BIOma sudplus

GUIDELINES FOR ASSESMENT OF APPROPRIATE PERFORMANCE CONDITIONS OF SMALL DOMESTIC HEATING APPLIANCES WITH RELEVANT MEDITERRANEAN SOLID BIOFUELS

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1. INTRO DUCTION

A significant market of solid biofuels for heating applications in the residential sector exists in most of the Mediterranean countries, principally in Italy and Spain. In most of Mediterranean countries, in addition to wood pellets and chips a number of solid biofuels derived of typical Mediterranean biomasses are utilised being olive stones the most important of them. However, the use of these biofuels is generally made out of quality standards and often in appliances which have not been designed for those fuels. In addition, some typical and important Mediterranean biofuels, like the cited olive stones and nut shells, are not classified in the standard ISO 17255:2014 which does not contribute to improve the modern market of these products. Moreover, a number of biomasses of widespread production in the Mediterranean countries have been identified to have a large potential as feedstocks for the production of fuels for residential sector in those.

In recent years specific quality classification standards for olive stones and some types of nutshells have been elaborated in Spain, and different manufacturers have developed appliances which have been tested or can be suitable (e.g. for high ash content fuels) for the Mediterranean biofuels which is fostering the use of these fuels, particularly in those countries where the market is more developed. But new elements, such us the Eco-design Directive which will enter into force for all EU countries shortly have put in scene new challenges that must be addressed for the small combustion installations.

In the present context, these Guidelines have the objective to assess the suitability of state-of-the-art small scale biomass combustion technologies utilizing typical Mediterranean biofuels in regard to operational performance and efficiency of the devices and the requirements in terms of emissions of the Eco-design Directive and to identify improvements in order the appliances to comply that Directive. Secondary, it is objective of the Guidelines the evaluation of the suitability of some high potential Mediterranean biofuels to be used in residential heating appliances.

It is important to remark that all recommendations given in these Guidelines are based on the combustion tests results obtained with a reduced num-

ber of state-of-the-art stoves and small residential boilers and with some selected Mediterranean biofuels.

These Guidelines have been developed in the framework of the H2020 Biomasud Plus project (http://biomasudplus.eu/) ("Developing the sustainable market of residential Mediterranean solid biofuels") which overall goal is to develop integrated solutions to promote the sustainable market for Mediterranean solid biofuels for residential heating.

2. BACK GROUND

2.1. Mediterranean solid biofuels

One of the distinguishing features of the southern Europe countries is their floristic diversity, both in the forest-natural and agricultural areas. The diversity of species generates a great variety of biomass which is used or can potentially be used to produce a large variety of biofuels. Wood pellets, wood chips, olive stones, fruit kernels and a diversity of fruit shells (almond, walnut, hazelnut, pistachio, and pine nut) can be highlighted.

Within the Biomasud Plus project, seven countries in southern Europe (Croatia, Greece, Italy, Portugal, Slovenia, Spain and Turkey) have reported information about solid biofuels marketed in each country [Bados et al]. This information shows that the most commercialised solid biofuels are firewood (25.3 Mt/y) and wood chips (8.7Mt/y) followed by wood pellets with 4.5 Mt/y. On the other hand, typical Mediterranean biofuels, principally olive stones, are being widely commercially used as domestic fuels in some countries (about 0.2Mt/y), and agricultural pruning from olive trees and vineyards are reported as biomasses with high potential for solid biofuels production in that sector. Table 1 shows the production of these materials in different Mediterranean countries.

Table 1. Pruning biomass with potential interest in Biomasud Plus project countries (source: Eurostat 2014)

COUNTRY	Vineyard pruniung (t DM/y)	Olive tree pruning (t DM/y)
Croatia	41.262	4.420
Greece	520.156	1.178.489
Italy	2.079.240	981.835
Portugal	245.664	227.685
Slovenia	28.284	405
Spain	1.866.498	2.288.895
Turkey	1.252.500	884.000
Total	**6.033604**	**5.565.729**

t DM/y: tons of dry matter per year

2.2. European standards and legislation

2.2.1. Solid biofuels standars

Solid biofuels quality classification standards are below described including relevant comments related to Mediterranean biofuels.

ISO 17225:2014 "Fuel specifications and classes" defines the specifications to be fulfilled by biomass fuels in order to be classified. In this sense, the standard is divided into 7 parts:

- ISO 17225-1:2014: General requirements.
- ISO 17225-2:2014: Graded wood pellets. In this part, wood pellets are classified as A1, A2 or B.
- ISO 17225-3:2014: Graded wood briquettes. Where the classes considered for wood briquettes are: A1, A2 and B.
- ISO 17225-4:2014: Graded wood chips. Three classes are stated for chips: A1, A2, B1 and B2.
- ISO 17225-5:2014: Graded firewood. Where firewood is classified as A1, A2 or B.
- ISO 17225-6:2014: Graded non-woody pellets. In this part, non-woody pellets are classified as A or B.
- ISO 17225-7:2014: Graded non-woody briquettes. Two classes are considered for non-woody briquettes: A and B.

The quality of some important Mediterranean biofuels, like olive stones and nut shells is not graded by this standard. Vineyard pruning and olive tree pruning derived biofuels, some of the Mediterranean biofuels with larger potential (Table 1), are not within some of the limits established for the corresponding quality classes in this standard.

In Spain there are specific standards for olive stones and some types of fruit shells. They are: **UNE 164003:2014** "Solid biofuels. Fuel specifica-

tions and classes. Graded olive stones" and **UNE 164004:2014** "Solid biofuels. Fuel specifications and classes. Graded fruit shells". Class types A1, A2 and B are established in both standards.

2.2.2. European standars and legislation on biomass heating systems for the domestic sector and their relation with the mediterranean biofuels

2.2.2.1. The EN 303-5:2012 Standard for biomass boilers

The EN 303-5:2012 standard specifies requirements and test methods for safety, combustion quality, functional characteristics, labelling and maintenance of central heating boilers with solid fuels (including solid biofuels) with maximum nominal thermal power up to 500 kW. Local heating installations, such as fireplaces or stoves and condensing boilers are not included in the scope of the EN 303-5:2012.

