A guide for

Agroindustrial residues to energy

Promoting the penetration of agrobiomass in European rural areas

2022

AgroBioHeat

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ABOUT THIS DOCUMENT

The publication "Agro-industrial residues to Energy", made by the Spanish Bioenergy Association (AVEBIOM) and Centre for Research and Technology Hellas (CERTH), is part of a series of authoritative guides prepared within the framework of the AgroBioHeat project that aim to provide a systematic knowledge about the utilization of different types of agrobiomass resources.

In particular, it focuses on several biomass assortments generated as production residues of agro-industries that process agricultural products. Assortments such as olive stones, olive cake, dry nut shells, sunflower husks and other have a quite high calorific value and sufficiently low costs so as to be very attractive fuels for a wide range of bioenergy applications, from domestic heating all the way to large, industrial heat or power generation.

The AgroBioHeat project aims to produce a mass deployment of improved and market ready agrobiomass heating solutions in Europe. Agrobiomass is a large, underexploited and indigenous resource, which can support the achievement of the European Energy and Climate targets, while promoting rural development and circular economy. The project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 818369.

For more information about the project, please visit:

www.agrobioheat.eu

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ABBREVIATIONS

Abbreviation	Explanation
a.r.	As received
CHP	Combined Heat and Power
CTN	Normalisation Technical committee
d.b.	Dry basis
EU	Europe Union
FAO	Food and Agriculture Organization of the United Nations
H2020	Horizon 2020 funding program
ha	Hectare
ICNF	Institute for the Conservation of Nature and Forests (Portugal)
kWe	Electric kilowatts
kWh	Kilowatt hour
Mha	Million Hectares
MITECO	Ecological Transition Ministry of Spain
mm	millimetres
MW	Megawatts
MWt	Thermal megawatts
NCV	Net Calorific Value
PM	Particulate matter
RD	Royal Decree
SGC	Spent coffee grounds
t	ton
UNE	Spanish Normalisation Association
UNI	Italian Normalisation Association

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Introduction: agro-industrial residues

The agro-industrial solid biofuels are obtained as a residue of the different processing of agriculture products in an agro-industry (vegetable oil industries, dry nut processing facilities, and others). Despite some local use in old traditional appliances, many of them were considered an environmental problem not so many years ago because huge quantities were accumulated without a proper treatment or destination. For example, until 20 – 30 years ago olive cake was accumulated in ponds that leached to the aquifers and, besides some local use in traditional stoves, there was no other use. Others like almonds shells were also used locally in traditional stoves but the quantities that a nut processing facility can produce in a very narrow time window can be overwhelming for such uses.

Different agro-industries produce a variety of residues and almost all of them can be exploited for the production of bioenergy or other applications. However, when it comes to the use of residues as solid biofuels there are certain variables that narrow this assortment to a specific few:

Moisture content: many agro-industrial residues have a high moisture content (bagasses, peels, etc.). Although it is possible to combust such fractions in specialized installations, it is more frequent to use them as feedstocks for the production of biogas, for the production of biochar or for animal feeding. Biomass assortments like husks, shells, pits or others that have a relatively low moisture content after a drying process can be more easily valorised as solid biofuels. Moreover, their low moisture content increases their energy density, which eases the storage and transportation.

Quantities: one of the main advantages of agro-industrial solid biofuels is that the quantities produced are large. But this factor is affecting in two levels:

Macro level (i.e. country, region). The residues most used nowadays have developed markets because there was a huge production concentrated in a region. For example, olive stones are very commonly used for bioenergy in Spain because the olive oil production is massive and, obviously, sooner or later a solution had to be found for the residues of its production. But there are some other countries with small productions of olive oil but the olive stones market is still not at all developed. In these regions or countries with a massive production, some years ago it was a problem but now with an appropriate valorisation and technology (adapted devices), now is an economic renewable energy source.

Facilities level. It is important that the facility produces a certain level of quantities of the by-product. If the quantities are low it is difficult that, the facility invest in modifications or improvements to valorise the residue or by product and, in the other hand, it's difficult to trigger the consumption near as sometimes, a modification is needed in order to consume it and therefore is complicated that consumers invest for a small quantity.

No other uses: usually, if a residue is used as solid biofuel it is because there is no other use possible or, at least, the alternative use is not capable of absorbing all the quantities produced. For example, many residues have a low protein content and nutritional value and therefore are not relevant for their use as animal feed. Olive stones can be used by the cosmetics industry to produce scrubbing / exfoliating creams, but this is a niche market, using extremely small markets shares of that residue. If an alternative, non-energy market exists or develops, then producers of these residues can fetch higher prices and will prioritize them over the energetic uses.

Europe has a significant potential of agro-industrial residues that can be used as solid biofuels due to its diversity in crops and agro-industries that process them. Countries like Spain, Italy and Greece with olive oil, Russia and Ukraine with sunflower oil, and Turkey with dry nuts are world leaders in the production of these crops and consequently in their respective processing residues.

Depending on the processes from which they are generated, the resulting solid biofuels have different qualities. Residues which only underwent a physical treatment (separation in most of the cases) have a good quality as solid biofuel and they are suitable even for domestic use in small boilers or even stoves. This is the case for olive stones, dry nut shells, peach pits, etc. with only need to adjust moisture (or just protect from rain) and modify particle size in some cases to homogenize them (remove fines, break large particles, etc.). Biomasses coming from oil extraction processes (olive cake, grape pit powder) that have suffered a chemical extraction with hexane and that are primarily composed of the exhausted flesh of the fruit, usually have more ash and other characteristics (e.g. chlorine) that do not make them suitable for smaller combustion systems; industrial applications are therefore preferred.

Some of the agro-industrial residues already have a quite well developed market, either for industrial or domestic appliances for bioenergy purposes; this is the case for olive cake and olive stones in Spain. For other residues or other countries, the situation is not the same. The goal of this Guide is to share part of the knowledge and state-of-the-art in the valorisation of these residues, based on the experiences of the countries with more advances markets and of specific, exemplary cases.

The potential as shown in this guide is large and agro-industrial solid biofuels could support in an energy transition and assist the European Union in achieving the objectives of decarbonisation for 2030 and 2050 in a cost-effective way. However, it is essential to use them with the appropriate, modern technologies, adapted to the fuel peculiarities, in order to avoid malfunctioning or excessive emissions.

Residues, by-products or wastes?

In common parlance, markets and occasionally in scientific literature, terms such as "residues", "wastes" or "by-products" are often used interchangeably to describe biomass assortments that are generated by agro-industries. The issue is that – at least in the European legal context, as defined by the Waste Framework Directive – these terms have different implications.

A **product** is a material that is deliberately created in a production process.

A **production residue** is a material that is not deliberately produced in a production process. It may be or it may not be a waste.

A **waste** is any substance or object which the holder discards or intends or is required to discard. The holder of waste has to fulfil specific legal obligations.

A **by-product** is a production residue that is not considered as a waste provided that the following conditions are met:

a. further use of the substance or object is certain;
b. the substance or object can be used directly without any further processing other than normal industrial practice;
c. the substance or object is produced as an integral part of a production process; and
d. further use is lawful, i.e. the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts.

The definition of criteria for the characterization of a production residue as a "by-product" can be done either at the European level (through implementing acts of the European Commission) or at the Member State level (following a notification procedure).

The legal status of agro-industries residues is often complicated by the absence of such acts either on the EU level or on the Member State level. At the time of writing, there is an ongoing process in Spain to characterize olive pomace as a "by-product"[1] , but binding, national legal acts are not yet in force.

The authors of this Guide consider that the biomass assortments covered therein generally fulfil the criteria for the characterization as "by-products", at least in the Member States where their production is concentrated. However and in order to avoid misunderstandings, the more neutral term "residue" is employed throughout the Guide.

1 END OF TERM 30th-11-2020. Draft Ministerial Order determining when olive pomace from oil mills an destined for the extraction of olive pomace oil are considered by-products, in accordance with Law 22/2011 of 28th July regarding Waste and Contaminated soil". www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/participacion-publica/PP-Residuos-2020-Proyecto-Orden-determina-cuando-orujos-grasos-extraccion-aceite-orujo-subproductos.aspx

Olive stones

DESCRIPTION

Olive stones are a solid biomass residue coming from the olives used in the olive oil production. This assortment is composed by the endocarp (“stone” or “bone”) of the olive. Olive stone is found in crushed pieces, since olives are grinded previously in order to improve the olive oil extraction process through physical methods. The flesh and skin of the olive fruits together with the stones comprise what is known as the “olive pomace”. Therefore, olive stones are generated as a separate fraction by olive mills which integrate a physical process to separate the olive stone from the olive pomace, typically followed with a drying stage to reduce their moisture content.

In addition, olive stones can also be obtained at the olive pomace oil extraction industries. In such cases, the olive stone usually is obtained from the olive pomace prior to the chemical extraction of the olive pomace oil so olive stones are not mixed with chemicals and their quality is better. In Spain, it is now a common practise to separate the olive stone pieces previous to the chemical oil extraction, therefore the content of olive stones contained in the olive cake are lowering in the last years with consequences in the mass balance and quality of the olive cake. In Greece, the separation of the olive stones from the olive pomace is still not a widespread practice.

Alternatively, in some cases, olive stone can be obtained from the exhausted olive pomace (olive cake) after the chemical extraction. This separation consist of a physical separation process; it is not needed anymore to perform additional drying of the olive stone, since they are already have a low moisture content. A summary of the operations from where olive stone can be obtained in the olive oil and olive pomace oil industry is presented in **Figure 10**.

Moisture content of the olive stone, obtained either at the olive mill or at the olive pomace extractor facilities, is quite high - around 22-25 % weight. Additionally, there is a limited capacity in the separation of all the endocarp from the olive cake, and thus, the smaller fractions remains in the cake.

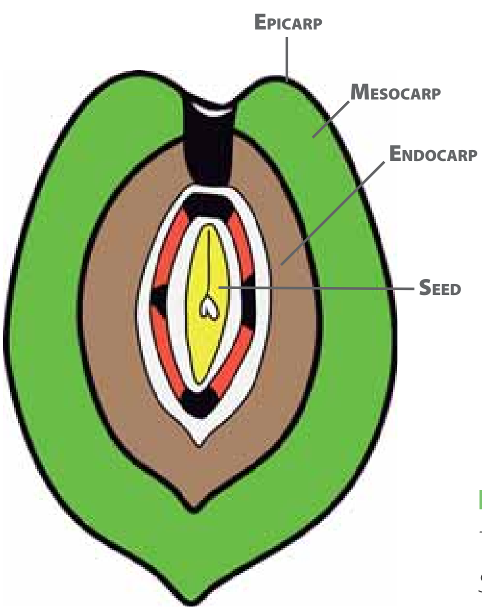


Figure 1
The parts of an olive fruit.
Source: AVEBIOM

Figure 2
Clean and dried valorised olive stones. Source: AVEBIOM

Olive oil extraction can be performed with different processes, though most extended in Europe are the two- and the three-phase olive oil centrifugation processes. The two-phase process is considered the more modern and efficient one and now has the largest market share. The mass balance of a two-phase process is presented in **Figure 3**; as observed each tonne of olives leads to about 8.3 % of olive stones (in weight as received, respect the weight of olives processed); the actual yield may vary depending on the olive variety and the technical configurations of the processes.

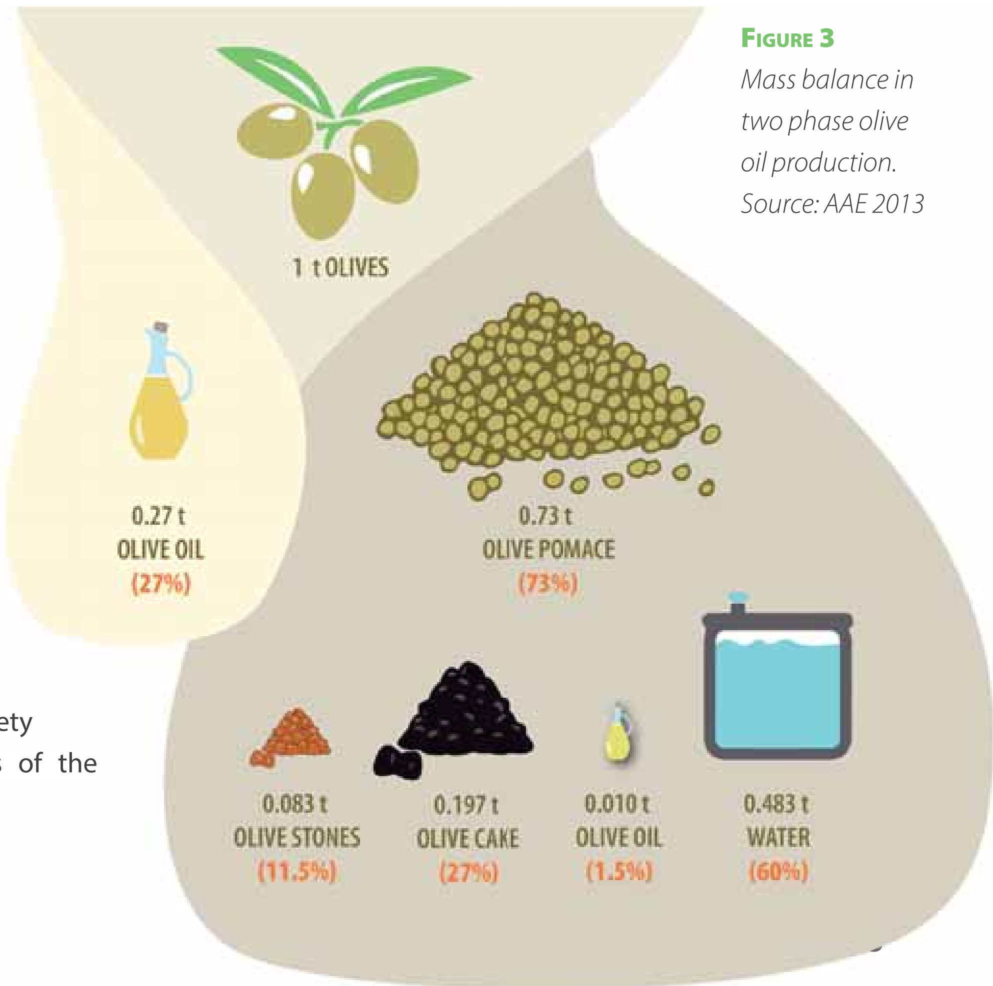


Figure 3
Mass balance in two phase olive oil production. Source: AAE 2013

POTENTIALS AND DISTRIBUTION IN EUROPE

The availability of the olive stones is linked to the olive oil production cultivation, and therefore its availability in Europe is principally at Mediterranean countries. The total surface dedicated to the olive cultivation as per FAO data (http://faostat.fao.org) is around 10.5 Mha (2019).

Spain is first world olive oil producer, and correspondingly, the world largest producer of olive stones. In Spain olive cultivation extends in 2.6 Mha (2019). Second largest cultivated area is found in Tunisia occupying about 1.6 Mha (2019). However, is remarkable that in Spain the average yield of olive is 5 times larger than in Tunisia (2.8 t/ha vs 0.5 t/ha). The European production of olive oil represents more than 70 % of the world production.

Other European countries with important productions of olive oil are Italy, Portugal and Greece. Other non-EU countries producing olive oil are found principally in the Mediterranean basin: Tunisia, Turkey, Morocco, Egypt, Algeria, or Syria, for example.

Olives production are subjected to strong variations yearly due to the meteorological conditions, as much of the land is cultivated without irrigation, and in climates with annual variations in the rainfall regime. Furthermore, the alternate bearing character of olive tree species, further impacts the yields of olive production, and subsequently, impacts on the olive oil production and olive stone availability.

