Techno-economic analysis of the selected biomass fuels combustion

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1. Introduction and Objectives

Currently BiomasudPlus fuels like olive stones, vineyard and olive tree pruning pellets are scarcely used for heating purposes, but they represent a significant, untapped biomass potential in Mediterranean regions. This fuel potential is of increasing interest for the market since the prices for BiomasudPlus fuels in Mediterranean regions are expected to be lower than the prices for wood pellets.

The main objective of this Deliverable Report is to evaluate the technical and economic performance of current residential heating boilers and stoves operated with BiomasudPlus fuels. Thereby, the performance parameters of these stoves and boilers and an evaluation of the economy of the whole system (investment and operation costs) should be compared with techno-economic performance data of state-of-the-art residential wood pellet as well as natural gas fired boilers. These evaluations and calculations were performed using inputs obtained from Task 5.2 (*State of the art of the combustion devices for the selected biofuels*) and 5.3 (*Characterization of selected biofuels combustion in commercial stoves and boilers*) and the results of the market studies performed within Task 2.1 (*Residential heating solid biofuels market state of the art*).

The main results of this Deliverable Report comprise conclusions regarding the suitability of the combustion equipment investigated within Task 5.3 to comply with the efficiency and emission limits established in the existing relevant standards and legislation, the identification of technological improvements as well as conclusions regarding the economic competiveness of these appliances when utilising BiomasudPlus fuels.

2. Methodology

The framework conditions for residential heating systems regarding full load operating hours, common capacity ranges, fuel costs and investment costs as well as regarding available public funding vary strongly within the EU. Therefore, in order to receive reliable and comparable data, techno-economic analyses have to refer to specific regions. Since the BiomasudPlus fuels originate from Mediterranean countries, Spain and Greece have been chosen as reference regions for the investigations.

In order to define the constraints for the techno-economic analyses, a close cooperation and an intensive information exchange between the project partners BIOS, CIEMAT and CERTH took place. Questionnaires regarding the different technologies (stoves and boilers) tested within Task 5.3 as well as the national framework conditions concerning residential biomass combustion in Spain and Greece have been prepared by BIOS and forwarded to CIEMAT and CERTH. The filled in questionnaires have been returned to BIOS and open questions have been discussed bilaterally.

Based on these data, a technical evaluation regarding the utilisation of the selected BiomasudPlus fuels in the different stoves and boilers tested within Task 5.3 took place. Evaluations regarding the suitability of the combustion equipment to comply with the efficiency and emission limits established in relevant existing standards and legislations have been performed.

In Greece, there are funding options for residential biomass heating systems, usually tied to measures for energy upgrade of buildings but the access is quite complicated. In Spain, funding is available only in some regions. Thus, funding is not considered within the economic calculations. However, the sensitivity studies performed regarding investment costs show the impact of a possible funding.

The evaluations took place for the BiomasudPlus fuels tested within Task 5.3 which are

- Olive stones (OS),
- Vineyard pruning pellets (VYP) and
- Olive tree pruning pellets (OTP).

However, it turned out that qualities of the vineyard pruning pellets (VYP) and olive tree pruning pellets (OTP) tested within Task 5.3 were not suitable for residential stoves and boilers. They showed very high contents of ash forming elements (especially of K, which is a main actor in fine particulate emission formation) leading to unacceptably high dust emissions, and of N, which lead to elevated NO_x emissions (see section 3.1). For both parameters, the quality criteria defined within Deliverable Report D3.3 were significantly exceeded. However, if the proposed quality criteria for ash and N-contents of OTP and VYP according to D3.3 can be achieved (see Table 2.1), their use in residential stoves and boilers without exceeding emission limits regarding NO_x and TSP (total suspended particulate matter = total dust) seems to be realistic.

Table 2.1. Comparison of the fuel quality tested within Task 5.3 and the proposed limits for olive tree pruning pellets (see D3.3).

<u>Explanations:</u> d.b. … dry basis

	Ash-content wt% d.b.	N-content wt% d.b.
Fuel used for the test runs within Task 5.3		
Mean	4.2	0.9
Minimum	1.7	0.2
Maximum	6.4	1.7
Proposed limits for olive tree pruning pellets according to D3.3		
class A1	0.7	0.3
class A2	1.2	0.5
class B	2.0	1.0

Therefore, in this report, only economic evaluations for the utilisation of olive stones (OS) and wood pellets (as reference fuel) in the stoves and boilers tested within Task 5.3 have been performed and a comparison with state-of-the-art gas fired stoves and boilers took place. Regarding OTP and VYP, an utilisation in larger-scale combustion plants (1 MW_{th}) was investigated, since such plants can also utilize fuels with elevated ash and N-contents as they have been tested within Task 5.3.

3. Description and technical evaluation of the technologies investigated

BIOS, CERTH and CIEMAT have tested the selected BiomasudPlus fuels (olive stones - OS, vineyard pruning pellets - VYP and olive tree pruning pellets - OTP) regarding their utilisation in residential heating boilers and stoves. Therefore, within Task 5.2 (*State of the art of the combustion devices for the selected biofuels*) a review of state-of-the-art biomass stoves and boilers, which in principle should be suitable for these biomass fuels, has been performed and based on that boilers and stoves to be tested within Task 5.3 (*Characterization of selected biofuels combustion in commercial stoves and boilers*) have been selected. Each partner tested one stove and one boiler under well controlled test stand conditions and utilising common procedures which have been defined prior to the test runs.

3.1. Description of the stoves and boilers tested within Task 5.3

In Table 3.1 and Table 3.2 the most relevant characteristics of the stoves and boilers tested at CIEMAT, CERTH and BIOS are summarised.

Table 3.1. Specification of the stoves tested by CIEMAT, CERTH and BIOS.

<u>Explanations:</u> *) with wood pellets EN ISO 17225-2 class A1; PA … primary air; SA … secondary air; WA … window air; ACC … automatic combustion control

		Stove I	**Stove II**	**Stove III**
Tested by		CIEMAT	CERTH	BIOS
Manufactured in		Spain	Italy	Austria
Nominal thermal power	kW	10.4	21.2	10
Water jacket		no	yes	no
Efficiency according to manufacturer *)		89%	88%	90%
Dimension (LxWxH):	m	0.5x1.1x0.5	0.8x2.2x0.8	0.7x0.6x1.2
Diameter of chimney connection	mm	80	80	100
Weight	kg	125	200	200
Fuel feeding to the fuel bed		from above	from above	from above
Grate technology		moving grate	fixed grate	rotating grate
De-ashing of the grate		automatic	manual	automatic
Cleaning of heat exchanger surfaces		manual	manual	manual
Combustion air flow		PA & WA	PA & WA	PA, SA & WA
Control system		ACC	ACC	ACC

Table 3.2. Specification of the boilers tested by CIEMAT, CERTH and BIOS.