The solid fuels defined in this standard to be used in the boilers are: fossil fuels, biogenic fuels and other fuels such as peat, as specified for their use by the boiler manufacturer. Biogenic fuels are categorised as log wood (A), chipped wood (B1 and B2), pellets (C1), briquettes (C2), sawdust (D) and non-woody biomass, such as straw, miscanthus, reeds, kernels and grains (E). Taking into account this classification and the specifications stated by the EN-ISO 17225 standard, Mediterranean biofuels could be included as A, B1, B2, C1, C2 or E fuels.

On the other hand, the EN 303-5 standard defines the test fuel as "a fuel of commercial quality which is used for testing heating boilers and which is characteristic of the type of fuel specified by the boiler manufacturer". The standard specifies that for the installation and operation of boilers using fuels of class E, national regulations might give rules in

which test fuels cover commercial fuels, as available in the relevant country and that criteria might be also different regarding calorific value, moisture content, ash content, bulk density and elemental content.

2.2.2.2. EN Standards for biomass stoves

EN 13240:2001 + A2:2004 "Roomheaters fired by solid fuel – Requirements and test methods" (incorporating corrigenda September 2003, June 2006 and August 2007) specifies requirements relating to the design, manufacture, construction, safety and performance (efficiency and emission) instructions and marking together with associated test methods and test fuels for type testing residential roomheaters fired by solid fuels. This standard is applicable to non-mechanically fed appliances which provide heat into the space where they are installed. Additionally, where fitted with a boiler, they also provide domestic hot water and/or central heating. This standard is not applicable to appliances with fan assisted combustion air.

With regard to the fuels, the considered appliances may burn either solid mineral fuels, peat briquettes, natural or manufactured wood logs or be multi-fuel in accordance with the appliance manufacturer's instructions. The test fuel must be selected among the commercial quality fuels specified by the manufacturer and established in a table shown by the standard. In this table, only wood logs (beech, birch or fir) appear as biogenic fuels, so that typical Mediterranean biofuels cannot be considered as test fuels.

Other types of inset appliances are covered by **EN 13229:2001** "Inset appliances including open fires fired by solid fuels – Requirements and test methods", where the test fuels are the same as in EN 13240:2001.

EN 14785:2006 "Residential space heating appliances fired by wood pellets – Requirements and test methods" specifies requirements relating

to the design, manufacture, construction, safety and performance (efficiency and emissions), instructions and marking together with associated test methods and test fuels for type-testing residential space heaters fired by wood pellets, and mechanically fed up to 50 kW nominal heat output. These appliances may be freestanding or inset appliances and provide heat into the space where they are installed and may be operated with either natural draught or fan-assisted combustion air. Additionally, where fitted with a boiler, they also provide domestic hot water and/or central heating.

These appliances use wood pellets only, in accordance with the appliance manufacturer's instructions and they operate with firedoors closed only. The test fuel must be selected among the commercial quality fuels specified by the manufacturer and it must be pellets without additives, made of wood and/or bark particles, where natural binding agents such as molasses, vegetable paraffins and glucose can be used. Considering the specifications of the test fuel stated by the standard, it can be observed that some Mediterranean biofuels, previously pelletised, could be used as test fuels whenever the ash content is controlled.

2.2.2.3. The Eco-design Directive

The European Union's Eco-design Directive (Directive 2009/125/EC) establishes a framework to set mandatory ecological requirements for energy-using and energy-related products sold in all 28 Member States. The EU Ecodesign Directive covers all energy-related products sold in the domestic, commercial and industrial sectors, with the exception of all means of transport.

The Eco-design Directive sets only the frame; specific implementing measures for a particular product group ("Lot") are elaborated in a subsequent process. The specific Regulation for the Eco-design requirements for Lot 15 (biomass boilers) and Lot 20 (solid fuel local space heaters) were adopted by the Commission in April 2015.

Commission Regulation (EU) 2015/1189 of 28 April 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to eco-design requirements for solid fuel boilers

Without prejudice to Directive 2010/75/EU of the European Parliament and of the Council, this Regulation establishes eco-design requirements for placing on the market and putting into service solid fuel boilers with a rated heat output of 500 kW or less, including those integrated in packages of a solid fuel boiler, supplementary heaters, temperature controls and solar devices as defined in Article 2 of Delegated Regulation (EU) 2015/1187. This Regulation shall not apply to non-woody biomass boilers and its fulfilment will be compulsory by 1st January 2020. This aspect leaves out some biofuels, including some typical Mediterranean biofuels, which are considered non-woody biomass by the Regulation. This includes, among others, straw, miscanthus, reeds, kernels, grains, olive stones, olive cakes and nut shells); however, this Regulation shall be reviewed no later than 1st January 2022 and this revision will include, inter alia, non-woody biomass boilers.

Regarding the fuels, two concepts are used in this Regulation:

- "Preferred fuel: single solid fuel which is to be preferably used for the boiler according to the manufacturer's instructions".
- "Other suitable fuel: solid fuel, other than the preferred fuel, which can be used in the solid fuel boiler according to the manufacturer's instruction and includes any fuel that is mentioned in the instruction manual for installers and end users, on free access websites of manufacturers, in technical promotional material and in advertisements".

All the requirements (concerning efficiency and emissions) will have to be met for the preferred fuel and for any other suitable fuel. These fuels (preferred or any other suitable) can be: log wood with moisture content 25%, chipped wood with moisture content 15-35%, chipped wood with

moisture content > 35%, compressed wood in the form of pellets or briquettes, sawdust with moisture content 50%, other woody biomass, bituminous coal, brown coal (including briquettes), coke, anthracite, blended fossil fuel briquettes, other fossil fuel, blended biomass (30-70%) / fossil fuel briquettes, other blend of biomass and fossil fuel.

Commission Regulation (EU) 2015/1185 of 24 April 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for solid fuel local space heaters.

This Regulation establishes ecodesign requirements for the placing on the market and putting into service of solid fuel local space heaters with a nominal heat output of 50 kW or less. This Regulation shall not apply to solid fuel local space heaters that are specified for the combustion of non-woody biomass only and its fulfilment will be compulsory by 1st January 2022. This aspect leaves out some Mediterranean biofuels which are considered non-woody biomass, as happened with the Regulation concerning solid fuel boilers.