OLIVE STONES PRODUCTION ESTIMATION SHARE BY COUNTRY *(average 2010- 2019)*

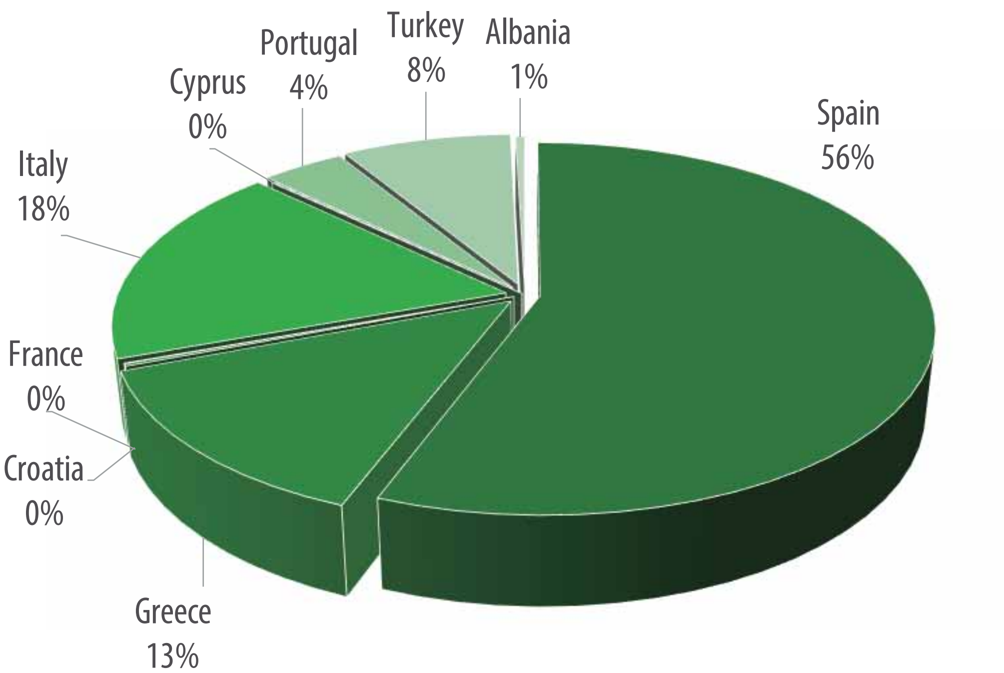


Figure 4

Distribution of theoretical olive stone potential in the EU + Turkey + Albania (2019). Source: AVEBIOM elaboration with FAOstat data

Figure 4 and **Figure 5** present an estimation of the olive stone quantities produced in Europe. The estimation is based on the annual production of olive for olive oil production. The quantities present a theoretical potential, as the real availability depends upon: a) the actual amount of olive cake processed to separate the olive stone; b) the efficiency of such systems (it must be noted, if inefficient separation systems are deployed at the olive mill or at the extractor facilities, a not negligible part of the olive stone will remain unseparated into the olive cake). Correspondingly an estimation of the available olive stone found per country or area should base on the actual management of olive cake under practice.

In terms of the prospective of olive stone potentials, it is expected a growth in its availability for the market given two principal reasons: 1) the practice of olive stone separation from the olive cake (before the chemical extraction of the oil at the extractors facilities) is being extended more and more; accordingly olive cake contains less stones; and 2) the area of olive groves is expanding, modernizing and providing irrigation systems, so production tends to increase.

OLIVE STONES PRODUCTION ESTIMATION SHARE BY COUNTRY *(average 2010- 2019)*

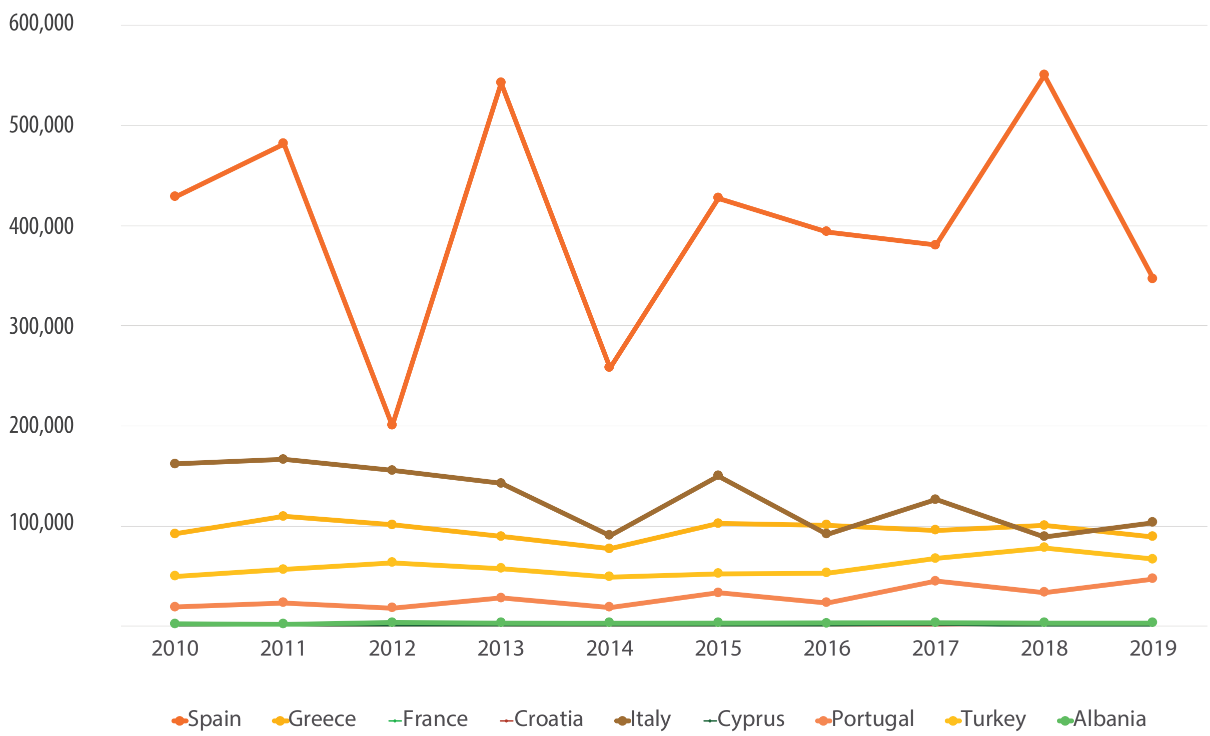


Figure 5

Annual theoretical potential of olive stones (in tons) per country.
Source: AVEBIOM elaboration with FAOstat data

CHARACTERISTICS: WHERE AND HOW IS IT UTILIZED?

Olives are crushed in the oil extraction mills for improving the efficiency of the process and consequently stones are crushed too. The format is granular with sizes between 2 – 4 mm approximately. Coming from the standarisation works of Biomasud (SUDOE – Interreg) and Biomasud Plus (H2020) project, there is a quality standard in Spain UNE 164003:2014 establishing main physical and chemical characteristics as solid biofuel. This standard is being updated by the Spanish committee (CTN-164) with some slight changes in the thresholds and is expected to be approved by the beginning of 2022. Also, it in the process to be replicated with minor differences by the analogue committee in Italy (the standard will be named UNI 1609270).

When separated, the olive stones have a 20 – 22 % moisture content and have quite high content of fines which worsen the quality as biofuel. A valorisation process can be implemented which basically consists of two steps: reducing the moisture and removing the fines by sieving. The process can be easily integrated in the facilities of either olive mills or the olive pomace extractors, or alternatively, in separate facilities of third companies.

Olive stones have a low ash content and therefore can be used in all kind of devices from the smallest (stoves and domestic individual boilers) up to industrial boilers. Nowadays, the use of olive stones without any valorisation (drying and cleaning of fines) is still very common (i.e. around 70-80 % in Spain).

PARAMETER	QUALITY CLASS			UNIT
	A1	A2	B	
Moisture	≤ 12	≤ 12	≤ 16	w-% a.r.
Ash	≤ 0.7	≤ 1.0*	≤ 1.3*	w-% d.b
Oil content	≤ 0.6	≤ 1.0	≤ 1.5	w-% d.b.
Fines (F<2mm)	< 15	< 15	< 25	w-% a.r.
Net Calorific Value	≥ 15.7	≥ 15.7	≥ 14.9	MJ/kg (a.r.)
Nitrogen	≤ 0.3	≤ 0.4	≤ 0.6	w-% d.b.
Sulphur	≤ 0.03	≤ 0.04	≤ 0.05	w-% d.b.
Chlorine	≤ 0.03	≤ 0.04	≤ 0.05	w-% d.b.

Table 1
Limits of the main parameters for olive stones as per BIOmasud® certification system

**Ash content values of the Spanish standard (UNE 164003) were being updated by the committee CTN-164 in the beginning of 2022 and the value will be set 1,2% for A2 and 2,0 for B. Italian Standard (UNI 1609270) will be also published by the first half of 2022 and the values will be most probably the same 1,2% for A2 and 2.0% for B*

In these conditions, most of the olive stones are consumed in industrial facilities which, if equipped with advanced combustion and gas cleaning technologies, can utilise the olive stone without combustion problems or environmental impacts. Issues arise when this is not the case, for example when using un-valorised (uncleaned) olive stones are used in obsolete stoves or boilers in towns or cities, generating emissions, smoke and smell problems, something that is incompatible with air quality.

When valorised, olive stones are a very high quality solid biofuel with characteristics very close to good quality wood pellets and therefore are suitable to be used in the domestic and tertiary sector. In the **Table 1**, main specifications of the valorised olive stones (as per BIOmasud® certification system) can be found.

Already, several biomass boiler manufactures are producing boiler models that are adapted to this fuel, achieving excellent results of efficiency and air emission limits. Additionally, many wood pellets devices can use olive stones too with few adaptations required given the different size of wood pellets and crushed olive stones (feeding system, burn pot, grate, air regulations to be adapted).

Like other agrobiomass assortments, olive stones are not out of scope of the Commission Regulation 2015/1189 setting Ecodesign requirements for solid fuel boilers. Within the AgroBioHeat project, the combustion performance of olive stones – along with several other agrobiomass fuel assortments – has been investigated in a series of tests. The tests were performed under laboratory conditions, using state-of-the-art biomass boilers and a common test procedure following the boiler testing standard EN 303-5.

In particular, olive stones were combusted in a 49 kW boiler that employs moving grate firing technology, coupled with an ESP system for control of the particle emissions. The seasonal emissions of CO, OGC, NOx and PMs were found to be below the limits of Ecodesign Regulation for woody biomass fuels. This highlights how such a biomass assortment can be used in a modern boiler system, achieving emissions equivalent with woody biomass.

For more information:

Brunner, T., Nowak, P., Mandl, C., Obernberger, I. (2021) Assessment of Agrobiomass Combustion in State-of-the-Art Residential Boilers. Proceedings of the 29th European Biomass Conference and Exhibition, pages 379 – 388. DOI: 10.5071/29thEUBCE2021-2AO.5.1. Available for download following registration from the following website: http://www.etaflorence.it/proceedings/

FIGURE 6

Olive stones. Source: AVEBIOM

CASE EXAMPLES

OLIVE STONES FOR HEATING A SCHOOL IN GRANADA

The Secondary Education Center CES Santiago Ramón is an educational facility that includes Secondary Obligatory Education, Baccalaureate, and various Professional Training degrees, located in the western part of the city of Granada in Spain. It is very close to one of the main entrances to the city centre and to the Fuentenueva university campus, where most of the science and engineering degrees of the University of Granada are located.

The biomass installation of the CES Ramón y Cajal de Granada was carried out in 2018. It is part of an energy rehabilitation project with support from the IDAE (Institute for the Energy Diversification and Saving), within the PAREER-CRECE program[1].

The building of CES Ramón y Cajal was 1983, with a constructed area of 7,602 m^2. At the time of the energy upgrading, the energy rating it had was C. Before the installation of the biomass boiler, a heating oil boiler was used with a nominal power of 476 kW and a seasonal efficiency of 52 %. The heating oil consumption of approximately 13,767 liters *per year*.

The new biomass installation has a multi-fuel boiler of the ITB brand, model INV-9245050, with a power of 450 kW, accompanied by a buffer tank of 4,000 liters (a slightly lower power could be installed due to the improvement of windows and control of the air conditioning system, all framed within the energy improvement project), with a seasonal efficiency of 82.80 %. The system is fed from a vertical silo of 38 cubic meters, which is masked in a way that does not affect the aesthetics of the building. This system is also connected to IDAE's PRETEL remote monitoring system.

The fuel switch from heating oil to biomass resulted in annual fuel cost savings of more than 48 % (2019 prices). With current prices, and given the stability of olive stones, which is the fuel that is mostly used, the cost savings would be greater. In additional, the phase-out of heating oil reduced the CO_2 emissions by more than 180 tons *per year*.

Figure 7 and 8

(left) CES Ramón y Cajal and (right) boiler's room with main elements of the instalation. Source: Intecbio S.L.

1 *PAREER CRECE is a support program for the energy rehabilitation of existing buildings funded with ERDF funds, More info: https://www.idae.es/ayudas-y-financiacion/para-rehabilitacion-de-edificios-programa-pareer/programa-de-ayudas-para-la*

FIRST HOTEL IN JAÉN, SPAIN, USING OLIVE STONES AS FUEL

Already in 2006, Hotel Spa Sierra de Cazorla located in La Iruela, Jaén, Spain decided to go away from fossil energies and became one of the first energy sustainable hotels in Spain and the first using as fuel olive stones. Although nowadays it may be seen as a logical solution since the region of Jaén is a world leader in the production of olive oil – and hence derived residues – until that time olive stones were only used in traditional and obsolete appliances. Using olive stones in a modern boiler was a challenge as there were no standard and conditions between suppliers were sometimes different and therefore. After many years of successful operation, it is possible to say that this experience has passed the test of time and can be considered as a good example.

The facility has a total capacity of 800 kW, featuring two HERZ Biomatic boilers of 400 kW and was carried out by its Spanish partner Termosun Energías S.L. These boilers, even though they have 15 years of operating life, they still achieve efficiencies of more than 95 %. They have a "multiple process unit" for automatic control of the heat, flue gas cleaning and particles control and also they modulate the heat. Likewise, the boilers feature automatic safety controls against fires and automatic ash collection. The olive stones are fed from two silos, each with a capacity of 45 t. The heat produced by the boiler is used for hot sanitary water, space heating, the spa and the gym. On winter days, when the boilers operate at full power around 1,300 kg of olive stoner per day are consumed, while the average annual daily consumption is around 730 kg of olive stones (working eleven months of the year primarily for the spa and the hot water generation).

Figure 9
Hotel Spa Sierra de Cazorla.
Source: Termosun Energías S.L

KEYS FOR UTILISATION OF OLIVE STONES

Utilisation of olive stone for heating in small and medium scale heating applications is feasible. For assuring an efficient and environmental performance, some keys are:

VALORISATION. To have high quality olive stones is crucial step to improve fuel quality. Valorisation process include operations of drying and removal of fines. With this valorisation process a good quality solid biofuel is obtained suitable even for smallest domestic devices.

The utilisation of olive stones does not entail problems regarding fuel handling and fuel feeding. However, considering the **SMALL FUEL PARTICLE SIZE** of crushed olive stones compared to e.g. pellets, a specifically designed grate is needed in order to prevent the fuel slipping through the grate openings directly into the ash box.

INDEPENDENT CERTIFICATION of the quality by third parties with a scheme such as BIOmasud® is more and more necessary.

Good quality valorised olive stones assures more constant and appropriate fuel properties, inside the standards range, and therefore better performance at stoves and boilers already tuned and optimised for these fuel standard.

Certified olive stone provides trust. On the one side, to the customers, who rely more on the fuel and supplier. On the other hand, to policy makers and authorities, who understand a certified fuel as a proof for good boiler operation, and therefore, low air emissions, and compatibility with air quality. In that sense, more and more public tenders are requiring or give additional points to certified biomass or even subordinating the procurement of funding and grants to the fuel certification (i.e. the Spanish law RD 477)

The **BURNOUT TIME OF THE GRATE** (in case of moving grates with continuous de-ashing) or the grate cleaning intervals (in case of discontinuous grate cleaning) have to be adjusted to the charcoal burnout time of the olive stones in order to achieve a high carbon conversion and, consequently, a low carbon content of the grate ash.[1]

1 Source: Biomasud Plus project deliverable 5.5 "Guidelines for assessment of appropriate performance conditions of small domestic heating appliances with relevant Mediterranean solid biofuels"

Olive cake *'exhaust olive pomace'*

DESCRIPTION

Olive cake (also called exhausted olive pomace) is a residue produced from the olive pomace obtained in the olive mills after the olive oil extraction process. Olive pomace is composed by the remaining endocarp (stone - bone), mesocarp (pulp) and epicarp (peeling) of the olive after the physical extraction of the oil.