Explanations: *) with wood pellets EN ISO 17225-2 class A1; **) Test runs performed with a return temperature of 50°C at non-condensing operation since the flue gas dew point is significantly below 50°C; PA … primary air; SA … secondary air; ACLC … automatic combustion and load control; MLC … manual load control

Tested by		**Boiler I** CIEMAT	**Boiler II** CERTH	**Boiler III** BIOS
Manufactured in		Spain	Greece	Austria
Nominal thermal power	kW	25	28	40
Condensing boiler		yes **)	no	no
Efficiency according to manufacturer *)		102%	80%	95%
Dimension (LxWxH):	m	0.9x1.5x1.3	0.8x2.2x1.2	2.1x1.4x1.6
Diameter of chimney connection	mm	150	180	150
Weight	kg	550	225	980
Fuel feeding to the fuel bed		from below	from below	from the side
Grate technology		moving grate	fixed grate	moving grate
De-ashing of the grate		automatic	manual	automatic
Cleaning of heat exchanger surfaces		automatic	manual	automatic
Combustion air flow		PA & SA	PA & SA	PA & SA
Control system		ACLC	MLC	ACLC
Class according to EN 303-5		Class 5	Class 3	Class 5

3.2. Operational aspects

Stoves

With the three stoves listed in Table 3.1, comprehensive test runs with OS, OTP and VYP have been performed by CIEMAT, CERTH and BIOS. The detailed test run results are presented in Deliverable Report D5.3.

Based on the experiences made and the data gained during these test runs, the utilisation of the three BiomasudPlus fuels in the stoves can be assessed as follows:

Fuel feeding: No problems occurred for the different BiomasudPlus fuels tested as the fuels were used in granular (OS) or pelletised (OTP/VYP) form. The feeding systems of the different stoves are already designed for the related bulk and energy densities.

Ash melting/slagging: No problems with ash melting or slagging on the grate and in the combustion chamber were observed.

De-ashing: The ash contents of OTP (4.43 wt% d.b.) and VYP (5.57 wt% d.b.) were very high compared to class A1 wood pellets (0.5 wt% d.b.). OTP and VYP partly keep their shape during combustion due to their high ash contents and therefore a high volume ash consisting of "ash pellets" results (see also Figure 3.1). This leads to a fast growing ash bed on the grate. Therefore, a self-cleaning (moving) grate is necessary for a continuous de-ashing. Systems with fixed grates and manual de-ashing are not suitable.

Cleaning of heat exchanger surfaces: The BiomasudPlus fuels tested caused increased ash and aerosol deposits in the combustion chamber and on heat exchanger surfaces that may have a negative impact on the heat exchange and therefore have to be periodically manually removed. Significantly more frequent manual cleaning is needed than for wood pellet utilisation.

Vision panel (window): Severe aerosol depositions of the vision panel (window) occurred for Stove II and Stove III during operation with OTP and VYP, which partly blocked the view on the flame. This is an undesired effect for stoves since flame visibility is an important customer need (see Figure 3.2).

Figure 3.1. Ash box of Stove III after test runs with OTP - OTP and VYP keep their shape during combustion due to their high ash contents

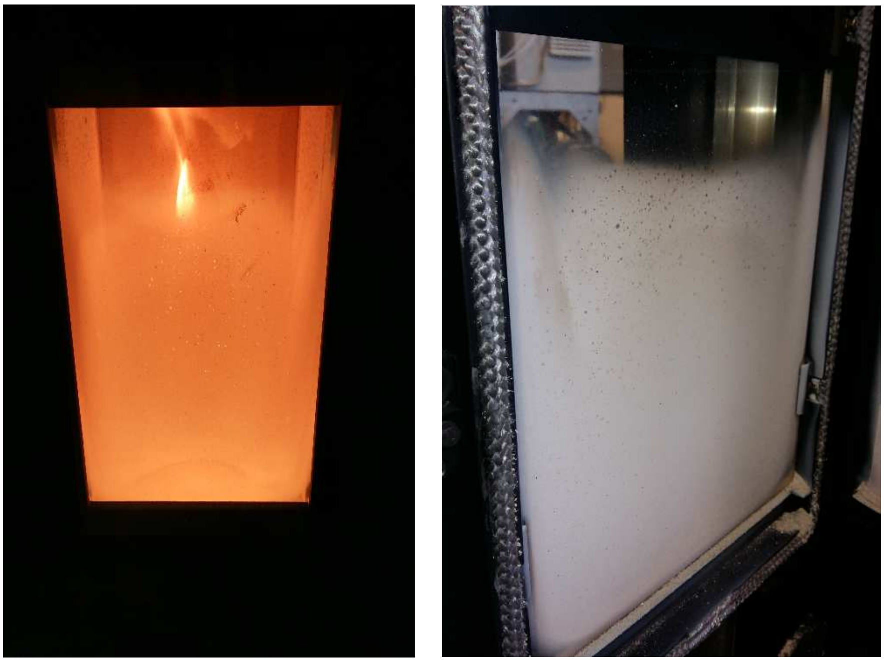

Figure 3.2. Severe aerosol depositions contamination of the vision panel during operation with OTP and VYP observed at Stove III

Boilers

The three boilers listed in Table 3.2 have been tested with the same three BiomasudPlus fuels as the stoves (OS, OTP and VYP) at CIEMAT, CERTH and BIOS (for details see Deliverable Report D5.3).

Based on the experiences made and the data gained during these test runs, the utilisation of the three BiomasudPlus fuels in these boilers can be assessed as follows:

Fuel feeding: No problems occurred for the different BiomasudPlus fuels tested as the fuels are used in granular (OS) or pelletised (OTP/VYP) form. The feeding systems of the different boilers tested are designed for such fuel shapes and the related energy densities.

Ash melting/slagging: No problems with ash melting or slagging on the grates and in the combustion chambers were observed.

De-ashing of the grate: The high ash contents of OTP and VYP can lead to ash accumulations on the grate. Also the ash boxes had to be emptied more often compared to the operation with class A1 wood pellets.

Cleaning of heat exchanger surfaces: The BiomasudPlus fuels, especially OTP and VYP, caused increased ash and aerosol deposits on the heat exchanger surfaces that may have a negative effect on the heat exchange and therefore have to be periodically removed. Thus, an automatic cleaning system of the heat exchanger surfaces is recommended for the operation with BiomasudPlus fuels (as it was installed at boiler I and boiler III).

3.3. Gaseous and particulate emissions

As a first step of the test runs, the control settings of the different stoves and boilers have been adjusted to the respective BiomasudPlus fuel. The CO, OGC (organic gaseous carbon), TSP (total suspended particles) and NO_x emissions have been determined at nominal and 30% part load operation and have been compared with the current and upcoming emission limits valid in Europe. These emission limits are listed in Table 3.3.

EN 14785: 2006 - Residential space heating appliances fired with wood pellets is valid for automatically fed stoves fired with compressed wood pellets. This does not include olive stones, however, for olive stones combustion presently no dedicated emission limits exist.

EN 303-5: 2012 Class 3, 4 and 5 applies for boilers heated with solid fuels (including solid biomass fuels) with a maximum thermal power of 500 kW.