All the requirements (with regard to efficiency and emissions) will have to be met for the preferred fuel and for any other suitable fuel, concepts defined similarly in the Regulation concerning solid fuel boilers.

2.3. Commercial biomass stoves and boilers

The information given in this section reflects the main results of a domestic heating systems market study carried out within the Biomasud Plus project on small domestic sector combustion appliances for residential sector [Violidakis et al.]. The study shows information provided by partners in Bio-

masud Plus project on appliances produced by national manufacturers that can be suitable for Mediterranean biofuels.

2.3.1. Croatia

According to the study published by the Croatian Bureau of Statistics [Croatian Bureau of Statistics], wood is the most used source of energy for heating in households and services; being the pellets, briquettes and chips the fuel used only in a 1.1% of the total biomass combustion appliances for heating. The remaining 98.9% corresponds to wood logs.

In the Croatian market there are a few national manufacturers of biomass heating systems and they produce only stoves and boilers for wooden biomass, because in this country there is not demand for heating systems with focus on Mediterranean biofuels.

2.3.2. Greece

Boilers are the most common heating system in Greece (71.12%) followed by stoves (11.61%), portable electric heaters (5.20%), air-conditioning split units (5.17%), fireplaces (4.31%) and others (electric thermal storage systems, district heating pumps) [Hellenic Statistical Authority, 2013].

Interviews with boiler manufacturers suggest that the main market for biomass boilers in Greece is the single-family houses one, with capacities up to 30 kW. This market supposes around 90% of the total sales.

Among biomass heating systems manufacturers in Greece, the following four main manufacturers were contacted in order to obtain information: N. Samaras, Kombi-Thermodynamiki, Thermostahl and Nitadoros. All of

them produce boilers with a range of nominal thermal load between 18 and 814 kW which can use, inter alia, Mediterranean fuels (such as olive stones or almond shells) in some cases.

2.3.3. Italy

In 2014 the thermal energy produced by solid biomass in Italy was 273,000 TJ (corresponding to 6.52 Mtoe) [GSE, 2015] and 97% of the solid biomass used for thermal energy purposes was delivered to residential users, where there are installed more than 11,000,000 stoves and 500,000 boilers. Although pellet stoves are increasing their share, 80% of domestic stoves are fed with wood logs.

The number of biomass boilers and stoves manufacturers is large, but there are only three companies which include top performance systems designed to burn Mediterranean fuels: CS Thermos, D'Alessandro Termomeccanica and Pasqualicchio. They produce stoves and boilers with a range of nominal thermal load between 9.04 kW and 92 kW which can use different fuels, like wood pellets, wood chips, shells (almond, hazelnut, others), olive stones and olive cake.

2.3.4. Portugal

According to the 2010 Survey on Energy Consumption in Households [INE, I.P. and DGEG], concerning the period between October 2009 and September 2010, electricity was the main source of energy consumed in households, representing 42.6% of the total energy consumption and firewood was the second one, with 24.2%. Considering the main sources of energy used for space heating, the first one was biomass, followed by heating oil, electricity and LPG.

The market research on biomass combustion systems showed three national manufacturers whose boilers can use Mediterranean fuels: Solzaima, Torbel and Ventil. All of them produce boilers with a range of nominal thermal load between 18 kW and 6 MW which can use different fuels, such as wood pellets, wood chips, olive stones or nut shells, inter alia.

2.3.5. Slovenia

In Slovenia, biomass is an important source of energy and households are the largest consumers of wood fuels with a total of 1.24 million tons in 2015 (Energy balance of the Republic of Slovenia, 2015). According to the structure of final energy consumption by end use for space heating performed by the Statistical Office of the Republic of Slovenia (SORS) in 2016, wood fuels represent 50.2% of final energy consumption for space heating, water heating and cooking in households.

Biomass combustion plants market in Slovenia is very dynamic and seven manufacturers fulfilling conditions of Eco Fund have been identified. However, none of them showed Mediterranean fuels as alternative fuels for their combustion appliances.

2.3.6. Spain

According to the National Observatory of Biomass Boilers (ONCB) database, where information on biomass for heating systems in Spain has been collected by AVEBIOM (Spanish Biomass Association) since 2009, the number of estimated biomass appliances installed is 160,000 until the end of 2015, which corresponds to an installed capacity of 7,275 MW.

Approximately one hundred Spanish manufacturers of small to medium scale biomass combustion devices have been identified. Some of these ma-

nufacturers (up to 500kW), were requested for detailed information about their relevant products: Biocurve, Bronpi, Carsan, Domusa, Industrias Hergom, Intecbio, LASIAN Tecnología del Calor, Natural Fire and Tubocás. They produce boilers with a range of nominal thermal load between 10.1 and 250 kW which can use different fuels, such as high and low quality pellets, fruit stones (olive, apricot, peach), fruit shells (almond, hazelnut, walnut) or wood logs. One of them (LASIAN Tecnología del Calor) produces stoves (10.4-12 kW) which can burn high and low quality pellets, crushed husks and olive stones.

2.3.7. Turkey

From 1985 up to now, the usage of natural gas in residential sector has increased remarkably at the expense of petroleum liquid products and coal. On the other hand, according to the Turkish Statistical Institute, the share of renewable energy in residential sector has been increasing from almost 0% to 5% since 2005. The initiation of governmental support for purchase of biomass heating systems might promote solid biofuel use in Turkey.

There are eight biomass combustion system manufacturers in Turkey, but only three of them produce boilers which can burn Mediterranean fuels: Kozlusan Heating Systems, Ozerteknik (Ifyil) and Yakar Soba (Karmasan). These boilers have a nominal thermal load between 23 and 1161 kW and can use different fuels, such as coal, wood pellets, olive husk, olive husk pellets, olive stones, olive pomace, hazelnut shells and apricot and peach stones.