Olive pomace retains a not insignificant amount of residual oil that can be obtained through additional processing. In some countries, a second physical extraction named "repaso" (repass/reprocess) is employed to reduce the residual oil content from 6 – 7 % to 1.5 % (as received) approximately by means of a centrifugation process for extracting olive oil (physical extraction method) in a "decanter". Additional oil can be further reduced through chemical extraction methods, employed at facilities known as olive pomace mills. In countries where the repaso process is not widespread, olive pomace mills handle olive pomace with higher amounts of residual oil. The raw material of olive pomace mills can be either raw wet olive pomace, or wet olive pomace with less content of crushed olive stone, if this separation has been previously applied.

Olive pomace mills perform drying of the incoming olive pomace (raw material) to reduce its water content, and then apply the chemical extraction. Their main product is crude olive pomace oil, which can be further refined to olive pomace oil for the market. Their main residue is the olive cake ("exhausted olive cake"), which is a very dry and granulated material. Nowadays, many extraction facilities – especially in Spain – separate the remaining endocarp (bone) from the olive pomace before the chemical extraction, as it is more valuable. However, it is not possible to reach a complete separation of all the endocarp, and the smaller fractions remains in the olive cake to be processed, and thus, in the exhaust olive pomace.

Figure 10 depicts the alternative paths to obtain the different solid biofuels in the cascade of olive pomace management. The diagram is simplified and only incorporates principal options. It does not provide details of internal operations (different stages for water adding and recovery, centrifugation and decanting). The liquid residual and waste fractions are also not being depicted.

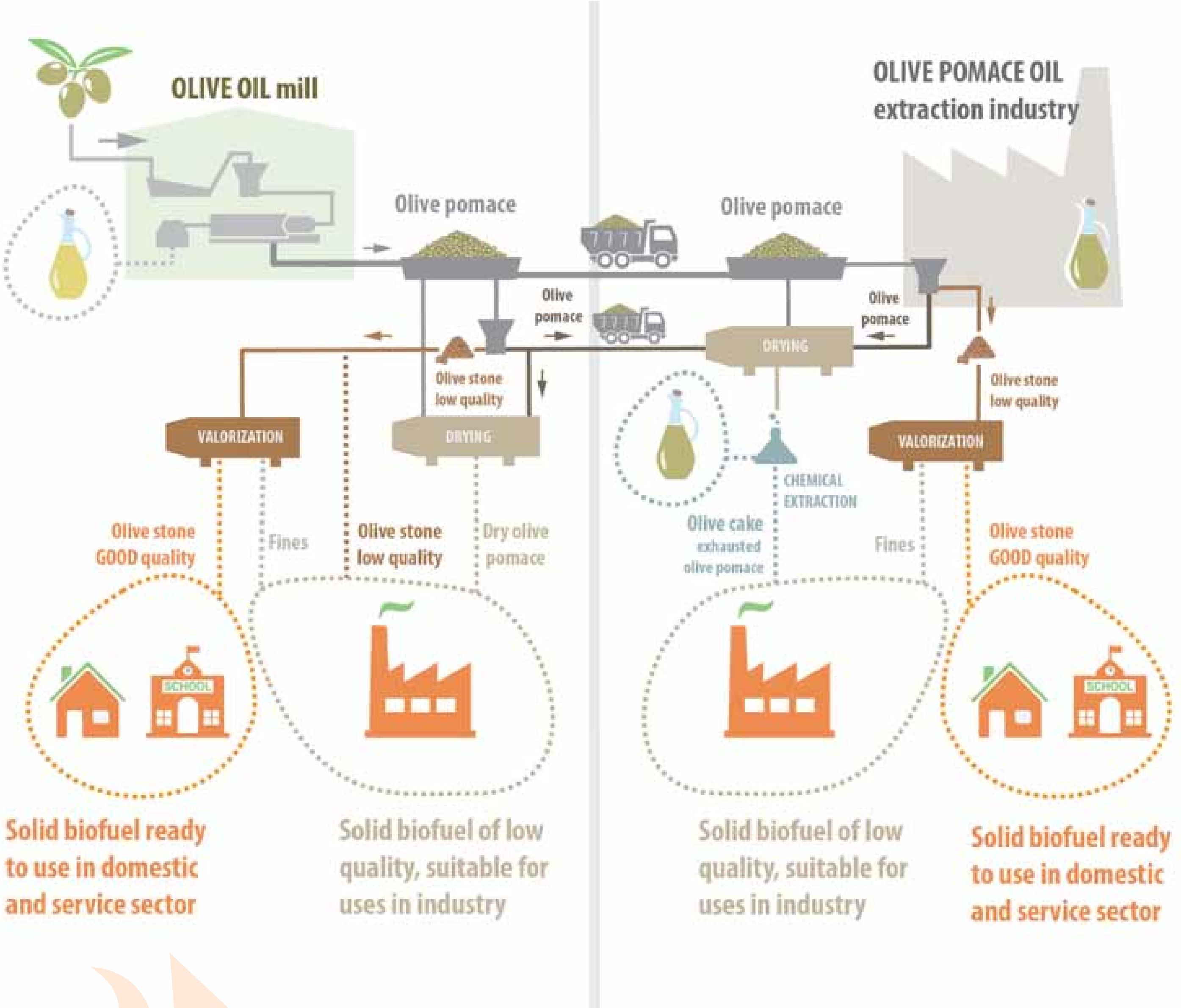


FIGURE 10

Alternatives to obtain solid biofuels (olive pomace, olive cake and olive stone) in olive oil mills and olive pomace oil extraction industries. Source: AVEBIOM.

POTENTIALS AND DISTRIBUTION IN EUROPE

As olive stones, the distribution of the olive cake is linked to the olive tree cultivation. Olive pomace is predominantly found raw from mills in countries or areas with small productions, where chemical extraction facilities are not usually available. In dense zones for olive oil production, it is usual that the raw olive pomace is object of chemical extraction, and then the olive cake is produced (exhaust olive pomace). The main producers in Europe are Spain, Greece, Italy, and Portugal.

An estimation of the olive cake production with the mass balance of **Figure 3** has been performed in the **Figure 11**. In average, 0.197 t of olive cake are generated out of every ton of olive processed for olive oil extraction (circa 20 %).

Some of the olive cake quantities are self-consumed in the process of olive pomace oil production as it needs heat to dry the wet olive pomace and steam for the chemical extraction. In some countries, it is also common to produce the process heat from natural gas CHP units. **Figure 11** presents the theoretical potential of olive cake; to find the available market potential it is needed to subtract the olive cake already being utilised in self-consumption for producing heat at the olive pomace mill plants.

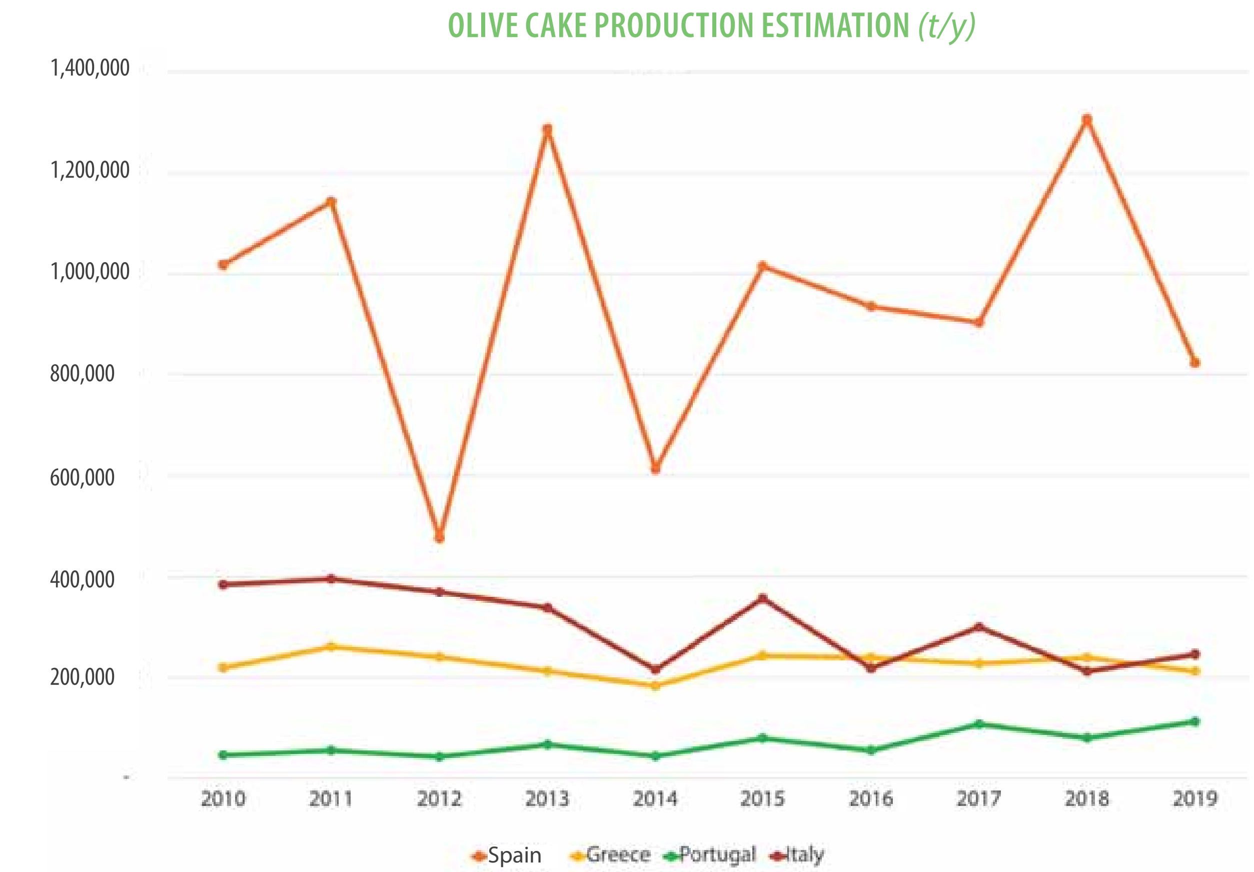


Figure 11

Olive cake (exhaust olive pomace) production per country in tons per year (2019). Source: AVEBIOM elaboration with FAOstat data.

CHARACTERISTICS: WHERE AND HOW IS IT UTILIZED?

There is no dedicated standard for olive cake as a solid biofuel; however, indicative values are presented in ISO 17225-1. The format is granular and it can be easily pelletized. It is already quite dense (600 – 650 kg/m^3) so pelletizing, rather than improve the transport cost, can be an option to improve the feeding or minimising the losses.

PARAMETER	TYPICAL RANGE	TYPICAL VALUE	UNIT
Moisture	12 – 18	15	w-% a.r.
Ash	5 – 10	7.2	w-% d.b.
Net Calorific Value	15.0 – 16.2	15.7	MJ/kg (a.r.)
Oil content	< 2	1.3	w-% a.r.
Bulk density	600 – 650		kg/m^3
Nitrogen	1.0 – 2.0	1.2	w-% d.b.
Sulphur	0.07 – 0.15	0.08	w-% d.b
Chlorine	0.12 – 0.40	0.2	w-% d.b

Table 2

Typical values for olive cake. Source: AVEBIOM own elaboration

Its moisture is about 20 % after the extraction process, but then is being dried naturally progressively and usually is possible to find in lower moistures (about 15 %).

As fuel, main chemical characteristics to be considered are the high ash – potentially more than 10 times higher than that of wood pellets or olive stones – nitrogen, sulphur and chlorine. Table 2 summarises the typical properties of exhausted olive cake as solid biofuel. EU establishes a maximum of 3% of oil content in the trades of olive cake for bioenergy purposes, a higher content implies a tax because it's considered that its use will be animal feeding. National laws may regulate the maximum residual oil content in olive cake.

Because of these characteristics, olive cake is clearly a solid biofuel better suited for industrial purposes. As such, it requires equipment able to cope with the ash production, and in simple domestic heatings can cause the user a non-friendly uncomfortable practice, as user may have to take care of the cleaning in small appliances without an automatized cleaning system.

Also other parameters like fines, nitrogen or chlorine make difficult its use in domestic devices due to emissions, corrosion of metal components of the devices, etc. Most of the olive cake is utilised in industrial activities (self-consumption in the olive pomace mills, brick factories, cement kilns, as co-firing fuel in coal power plants or as a dedicated fuel for biomass power plants, etc.). However, still some quantities are being burnt in obsolete devices as domestic devices in certain regions, since olive cake has a very competitive price compared to most fossil or biomass alternatives.

Figure 12

Olive cake (Source: AVEBIOM)

CASE EXAMPLES

DRIED OLIVE POMACE GASIFICATION AT ACEITES GUADALENTÍN

For olive mills, handling of the large quantities of olive pomace they produce as a residue is a major issue that requires an environmentally sustainable and economically feasible management. In areas with significant volumes of olive oil production, the olive pomace is typically supplied to olive pomace mills, which perform the chemical extraction of the crude olive pomace oil. However, olive mills in areas without olive pomace mills need to find alternative treatment methods.

In many regions, the relations between oil mills and olive pomace mills have undergone changes through last years. The switch to the two-phase olive oil production results in the production of much wetter olive pomace, with a moisture content often exceeding 70 % (compared to around 55 % in the three-phase system). Several olive mills perform a separation of the olive stones as a separate fraction, and others implement a secondary physical olive oil extraction ("repaso"). These changes the olive pomace mills to undertake new investments in ponds for their storage and to increase their processing costs, especially energy, which in situations of low price of olive pomace oil (their principal product) and olive cake (their principal by-product), generates significant economic stress. This situation has led to an unstable and difficult framework for extractors, and the creation of more tensions between both types of industries, though both are in the end compelled to co-exist and understand each other, since both are fundamental in the olive oil value chain.

This is the context for the case of the project promoted by the family company Aceites Guadalentín, S.L. located in Pozo Alcón (Jaén province). This olive oil producer (olive mill) manages a pond of alpeorujo (olive pomace) with a capacity of about 65,000 tons, both for its own production but also for quantities produced by neighbouring mills. Its management represents a significant cost, among other issues due to its location away from any olive pomace industry. The company that processed the wet olive pomace to extract oil ("repaso", a second physical extraction) had a big off-grid electrical consumption, and is producing a dried olive pomace (moisture < 15 %, residual oil content of about 1.5 %), which is not further object of chemical extraction.

The origin of the case started from the intend of Aceites Guadalentín to reverse the current practice, transform the current linear practice to circular economy, and change the current problems into an opportunity for new incomes and savings, with a much better environmental performance.

The core of the project is a new gasifier for olive cake or dried olive pomace. The gasifier consumes about 970 kg/h of dried olive pomace, producing 2,615 kg/h of syngas (with a NCV of around 5.6 MJ/Nm^3) and 146 kg/h of biochar (with a carbon content of around 66.58 %). The syngas is combusted in engines with a combined electrical capacity of 1 MWe (2 x 500 kWe), while 1.88 MWt of heat is available (from refrigeration and exhaust gases) – the total efficiency of the system is around 62.5 %. The electricity is used for self-consumption, substituting that provided by an oil generator unit, while the heat is used for drying and other internal needs.

The installation started working December 2021. The total investment amounts to 3 million EUR (including civil works), 40 % of which is supported by the Andalusian Energy Agency. The system achieves savings of about 200,000 liters of heating oil *per year*, used before for the off-grid electricity generation. Additional revenues are generated from the fact that the olive stones separated from the olive pomace can now be sold in the market (heat from the gasifier substitutes the heat from an olive stone boiler used in the repaso process); Aceites Guadalentín will implement a cleaning and drying system to produce clean olive stones for this purpose. Additional revenues can be produced from the valorisation of biochar (e.g. as a soil amendment agent), while a hydrogen production unit could be implemented in the future. The gasification system results in a drastic reduction of the CO_2 emissions, but also to a reduction of the dust emissions that would have occurred if olive cake was combusted.