The up-coming Eco-Design Directive is valid for wood fuels (and therefore also for OTP and VYP). Olive stones are not covered by this directive

Table 3.3. Applicable emission limit values

Explanations: OGC … organic gaseous carbon; TSP … total suspended particulate matter (=total dust emissions); NO_x = NO + NO_2 expressed as NO_2; Emission limit values according to the Eco-Design Directive for boilers are annual emissions which are calculated as 0.85 * emission at part (30%) load + 0.15 * emission at nominal load.

Pellet stoves	Nominal load	Emission limits [mg/Nm³] (related to dry flue gas and 13% O_2)			
		CO	OGC	TSP	NO_x
EN 14785 full load	<50 kW	500	-	-	-
EN 14785 part load (30% of nominal load)	<50 kW	750	-	-	-
Eco-Design Directive	<50 kW	300	60	20	200

Pellet boilers	Nominal load	Emission limits [mg/Nm³] (related to dry flue gas and 13% O_2)			
		CO	OGC	TSP	NO_x
EN 303-5 Class 3	<50 kW	2.181	73	109	-
EN 303-5 Class 4	<500 kW	727	22	44	-
EN 303-5 Class 5	<500 kW	364	15	29	-
Eco-Design Directive	<500 kW	364	15	29	145

Detailed information about the emissions measured during the combustion tests is provided within Deliverable Report D5.3. In this report a brief qualitative summary is given.

Stoves

During combustion of *olive stones*, Stove I exceeded the CO emission limits of EN 14785 at full and part load by about 2 times while Stove II exceeded these limit values by about 1.5 times (full load) and 2 times (part load). With Stove III the CO emission limit according to EN 14785 could be kept.

The CO emissions of Stove III also were below the emission limit of the Eco-Design directive at full load and only slightly exceeded them at partial load. Stove III also keeps the Eco-Design Directive emission limit values for TSP, NO_x and OGC at full and partial load while for Stove I and Stove II especially the TSP emissions where significantly higher than prescribed by the Eco-Design directive. However, this directive does not apply for olive stones since it is made for wood fuels only.

During combustion of *OTP and VYP* significantly increased emissions have been determined for all stoves tested. This effect is mainly due to the high N and ash contents of the VYP and OTP assortments utilised which makes them not suitable for conventional pellet stoves. Consequently, the emission limit values for CO according to EN 14785 were exceeded by 1.2 to 9 times, whereby Stove III again showed the lowest emissions.

Furthermore, the evaluation of the test runs shows generally too high NO_x emissions due to the high N content of these fuels, which lead to significant exceedances of the respective Eco-Design limit value. The NO_x emissions cannot be reduced by primary (combustion technology related) improvements. Thus, the high N content of the fuels is a KO criterion for the application of OTP and VYP in stoves. Regarding TSP emissions, the test runs pointed out that due to the high ash and especially K contents of these fuels also the TSP emission limits of the Eco-Design directive were exceeded significantly (values of at least 100 mg/Nm³ related to dry flue gas and 13 vol% O_2). These high TSP emissions can only be controlled by application of electrostatic precipitators.

Boilers

Regarding *olive stone* combustion Boiler I and Boiler III kept the EN 303-5 class 5 emission limit at full load but exceeded it during part load operation by a factor of about 2.5 to 3. About the same trend has been observed for the OGC emissions. However, it is assumed that with some minor adaptations of the control system also this problem could be overcome. Regarding TSP emissions Boiler I kept the EN 303-5 class 5 emission limit while Boiler III exceeded the emission limit by 3 times at full load and by 43% at part load.

For Boiler II, the EN 303-5 class 3 emission limit for CO was exceeded by 1.5 times at full load and by 2.5 times at part load. The OGC emissions were kept at full load but about 65% above the limit value at part load. The TSP emission limit was exceeded by 13% at full load and was reached at part load.

As already observed during the test runs with the stoves, also during the combustion tests with the boilers VYP and OTP caused exceedances of almost all emission limit values (with the exception of the full load OGC emissions). The most severe exceedances have to be reported for TSP and NO_x emissions, which amounted at least to the double value of the respective limit value of the Eco-Design Directive. While TSP emissions can be controlled by the application of ESPs, the NO_x emissions, which are caused by the high N contents of the fuels, cannot be reduced with acceptable efforts and therefore, these emissions represent a KO criterion for the application of VYP and OTP in residential heating boilers.

3.4. Thermal efficiency

Stoves

In Table 3.4 the thermal efficiencies determined for the stoves during the test runs performed are shown. These results show that during operation with BiomasudPlus fuels the thermal efficiencies of Stove II and Stove III were slightly lower than during operation with class A1 wood pellets. For Stove I (full and partial load) this decrease of efficiencies is more pronounced than for the other stoves tested due to the very high O_2 content in the flue gas measured during these test runs. With an appropriate adjustment of the combustion air ratio an increase of the efficiencies may in this case be achieved.

Table 3.4. Thermal efficiency of the stoves tested by CIEMAT, CERTH and BIOS.

	Stove I	Stove II	Stove III	Stove I	Stove II	Stove III
	Thermal efficiency at full load [%]			Thermal efficiency at 30% partial load [%]		
Wood pellets	89.0	88.0	90.0	85.0	76.9	94.0
Olive stones	78.1	86.2	87.3	81.3	75.1	91.9
Vineyard pruning pellets	69.7	85.1	88.3	78.5	76.7	93.1
Olive tree pruning pellets	68.7	84.5	85.8	70.4	73.4	90.8

Boilers

Regarding the boilers tested (Table 3.5) the test run data revealed about the same respectively slightly lower efficiencies than during operation with class A1 wood pellets for Boiler I and III. For Boiler II (full load) the decrease of efficiencies when using BiomasudPlus fuels is with up to 15% higher than for the other boilers tested which is mainly due to the simple technology (correlating with low investment costs of this boiler) of Boiler II. The reason mainly was due to increased excess oxygen contents and therefore, with an appropriate adjustment of the combustion air flow control settings the efficiencies can be increased also for Boiler II.

Table 3.5. Thermal efficiency of the boilers tested by CIEMAT, CERTH and BIOS.

	Boiler I	Boiler II	Boiler III	Boiler I	Boiler II	Boiler III
	Thermal efficiency at full load [%]			Thermal efficiency at 30% partial load [%]		
Wood pellets	95.0	83.5	92.6	90.9	65.0	90.3
Olive stones	93.6	77.9	93.1	87.5	71.2	90.2
Vineyard pruning pellets	94.2	69.9	93.1	85.6	62.2	88.7
Olive tree pruning pellets	94.3	67.0	92.8	87.1	66.2	89.9

3.5. Maintenance, user-friendliness and availability of the stoves and boilers tested

No specific problems regarding fuel handling and fuel feeding occurred during the operation with BiomasudPlus fuels for all stoves and boilers tested. The common service interval for wood fuels (once a year) should also be valid for the operation with BiomasudPlus fuels.

The ash box had to be emptied more often during operation with OTP and VYP due to their, compared to class A1 wood pellets, significantly higher ash contents. The high ash contents of OTP and VYP can lead to ash deposit formation in the stoves and boilers. Therefore, shorter cleaning intervals become necessary compared to the operation with wood pellets or OS.