2.4. Selection of biofuels and tecnologies for testing

2.4.1. Selection and characterisation of biofuels for testing

Taking into account a widespread production in the Mediterranean area and the actual and potential market as fuels in residential sector, according to inputs from partners in Biomasud Plus project [Bados et al.], three biofuels were selected to be tested in different combustion small appliances: olive stones, vineyard pruning pellets and olive tree pruning pellets. In Figure 1 pictures of the selected fuels and the pruning biomass feedstock are shown.

Olive stones are widely used today as fuels in the domestic sector in countries like Spain, Portugal and Italy, while pellets and chips from vineyard and olive tree pruning were considered by Biomasud Plus project partners to have a large potential in that market. This was the reason to be selected for testing despite they do not most generally comply with the limits in the ISO quality standard for some relevant parameters.

Figure 1. Mediterranean biofuels. From left to right and from top to bottom: olive stones; olive tree pruning; olive tree pruning pellets; vineyard pruning; vineyard pruning pellets.

Table 2 shows the characterisation results of the biofuels used during the combustion tests carried out. The following codes are used: OS – olive stones, OTP – olive tree pruning pellets, VP – vineyard pruning pellets.

The olive stones fulfilled the limits established for class A2 of the standard UNE 164003:2014. Both types of pruning pellets were in general within the typical average values for these biofuels. However, the olive tree and vineyard pruning show significantly increased ash contents with respect to limits established in ISO 17225-2:2014 (0.7% for class A1, 1.2% for A2 and 2.0% for B). Moreover, they also show higher nitrogen, and in most of cases sulphur and copper contents compared to the limit values established

Table 2. Characterisation of Mediterranean biofuels used during the combustion tests

	OS	OPT	VP
Moisture (wt. % w.b.)*	9.8	8.4	10.4
Ash (wt. % d.b.)	0.8	4.6	4.3
Bulk density (kg/m^3)*	800	590	630
Mechanical durability (wt. %)*	n.a.	97.6	98.5
Fines < 1 (wt. %)*	0.15	0.8	1.1
Fines < 2 (wt. %)*	14.9	n.a.	n.a.
NCV (MJ/kg) (d.b.)	19.0	18.3	17.8
Nitrogen (wt. %, d.b.)	0.21	0.69	0.62
Sulphur (wt. %, d.b.)	0.02	0.07	0.05
Chlorine (wt. %, d.b.)	0.02	0.02	0.01
Oil content (wt. %, d.b.)	0.24	n.a.	n.a.
Skin content (wt. %, d.b.)	2.0	n.a.	n.a.
Arsenic, As (mg/kg, d.b.)	< 0.4	< 0.4	< 0.4
Cadmium, Cd (mg/kg, d.b.)	< 0.10	< 0.10	< 0.10
Chromium, Cr (mg/kg, d.b.)	< 1.0	1.0	1.4
Copper, Cu (mg/kg, d.b.)	2.3	45	7.8
Lead, Pb (mg/kg, d.b.)	< 1.0	< 1.0	< 1.0
Mercury, Hg (mg/kg, d.b.)	0.001	0.012	0.001
Nickel, (mg/kg, d.b.)	1.0	< 1.0	1.0
Zinc, (mg/kg, d.b.)	< 5.0	11.7	17

**: as received. Fines < 1: fines content below 1 mm; Fines < 2: fines content below 2 mm; NCV: net calorific value; wt.%: weight %;w.b.: wet basis; d.b.: dry basis; n.a.: not applicable.*

in ISO 17225-2:2014. For the case of olive tree pruning in general, the analytical studies carried out within the Biomasud Plus project have revealed the possibility to obtain products with reduced ash, nitrogen, sulphur and copper contents by discarding the leaf fraction during collection and preparation of the biomass prior to pelletisation [Barro et al.]. Such pellets may, with the exception of a slight deviation of the lower limit regarding the calorific value, be classified as class B pellets in ISO 17255-2:2014.

2.4.2. Combustion technologies tested

Considering the above mentioned market study on domestic heating devices suitable for Mediterranean biofuels, three stoves and three boilers which, according to manufacturer's information, could be suitable for combustion of olive stones, olive tree pruning pellets and vineyard pruning

Table 3. Characteristics of the stoves used in combustion tests within the Biomasud Plus project

	Stove I	Stove II	Stove III
Nominal load (kW)	10.4	21.2 18.4 to water cycle and 2.8 to the room	10
Efficiency declared by manufacturer (1)	89%	88%	90%
Water jacket	No	Yes	No
Fuel feeding to the fuel bed	From above	From above	From above
Grate technology	Moving grate	Fixed grate	Moving grate
De-ashing of the burner	Automatic	Manual	Automatic
Cleaning of heat exchanger surfaces	Manual	Manual	Manual
Combustion air flows	Primary air Window purge air	Primary air Window purge air	Primary air Secondary air Window purge air
Control system	Automatic combustion control	Automatic combustion control	Automatic combustion control

(1) With wood pellets EN ISO 17225-2 class A1

pellets, have been selected. The appliances were manufactured in Austria, Greece, Italy and Spain.

The main characteristics of the selected combustion appliances are shown in Tables 3 and 4.

Table 4. Characteristics of the boilers used in combustion tests within the Biomasud Plus project

	Boiler I	Boiler II	Boiler III
Nominal load (kW)	25	28	40
Class according to the EN 303-5	Class 5	Class 3	Class 5
Efficiency declared by manufacturer (1)	95%	80%	95%
Fuel feeding to the fuel bed	Underfed stoker	Underfed stoker	Horizontal stoker
Burner	Moving grate	Fixed grate	Moving grate
De-ashing of the burner	Automatic	Manual	Automatic
Cleaning of heat exchanger surfaces	Manual	Manual	Manual
Combustion air flows	Primary air Secondary air	Primary air Secondary air	Primary air Secondary air
Control system	Automatic combustion and load control	Manual	Automatic combustion and load control

(1) With wood pellets EN ISO 17225-2 class A1

3. RESULTS OF THE BIOMASUD PLUS PROJECT: COMBUSTION TESTS

In order to investigate the performance of the stoves and boilers specified in Table 3 and Table 4 with the selected biofuels, testing work has been performed at three laboratories, all of them Biomasud Plus project partners: BIOS BIOENERGIESYSTEME GmbH (BIOS) in Austria, CERTH (Centre for Research and Technology - Hellas) in Greece and CIEMAT (Centre for Energy, Environment and Technology) in Spain. Each laboratory tested one stove and one boiler (see Tables 3 and 4) under well controlled test stand conditions and utilizing common procedures. Two loads were used during the tests: nominal load and partial load (30% of the nominal load).