The system employed by Aceites Guadalentín could be replicated by other olive mills, of larger and smaller size, since the gasification processes and engines can be of diverse sizes, or applied in modules. The model can also be transferred to olive pomace mills who then could consume their olive cake in the gasification. This kind of installation could be a game-changer for the olive oil industry, and contribute to drastically reduce its emissions. The expectations are high and multiple administrations, policy makers and extractors are looking forward seeing the evolution and steady performance of this unique pilot plant.

Figures 13 and 14

Left: Alpeorujo pond .Down: Olive cake gasification unit (4 MWt and 1 MWe). Source: AVEBIOM

VIOPAR S.A. – GREECE'S LARGEST AND NEWEST BIOMASS POWER PLANT

Within an installed capacity of 5 MWe, the biomass power plant of VIOPAR S.A. is currently both the largest and the most modern such unit operating in Greece. Major landmarks in the company history were the completion of the licensing procedure in 2016, its merger into the Ravago Group and in 2017 and the start of plant construction in 2018. With construction finished in 2019, full operation has initiated in 2020.

The plant is located in the 2nd Industrial Zone of Volos, in close proximity to the port (17 km) and the agricultural areas of Thessaly (around 30 km), allowing for flexibility in the exploitation of both domestic and imported biomass fuels. The plant is licensed to operate using exhausted olive cake, sunflower husk pellets or cotton ginning residues as fuels. The annual fuel consumption is around 38,000 tons.

Currently, the plant utilizes primarily olive cake of two main varieties: "regular", which has a more typical size distribution, and "powder", which is a finer material, more difficult to handle by conventional firing systems. VIOPAR employs a moving grate furnace along with a separate pneumatic injection system for the powder fuel. The plant uses the Organic Rankine Cycle (ORC) technology, which provides multiple benefits (minimization of water consumption, avoidance of visual disturbances), and is fully equipped with antipollution measures (electrostatic precipitator, anti-SOx and anti-NOx measures), bringing its emissions within the limits established by the EU Directives.

The plant operation also provides multiple benefits for the local economy: 7 permanent job positions for the plant operation, 120 persons employed during construction, 200,000 € *per year* of contributions to the local municipality, more than 230,000 € *per year* of revenue to the Port of Volos and at least 200,000 € *per year* to local suppliers (transporters, maintenance teams, providers of consumables, etc.). VIOPAR is also actively involved in RTD activities, looking for ways to provide waste heat from its production to local district heating networks or for valorising the combustion ash residues.

Figure 15 y 16. *Aerial photo of the 5 MWe biomass power plant & furnace of VIOPAR S.A. in Volos, Greece (Source: VIOPAR).*

KEYS FOR UTILISATION OF OLIVE CAKE

Utilisation of olive cake for heating is feasible, especially in industrial applications. It is a more complex fuel, and then the keys for an appropriate use as solid biofuel are:

QUALITY. Although olive cake is an industrial fuel, there are certain parameters that should be monitored as:

MOISTURE / TEMPERATURE: just after the extractor facility can have a higher moisture content that with time, transports and movement it is going down until his average typical of 15%, but usually it is stored in store yards without any kind of protection of roof. Moisture can be problematic in the boilers but also in the logistic and storage. A high content of moisture can bring a self-combustion problem.

TEMPERATURE: It is important to monitor the temperature as self-combustion in storage may occur if moisture is high enough and increased with high exterior temperatures. Stored piles should be monitored and measures must be put in place in case of increasing temperatures (ambient and pile). A proper inspection should be done by opening the pile; visual inspections of the surface is not enough since self-combustion typically starts on the inside.

CHLORINE: Olive cake has already naturally a quite high chlorine content. Some similar biomasses like the residues of the table olive production are sometimes mixed and due to the processes they undergo (i.e. adding salt and other additives), the chlorine can be increased even further. This has consequences to the combustion system (corrosion) and emissions (HCl). The materials of the boiler has to be enough resistant to support the content of this biomass and avoid corrosion.

ASH: Ash content of olive cake is by itself quite high. Olive cake may be mixed with biomass fractions of even worse quality parameters or contaminated with exogenous inert material (sand, soil, stones), which increase the total ash content even further. Considering also the ash composition (e.g. increased concentration of alkalis), there are several implications to the operation of any combustion system: increased cleaning frequencies, slagging, higher particle emissions, etc. When using olive cake as a fuel, attention should be put in these parameters.

Due to this industrial quality and relatively high content of nitrogen, chlorine, ash, etc., **APPROPRIATE TECHNOLOGIES** (filters, urea injection,…) for an optimal combustion must be put in place to avoid overpassing emissions thresholds of the legislation (HCl, particles, NOx).

Dry nut shells

DESCRIPTION

There are certain dry nut trees the fruit shells of which are possible to be used as biomass for energy purposes. The nut fruits are transported into agro-industries where the nut is separated and the shells remain apart. Typically, they are stored and sold locally as source of energy. The nut processing window is quite narrow, so large volumes are produced in a short amount of time and large storage areas are required.

Crushing is the main process used to separate the flesh of the nut from the shell. The obtained shells consist of fragments which are not homogenous in size. In order to improve feeding and combustion in the appliances and convert these shells in standardized solid biofuels, some valorizations are recommended, such as crushing in smaller fragments and sieving to remove the fines (< 2 mm) to get a homogenous particle size.

The natural moisture of the shells after crushing is adequate low for combustion. However, as the shells are often stored outside without a roof for the aforementioned reasons, the moisture content when obtained can be higher.

There is a quality standard for dry fruit shells in Spain (UNE 164004:2014) that includes pine nuts shells, almond shells, hazelnuts shells and chopped pine cones. This standard was developed by the Spanish committee CTN-164, primarily using data from the BIOmasud project. This standard is under revision and besides some slight changes in the thresholds; main difference is the incorporation of pistachio and walnut shells. The revision, which is in its final stage, is expected to be published within 2022.

There are many kinds of dry fruits but certain sorts are frequently used as solid biofuels because of tradition or easiness of use. These are almonds shells, chopped pine cones, pine nut shells, hazelnut shells, pistachio shells and walnut shells.

ALMOND SHELLS

They are one of the most commonly used for energy. They are covered in the Spanish standard UNE 164004 and by BIOmasud® certification Scheme. The almond shells may be from around 62 to 78 % of the weight of the whole almond fruit, depending on the variety. An average of 70 % has been taken into account for the estimations on **Figure 26.**

Figure 17 *Almond shells, just as obtained from the nut extraction. Source: AVEBIOM*

Figure 18 *Crushed almond shells*

PINE NUT SHELLS

They are one of the solid biofuels most commonly used for energy. They are covered in the Spanish standard UNE 164004 and by the BIOmasud® certification scheme.

Regarding the mass balance, pine cone's moisture content is high (32 – 38 %) and pine cones are dried in the process of obtaining the pine nuts. 100 kg of pine cones approximately contains 5 – 20 kg of pine nuts with shells. Out of this 5 – 20 kg, approximately 25 % is the nut itself and the remaining are shells.

Figure 19 *Pine nut shell. Source: AVEBIOM*

Unfortunately, production of pine nuts has been drastically reduced since 2013, mainly in Spain but also in Portugal. Both countries were seriously affected by a plague of a certain insect (Leptoglossus occidentalis) which is affecting the pines cones by sucking them out and consequently drying them. Out of this plague before 2013 around 200 kg of pine nuts with shells were obtained out of 1 t of pine cones (not dried); since 2014 only around 80 kg are obtained. As a result, in the last years, Spanish companies are buying and processing most of the Portuguese pine cones (80-90 %) in the last years (and consequently all these shells remain in Spain).

CHOPPED PINE CONES

They are not *"per se"* a nut but a fructification containing the nuts. Out of 100 kg of pine cones, after drying them, approximately 48 – 57 kg of chopped pine cones are obtained.

They are usually chopped and sometimes used mixed with pine nut shells as it improves combustion. Occasionally, the center of the pine cone is removed and only the bracts are used as fuel. This type of solid biofuel is covered in the Spanish standard UNE 164004 and by the BIOmasud® certification scheme.

FIGURE 21 AND 22
Chopped pine cones.
Up: whole pine cones.
Right: pine cone bracts.
Source: AVEBIOM

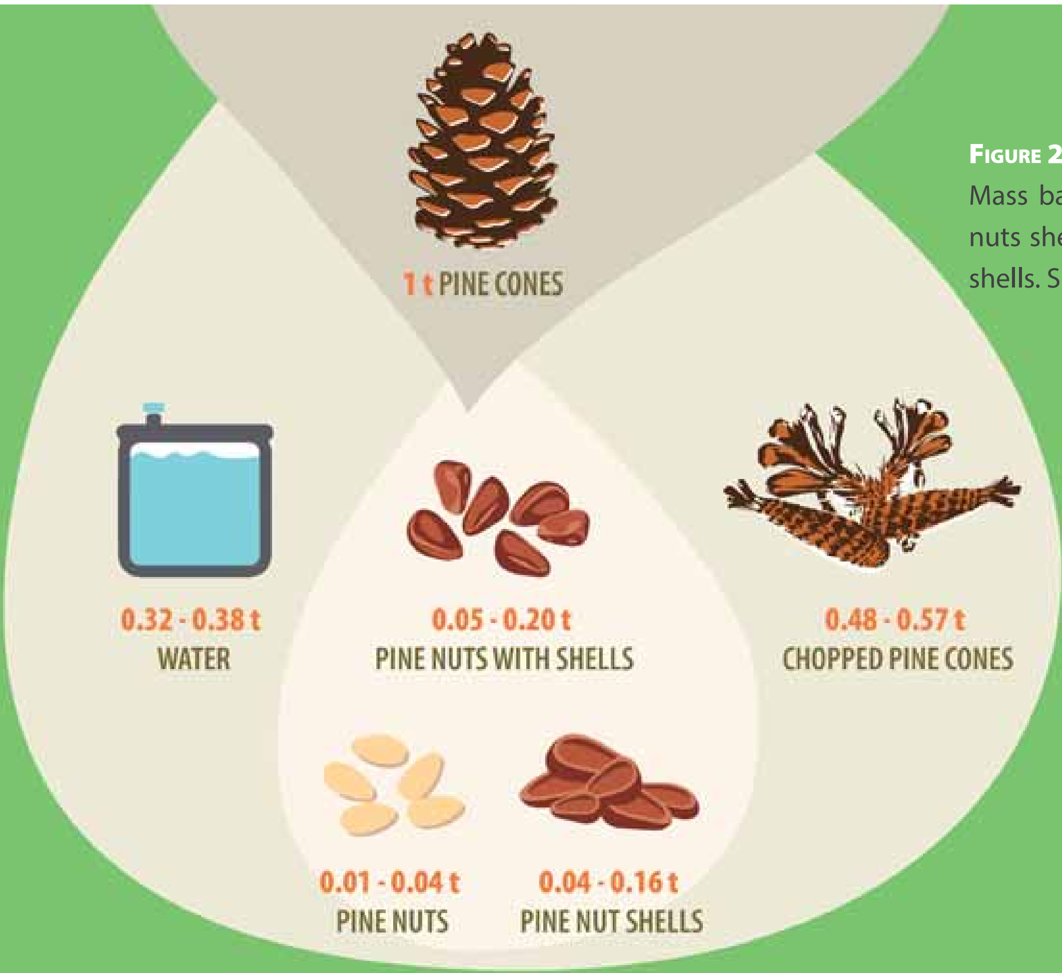


FIGURE 20
Mass balance of the Pine nuts shells and pine cone shells. Source: AVEBIOM

HAZELNUT SHELLS

They are covered in the Spanish standard UNE 164004 and by the BIOmasud® certification scheme. The hazelnut shells may be from around 53 to 55 % of the weight of the whole hazelnut fruit, depending on the variety. An average of 54 % has been taken into account for the estimations on table 6.

PISTACHIO SHELLS

They are not covered in the Spanish standard UNE 164004 but there were studied in the Biomasud Plus project and its inclusion in the standard is currently in process (approval of the updated standard is foreseen within 2022). However, pistachio shells are already covered by the BIOmasud® certification scheme. The pistachio nuts without shells represent 50 – 60 % of the whole fruit (dried and without the husk) therefore, shells fraction is in the range 40 – 50 %.

Figure 23
Hazelnut shells. Source: AVEBIOM
Figure 24
Pistachio shells. Source: CIEMAT
Figure 25
Walnut shells. Source: CIEMAT

WALNUT SHELLS

They are not covered in the Spanish standard UNE 164004 but there were studied in the Biomasud Plus project and its inclusion in the standard in process (approval of the updated standard is foreseen within 2022). They are covered by BIOmasud® certification Scheme. The nut without shells represent between 45 – 55% of the whole fruit. For the estimations in the graph below, an average yield of 50 % was considered (see table 8).

POTENTIALS AND DISTRIBUTION IN EUROPE

Logically the production of dry fruit shells is linked to the origin of their respective cultivations which are different for every species mentioned. In addition, statistics found are usually for the crops and not for the shells, so in order to estimate shells production a ratio between weight with and without shells is used. This ratio depends on the conditions of the year and of the variety. In the following pages a short overview of the production and distributions in Europe for main sorts of dry nut shells used for bioenergy are shown:

ALMOND SHELLS

Spain is the first European producer of almonds, and second world producer, far away from the first, USA (Spain produces approximately 10 times less than USA). In Europe, the second producer is Turkey followed by several Mediterranean countries.

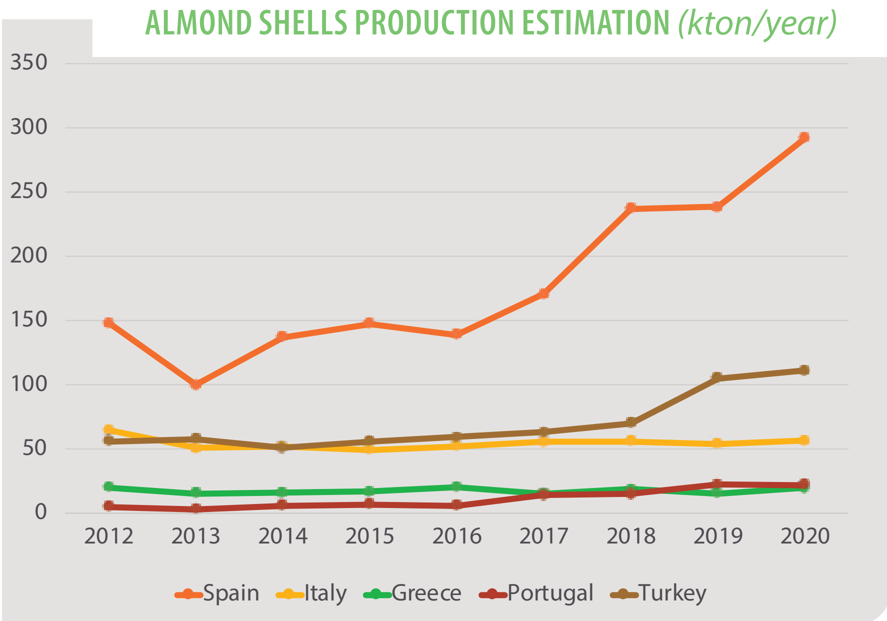


Figure 26

Almond shells *production per country in tons per year.*

Source: AVEBIOM elaboration with Eurostat data.

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Spain	148,218	100,156	136,990	147,756	139,139	170,716	237,321	238,294	291,865
Italy	64,785	50,806	51,814	49,280	52,206	55,720	55,860	54,110	56,364
Greece	20,293	15,414	15,946	17,157	20,426	15,498	18,697	15,365	19,768
Portugal	5,026	3,115	6,321	7,063	6,097	14,098	15,148	22,610	22,127
Turkey	56,000	58,100	51,100	56,000	59,500	63,000	70,000	105,000	111,300

Table 3

Almond shells production per country in tons per year. Source: AVEBIOM elaboration with Eurostat data.