The operation with OTP and VYP lead for Stove II and Stove III to severe particle depositions on the vision panel (window). A higher cleaning effort by the user is therefore necessary compared to wood pellets or OS.

The availability of the tested stoves and boilers during operation with wood pellets is up to 99% (based on long-term test runs and field experiences). During operation with OS the availability is expected to be in the same range like during operation with wood pellets, because the combustion of OS did not lead to specific problems in the tested stoves and boilers. Due to the higher ash content of OTP and VYP and the resulting higher cleaning efforts, for these fuels a slightly reduced availability is expected compared with wood pellets and OS.

4. Economic evaluation of the technologies investigated

4.1. General aspects

As already explained within section 3, the OTP and VYP assortments tested are not suitable for an application in residential biomass boilers and stoves. However, if the proposed fuel qualities according to D3.3 (class A1 and A2) can be achieved, it seems also to be realistic that the respective emission limits can be kept. However, since the economic evaluation is based on the test run results achieved, OTP and VYP are not considered for the economic evaluation of the tested stoves and boilers. As an alternative for OTP and VYP, an utilisation in medium-scale heating plants (1 MW) has therefore been economically evaluated.

The economic evaluations refer to the reference regions Spain and Greece (home countries of the project partners CIEMAT and CERTH who were involved in the test runs). These countries are typical representatives for Mediterranean heating behaviour and the project partners CIEMAT and CERTH could provide the necessary input data.

For the technologies investigated, a full cost calculation according to VDI 2067 has been performed and annual costs were determined. Furthermore, the results achieved regarding the economic evaluation were compared with operation with class A1 wood pellets as well as with economic performance data of state-of-the-art residential natural gas and liquid gas (propane) fired stoves and boilers.

According to the full cost calculation based on the guideline VDI 2067, costs are divided into four groups:

- *Capital bound costs*: annual capital costs under consideration of the investment costs, interest rate, inflation and the lifetime.
- *Maintenance costs*: they were calculated based on input data from CIEMAT and CERTH. Regarding the building and the fuel storage the maintenance costs are based on VDI 2067.
- *Operation based costs* include effort of the end user, costs for the chimney sweeper and insurance costs.
- *Consumption costs* include all costs related to the operation of the heating system, e.g. fuel costs, electricity consumption, etc.

The prices are given including VAT, as the users are typically end customers. Annual heat generation costs are calculated based on the framework conditions in the year 2017 (see Table 4.1).

Table 4.1. General framework conditions for the economic evaluations for Greece and Spain
Explanations: w.b. … wet basis; prices incl. VAT; for the specific electricity costs and the costs for natural gas mean values from 2012 to 2016 gained from Eurostat are used; fuel prices, labor and chimney sweeper costs are based on input from CIEMAT and CERTH

Frame work conditions		**Greece**	**Spain**
General price index	[%/a]	2.0%	2.0%
Interest rate	[%/a]	4.0%	4.0%
Insurance	[% of invest/a]	1.0%	1.0%
Specific electricity costs	[Ct/kWh]	16.41	22.15
Period under consideration	[a]	15	15
Expected lifetime for stoves and boilers	[a]	20	20
Labour costs	[€/h]	10	20
Chimney sweeper for biomass fired stove/boiler	[€/a]	30	120
Chimney sweeper for gas fired stove/boiler	[€/a]	30	40
Fuel costs			
Costs for wood pellets	[€/t]	300	213
NCV of wood pellets	[MJ/kg w.b.]	18.7	18.7
Costs for wood pellets	[Ct/kWh]	5.78	4.09
Costs for olive stones	[€/t]	150	141
NCV of olive stones	[MJ/kg w.b.]	15.6	15.6
Costs for olive stones	[Ct/kWh]	3.47	3.27
Costs for liquid gas	[Ct/kWh]	8.37	8.37
Costs for natural gas	[Ct/kWh]	6.85	7.11

Due to the different framework conditions regarding fuel costs, electricity costs, labor costs and chimney sweeper costs in the reference regions, the cost calculations have been performed separately for Greece and Spain. Besides the devices tested in each country also the devices tested in Austria (Stove III and Boiler III) were considered, even though they are presently only available on the Spanish market but not in Greece. Summing up, the following evaluations have been performed:

- For Spain: Stove I & III and Boiler I & III
- For Greece: Stove II & III and Boiler II & III

For the calculation of the specific heat generation costs for the boilers also the costs for the building (fuel storage and space requirement for the heat generation - cellar) are considered.

4.2. Economic evaluation of the stoves for the Spanish framework conditions

In Table 4.2, the specifications and the framework conditions in Spain for the investigations regarding stoves are summarised.

Table 4.2. Economic evaluations of stoves in Spain: specification of the stoves investigated

Application		**Stove I**		**Stove III**		**Gas stove**	
Fuel type		Olive stones	Wood pellets	Olive stones	Wood pellets	Natural gas	Liquid gas
Nominal load							
Heating capacity	[kW]	10.4	10.4	10.0	10.0	10.0	10.0
Thermal efficiency	[%]	78.1	89.0	87.3	90.0	82.0	82.0
Fuel power input (related to NCV)	[kW]	13.3	11.7	11.5	11.1	12.2	12.2
Electricity demand	[kW]	0.150	0.150	0.040	0.040	-	-
30% partial load							
Heating capacity	[kW]	3.1	3.1	3.0	3.0	3.0	3.0
Thermal efficiency	[%]	81.3	85.0	91.9	94.0	82.0	82.0
Fuel power input (related to NCV)	[kW]	3.8	3.7	3.3	3.2	3.7	3.7
Electricity demand	[kW]	0.090	0.090	0.024	0.024	-	-
Operating hours at full load	[h/a]	200					
Operating hours at 30% partial load	[h/a]	1,000					
Total operating hours	[h/a]	1,200					
Full load operating hours	[h/a]	500					
Annual heat production	[MWh/a]	5.0	5.0	4.9	4.9	4.9	4.9
Annual fuel consumption	[MWh/a]	6.5	6.0	5.6	5.4	6.1	6.1
Annual electricity consumption	[kWh/a]	120	120	32.0	32.0	-	-
Annual thermal efficiency	[%]	77.6	84.0	87.3	89.6	79.5	79.5
Unit price	[€]	2,450	2,450	4,500	4,500	2,600	2,600
Additional components	[€]	-	-	-	-	-	-
Installation costs	[€]	150	150	150	150	250	250
Connection to natural gas grid	[€]	-	-	-	-	1,300	-
Liquid gas tank	[€]	-	-	-	-	-	900
Investment costs for the stove	**[€]**	2,600	2,600	4,650	4,650	4,150	3,850
Maintenance costs	[€/a]	50	50	180	180	60	80
Maintenance costs	[% of invest/a]	2.0%	2.0%	3.9%	3.9%	1.4%	2.1%
Expenditure of time for the user	[h/a]	6	6	6	6	1	1
Labour costs	[€/h]	20	20	20	20	20	20
Labour costs	[€/a]	120	120	120	120	20	20

In Table 4.3, the specific heat generation costs of Stove I and III for the operation with OS and class A1 wood pellets are presented and compared with the specific heat generation costs for natural gas and liquid gas stoves.