The control parameters (settings of the control system) of the boilers and stoves were modified in order to achieve the lowest possible emissions with the different fuels, but no reconstructions or process control hardware adaptations were made.

According to the techno-economic analysis of the combustion tests carried out in the Biomasud Plus project [Brunner et al.], vineyard pruning pellets and olive tree pruning pellets performed in principle similarly in all the tested appliances. Because of the higher ash contents (see Table 2) compared to A1 wood pellets, rapid ash accumulation on the grates, both in stoves and boilers, was observed which demands for an automatic de-ashing system with rather short deashing intervals or a continuous de-ashing (such as with moving grates). However, slagging was not observed in the accumulated ash. On the other hand, the utilisation of these fuels entailed higher particulate matter emission and the formation of deposits on heat exchanger surfaces, especially when there was not automatic cleaning system for the heat exchangers installed. Furthermore, the high particulate matter emissions caused deposits on the vision window in two of the stoves, making the view on the flame difficult. Some photos of these issues are shown in Figure 2.

For olive stones, the big differences in comparison to A1-class wood pellets regarding particle shape and particle size distribution (see Figure 1 and Table 2) did not cause any problem with the fuel feeding systems of the selected heating appliances. The main problem observed during olive stones combus-

Figure 2. Ash-related problems observed during pruning pellets combustion tests. From left to right and from top to bottom: ash accumulation on the stove grate without automatic de-ashing; ash deposition on the stove heat exchanger surfaces; ash deposition on a stove vision window; ash deposition on the grate of a boiler (fixed grate without automatic de-ashing).

tion was a very high proportion of unburnt matter in the ash box. This could be due to an inappropriate adjustment of the automatic cleaning systems which caused the release of olive stones to the ash box before they have been completely burnt. In Figure 3, the ash contained in the ash box after a combustion test run with olive stones in a boiler can be seen. The black particles are unburnt olive stones.

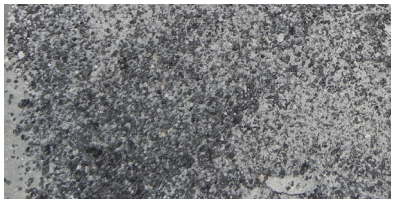

Figure 3. Ash box after a combustion test with olive stones in boiler I.

From Figure 4 to Figure 9 the emissions determined during the combustion tests with the selected biofuels in stoves and boilers are shown. These emissions have been expressed taking into account the instructions stated in the Eco-design Directive. Therefore, in the case of tests carried out in boilers, the seasonal space heating emissions (Es) have been calculated as follows:

$$E_s = 0{,}85 \times E_{s,p} + 0{,}15 \times E_{s,n}$$

Where:

$E_{s,p}$ are the emissions of respectively particulate matter, organic gaseous compounds, carbon monoxide and nitrogen oxides measured at 30 % the nominal heat output.

$E_{s,n}$ are the emissions of respectively particulate matter, organic gaseous compounds, carbon monoxide and nitrogen oxides measured at nominal heat output.

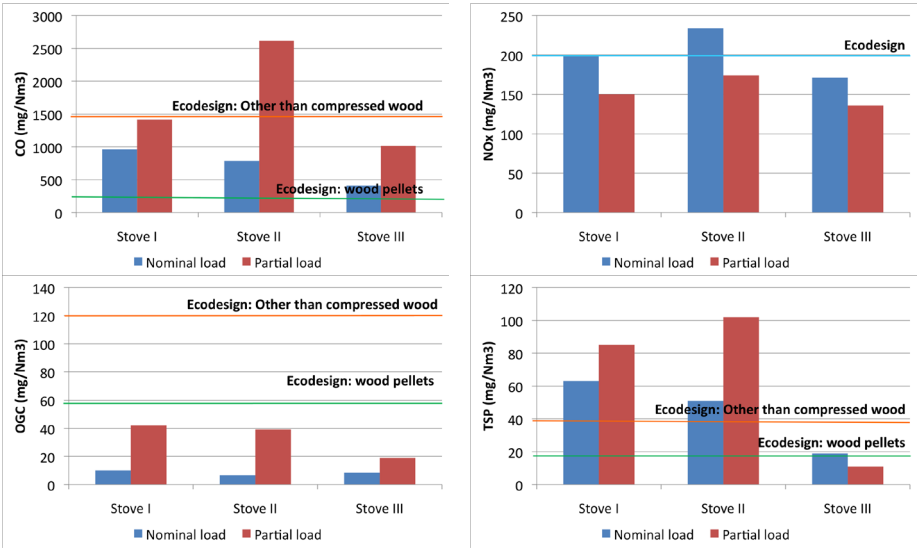

Figure 4. Emissions determined during the combustion tests with olive stones in stoves, expressed in dry basis and at 13% O2.

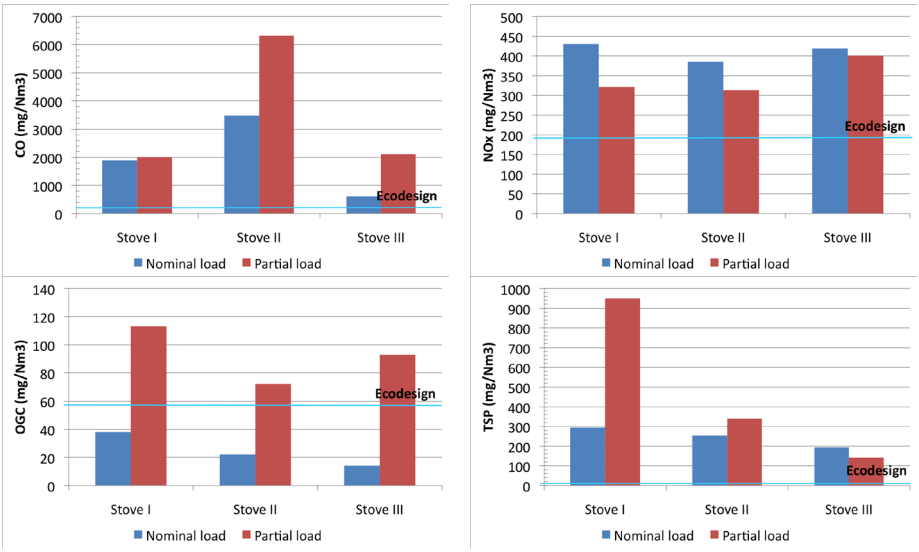

Figure 5. Emissions determined during the combustion tests with olive tree pruning pellets in stoves, expressed in dry basis and at 13% O2