PINE NUT SHELLS AND CHOPPED PINE CONES

There are many species of pine with edible nuts but in Europe there quite few and the most important is Pinus Pinea because of their culinary value and production which grows mainly in the Mediterranean countries. Portugal and Spain have approximately 500,000 hectares of Pinus Pinea, which represents 75% of the world distribution of this species which is also present in other countries of the Mediterranean basin. The annual production of pine nuts/cones presents a strong variation due to the fact that the species is alternate bearing and very sensitive to the influence of climatic factors, mainly to severe and prolonged drought. Also, as previously mentioned, since 2013 the production in Spain and Portugal was seriously affected due to the Leptoglossus occidentalis

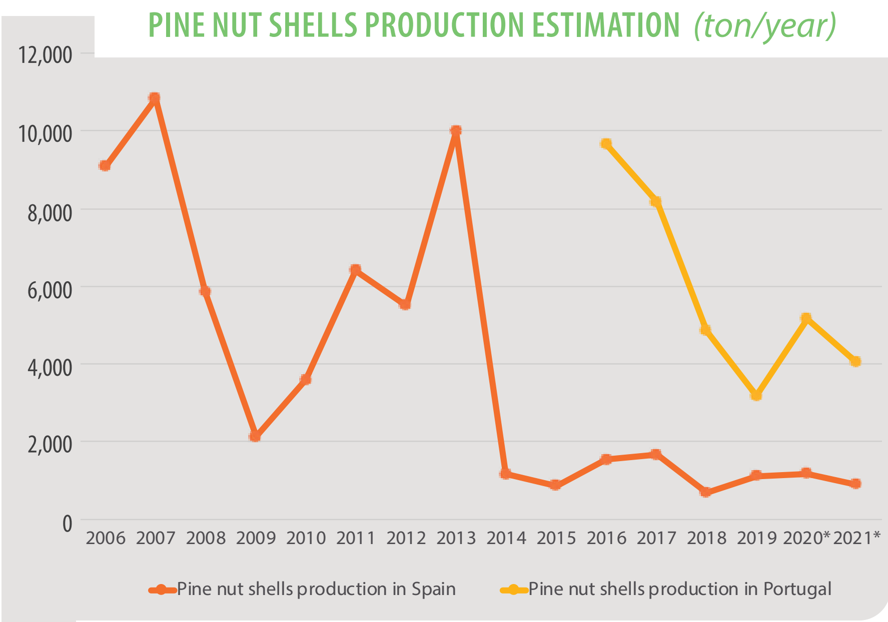


FIGURE 27

***Pine nut shells** production per country in tons per year.*

Source: AVEBIOM elaboration with MITECO (Spain) and ICNF (Portugal) data. (estimation)*

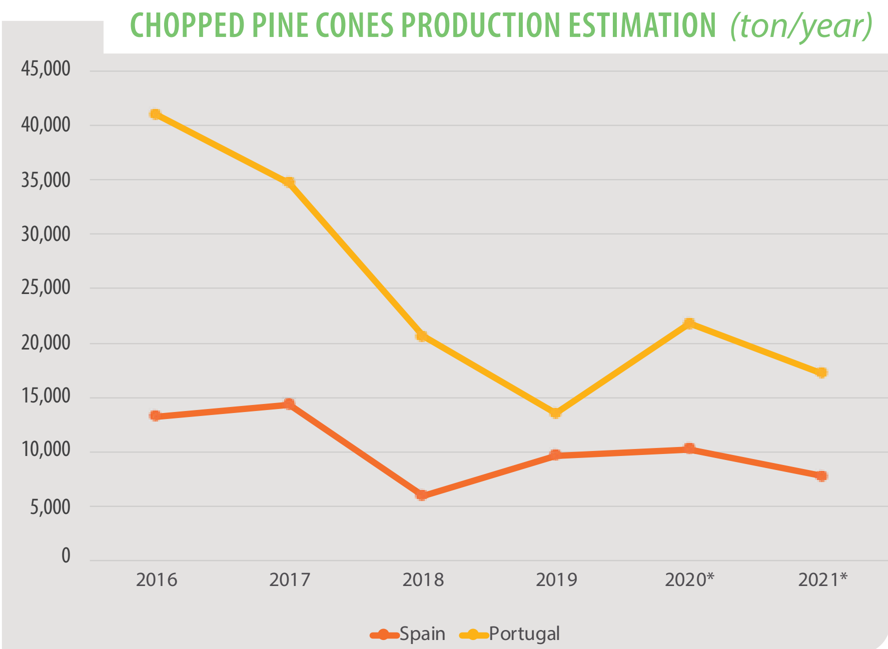


FIGURE 28

***Chopped pine cones** production per country in tons per year.*

Source: AVEBIOM elaboration with MITECO (Spain) and ICNF (Portugal) data. (estimation)*

YEAR	SPAIN	PORTUGAL
2006	9,076	
2007	10,828	
2008	5,843	
2009	2,126	
2010	3,588	
2011	6,407	
2012	5,502	
2013	9,985	
2014	1,163	
2015	864	
2016	1,537	9,648
2017	1,660	8,170
2018	689	4,855
2019	1,121	3,186
2020*	1,184	5,157
2021*	896	4,043

Table 4

Annual theoretical potential of ***pine nut shells*** *(in tons) per country. Source: AVEBIOM elaboration with MITECO (Spain) and ICNF (Portugal) data. (* estimation)*

YEAR	SPAIN	PORTUGAL
2016	13,255	41,002
2017	14,318	34,723
2018	5,941	20,635
2019	9,667	13,539
2020*	10,212	21,791
2021*	7,728	17,182

Table 5

Annual theoretical potential of ***chopped pine cones*** *(in tons) per country. Source: AVEBIOM elaboration with MITECO (Spain) and ICNF (Portugal) data. (* estimation)*

Figure 29

Pine nut shells. Source: Biomasas Herrero

HAZELNUT SHELLS

Turkey is the largest producer in Europe and in the world. The second world producer is Italy. There are more countries with a small production, between 3,000 and 10,000 t of fruits, in EU like Spain, France and Poland.

YEAR	SPAIN	FRANCE	ITALY	POLAND	TURKEY
2012	7,906	5,416	58,671	2,268	356,400
2013	8,262	4,374	60,831	2,754	296,460
2014	7,312	5,967	40,748	2,970	222,480
2015	6,167	4,806	54,886	2,916	348,840
2016	5,135	6,907	65,108	2,986	226,800
2017	5,665	6,512	70,891	2,500	364,500
2018	4,336	8,456	71,658	3,586	278,100
2019	6,680	6,296	53,206	2,938	419,040
2020	2,943	5,233	75,902	4,104	359,100

TABLE 6

*Annual theoretical potential of **hazelnut shells** (in tons) per country. Source: AVEBIOM elaboration with Eurostat data.*

PISTACHIO SHELLS

In Europe, the largest productions of pistachio are distributed by countries of the Mediterranean basin, not in vain the plant was already known in times of the Roman Empire. The cultivation area remained more or less stable until the first decade of the year 2000. Since then its production has been gradually expanded in quantities due to modernization and intensive cultivation. The main countries producing pistachios are Turkey, Greece, Italy and, since a few years ago, Spain where lately is growing its cultivation. USA is the world leader in pistachios production followed by China and Iran.

YEAR	SPAIN	GREECE	ITALY	TURKEY
2012	1,206	3,598	424	67,500
2013	1,120	3,205	1,452	39,870
2014	1,182	3,855	1,600	36,000
2015	1,170	4,385	1,741	64,800
2016	2,528	5,069	1,642	76,500
2017	3,395	5,326	1,743	35,100
2018	n.a.	n.a.	n.a.	108,000
2019	n.a.	n.a.	n.a.	38,250

TABLE 7

*Annual theoretical potential of **pistachio shells** (in tons) per country. Source: AVEBIOM elaboration with FAO data.*

WALNUT SHELLS

Turkey is the largest producer of Europe and 4th in the world behind China, USA and Iran. In European production is more modest with presence mainly in Romania, France, Greece, Spain and Italy.

YEAR	GREECE	SPAIN	FRANCE	ITALY	ROMANIA	TURKEY
2012	12,105	6,820	18,040	n.a.	14,195	101,500
2013	12,615	7,125	17,755	n.a.	14,785	106,000
2014	11,205	7,795	17,385	n.a.	14,685	90,500
2015	12,610	7,160	21,140	n.a.	15,660	95,000
2016	14,025	7,460	20,235	6,080	15,970	97,500
2017	13,960	7,870	16,520	6,075	21,860	105,000
2018	15,930	7,590	18,845	6,225	27,000	107,500
2019	15,520	8,770	17,475	5,400	24,790	112,500
2020	18,200	8,555	17,850	7,745	24,175	143,500

TABLE 8

*Annual theoretical potential of **walnut shells** (in tons) per country. Source: AVEBIOM elaboration with Eurostat data.*

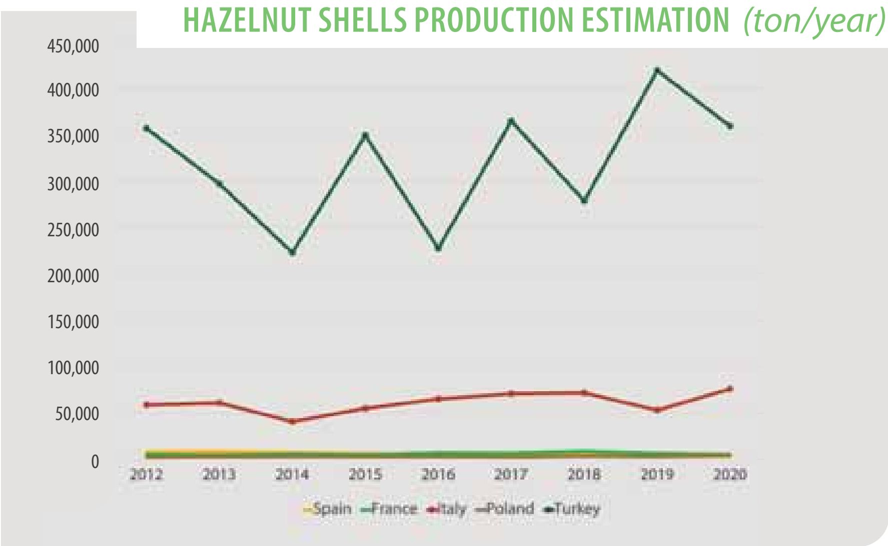


Figure 30

Hazelnut shells *production per country in tons per year. Source: AVEBIOM elaboration with with Eurostat data.*

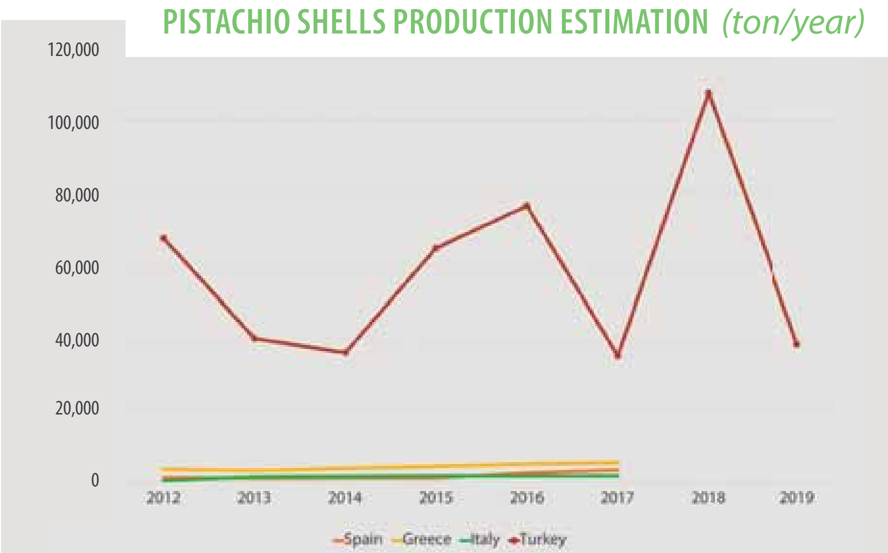


Figure 31

Pistachio shells *production per country in tons per year. Source: AVEBIOM elaboration with with FAO data.*

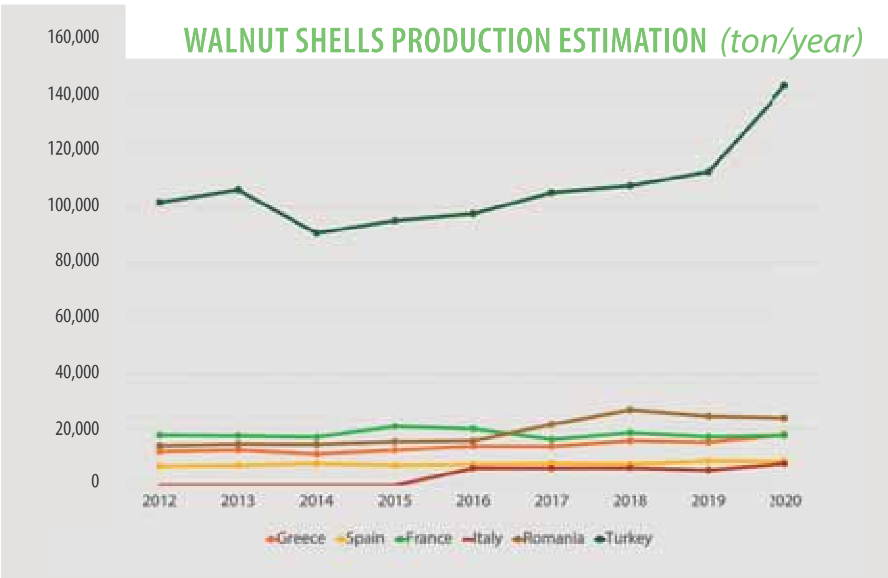


Figure 32

Walnut shells *production per country in tons per year. Source: AVEBIOM elaboration with with Eurostat data.*

CHARACTERISTICS: WHERE AND HOW IS IT UTILIZED?

Usually shells are used locally in farms, greenhouses and other similar installations directly without any valorisation process. However, as previously commented, if minimally processed to homogenise their particle size by sieving out fines, and crushing to eliminate the larger parts, a good quality solid biofuel can be obtained, which is suitable even for small devices. Moisture content should not be high if stored in good conditions but many times, agro-industries where by-product is generated cannot store them as needed because a lot of quantity is generated at the same time as previously commented. Therefore, this residue is usually stored outside without any roof which is the reason why shells are often not sufficiently dry in the market.

In some areas there's been a traditional use due to the abundance in the region of this biofuel (i.e. Pine nut shells / chopped pine cones in the area of Valladolid / Segovia (Spain) where there is a huge concentration of the production of pine nut and consequently by-product. Unfortunately boilers or stoves are not always the most advanced technologically and a renovation should be promoted in order to improve performance and lower emissions. On the other hand, due to its traditional utilisation, people know well the possibilities of the fuel and even they traditionally use it mixed (pine nuts shells & chopped pine cones which improves the behaviour in their combustions by combining it).

Table 9

Limits of the main parameters for dry fruit shells as per BIOmasud®Certification System

PARAMETER	MATERIAL	QUALITY CLASS			UNIT
		A1	A2	B	
MOISTURE		≤ 12	≤ 12	≤ 16	w-% a.r.
ASH					
	Almond shells	≤ 0.7	≤ 1.6	≤ 2.0	w-% d.b
	Hazelnut shells	≤ 0.7	≤ 1.6	≤ 2.0	w-% d.b
	Pine nut shells	≤ 0.7	≤ 1.5	≤ 2.0	w-% d.b
	Pistachio shells	≤ 0.7	≤ 1.6	≤ 2.0	w-% d.b
	Walnut shells	≤ 0.7	≤ 1.6	≤ 2.0	w-% d.b
	Chopped pine cones	≤ 0.8	≤ 1.1	≤ 1.5	w-% d.b
OIL CONTENT		≤ 0.6*	≤ 1.0*	≤ 1.5*	w-% d.b.
FINES (F < 2 MM)		< 2.0	< 2.0	< 4.0	w-% a.r.
NET CALORIFIC VALUE					
	Almond shells	≥ 15.0	≥ 15.0	≥ 14.0	MJ/kg (a.r.)
	Hazelnut shells	≥ 15.0**	≥ 15.0**	≥ 14.0**	MJ/kg (a.r.)
	Pine nut shells	≥ 16.0	≥ 16.0	≥ 15.0	MJ/kg (a.r.)
	Pistachio shells	≥ 15.0	≥ 15.0	≥ 14.0	MJ/kg (a.r.)
	Walnut shells	≥ 16.0	≥ 16.0	≥ 15.0	MJ/kg (a.r.)
	Chopped pine cones	≥ 15.8	≥ 15.8	≥ 14.9	MJ/kg (a.r.)

