent to the Bois-Rouge sugar refinery which, during the sugar harvests, feeds it with the bagasse needed for its activity. The Bois-Rouge plant processed bagasse and green pulp into low pressure steam and electricity. Faithful to the cogeneration principle, part of this energy return to the neighbouring sugar refinery, whilst the rest is sent to the Réunion grid. In 2020, this part was 530 GWh. Albioma announced on 8 December 2020 the complete discontinuation of coal at its historic Bois-Rouge plant on Reunion Island, following the deliberation by the Energy Regulatory Commission (CRE). The latter validated on 3 December 2020 the offsetting resulting from the signature of an amendment to the power purchase agreement signed by EDF for the conversion of the Albioma Bois-Rouge power generation facility to biomass. Conversion work already has started so that the plant can be 100 % biomass-powered in the second half of 2023, with priority given to the local biomass deposits available (straw, bagasse, forest wood, pruning wood, etc.), supplemented by imported wood pellets from FSC and PEFC-certified forests, the traceability procedure of which will be compliant with the EU Wood Regulation (RBUE).

Supplying plants with bagasse in return for a supply of steam and electricity for sugar mills is a sustainable model that gives these refiners a decisive competitive edge. Similarly, the energy efficiency of Albioma's plants

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enables us to sell the power we produce to electricity distributors, helping them cope with increasing consumption.
In France and Mauritius, during the sugar campaign which lasts between four and six months, the plants operate as cogeneration units, with bagasse as the main fuel. Between harvesting campaigns, they operate using a condensing process in the same way as conventional power plants, using coal. It can be used in a hybrid-combustion configuration to supply energy all year round at a competitive cost while complying with European and French atmospheric emissions standards
In Brazil, the duration of sugar campaigns (nine or ten months) and the quantity of sugar cane processed by sugar mills enables the Group's cogeneration facilities to operate using bagasse all year round (i.e.: 11 months out of 12, with the remaining month set aside for annual maintenance).
Thus, the knowledge developed in Brasil in the framework of Becool Project is extremely important in order to let the European stakeholder committed to evaluate which local biomass can contribute to the feeding of the power plant totally with woody material; The need to tranfer the data obtained in Brasil on straw removal and recovery and in particularly:
REMOVAL: identify how much straw are in the cane fields, what are the impacts of straw mulch on the soil health and sugarcane yields and what is the minimum amount of straw that must remain on the ground to maintain soil health and sugarcane yields.
RECOVERY: which is the best technology for straw to be recovered, transported, stored, processed and burned in the bagasse boilers? This issue include mass, energy and GHG emissions balances, economic evaluations and straw quality parameters especially the ash content (mineral impurities plus biomass constituent ashes) along the value chain.
A specific meeting with research sector was organized with Dr Pierre Todoroff and Dr Francois Broust of CIRAD. CIRAD is the French agricultural research and cooperation organization working for the sustainable development of tropical and Mediterranean regions. CIRAD works with its partners to build knowledge and solutions and invent resilient farming systems for a more sustainable, inclusive world. It mobilizes science, innovation and training in order to achieve the Sustainable Development Goals. Its expertise supports the entire range of stakeholders, from producers to public policymakers, to foster biodiversity protection, agroecological transitions, food system sustainability, health (of plants, animals and ecosystems), sustainable development of rural territories, and their resilience to climate change. CIRAD was founded in 1984 as a public establishment (EPIC), following a merger of French tropical agricultural research organizations, and is under the joint authority of the Ministry of Higher Education, Research and Innovation and the Ministry for Europe and Foreign Affairs. As such, it supports French science diplomacy operations. CIRAD works in some fifty countries on every continent, thanks to the expertise of its 1650 staff members, including 1140 scientists, backed by a global network of some 200 partners. CIRAD's expertise encompasses the following fields: production and productivity within the context of the agroecological transition; crop protection; genetic improvement; food and non-food product processing; sustainable sourcing; adapting value chains to climate change; multi-criteria performance assessment (LCA - life cycle assessment); building markets and standards that reward sustainable production and social responsibility within value chains; and academic and technical training for value chain stakeholders. There is a specific regional office in Reunion dedicated on sugarcane crop.

Dr Francois Broust presented the situation of the sugar factories and power plants at La Reunion. There are two sugar factories with the adjacent power plants.