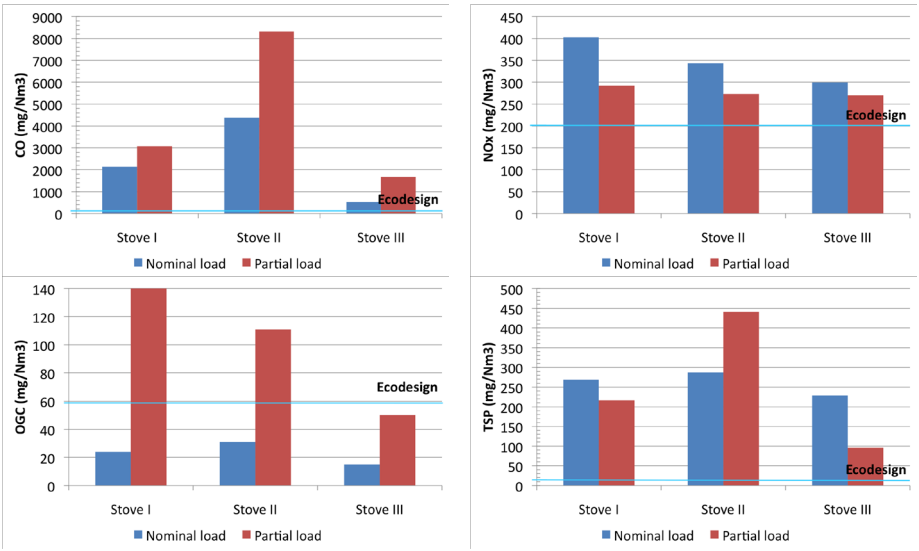

Figure 6. Emissions determined during the combustion tests with vineyard pruning pellets in stoves, expressed in dry basis and at 13% O2

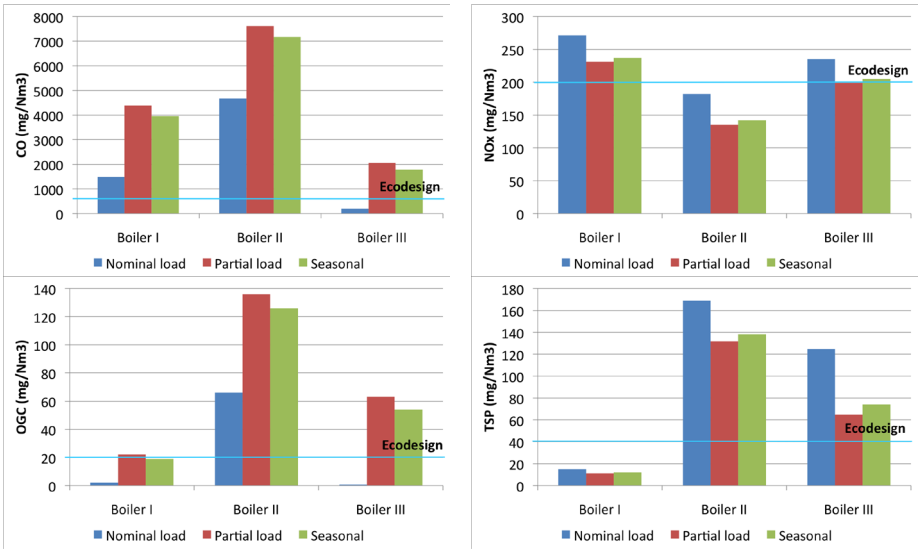

Figure 7. Emissions determined during the combustion tests with olive stones in boilers, expressed in dry basis and at 10% O2

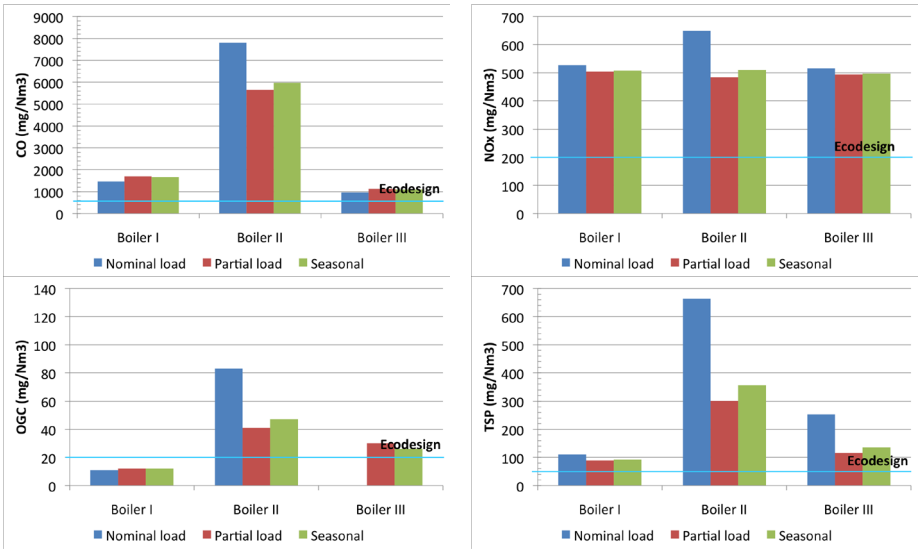

Figure 8. Emissions determined during the combustion tests with olive tree pruning pellets in boilers, expressed in dry basis and at 10% O2.