PARAMETER	MATERIAL	QUALITY CLASS			UNIT
		A1	A2	B	
DENSITY					
	Almond shells	≥ 450	≥ 300	≥ 270	kg/m³ (a.r.)
	Hazelnut shells	≥ 300	≥ 300	≥ 270	kg/m³ (a.r.)
	Pine nut shells	≥ 470	≥ 470	≥ 450	kg/m³ (a.r.)
	Pistachio shells	≥ 300	≥ 300	≥ 270	kg/m³ (a.r.)
	Walnut shells	≥ 250	≥ 200	≥ 200	kg/m³ (a.r.)
	Chopped pine cones	≥ 400	≥ 350	≥ 300	kg/m³ (a.r.)
NITROGEN					
	Almond shells	≤ 0.4	≤ 0.6	≤ 0.8	w-% d.b
	Hazelnut shells	≤ 0.4	≤ 0.6	≤ 0.8	w-% d.b
	Pine nut shells	≤ 0.4	≤ 0.6	≤ 0.8	w-% d.b
	Pistachio shells	≤ 0.4	≤ 0.6	≤ 0.8	w-% d.b
	Walnut shells	≤ 0.4	≤ 0.6	≤ 0.8	w-% d.b.
	Chopped pine cones	≤ 0.3	≤ 0.4	≤ 0.6	w-% d.b
SULPHUR					
	Almond shells	≤ 0.03	≤ 0.03	≤ 0.05	w-% d.b.
	Hazelnut shells	≤ 0.03	≤ 0.03	≤ 0.05	w-% d.b.
	Pine nut shells	≤ 0.03	≤ 0.03	≤ 0.05	w-% d.b.
	Pistachio shells	≤ 0.03	≤ 0.03	≤ 0.05	w-% d.b.
	Walnut shells	≤ 0.03	≤ 0.03	≤ 0.05	w-% d.b.
	Chopped pine cones	≤ 0.03	≤ 0.03	≤ 0.04	w-% d.b.
CHLORINE					
	Almond shells	≤ 0.02	≤ 0.03	≤ 0.04	w-% d.b.
	Hazelnut shells	≤ 0.02	≤ 0.03	≤ 0.04	w-% d.b.
	Pine nut shells	≤ 0.02	≤ 0.03	≤ 0.5	w-% d.b.
	Pistachio shells	≤ 0.02	≤ 0.03	≤ 0.04	w-% d.b.
	Walnut shells	≤ 0.02	≤ 0.03	≤ 0.04	w-% d.b.
	Chopped pine cones	≤ 0.05	≤ 0.07	≤ 0.10	w-% d.b.

NOTE: Spanish Standard UNE 164004 is going the be updated at the beginning of 2022 and some values may slightly differ, i.e NCV values of Hazelnut shells (**) will be updated (A1: 16 MJ/kg.;A2: 16 MJ/kg. and B: 15 MJ/kg.)

*Not apply to Chopped pine cones

As it can be seen in **table 9**, many dry nut shells present rather similar physical and chemical characteristics and this was the motive of the Spanish solid biofuel normalisation after the works performed in Biomasud Plus project to group them in a standard (UNE 164004). After the revision in 2022, the updated standard also will group many of the parameters in common except for some like NCV and Density that are the ones less similar.

CASE EXAMPLES

USE OF ALMOND SHELLS TO PRODUCE PAPRIKA

The Region of Murcia is one of the main paprika production areas in Spain. Specifically, the Guadalentín Valley produces about 4 million kg each year. Located at the town of Totana, the cooperative Francisco Palao operates one of the largest red pepper dryers in Spain – in the 2020 season around 1,200 tons were processed - mostly "Bola" and "Americano" varieties – from which paprika with Protected Designation of Origin "Pimentón de Murcia" is then obtained. The seasonal nature of the campaign, which runs from August 25 to December 31, means that all the peppers must be dried in 4 months, in a very labour-intensive and energy-intensive process and a significant part of the production costs. The drying facility of the cooperative includes five belt dryers, with the heat provided by biomass combustion.

Recently, the cooperative replaced its older biomass burners with a new 1.5 MW horizontal flame system, provided by Spanish manufacturer Natural Fire. The cooperative estimates that the energy efficiency has improved by 20 – 30 % thanks to the new system. The air is heated up to 90 ºC thanks to the combustion of almond shells. The pepper arrives with a humidity of around 80 % and, after about five hours of residence inside the dryer, it comes out with 9-10 %. The annual consumption of the dryer is around 1,500 tons of almond shells. Burners and combustion chamber need to be cleaned once a week.

FIGURE 33 AND 34

Dried peppers (down) and photography in the Cooperative Francisco Palao's dryer facility: Juan Tudela (left) President of the Cooperative, Pedro Sanchez (center) commercial of Natural Fire and Perfecto Forte General Manager of Natural Fire (right)

USE OF ALMOND SHELLS IN AN ORNAMENTAL FLOWER GREENHOUSE

The ornamental flower greenhouse of Besgastriflor, in Cehegín, Spain produces 10,000 packages of 5 stems of fresh daisies per week in an area of one hectare.

To achieve an ambient temperature of 20 ºC inside the greenhouse, an aerial pipe with water at 85 ºC runs through the plantation lines, distributing the heat. The energy to heat the water comes from a retrofitted heating oil boiler, currently retrofitted with a 1 MW biomass burner provided by Spanish manufacturer Natural Fire.

The burner is fuelled with almond shells, a very abundant solid biofuel in the area. To cover current energy needs, the boiler consumes between 1,200 and 1,400 kg of almond shells per day. According to the greenhouse manager, alternatives to diesel or natural gas would have made the profitability of the greenhouse unfeasible or very uncertain. With a bulk price of 110 – 150 €/t (delivered at the greenhouse), almond shells achieve cost savings of around 250 €/day compared to heating oil (priced at 0.8 €/liter).

The company has plans to double the greenhouse area and later on to further increase it by another 17,000 square meters. To provide service to this area, a new boiler will be installed, which is already in its facilities, equipped with a 2.5 MW biomass burner.

The boiler and the three pumps that serve the different sectors of the greenhouse are regulated automatically, depending on the required temperature, and can be managed remotely. Boiler and burner cleaning is done manually every 4-7 days. The manufacturer stresses out that regular maintenance of the equipment is essential in order to prolong its useful life.

The cost of an installation of this type – a existing diesel boiler retrofitted with a new biomass burner – can be a very cost-competitive option compared to installing a new biomass boiler.

Figure 35 and 36

(up) Greenhouse boiler with biomass burner 1 MW (front) and another of 2.5 MW (behind) and flowers in the greenhouse (right).

KEYS FOR UTILISATION OF SHELLS

As previously mentioned, to keep low the **MOISTURE** of this fuel is very important to allow an adequate combustion in boilers and stoves. Therefore, a proper storage is imperative in order to avoid that rain increase the water content.

HOMOGENISATION is also key for a good combustion, mainly because of the fines, and to avoid malfunctioning and clogging of feeding systems due to the larger fractions.

Sunflower husks

DESCRIPTION

Sunflowers are cultivated in several parts of the world and they can be divided in two main varieties. Oilseeds, represent the vast majority of the global sunflower production. On average, they contain around 50 % oil and 20 % protein and are primarily used in vegetable oil production. The remains of the seed following oil extraction are known as sunflower meal and due to their remaining protein they are a valuable material for animal feed. Non-oilseeds, also known as confectionary sunflower, are primarily used as human and bird food.

In both varieties, the kernel of the sunflower is enclosed by a hull. The hull is generally dark of color for the oilseed varieties (grayish in some special ones) and more closely attached to the kernel. Non-oil seed varieties have hulls that are whiter in color and more loosely attached to the kernel. Hulls are around 20 – 30 % of the total weight of the seed . and consist mostly of low value fibers with very low protein content so as to be of use as animal meal.

The presence of hulls during the sunflower oil extraction has a negative impact on the quality of both oil and meal, since it increases the concentration of waxes in the former and reduces the content of protein in the latter. Therefore, the dehulling process is often implemented as one of the first steps in many sunflower processing plants. Dehulling is preceded by a drying step, which facilitates the separation of the hull from the kernel.

Sunflower hulls (alternatively referred to as "sunflower husks") are therefore the solid residue of the dehulling process employed by sunflower processing plants. Sunflower hulls have a high energy content, medium ash content and a relatively low price, making them quite popular as a solid biofuel for various applications. When not used on-site at the sunflower processing plants, sunflower hulls are typically pelletized before they are sold in the market, see **Figure 38**.

Figure 37

Anatomy of a sunflower seed. Source: AVEBIOM

POTENTIALS AND DISTRIBUTION IN EUROPE

Compared to other oilseed crops, the sunflower seeds have a low bulk density which limits the distances over which they can be economically transported before processing.

Therefore, the production sites of sunflower hulls are generally closely linked with the cultivation areas of sunflowers.

Russia and Ukraine have an almost equal share of the global production; however better yields are experienced in Ukraine. The EU (as an aggregate) is the third biggest producer of sunflowers in the world, amounting to around 15.9 % of the cultivated area and 18.3 % of the production. There is also sizeable production in Argentina, China, Turkey, USA, Kazakhstan, Moldova and Serbia **(Table 10)**.

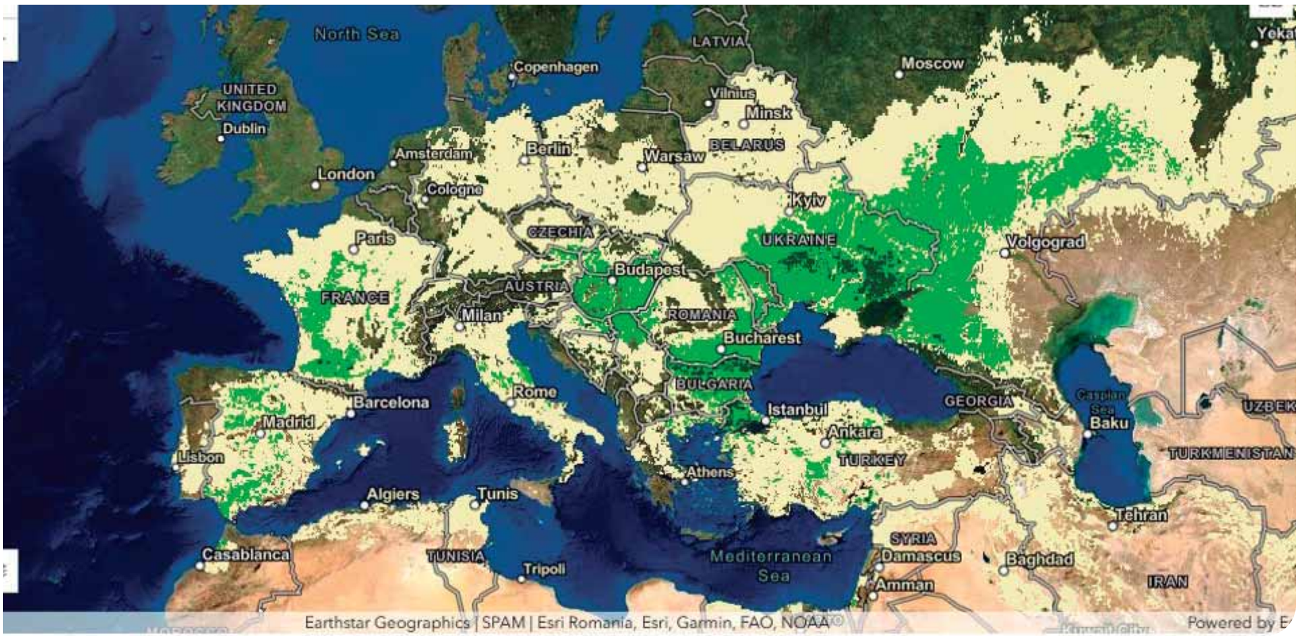


FIGURE 38

Sunflower production areas in Europe (Source: US Department of Agriculture, Foreign Agricultural Service, International Production Assessment Division)

TABLE 10

Top-10 sunflower producing countries in the world (FAOSTAT, 2019).

COUNTRY	AREA (HA)	SHARE / GLOBAL (%)	PRODUCTION (T)	SHARE / GLOBAL (%)
RUSSIA	8,414,731	30.75	15,379,287	27.43
UKRAINE	5,958,900	21.77	15,254,120	27.20
EUROPEAN UNION	4,338,740	15.85	10,281,250	18.34
ARGENTINA	1,875,938	6.85	3,825,750	6.82
CHINA	850,000	3.11	2,420,000	4.32
TURKEY	751,693	2.75	2,100,000	3.75
USA	503,640	1.84	881,530	1.57
KAZAKHSTAN	815,288	2.98	838,710	1.50
MOLDOVA	357,082	1.30	811,442	1.45
SERBIA	219,404	0.80	729,079	1.30
REST OF THE WORLD	3,283,350	12.00	3,551,578	6.32
TOTAL	**27,368,766**	**100.00**	**56,072,746**	**100.00**

Within the EU, around 90.4 % of the production is concentrated in five countries: Romania, Bulgaria, Hungary, France and Spain. Four more countries – Greece, Italy, Slovakia and Croatia – amount to around 8 % of the EU production, while the rest play only a marginal role (**Table 11**).

In general, sunflower enjoys a growing popularity as a crop due to its versatility, consumer and market preferences. Production yields are also on an increasing trend, especially in Eastern Europe.

COUNTRY	AREA (HA)	SHARE / GLOBAL (%)	SHARE / EU (%)	PRODUC-TION (T)	SHARE / GLOBAL (%)	SHARE / EU (%)
Romania	1,282,700	4.69	29.56	3,569,150	6.37	34.72
Bulgaria	815,560	2.98	18.80	1,937,210	3.45	18.84
Hungary	564,110	2.06	13.00	1,706,850	3.04	16.60
France	603,920	2.21	13.92	1,298,140	2.32	12.63
Spain	701,770	2.56	16.17	782,290	1.40	7.61
Greece	100,720	0.37	2.32	298,960	0.53	2.91
Italy	118,520	0.43	2.73	294,730	0.53	2.87
Slovakia	48,550	0.18	1.12	129,670	0.23	1.26
Croatia	35,980	0.13	0.83	106,560	0.19	1.04
Austria	21,250	0.08	0.49	64,540	0.12	0.63
Rest of EU-27	45,660	0.17	1.05	93,150	0.17	0.91
TOTAL EU-27	**4,338,740**	**15.85**	**100.00**	**10,281,250**	**18.34**	**100.00**

Table 11

Top-10 sunflower producing countries in the EU (FAOSTAT, 2019)

Figure 39

Sunflower hull pellets

[Image source: CERTH]

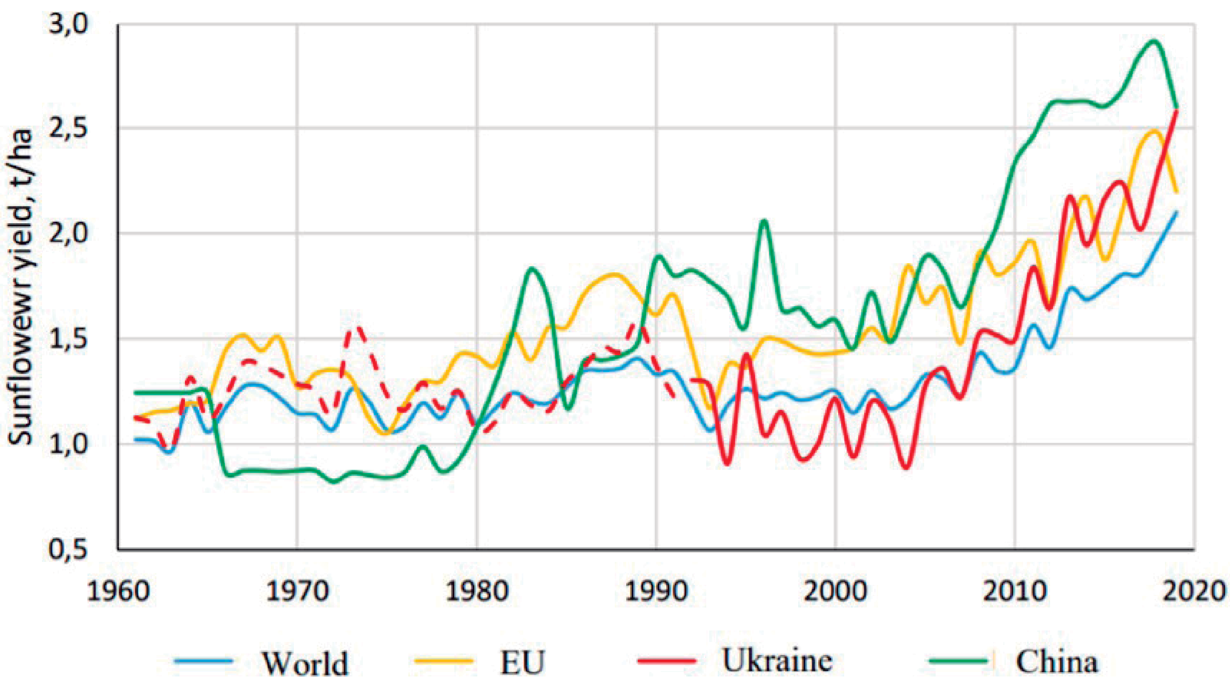
The theoretical biomass potential of sunflower hulls can be calculated from the values above, considering that hulls are approximately 20 – 30 % of the seed weight, while taking into account that the standard moisture content of the sunflower seeds is 9 %. Therefore, the theoretical potential in the world can be expected to be between 10.21 - 15.31 million tons (dry matter), while the EU potential is around 1.87 - 2.81 million tons (dry matter).