Table 4.3. Economic evaluations of stoves in Spain: specific heat generation costs

Application		**Stove I**		**Stove III**		**Gas stove**	
Fuel type		Olive stones	Wood pellets	Olive stones	Wood pellets	Natural gas	Liquid gas
Total investment costs	**[€]**	**2,600**	**2,600**	**4,650**	**4,650**	**4,150**	**3,850**
Capital bound costs	[€/a]	201	201	360	360	292	270
Maintenance costs	[€/a]	59.1	59.1	205	205	64.8	85.2
Operation based costs	[€/a]	302	302	326	326	115	111
Fuel costs	[€/a]	242	280	206	252	493	580
Electricity costs	[€/a]	30.2	30.2	8.1	8.1	-	-
Total costs per year	**[€/a]**	**835**	**872**	**1,105**	**1,150**	**965**	**1,046**
Annual heat production	[MWh/a]	5.0	5.0	4.9	4.9	4.9	4.9
Specific heat generation costs	**[€/MWh]**	**165**	**173**	**228**	**237**	**199**	**216**

For both stoves the specific heat generation costs for operation with OS are 4% lower than for the operation with class A1 wood pellets (due to the lower fuel costs). Due to the lower investment costs of Stove I, the specific heat generation costs of this application are about 27% lower than for Stove III.

The gas-fired stoves show lower capital bound, maintenance and operation based costs but higher fuel costs compared to the two biomass-fired stoves. However, the specific heat generation costs for Stove I are clearly below the costs for the gas fired stoves. Due to the higher investment costs of Stove III, the specific heat generation costs are slightly higher than for the gas-fired stoves.

4.3. Economic evaluation of the boilers for the Spanish framework conditions

Table 4.4 shows the specification of the boilers investigated for Spain. In addition to the efficiencies and heating capacity, also the annual operating hours defined and the resulting annual heat production and fuel consumption are shown for the biomass boilers and the state-of-the-art gas boilers. Furthermore, the investment, maintenance and labor costs for the boilers are listed.

Table 4.4. Economic evaluations of boilers in Spain: specification of the stoves investigated

Application		**Boiler I**		**Boiler III**		**Gas Condensing Boiler**	
Fuel type		Olive stones	Wood pellets	Olive stones	Wood pellets	Natural gas	Liquid gas
Nominal load							
Heating capacity	[kW]	25.0	25.0	40.0	40.0	30.0	30.0
Thermal efficiency	[%]	93.6	95.0	93.1	92.6	98.0	98.0
Fuel power input (related to NCV)	[kW]	26.7	26.3	43.0	43.2	30.6	30.6
Electricity demand	[kW]	0.085	0.085	0.150	0.150	0.083	0.083
30% partial load							
Heating capacity	[kW]	7.5	7.5	12.0	12.0	9.0	9.0
Thermal efficiency	[%]	87.5	90.9	90.2	90.3	98.0	98.0
Fuel power input (related to NCV)	[kW]	8.6	8.3	13.3	13.3	9.2	9.2
Electricity demand	[kW]	0.051	0.051	0.090	0.090	0.050	0.050
Operating hours at full load	[h/a]	400					
Operating hours at 30% partial load	[h/a]	2,000					
Total operating hours	[h/a]	2,400					
Full load operating hours	[h/a]	1,000					
Annual heat production	[MWh/a]	24.3	24.3	38.8	38.8	29.1	29.1
Annual fuel consumption	[MWh/a]	27.8	27.0	43.8	43.9	30.6	30.6
Annual electricity consumption	[kWh/a]	136	136	240	240	133	133
Annual thermal efficiency	[%]	87.1	89.7	88.6	88.5	95.1	95.1
Unit price	[€]	8,200	8,200	14,000	14,000	3,700	3,700
Additional components	[€]	4,500	4,500	7,500	7,500	-	-
Installation costs	[€]	2,200	2,200	2,500	2,500	400	400
Connection to natural gas grid	[€]	-	-	-	-	1,300	-
Liquid gas tank	[€]	-	-	-	-	-	4,700
Investment costs for the boiler	**[€]**	**14,900**	**14,900**	**24,000**	**24,000**	**5,400**	**8,800**
Maintenance costs	[€/a]	140	140	280	280	150	240
Maintenance costs	[% of invest/a]	0.9%	0.9%	1.2%	1.2%	2.8%	2.7%
Expenditure of time for the user	[h/a]	7	7	9	9	1	1
Labour costs	[€/h]	20	20	20	20	20	20
Labour costs	[€/a]	140	140	180	180	20	20

In Table 4.5, the specific heat generation for Boiler I and Boiler III for the operation with OS and class A1 wood pellets are shown and compared with the specific heat generation costs for natural gas and liquid gas boilers.

For the biomass fired boilers increased building costs result compared to the gas boilers due to the higher space requirement for the technology and the additional space requirement for the fuel storage. The space requirement for the fuel storage for OS is slightly higher than for wood pellets, because of their lower energy density. For the liquid gas tank no building costs are considered, because usually it is installed outside.

Table 4.5. Economic evaluations of boilers in Spain: specific heat generation costs

Application		**Boiler I**		**Boiler III**		**Gas Condensing Boiler**	
Fuel type		Olive stones	Wood pellets	Olive stones	Wood pellets	Natural gas	Liquid gas
Investment costs for the boiler	[€]	14,900	14,900	24,000	24,000	5,400	8,800
Building costs	[€]	4,700	4,600	7,200	7,100	400	400
Total investment costs	**[€]**	**19,600**	**19,500**	**31,200**	**31,100**	**5,800**	**9,200**
Capital bound costs	[€/a]	1,413	1,407	2,255	2,249	411	645
Maintenance costs	[€/a]	212	211	400	399	175	282
Operation based costs	[€/a]	518	517	695	694	134	173
Fuel costs	[€/a]	1,034	1,258	1,628	2,040	2,473	2,912
Electricity costs	[€/a]	34	34	60	60	33	33
Total costs per year	**[€/a]**	**3,211**	**3,427**	**5,038**	**5,443**	**3,227**	**4,045**
Annual heat production	[MWh/a]	24.3	24.3	38.8	38.8	29.1	29.1
Specific heat generation costs	**[€/MWh]**	**132**	**141**	**130**	**140**	**111**	**139**

The specific heat generation costs for the two biomass boilers are for operation with OS about 7.5% lower than for the operation with class A1 wood pellets (due to the lower fuel costs). Because of the higher nominal load of Boiler III the specific heat generation costs are in the same range as for Boiler I although the investment costs are higher.

The natural gas-fired boiler show with 111 €/MWh lower specific heat generation costs than Boiler I and III fired with OS. Due to the higher investment costs (compared to the natural gas-fired boiler) and the high fuel costs the specific heat generation costs of the liquid gas fired stove are 7% higher than for the boilers fired with OS.