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Bois-Rouge power plant is located in the north of Réunion Island, the cogeneration plant has an installed capacity of 108 MW, compared to 60 MW when it first opened in 1992. It is adjacent to the Bois-Rouge sugar refinery which, during the sugar harvests, feeds it with the bagasse needed for its activity.
The Bois-Rouge plant processed bagasse and green pulp into low pressure steam and electricity. Faithful to the cogeneration principle, part of this energy return to the neighbouring sugar refinery, whilst the rest is sent to the Réunion grid. In 2020, this part was 530 GWh. Albioma, owner of the power plant, announced on 8 December 2020 the complete discontinuation of coal at its historic Bois-Rouge plant on Reunion Island, following the deliberation by the Energy Regulatory Commission (CRE).
Le Gol, located near Saint-Louis, is the second thermal biomass power plant built by Albioma on Reunion Island, after the Bois-Rouge facility. It was commissioned in 1995 and has an installed capacity of 122 MW.
In 2020, the Le Gol cogeneration plant generated 713 GWh of electricity as well as producing low-pressure steam. Some 272,000 tonnes of bagasse from the island's sugar cane plantations were used as fuel. The share of locally-sourced biomass is set to increase further in coming years, as Albioma intends to convert the plant to operate exclusively using biomass by 2023. Outside sugar harvests, the Group is seeking to replace coal with other locally-available sources of biomass. Several potential solutions are currently being studied, including using shredded green waste or establishing a forestry biomass industry in conjunction with the Regional Authority and the national forestry office (ONF).
Currently the power plants are fed by bagasse during the harvesting seasons of sugarcane and by coal in the remaining months. Considering the new regulations, they have the need of finding new source of biomass and sugarcane straw resulted of great interest.
After the CIRAD presentation, Dr Simone Bergonzoli from CREA, online connected, presented the BECOOL and BioVALUE projects, and the willingness to transfer knowledge to the European stakeholder of sugarcane sector. Activities and results of CREA in the framework of the project were also presented as well as the results obtained with the SUCRE project.
Dr Todoroff presented the specific situation of sugarcane production of Reunion. Farm size is very low, as well as the level of mechanization mainly for the harvesting phase. The sector is highly subsidised to maintain the production. The interest of the local government for sugarcane sector is due to the level of job offered, to environmental, traditional, and touristic reason. Furthermore, the two sugar mills could works if the quantity of biomass reach a certain quantity and they operate efficiently, if the production of sugarcane were to decrease maybe one sugar factory could stop the activity with strong impacts on the island.
Moreover, Dr Todoroff presented his own research activity that is based mainly on modelling and remote sensing of sugar cane. The aim is using these two techniques to forecast yield, stress, water need and other crop requirements. Particular attention of the resource groups is given to the weeds control, minimizing the use of chemicals.
The technical visit and the meetings with the various EU stakeholders engaged in the production of sugar and energy from sugar cane allowed to highlight the extreme importance of transferring the knowledge matured in Brazil within the Becool / Biovalue Projects, especially as regards the possibility of exploiting the straw resource for the production of electricity to replace coal.
The issues addressed are different and needs further meetings.
In addition, the visits to the field showed a low incidence of mechanized harvesting around 25 % of the total, due to the difficulty of adapting the large and heavy sugar cane harvesters developed to operate in flat and large-sized soils to the particular operating environment. CREA, having worked on the subject in the past, will help to identify the best existing mechanical solution, a machine that can operate even on steep slopes, in the presence of stones, with cane that can be logged, providing for the separation of the stem from the straw.

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Another point of extreme interest is the fight against weeds on sugar cane, in light of the recent European restrictions in the use of herbicides. CREA believes that lawn tractors with a 90 cm track can conveniently operate in the inter-row for cutting weeds and will provide the list of European companies that build these mini tractors (to operate in terraces) to find a possible solution to the exposed problem.

Considering the result of CREA activities in the framework of Becool project, the results of the experimental activity allowed to define the value chain for biomass collection for each crop tested. These results will foster the adoption of such techniques and the valorization of these still untapped biomass for energetic purposes. Crop studied are very spread in Europe so the results could be capitalised very easily in all European countries. Furthermore, the activities on crop by-products are of extreme interest for the current context because do not cause ILUC effect differently from energy crops cultivation.

Results were divulgated through the following scientific publications:

1) Palmieri, N., Suardi, A., Latterini, F., & Pari, L. (2020). THE EUCALYPTUS FIREWOOD: UNDERSTANDING CONSUMERS' BEHAVIOUR AND MOTIVATIONS. Agriculture, 10(11), 512.