The technical potential of sunflower hulls is lower than the theoretical potential for two main reasons. The first is that not all sunflower processing plants apply a dehulling process. The second is that full dehulling does not take place at the industrial scale for technical and economic reasons. On a technical level, a fully dehulled seed are difficult to pre-press; the pre-pressed cake has poor percolation during the solvent extraction step. From an economic perspective, a higher removal rate of the hulls results also in oil losses that cannot be compensated from the higher value of the meal. The difficulty of removing the hulls also varies depending on the sunflower variety. Different sources indicate that the level of hulls that remain in the seed are between 8 and 15 % of the processed seed weight.

The market availability of sunflower hulls also depends on the level of self-consumption by the sunflower processing industries. Most of the sunflower processing plants use a significant share of this residue to cover their own process heat demands; lately, several of the largest plants have implemented investments in biomass CHP systems to partially cover their electricity consumption as well. Moreover, as is the case with all agricultural products, the production level is also influenced by weather and other factors.

Figure 40

Evolution of sunflower seed yield from 1961 to 2019 (Source: FAOSTAT, UABIO)



CHARACTERISTICS: WHERE AND HOW IS IT UTILIZED?

Sunflower oil production is an energy intensive process. The electricity consumption is quoted to be in the range of 96.6 – 198 kWh per ton of oil and the heat consumption (in the form of steam) in the range of 348 – 1184 kWh per ton of oil. As aforementioned, sunflower oil mills combust a significant share of the sunflower hull residue to cover their process heat demands. The largest Ukrainian sunflower oil mills self-consumer around 46 – 48 % of their hull production for steam generation. The largest plants that have adopted biomass CHP systems use an even higher percentage of their hull production – a value of 57.8 % is quoted for a 12.3 MWe / 26.7 MWth system in Ukraine (formerly Kirovogradoliya LLC, currently Kropyvnytskyi Oil Extraction Plant PrAT).

Any sunflower hull quantities that are not self-consumed are typically made available for the market, following a pelletisation (or, more rarely, a briquetting) step. Densification is necessary, since otherwise the hulls have a very low bulk / energy density to be economically transported and stored.

PROPERTY	VALUE	UNIT
Moisture, M	10	w-% a.r.
Ash, A	4.0	w-% d.b.
Net Calorific Value, NCV	15.7	MJ/kg a.r.
Bulk Density, BD	550	kg/m^3 a.r.
Energy Density	2.40	MWh/m^3 a.r.
Nitrogen, N	0.8	w-% d.b.
Sulphur, S	0.1	w-% d.b.
Chlorine, Cl	0.06	w-% d.b.
Calcium, Ca	5.000	mg/kg d.b.
Potassium, K	11.000	mg/kg d.b.
Sodium, Na	50	mg/kg d.b.
Silica, Si	600	mg/kg d.b.

Table 12 presents an indicative fuel composition of sunflower hull pellets. It should be noted that actual characteristics may vary depending on the origin and pre-processing steps - ISO 17225-1 presents a more detailed overview of the fuel composition range for sunflower hulls. In general, the following main points can be made regarding sunflower hull pellets as a solid biofuel:

- The low moisture content and good calorific value, coupled with its relatively low price make it a very attractive and competitive fuel for many applications.

- The ash content is quite higher than the typical wood fuel assortments used for bioenergy production. Sunflower hull ash is high in potassium, which reduces the ash melting temperature, contributes to increased formation of slags and fouling deposits as well as to increased particle emissions during combustion.

- The nitrogen, sulphur and chlorine content is also higher than those of typical wood fuel assortments. During combustion, increased emissions of NOx and SO2 are to be expected. Sulphur and chlorine can also contribute to the formation of corrosion issues.

Table 12

Indicative fuel composition – sunflower hull pellets (Source: AgroBioHeat).

Considering their fuel properties, sunflower hull pellets are most frequently used in medium and large scale systems, typically employing the moving grate technology, for heat and/or power generation.

The relative low cost of sunflower hulls makes them also an attractive fuel for end-users with smaller scale systems: domestic heating, the commercial sector and smaller industries. Due to cost constraints, many of these appliances employ simple, fixed bed combustion systems or have been retrofitted with pellet burners. Sunflower hull briquettes are occasionally even used in small stoves. Typically, these systems exhibit a poor performance when it comes to emissions. More frequently cleaning internals due to the higher ash content of the fuel compared to woody biomass should also be expected. However, with a properly designed, modern combustion system, efficient and low-emission combustion of sunflower hull pellets can also be achieved even in smaller scale systems.

CASE EXAMPLES

USE OF SUNFLOWER HULLS FOR SUNFLOWER OIL EXTRACTION AND POWER PRODUCTION IN UKRAINE

As aforementioned, sunflower oil producers self-consume sunflower hulls for their own energy demands. In Ukraine, there are more than 60 such installations that produce process steam from sunflower hulls. A recent example is the company Agrotrade-2000, which has invested in a steam boiler of 4.5 t/h and a pressure of 14 kg/cm^2. The boiler was designed and constructed by Ukrainian manufacturer Kriger.

In addition, 7 biomass CHP and power plants in Ukraine operating using sunflower hulls and sunflower hull pellets; their total capacity is 55 MWe. The largest such installation to date is the "Ajax — Dnipro" plant which has capacity of 16 MWe. The plant was commissioned in 2020, after a 2-year implementation period. It features two steam boilers of 35 t/h each and steam parameters of 40 kg/cm^2 and 440 °C.

Similar plants have been implemented in other parts of the world where sunflower oil production takes place. A suitable sunflower hull-fired boiler allows producers to reduce their energy costs and greenhouse gas emissions, while also avoiding the disposal of the residue in landfills.

For more information:

AgroBioHeat video on the use of sunflower hull residues in Ukraine: https://www.youtube.com/watch?v=mVuXyjjro9U

Havrysh, V., Kalinichenko, A., Mentel, G., Mentel, U., Vasbieva, D.G. (2020) Husk Energy Supply Systems for Sunflower Oil Mills. Energies 2020, 13(2), 361; https://doi.org/10.3390/en13020361.

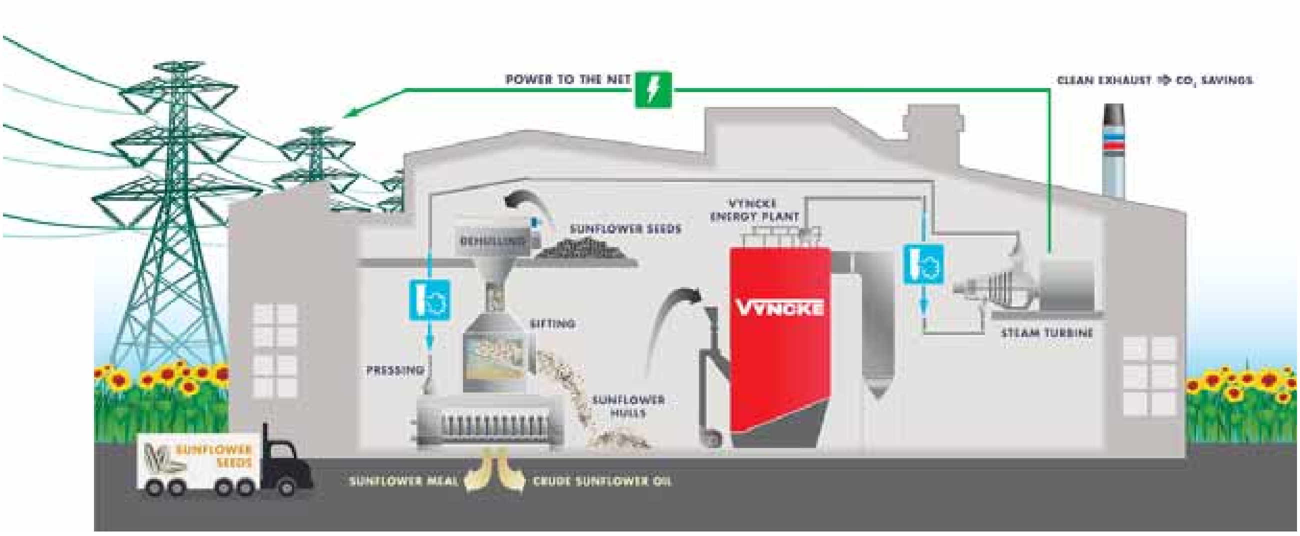


Figure 41

A biomass CHP installation for an Ukrainian sunflower oil refining plant (Source: Vyncke)

USE OF SUNFLOWER HULL PELLETS IN DOMESTIC BIOMASS BOILERS

Within the **AgroBioHeat project**, the combustion performance of sunflower hull pellets – along with several other agrobiomass fuel assortments – has been investigated in a series of tests. The tests were performed under laboratory conditions, using state-of-the-art biomass boilers and a common test procedure following the boiler testing standard EN 303-5.

In particular, sunflower hull pellets were combusted in a 45 kW boiler that employs the innovative extreme air staging concept. With the exception of the NOx emissions – which are linked to the fuel nitrogen content – the emissions of CO, OGC (organic gaseous compounds) and PM (particle matter) were measured to be well below the current limits of the Ecodesign Regulation, as they apply to woody biomass fuels. Good results can also be expected with a properly designed, moving grate furnace – with two additional remarks: a) the boiler should exhibit a good emission performance also during partial load operation, since this affects the seasonal emission factor of the Ecodesign Regulation, b) a secondary system, such as an ESP would be required for the control of the PM emissions in this case.

For more information:

Brunner, T., Nowak, P., Mandl, C., Obernberger, I. (2021) Assessment of Agrobiomass Combustion in State-of-the-Art Residential Boilers. Proceedings of the 29th European Biomass Conference and Exhibition, pages 379 – 388. DOI: 10.5071/29thEUBCE2021-2AO.5.1. Available for download following registration from the following website: http://www.etaflorence.it/proceedings/

GREENHOUSE HEATING WITH SUNFLOWER HULL PELLETS

The competitive advantages of using sunflower hull pellets are clearly demonstrated by the case of AGRIS S.A. in Northern Greece. The company operates a greenhouse nursery facility covering an area of more than three hectares. Space heating represents up to 13 % in the company's production costs. AGRIS installed eight biomass boilers (with a 9.28 MW total capacity in 2012 in order to use a lower-cost alternative compared to fuel oil. Initially using exhausted olive cake, AGRIS switched to sunflower hull pellets because it was considered as a superior fuel with no odour problems. The sunflower hull pellets are imported from Bulgaria and transported via truck to the company and unloaded in a roofed storage area. AGRIS estimates that switching to biomass fuels, has reduced the annual heating bill by 20 - 30 %.

For more information:

Stroia, C., Jansen, J. (2019) Competitiveness of corporate sourcing of renewable energy. Annex A.4 to part 2 of the study on the competitiveness of the renewable energy sector, Case study: AGRIS S.A. DOI: 10.2833/561885. Available online: https://op.europa.eu/s/vdNy

SHOPPING CENTRE HEATED WITH SUNFLOWER HULL PELLETS

Pellets from sunflower hulls offer similar advantages to wood pellets that enable them to be used in applications that are more constrained when it comes to space availability. Such as an example can be found in the shopping mall ACADEM-CITY in Kyiv, Ukraine. Two biomass boilers (500 kW & 320 kW) fuelled by sunflower hull pellets provide space heating for the building, which is located in a purely urban setting. A cyclone system is used to reduce the PM emissions to the atmosphere.

For more information:

Karampinis, M. (2020) AgroBioHeat Deliverable 3.1: Report on identified cases. Available online: https://agrobioheat.eu/wp-content/uploads/2020/10/AgroBioHeat_D3.1_agrobiomass-heating-facilities_v1.0-1.pdf

KEYS FOR UTILISATION OF HUSKS

Generally, sunflower hulls are an attractive option for bioenergy production in various scales: from small and medium scale systems all the way to large CHP and power generation plants. A key advantage of this fuel assortment is that it is already coming in the market in a pelletized form, facilitating transport, storage, handling and feeding.

Some key aspects regarding effective utilization of sunflower hull pellets:

PHYSICAL PROPERTIES OF SUNFLOWER HULL PELLETS. A parameter that seems to affect the market price is mechanical durability. Some sunflower husk pellets appear to be more durable and are less prone to breaking down to smaller particles during handling. Finally, end-users should take note that sunflower hull pellets typically have a diameter of 8 mm, rather than the 6 mm diameter of wood pellets, since this may have an impact on their fuel feeding system.

CHEMICAL PROPERTIES OF SUNFLOWER HULL PELLETS. The sulphur, nitrogen and ash content of sunflower hulls is higher than that of the typical wood biomass assortments. Therefore, the end-user should take note of this and consider whether their heating system is capable of handling the fuel while also keeping the emissions of SO2, NOx and particles within the legal requirements in their area.

BIOMASS COMBUSTION SYSTEM. Generally, sunflower hulls should be combusted in properly designed moving grate systems rather that fixed bed ones due to their high ash content.

TRUSTWORTHY SUPPLIERS. At the moment, there is no independent certification system of the quality of sunflower hulls. Therefore, consumers have to rely on the development of trust relationships with fuel suppliers. The largest fuel suppliers typically provide specifications on at least a few physical and chemical properties of the fuel: typically, calorific value, diameter, moisture, ash and sulphur content. Based on those, end-users can assess whether a shipment is compatible with the specifications of their biomass heating system.

Other residues

GRAPE PIT POWDER

The full grape cake (or grape bagasse) is a residue of wine production. One ton of full grape cake is obtained with a 3,333.33 l wine production and is composed of a mix of stalks, pulp and grape pits (seeds) in variable proportions (25, 55 and 20 % in average respectively). Their characteristics vary significantly depending on the kind of wine produced, grape variety and procedure of separation used.

The grape cake is the full grape cake from which it has been separated the stalks. The pulp is obtained by separating the pits from the grape cake.

The grape pits are composed of a highly lignified integument or covering and a lipid-rich albumen. The grape pits have an oil content of 14 – 18 %, which can be extracted to produce grapeseed oil, a highly valuable commercial oil used primarily for the cosmetics industry. The oil can be extracted from the grape pit either through mechanical extraction or through chemical / solvent extraction, using Soxlet methods and hexane in a similar process similar to the extraction of olive pomace oil. In order to facilitate the extraction, the grape pits can be grinded and pelletized. The residue of this process is call grape pit powder and can be used as a biomass fuel, but also has good properties for use as animal feed.

The format of the grape pit powder is granular, similar to olive cake, although it is common to pelletise it to improve the density and the logistics as it is quite powdery.