4.4. Economic evaluation of the stoves for the Greek framework conditions:

The specification of the biomass Stove III and the state-of-the-art gas stoves (natural gas and liquid gas) for Greece are shown in Table 4.6. Furthermore, the operating hours and the resulting annual heat production and fuel consumption are presented in this table.

Stove II is compared with the boilers (see Table 4.8 and 4.9) since this stove is equipped with a water jacked and only about 10% of the heat produced is released by radiation.

Table 4.6. Economic evaluations of stoves in Greece: specification of the stoves investigated

Application		**Stove III**		**Gas stove**	
Fuel type		Olive stones	Wood pellets	Natural gas	Liquid gas
Nominal load					
Heating capacity	[kW]	10.0	10.0	20.0	20.0
Thermal efficiency	[%]	87.3	90.0	82.0	82.0
Fuel power input (related to NCV)	[kW]	11.5	11.1	24.4	24.4
Electricity demand	[kW]	0.040	0.040	-	-
30% partial load					
Heating capacity	[kW]	3.0	3.0	6.0	6.0
Thermal efficiency	[%]	91.9	94.0	82.0	82.0
Fuel power input (related to NCV)	[kW]	3.3	3.2	7.3	7.3
Electricity demand	[kW]	0.024	0.024	-	-
Operating hours at full load	[h/a]	200			
Operating hours at 30% partial load	[h/a]	1,000			
Total operating hours	[h/a]	1,200			
Full load operating hours	[h/a]	500			
Annual heat production	[MWh/a]	4.9	4.9	9.7	9.7
Annual fuel consumption	[MWh/a]	5.6	5.4	12.2	12.2
Annual electricity consumption	[kWh/a]	32.0	32.0	-	-
Annual thermal efficiency	[%]	87.3	89.6	79.5	79.5
Unit price	[€]	4,500	4,500	2,600	2,600
Additional components	[€]	-	-	-	-
Installation costs	[€]	150	150	250	250
Connection to natural gas grid	[€]	-	-	1,500	-
Liquid gas tank	[€]	-	-	-	3,700
Investment costs for the stove	**[€]**	4,650	4,650	4,350	6,550
Maintenance costs	[€/a]	180	180	60	130
Maintenance costs	[% of invest/a]	3.9%	3.9%	1.4%	2.0%
Expenditure of time for the user	[h/a]	7	7	1	1
Labour costs	[€/h]	10	10	10	10
Labour costs	[€/a]	70	70	10	10

In Table 4.7, the specific heat generation costs of Stove III for the operation with OS and class A1 wood pellets are presented and compared with the specific heat generation costs for natural gas and liquid gas stoves.

Table 4.7. Economic evaluations of stoves in Greece: specific heat generation costs

Application		**Stove III**		**Gas stove**	
Fuel type		Olive stones	Wood pellets	Natural gas	Liquid gas
Total investment costs	**[€]**	**4,650**	**4,650**	**4,350**	**4,750**
Capital bound costs	[€/a]	360	360	419	472
Maintenance costs	[€/a]	205	205	99	151
Operation based costs	[€/a]	166	166	112	121
Fuel costs	[€/a]	219	355	475	580
Electricity costs	[€/a]	6.0	6.0	-	-
Total costs per year	**[€/a]**	**956**	**1,092**	**1,105**	**1,325**
Annual heat production	[MWh/a]	4.9	4.9	4.9	4.9
Specific heat generation costs	**[€/MWh]**	**197**	**225**	**228**	**273**

For Stove III for the operation with OS the specific heat generation costs are with 197 €/MWh 12% lower than for the operation with class A1 wood pellets (due to the lower fuel costs). Compared to the two gas fired stoves the specific heat generation costs of Stove III are considerably lower (-13% compared to the natural gas and -28% compared to the liquid gas stove). When using wood pellets as fuel, the specific heat generation costs for Stove III are in the range of the natural gas fired stove.

4.5. Economic evaluation of the boilers for the Greek framework conditions

Table 4.8 shows the specification of the boilers investigated for Greece. In addition to the efficiencies and heating capacity also the operating hours defined and the resulting annual heat production and fuel consumption is shown for the biomass boilers and the state-of-the-art gas boilers. Furthermore, the investment, maintenance and labor costs are shown in this table.

Table 4.8. Economic evaluations of boilers in Greece: specification of the stoves investigated

Application		**Boiler II**		**Stove II**		**Boiler III**		**Gas Condensing Boiler**	
Fuel type		Olive stones	Wood pellets	Olive stones	Wood pellets	Olive stones	Wood pellets	Natural gas	Liquid gas
Nominal load									
Heating capacity	[kW]	28.0	28.0	21.2	21.2	40.0	40.0	30.0	30.0
Thermal efficiency	[%]	77.9	83.5	86.2	88.0	93.1	92.6	98.0	98.0
Fuel power input (related to NCV)	[kW]	35.9	33.5	24.6	24.1	43.0	43.2	30.6	30.6
Electricity demand	[kW]	0.370	0.370	0.340	0.340	0.150	0.150	0.083	0.083
30% partial load									
Heating capacity	[kW]	8.4	8.4	6.4	6.4	12.0	12.0	9.0	9.0
Thermal efficiency	[%]	71.2	65.0	75.1	76.9	90.2	90.3	98.0	98.0
Fuel power input (related to NCV)	[kW]	11.8	12.9	8.5	8.3	13.3	13.3	9.2	9.2
Electricity demand	[kW]	0.222	0.222	0.204	0.204	0.090	0.090	0.050	0.050
Operating hours at full load	[h/a]	400							
Operating hours at 30% partial load	[h/a]	2,000							
Total operating hours	[h/a]	2,400							
Full load operating hours	[h/a]	1,000							
Annual heat production	[MWh/a]	27.2	27.2	20.6	20.6	38.8	38.8	29.1	29.1
Annual fuel consumption	[MWh/a]	38.0	39.3	26.8	26.2	43.8	43.9	30.6	30.6
Annual electricity consumption	[kWh/a]	592	592	544	544	240	240	133	133
Annual thermal efficiency	[%]	71.5	69.2	76.8	78.5	88.6	88.5	95.1	95.1
Unit price	[€]	4,200	4,200	2,800	2,800	14,000	14,000	3,700	3,700
Additional components	[€]	500	500	-	-	7,500	7,500	-	-
Installation costs	[€]	1,000	1,000	450	450	2,500	2,500	400	400
Connection to natural gas grid	[€]	-	-	-	-	-	-	1,500	-
Liquid gas tank	[€]	-	-	-	-	-	-	-	9,300
Investment costs for the boiler	**[€]**	**5,700**	**5,700**	**3,250**	**3,250**	**24,000**	**24,000**	**5,600**	**13,400**
Maintenance costs	[€/a]	155	155	40	40	280	280	150	340
Maintenance costs	[% of invest/a]	2.7%	2.7%	0.9%	0.9%	1.2%	1.2%	1.1%	2.5%
Expenditure of time for the user	[h/a]	28	28	28	28	9	9	1	1
Labour costs	[€/h]	10	10	10	10	10	10	10	10
Labour costs	[€/a]	280	280	280	280	90	90	10	10

Since Stove II is equipped with a water jacked and only about 10% of the heat produced is released by radiation, this stove is compared to the boilers (Boiler II and Boiler III as well as natural and liquid gas boilers).