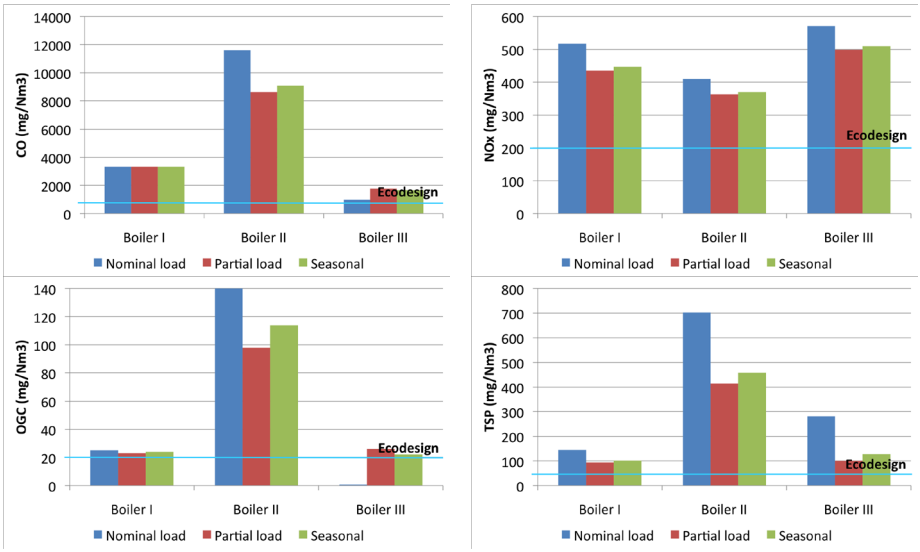

Figure 9. Emissions determined during the combustion tests with vineyard pruning pellets in boilers, expressed in dry basis and at 10% O2.

As Eco-design Directive states, CO, NOx (nitrogen oxides expressed as NO2), OGC (organic gaseous compounds) and TSP (total solid particles) emissions are expressed in mg/m3 dry flue gas calculated at 273 K and 1013 mbar, and expressed at 13% O2 (stoves) or 10% O2 (boilers).

Considering the emission limits applicable for the heating equipment used and established by the Eco-design Directive, it can be noticed that:

- When utilizing olive stones as fuel, the stoves tested were close to fulfilling the emission limits for "fuel different from compressed wood" according to the Eco-design Directive. Regarding the pruning pellets used, the emissions of CO, NOx and TSP were remarkably higher than the limits considered for wood pellets.
- Regarding the boilers tested, it must be remarked the high emissions of boiler II are mainly due to its simple technology, which is not flexible enough to be adapted to new fuels. Therefore, boiler II is also a good example that technology features such as grates with continuous or fre-

quent automatic de-ashing as well as flexible automated process control systems are needed for the utilisation of these fuels.

- With regard to boiler I, it can be seen that olive stones combustion is close to fulfil the limits for seasonal emissions established by the Eco-Design Directive if some improvements regarding operating conditions are performed to reduce CO and NOx emissions. Also for the combustion of both pruning pellets, the CO, OGC and TSP emission limits could be kept with some minor changes in the plant settings. However, the utilisation of primary measures would not be enough to reduce the high NOx emissions below the respective emission limit.
- Concerning boiler III, the combustion of all the selected fuels provides seasonal emissions of CO, OGC and TSP slightly above the limits established by the Eco-design Directive. When implementing some improvements regarding process control the respective emission limits are expected to be kept. Nevertheless, during pruning pellets combustion too high NOx emissions are obtained and the use of primary measures would not be enough to reduce these emissions below the respective limit value.

Thermal efficiencies for the appliances were calculated taking into account the following expression:

- For boilers:

Thermal efficiency = boiler load / fuel power input related to NCV x 100

Where the fuel power input related to NCV is the heat flow introduced with the fuel considering its net calorific value and the boiler load is the heat flow transferred to the water circuit.

- For stoves:

Thermal efficiency = (Fuel power input related to NCV – Flue gas heat losses) / Fuel power input related to NCV x 100

Where the fuel power input related to NCV is the heat flow introduced with the fuel considering its net calorific value and the flue gas heat losses is the sensible heat of the flue gas flow due to the difference between the flue gas temperature and the ambient temperature.

In Tables 5 and 6, the calculated thermal efficiencies for the selected stoves and boilers, respectively, are shown.

Table 5. Thermal efficiency of stoves tested

	Stove I	Stove II	Stove III	Stove I	Stove II	Stove III
	Thermal efficiency at nominal load (%)			Thermal efficiency at partial load (%)		
Wood pellets	89.0(*)	88.0(**)	90.0(**)	85.0(*)	76.9(**)	94.0(**)
Olive stones	78.1	84.4	87.3	81.3	74.4	91.9
Olive tree pruning pellets	68.7	83.5	85.8	70.4	73.0	90.8
Vineyard pruning pellets	69.7	84.2	88.3	78.5	76.2	93.1

(*) Declared by manufacturer with wood pellets EN ISO 17225-2 class A1.
(**) Obtained using A1 wood pellets

Table 6. Thermal efficiency of boilers tested

	Boiler I	Boiler II	Boiler III	Boiler I	BoilerII	Boiler III
	Thermal efficiency at nominal load (%)			Thermal efficiency at partial load (%)		
Wood pellets(1)	95.0(*)	83.5(**)	92.6(**)	90.9(*)	65.0(**)	90.3(**)
Olive stones	93.6	76.6	93.1	87.5	70.3	90.2
Olive tree pruning pellets	94.3	64.6	92.8	87.1	64.7	89.9
Vineyard pruning pellets	94.2	69.6	93.1	85.6	62.0	88.7

(*) Declared by manufacturer with wood pellets EN ISO 17225-2 class A1.
(**) Obtained using A1 wood pellets

As can be seen, the thermal efficiencies of stove II and stove III were slightly lower with the Mediterranean biofuels tested than the values obtained during tests with A1 wood pellets. However, the thermal efficiencies achieved during the tests with stove I were much lower than those declared by manufacturer. This fact was connected to the very high oxygen content in the flue gas measured during the test runs with this stove (13.5 vol% dry flue gas with olive stones, 16.5 vol% with olive tree pruning pellets and 16.3 vol % with vineyard pruning pellets). Applying the same excess oxygen ratios as during wood pellet combustion would have led to higher efficiencies, since all other parameters influencing the efficiency (flue gas temperature, fuel moisture content) have been well comparable with those of wood pellet combustion.