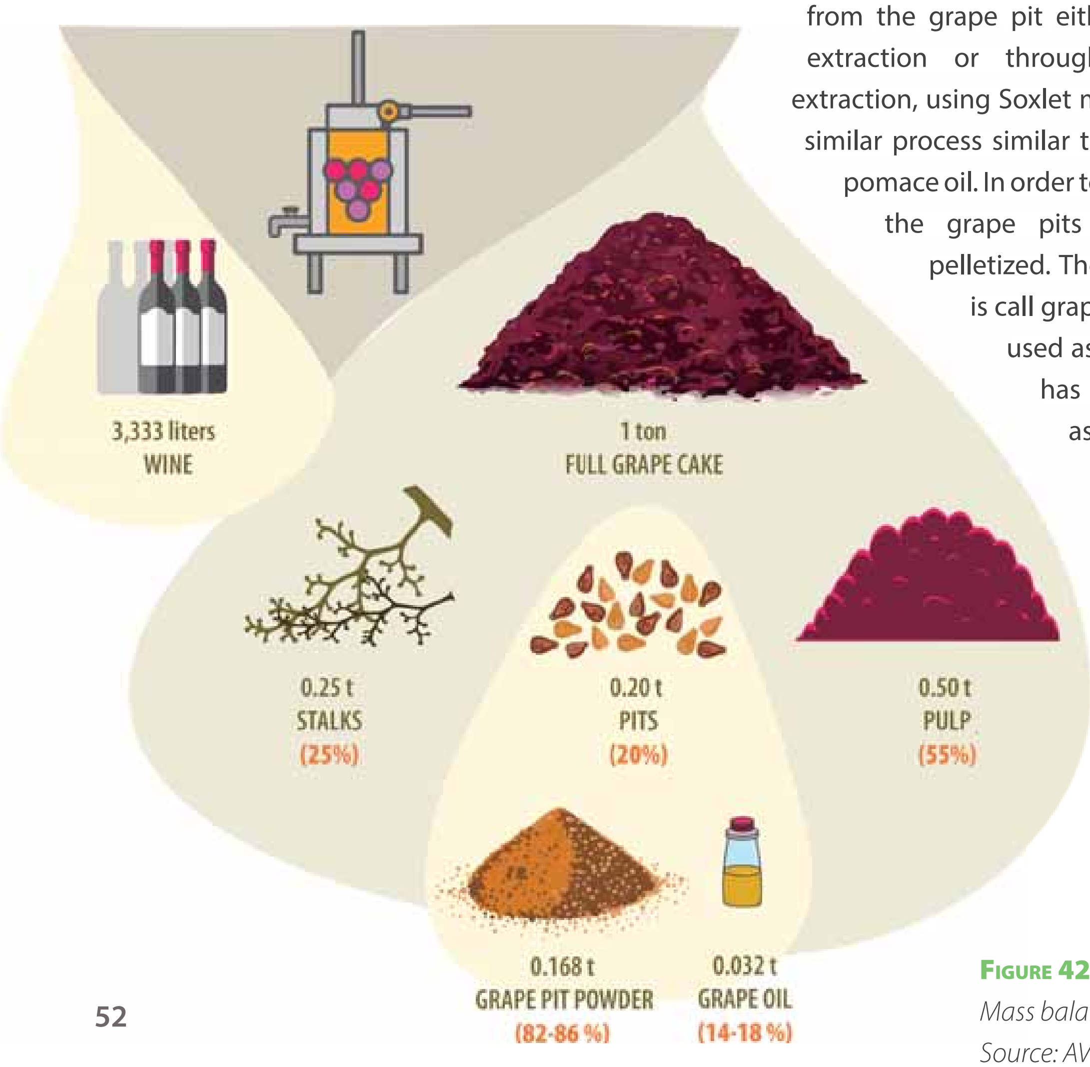


Figure 42

Mass balance of the grape pit powder. Source: AVEBIOM

PARAMETER	TYPICAL RANGE	TYPICAL VALUE	UNIT
Moisture	7 – 15	10	w-% a.r.
Ash	3.5 - 5	4	w-% d.b.
Net Calorific Value	> 16.7	17.4	MJ/kg (a.r.)
Bulk Density *(non-pelletised)*		450	kg/m^3
Nitrogen	1.5 – 2	1.7	w-% d.b.
Sulphur	< 0.2	0.12	w-% d.b.
Chlorine	< 0.1	0.06	w-% d.b.

Table 13

Typical values for grape pit powder. Source: AVEBIOM own elaboration

Considering that the EU wine production in 2019 reached 15.8 billion liters, the theoretical potential of grape pit powder in the EU could reach almost 800,000 tons according to the mass balance of **Figure 42**. However, the actual potential is much lower for a variety of reasons.

First, not all the residues of wine production are used for the production of grapeseed oil. Although there are no comprehensive market data, the grapeseed oil market appears to be quite small compared to its theoretical potential. Second, part of the grapeseed oil production takes place in very small-scale plants, which have limited possibilities to effectively valorise the residue. Third, even among the bigger grapeseed oil producers, a large percentage of the grape pit powder that is produced is used either as animal feed or for their own self-consumption needs in the extraction facilities. At the moment, grape pit powder remains a niche biomass for external markets.

Figure 43 and 44

Grape pit powder and pelletised grape pit powder (Source: AVEBIOM)

SPENT COFFEE GROUNDS

Spent coffee grounds (SCG) is the residue generated from coffee brewing. Considering that less than 1 % of the coffee compounds are extracted during brewing and the volume of coffee consumed globally, it is clear that there are huge amounts of SCG generated each year. Some amounts of SCG are used as a fertilizer after composting and there is a growing interest in using this feedstock in the wider bio-economy scene, e.g. for extraction of valuable compounds. At the moment, the most popular, alternative use of SCG is their use as a fuel for heat generation.

The valorization method for SCG depends heavily on their place and method of production. Larger industries that produce instant coffee generate significant volumes of SCG on-site. Several of them have taken steps to install special biomass boilers that make use of SCG - and if not enough, other biomass fractions as well - to produce steam or hot clean gases for their process. The high moisture content of SCG is an important factor that has to be considered for the boiler design.

For smaller coffee end-users – cafeterias and households - SCG is more of a "food waste" rather than a process residue and it is much more challenging to collect and valorize due to the dispersion of small volumes. However, various initiatives have emerged to that effect.

Bio-bean (www.bio-bean.com) is probably the best known such example: a UK-based company that collaborates with hundreds of cafeterias for the recycling of SCG. In 2021, the company collected 6,400 tons of SCG. The company has launched several different product lines and investigates alternative valorization routes for SCG . Two of its main products are Coffee Logs, a briquette from SCG that is sold in various retailers as an alternative for firewood, and coffee pellets, a product that is targeting mostly the business sector. In Greece, "Kafsimo" (www.incommon.gr/kafsimo) is a community-based project from the non-governmental organization InCommOn that aims to collect SCG from cafeterias in Northern Greece and convert them into biomass pellets.

Pellets made from SCG typically exhibit a slightly higher calorific value compared to standard wood pellets. Their ash content is typically around 2 %-w (dry basis), which is relatively low compared to other industrial solid biofuels. However, in order to achieve a higher mechanical durability, SCG have to be mixed with either an additive or another lignocellulosic feedstock. In addition, SCG pellets typically exhibit higher sulphur and chlorine contents compared to wood pellets.

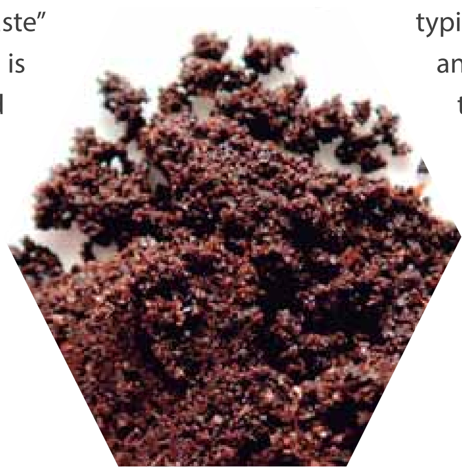


Figure 45

Spent coffee grounds. Source: AVEBIOM

FRUIT STONES

Fruit stones – also known as drupes – include fruit varieties with a hard "stone" endocarp that contains the seed. This fruit category includes almonds and olives, but also peaches, apricots, plums, cherries and the like. In this section, we focus on the latter group, from which the stone can be extracted by agro-industries that produce jams, compote or juices. Since the stone may be a significant percentage of the total fruit weight, these agro-industries accumulate significant volumes of these stones during their production periods and can further valorized them as solid biofuels. In theory, it would also be possible to use the stones generated from stone fruits consumed in the food market, however, their dispersion does not make this concept economically viable.

STONE FRUIT TYPE	% IN WEIGHT OF THE ENDOCARP (PIT)
Apricot	10%
Cherry	8%
Peach	15%
Plum	4%

Table 14

Percentage in weight of the endocarp of several fruits

PARAMETER	TYPICAL RANGE	TYPICAL VALUE	UNIT
Moisture	< 18	14	w-% a.r.
Ash	< 3	1.8	w-% d.b
Net Calorific Value	> 16,750	18,840	KJ/kg (a.r.)
Nitrogen		0.8	w-% d.b
Sulphur		0.035	w-% d.b

Table 15

Typical values for peach pits. Source: AVEBIOM own elaboration with Muns Agroindustrial and Phyllis' data

Fruit stones can be found in the market as "whole" pit (see **Figure 45**) and that can be used in more industrial boilers with big enough input systems and also crushed (see **Figure 46**) that can be used in smaller boilers but due to their high calorific value the feeding rhythm has to be lowered.

Greece is an EU leader in the production of peach compote. Peach stones are produced in significant quantities by the peach canning plants and in the past were available in local markets as solid biofuels. However, most of the largest canning plants have now installed biomass boilers that aim to cover – at least to a significant extend – their process heat requirements. As a result, almost all the peach stones are now self-consumed by the canneries and only limited quantities – if any – can be found on the market.

Figure 46 and 47

Whole peach pits and crushed peach pits

Source: Muns Agroindustrial

RICE HUSKS

Rice husks are the outer coating of the rice grains – also referred to as paddy rice – and are removed through milling. On average, the husk is around 20 % of the rice grain's weight. After milling, the brown rice can be further processed for the removal of the bran layer, which is another 10 % of the rice paddy grain. Bran is primarily used as an animal feed, while rice husk is increasingly being exploited for energy production.

With an estimated global production of 758 million tons of paddy rice, it is clear that the potential of this agro-industrial residue is huge. The vast majority of the world's rice production takes place in Asian countries. The EU annual production of paddy rice is around 2.8 million tonnes of paddy rice - around 1.7 million tonnes of milled equivalent rice. Production primarily takes place in Italy, but there are also cultivation centres in Spain, Greece, Portugal and a few other European countries.

Rice husks are an obvious energy source for rice mills, which require thermal energy in the form of hot water or steam for two main processes: the seasonal drying of the rice paddy and the continuous parboiling. The produced quantities can in fact meet the thermal energy demand of a typical rice mill and left-over qualities may be sold on the market as a solid biofuel or even find other, non-energy applications.

Compared to the other agro-industrial residues discussed in this guide, rice husks have two distinct characteristics. First, they have a very high ash content, which can reach up to 18 to 20 % weight (dry basis). Second, most of the rice husk ash is composed primarily of silica. The increased concentration of silica is what gives rice husk its distinct hardness and causes problems in processing machines, such as conveyors and mills. On the other hand, this gives an economic value for the rice husk ash, which can be used as a raw material for the concrete and steel industries, as well as other potential applications.

COTTON GINNING RESIDUES

The EU production of cotton is only 1 % (around 340,000 t in 2018) of the global one. However, cotton is a very important crop on a regional level, primarily in Greece – which amounts to 80 % of the EU production – and to some areas of Spain and Bulgaria.

After harvesting, seed cotton is transported to ginning plants, which separate the seed from the ginned cotton itself. The cotton seed can be used directly as animal feed, but it can also be processed for the production of cotton seed oil and cotton meal; the former can be used for various applications, including biodiesel production, while the latter is used an animal feed.

Around 10 % of the seed cotton weight remains as a fibrous residue at the cotton ginning plants. This material has a high ash content (15 w-% dry basis or more), but is sufficiently dry to be exploited as a solid biofuel, with a NCV of around 14.6 MJ/kg (moisture content of around 13 %).

Several cotton ginning plants in Greece self-consume this residue for steam production, used in various processes of the plant (cotton drying, cotton seed oil production, etc.). In 2014, a 1 MWe biomass CHP plant was built in Northern Greece, using cotton ginning residues and other local biomass assortments as fuels.

CORN COBS

Occasionally, grain maize is harvested together with the cob, from which it is separated in smaller or larger facilities. Corn cobs may therefore be a relevant biomass residue from an agro-industrial practice in these environments. In such instances, it can be used on-site, e.g. for drying the maize grain, and leftovers quantities can be made available to the market.

The ash content of maize cobs is quite low (around 2 % weight dry basis), which at first glances makes them a very interesting fuel. However, the key issue is the very high potassium content in the ash, which lowers the ash melting temperature and can create severe issues with slagging. On medium-scale systems, the combustion of maize cobs is possible through the application of specific technologies that mitigate such problems. More information on maize cob fuel properties and combustion peculiarities can be found on the dedicated guide of the AgroBioHeat project on "Maize Residues to Energy".

IMPORTED AGRO-INDUSTRIAL RESIDUES

Beyond the different agro-industrial residues generated within Europe, agro-industries located in other continents process different agricultural products and produce large quantities of residues. Some of the most relevant one are Palm Kernel Shells (PKS) and Palm Kernel Expeller (PKE), both residues from the palm oil industry, Cacao Shells from, a residue of the cacao processing, and sugarcane bagasse, a residue of the sugarcane industry.

Since these residues are generated out of Europe, they are not considered in-depth for this Guide. However, it should be noted that many such assortments are attracting interest in Europe, Asia and elsewhere, primarily as a fuel for displacing coal in industrial applications and power generation.

Figure 48

Seed cotton at a cotton ginning plant (Source: G&P Cotton Ginners S.A.)

Figure 49

Cotton ginning residues fed into a 1 MWe CHP plant (Source: Philippopoulos Energy Trchnical S.A.)

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Centre for Research and Technology Hellas (CERTH) is one of the leading research centres in Greece. Among its areas of expertise, activities in renewable energy sources, solid biofuels production and utilization, energy saving and environmental protection are included.

www.certh.gr

AVEBIOM is the Spanish Bioenergy Association which represents all the companies of the whole supply chain of the bioenergy in Spain.

www.avebiom.org

BIOS is an Austrian R&D and engineering company with more than 20 years of experience in the field of energetic biomass utilisation.

www.bios-bioenergy.at

Bioenergy Europe (formerly known as AEBIOM) is the voice of European bioenergy. It aims to develop a sustainable bioenergy market based on fair business conditions.

www.bioenergyeurope.org

Food & Bio Cluster Denmark is the national Danish cluster for food and bioresources. We promote increased cooperation between research and business and offer our members one-stop-shop access to networks, funding, business development, projects, facilities and offer various consultancy services.

www.foodbiocluster.dk

Technology Centre funded in Spain in 1993, seeking to provide innovative solutions in the field of energy for a sustainable development.

www.fcirce.es

INASO-PASEGES is a civil non profit organisation, established in 2005 in Athens by the Panhellenic Confederation of Unions of Agricultural Cooperatives (PASEGES).

www.neapaseges.gr

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The Green Energy Cooperative (ZEZ) was established in 2013 as part of the project "Development of Energy Cooperatives in Croatia" implemented by the United Nations Development Program (UNDP) in Croatia.

www.zez.coop

The Cluster's main purpose is to develop the bioenergy sector in Romania and raising the interest towards the production and utilization of the biomass.

www.greencluster.ro

UABIO was established in 2013 as a public organisation. The purpose of the Association's activity is to create a common platform for cooperation on the bioenergy market of Ukraine.

www.uabio.org

AILE is working on renewable energies and energy savings in agricultural and rural areas of Western France.

www.aile.asso.fr

White Research is a social research and consulting enterprise specialising in consumer behaviour, market analysis and innovation management based in Brussels.

www.white-research.eu

Agronergy is a French ESP (Energy Service Provider) dedicated to Renewable Heating.

www.agronergy.fr

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