The total costs per year and the specific heat generation costs for Greece of Boiler I and III as well as Stove II for the operation with OS and class A1 wood pellets as well as the state-of-the-art natural and liquid gas boilers are shown in Table 4.9.

Table 4.9. Economic evaluations of boilers in Greece: Specific heat generation costs

Application		**Boiler II**		**Stove II**		**Boiler III**		**Gas Condensing Boiler**	
Fuel type		Olive stones	Wood pellets	Olive stones	Wood pellets	Olive stones	Wood pellets	Natural gas	Liquid gas
Investment costs for the boiler	[€]	5,700	5,700	3,250	3,250	24,000	24,000	5,600	13,400
Building costs	[€]	5,000	5,100	-	-	7,200	7,100	400	400
Total investment costs	**[€]**	**10,700**	**10,800**	**3,250**	**3,250**	**31,200**	**31,100**	**6,000**	**13,800**
Capital bound costs	[€/a]	716	722	252	252	2,255	2,249	422	944
Maintenance costs	[€/a]	233	234	45	45	400	399	175	268
Operation based costs	[€/a]	474	475	389	389	491	490	114	202
Fuel costs	[€/a]	1,497	2,577	1,055	1,718	1,727	2,878	2,383	2,912
Electricity costs	[€/a]	110	110	101	101	45	45	25	25
Total costs per year	**[€/a]**	**3,030**	**4,118**	**1,843**	**2,506**	**4,917**	**6,061**	**3,119**	**4,351**
Annual heat production	[MWh/a]	27.2	27.2	20.6	20.6	38.8	38.8	29.1	29.1
Specific heat generation costs	**[€/MWh]**	**112**	**152**	**90**	**122**	**127**	**156**	**107**	**150**

Due to the lower fuel costs for the operation with OS the specific heat generation costs are considerably lower compared to the operation with class A1 wood pellets (23% for Boiler III and 36% for Stove II and Boiler II). The very low investment and maintenance costs of Stove II lead to lower specific heat generation costs than for the two biomass boilers investigated.

Although the thermal capacity of Boiler III is with 40 kW higher than for Boiler II (28 kW), the specific heat generation costs are only slightly higher than for Boiler II (due to the high investment costs for Boiler III).

For the operation with OS the specific heat generation costs for Boiler II and Boiler III as well as Stove II are clearly below the gas boiler for the operation with liquid gas. Compared to the natural gas boiler the specific heat generation costs for Stove II fired with OS are 16% lower, while the specific heat generation costs for Boiler II and Boiler III are 4 and 18% higher.

4.6. Sensitivity studies

To gain a better understanding of the most relevant influencing parameters on the economic performance, sensitivity studies regarding the investment costs, the full load operating hours (in order to consider the different climate zones in Spain and Greece) and the fuel costs have been performed for all technologies investigated.

As examples, the results of the sensitivity studies for the boilers investigated for Greece are shown in the following diagrams. For a better orientation, within each diagram the base case is marked accordingly.

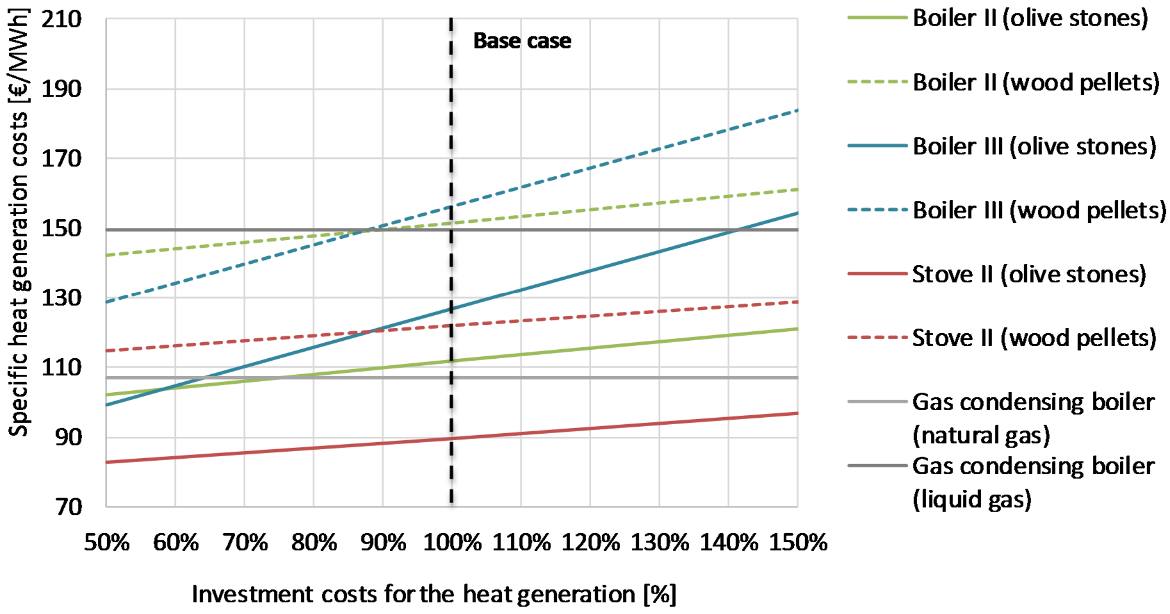

Figure 4.1. Sensitivity studies regarding investment costs for boilers in Greece

Effect of the variation of the investment costs of boilers: Also for a significant increase of the investment costs the specific heat generation costs for the operation with OS are lower than for the liquid gas fired boiler. For the two biomass boilers a decrease in the investment costs (or adequate investment subsidies) would be necessary to get lower specific heat generation costs than for the natural gas fired boiler.