2) Pari, L., Rezaie, N., Suardi, A., Cetera, P., Scarfone, A., & Bergonzoli, S. (2020). MEDIUM ROTATION EUCALYPTUS PLANT: A COMPARISON OF STORAGE SYSTEMS. Energies, 13(11), 2915.

3) Pari, L., Bergonzoli, S., Cetera, P., Mattei, P., Alfano, V., Rezaei, N., ... & Scarfone, A. (2020). STORAGE OF FINE WOODCHIPS FROM A MEDIUM ROTATION COPPICE EUCALYPTUS PLANTATION IN CENTRAL ITALY. Energies, 13(9), 2355.

4) Palmieri, N., Suardi, A., & Pari, L. (2020). ITALIAN CONSUMERS' WILLINGNESS TO PAY FOR EUCALYPTUS FIREWOOD. Sustainability, 12(7), 2629.

5) Pari, L., Bergonzoli, S., Suardi, A., Alfano, V., Scarfone, A., & Lazar, S. (2018, May). MAIZE COB HARVESTING: FIRST ASSESSMENT OF AN INNOVATIVE SYSTEM. In 26 th European Biomass Conference and Exhibition.

6) Pari, L., Bergonzoli, S., Leal, M. R. L. V., & Neves, J. L. M. INNOVATIVE SOLUTION FOR SUGARCANE STRAW RECOVERY. In 27th European Biomass Conference and Exhibition.

7) Luigi Pari, Simone Bergonzoli* Alessandro Suardi, Vincenzo Alfano, Nadia Palmieri, Walter Stefanoni, Paolo Mattei. COLLECTION OF CROP BY-PRODUCT: EXPERIENCE ON WHEAT CHAFF. In 28th European Biomass Conference and Exhibition.

8) Luigi Pari, Simone Bergonzoli*, Alessandro Suardi, Vincenzo Alfano, Nadia Palmieri, Walter Stefanoni, Paolo Mattei EUCALYPTUS STORAGE PERFORMANCE AFTER DEBRANCHING In 28th European Biomass Conference and Exhibition.

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7 Conclusions

The last European directive on the promotion of the use of energy from renewable sources bind European countries to find new sources of feedstock for bioenergy. The biomass studied appeared very promising and even is some bottlenecks still exist on them value chain, these feedstocks can apparently be appropriate substitutes for the traditional energy production systems.

The activity performed by CREA-IT inside the WP 1 shown as the optimal organisation of the value chain, strictly depends on the harvesting and storage of the biomass. The harvesting test carried out on wheat chaff, maize cob, olive pruning and on the storage of eucalyptus and giant reed were crucial to better understand the critical points of the value chain and fill the existent gaps.

The proper functioning of the Thievin and Racca systems and the quantity and quality of the wheat chaff and maize cob, also considering the availability of these products in EU, makes these untapped materials an attractive biomass resource that can be used for many purposes. Results conducted on Racca technology are even more interesting considering the possibility of using the same system to collect two different biomasses.

The results of olive pruning test demonstrated that the fuel consumption is essentially linked to the chopping phase and that harvesting in the hills does not seem to excessively influence the fuel consumption of the tractor-shredding.

The storage test of eucalyptus highlighted the importance of choosing the right period to store the biomass to limit dry matter losses and reduce the moisture content. However, the different type of storage of this biomass resulted very effective confirming that this feedstock could be used for many purposes such as firewood, chip and logs.

The fiber sorghum value chain studied, demonstrated that the development of the harvesting system fosters the following development of the entire supply chain. In fact, this is an example of the involvement of all the stakeholders from farmers to the energy plant manager. This synergy allowed to overcome problems related to the requirements of each step of the value chain and to define a strategy to cultivate, harvest, transport and store the biomass to be converted in energy in a more efficient way.

The storage test of giant reed caused a reduction of almost 50 % of the bulk density. The storage test highlighted as it was possible to reach a moisture content suitable for energy production processes in 7 months using a covering textile and to sharply reduce the bulk density. The covered treatment allows to reduce the dry matter losses that usually affects the storage of comminuted biomass.

The results of the research on sugarcane straw highlighted the complexity of the biomass harvesting. Different aspects are involved in the task: the environmental aspects of soil fertility and compaction, the quality of the biomass and the storage of the biomass. The two straw harvesting systems proposed tackle the problem providing a solution at the present bottlenecks.

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