Concerning the tests performed with the boilers I and III, slightly lower, respectively comparable or even higher thermal efficiencies compared to the values obtained with A1 pellets were observed. Regarding boiler II the differences were higher (nominal load) which was mainly due to the very high oxygen contents in the flue gas (12.4 vol% d.b. for olive stones, 15.7 vol % d.b. for olive tree pruning pellets and 15.0 vol% d.b. for vineyard pruning pellets). Again, the simple technology of this boiler was now able to appropriately adapt the operation to the properties of these fuels.

Considering the behavior of the vineyard pruning and olive tree pruning pellets during the combustion tests it must be concluded that they are not appropriate fuels for stoves and small boilers in the domestic sector. However, an exception could be made for low ash and low nitrogen content olive tree pruning pellets (see section 2.4.1) with which most probably also the emission limit regarding NOx could be kept.

4. RECOMMENDATIONS FOR MANUFACTURERS AND INSTALLERS

4.1. Stoves

4.1.1. Olive stones

Fuel supply and fuel feeding

The utilisation of olive stones does not entail problems regarding fuel handling and fuel feeding. However, considering the small fuel particle size of 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.

Combustion and combustion control including emission related issues

The appliances tested are not prepared enough to fulfil the emission limits established in the Eco-design Directive (mandatory from 1st January 2022 for stoves) for "wood pellets". Nevertheless, fulfilment of the emission limits for "other than compressed wood" can be achieved (see stove III in Figure 4). Therefore, in general, if manufacturers want to define olive stones as "other suitable fuel" (as stated in the Eco-design Directive), some adaptations of the combustion conditions, such as air flows, air staging settings and grate movement, are needed to decrease CO and/or particulate matter emissions.

De-ashing

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 to achieved a high carbon conversion and a low carbon content of the grate ash.

4.1.2. Olive tree pruning pellets and vineyard pruning pellets

Fuel supply and fuel feeding

The utilisation of pruning pellets does not entail problems regarding fuel handling and fuel feeding.

Combustion and combustion control including emission related issues

The combustion of pruning pellets does not comply with the emissions limits established in the Eco-design Directive (mandatory from 1st January 2022 for stoves) for "wood pellets", especially regarding NOx, which makes them not suitable for present small heating applications.

Several technology improvements could be carried out in domestic heating appliances to solve the problems observed:

- Adequate process control settings to guarantee low CO and OGC emissions.
- Low-NOx burner must be used in order to reduce the NOx emissions using suitable air staging.
- Utilisation of an adequate TSP abatement system, like electrostatic precipitators.
- Appropriate adjustment of the combustion air flow control settings to assure high thermal efficiency.

Moreover, the use of olive tree pruning pellets with low ash and nitrogen contents (see section 2.4.1) could allow the fulfilment of the Eco-design Directive limits, despite no specific combustion tests have been performed with this fuel

Deashing

The use of pruning pellets do not pose significant problems regarding ash sintering despite of their high ash content. However, automated cleaning of grate and heat exchanger surfaces is needed.

Cleaning and maintenance aspects

Suitable window purge air design to avoid aerosol deposition on the vision panel is needed.

4.2. Boilers

4.2.1. Olive stones

Fuel supply and fuel feeding

The utilisation of olive stones does not entail problems regarding fuel handling and fuel feeding. However, considering the small fuel particle size of 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.

Combustion and combustion control including emission related issues

The appliances tested are not prepared enough to fulfil the seasonal emission limits established in the Eco-design Directive (mandatory from 1st January 2020 for boilers). If manufacturers want to define olive stones as "other suitable fuel" (as stated in the Eco-design Directive), some adaptations of the combustion conditions, such as air flows, air staging settings

and grate movement, are needed to decrease CO and/or particulate matter emissions.

Deashing

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 to achieved a high carbon conversion and a low carbon content of the grate ash.

4.2.2. Olive tree pruning pellets and vineyard pruning pellets

Fuel supply and fuel feeding

The utilisation of pruning pellets does not entail problems regarding fuel handling and fuel feeding.

Combustion and combustion control including emission related issues

The combustion of pruning pellets does not comply with the seasonal emissions limits established in the Eco-design Directive (mandatory from 1st January 2020 for boilers), especially regarding NOx, which makes them not suitable for present small heating applications.

Several technology improvements could be carried out in domestic heating appliances to solve the problems observed:

- Adequate process control settings to guarantee low CO and OGC emissions.
- Low-NOx burner must be used in order to reduce the NOx emissions using suitable air staging.

- Utilisation of an adequate TSP abatement system, like electrostatic precipitators.
- Appropriate adjustment of the combustion air flow control settings to assure high thermal efficiency.

Moreover, the use of olive tree pruning pellets with low ash and nitrogen contents (see section 2.4.1) could allow the fulfilment of the Eco-design Directive limits, despite no specific combustion tests have been performed with this fuel

Deashing

The use of pruning pellets do not pose significant problems regarding ash sintering despite of their high ash content. However, automated cleaning of grate and heat exchanger surfaces is needed.

5. RECOMMENDATIONS FOR END USERS

To avoid problems related to the fuel behavior, it is important the acquisition of quality certified biofuels, according to relevant standards or Biomasud label quality requirements.

5.1. Olive stones

End users should obtain the guarantee (from manufacturer and/or installer) that the appliances they are acquiring can use olive stones as other fuel.

End users should be cautious during ash removal from the ash box because temperature could be high due to unburnt matter in ash.

5.2. Vineyard pruning and olive tree pruning pellets

Considering the high ash content of these pellets compared to high quality wood pellets, the ash box will have to be emptied more often during operation with these pellets.

Since particulate deposition on the stove vision window will be higher than with the use of high quality wood pellets, end user higher cleaning effort will be needed.

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