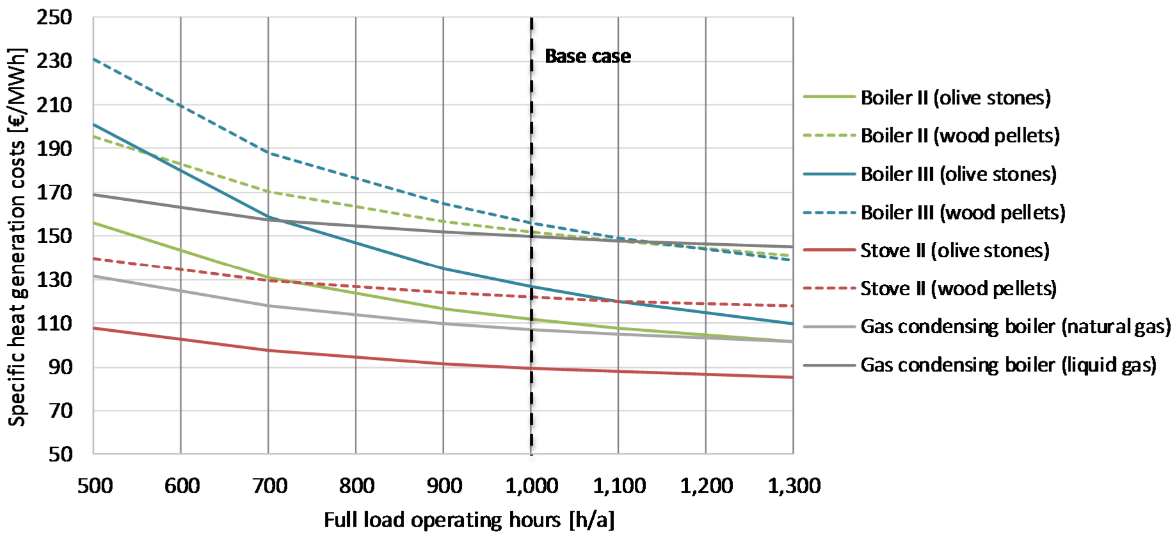

Figure 4.2. Sensitivity studies regarding full load operating hours for boilers in Greece

Effect of the variation of full load operation hours: For all applications, the specific heat generation costs increase with a decreasing number of full load operating hours. Furthermore, the heat generation costs for all applications are lower than for liquid gas boilers, even if the full load operating hours decrease down to 700 h/a.

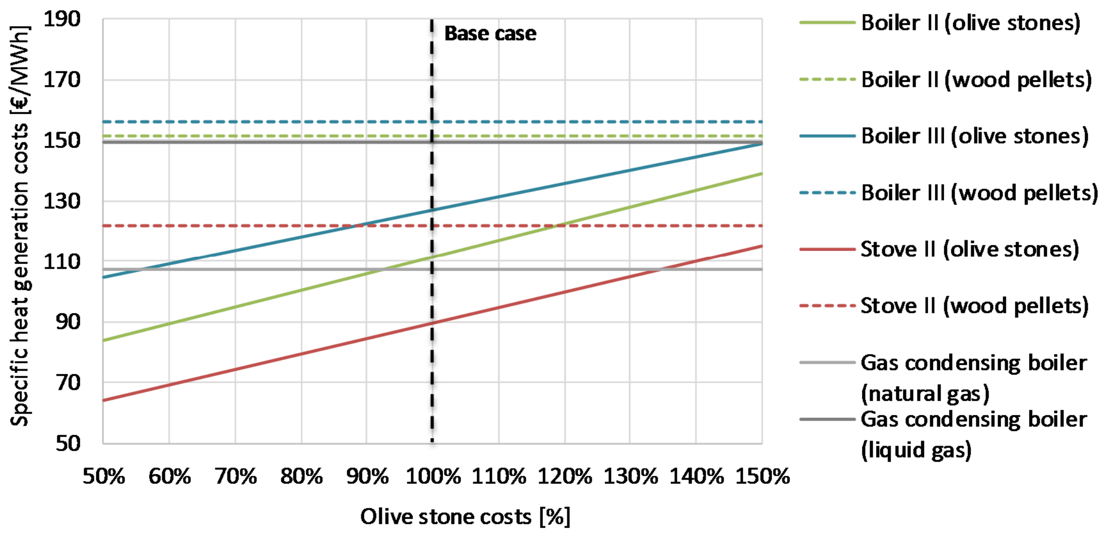

Figure 4.3. Sensitivity studies regarding costs for OS for boilers in Greece

Effect of the variation of the olive stone price: Even an increase of the fuel costs (OS) by 50% leads to lower specific heat generation costs for Boiler II and Boiler III we well as Stove II than for the liquid gas fired boiler. For Boiler II a decrease of the fuel costs by 10% would be necessary to achieve lower specific heat generation costs than for the natural gas fired boiler. For Boiler III a reduction down to 55% would be necessary to get lower specific heat generation costs than for the natural gas fired boiler.

5. Economic evaluation of a 1 MW biomass boiler

The technical evaluation of the stoves and boilers tested has revealed, that for residential scale applications the utilisation of the fuel qualities tested regarding OTP and VYP lead to inadmissibly high TSP, CO and NO_x emissions. Furthermore, due to the high ash contents of these fuels increasing deposit formation has to be expected. A higher effort regarding cleaning becomes necessary and, depending on the technology, problems with the de-ashing of the grate can occur. Thus, OTP and VYP with an ash and N content exceeding the class A2 limits (according to Deliverable Report D3.3) are not suitable for the utilisation in stoves and residential-scale boilers.

In order to investigate an adequate application for the BiomasudPlus fuels OTP and VYP of class B and beyond, a biomass boiler at the lower end of the MPC-DIRECTIVE power range (1 MW_{th}) has been evaluated.

Therefore, the operation of the 1 MW_{th} biomass boiler with VYP (only one pruning fuel has been evaluated, since heating value und bulk density of the two pruning pellets are very similar) has been compared with wood chips as well as class A1 wood pellets. The maximum fuel price for the vineyard pruning pellets for an economically feasible result has been calculated.

Regarding gaseous and particulate emissions for lager biomass boilers the emission limits according to the MCP-DIRECTIVE (EU) 2015/2193 on the limitation of emissions of certain pollutants into the air from medium combustion plants (> 1 MW) have to be considered. By the 1st of January of 2020 the Eco-Design Directive becomes compulsory for all EU member states. The Eco-Design Directive is valid for boilers up to 500 kW_{th} and thus not relevant for the evaluation of the 1 MW_{th} boiler. However, for a better comparability the related emission limits are also displayed in Table 5.1.

Table 5.1. Emission limits valid in Europe for lager biomass boilers

		CO	SOx	TSP	NOx
Eco-Design Directive	<500 kW	364		29	145
MCP-DIRECTIVE (EU) 2015/2193	1-5 MW	n.d.	107	27	267

Emission limits: mg/Nm³ at 13 Vol% O2
n.d. … not defined

Due to the higher nominal load and the robust and more flexible technology of biomass boilers in the 1 MW_{th} capacity range compared to small-scale residential boilers the following assumptions regarding the expected emissions have been made:

- *CO emissions:* It is expected, that for larger biomass boilers and adequate adjustment of the combustion air flows and air staging settings the CO emissions can be reduced down to the level of wood chips.
  → For the utilisation of OTP and VYP no additional investment costs occur.
- *TSP emissions:* To reach the emission limits for TSP of 27 mg/Nm³ (related to 13 vol% O_2) an adequate filter system (most probably multi cyclones and an electric precipitator) is obligatory for wood chips, wood pellets and BiomasudPlus fuels.
  → For the utilisation of OTP and VYP no additional investment costs occur.
- *NO_x emissions:* The NO_x emission measured during the test runs are related to the comparably high N content of the fuel and cannot be reduced by primary measures (optimisation of the combustion conditions). Thus, an adequate secondary measure for NO_x emission reduction (Selective Non-Catalytic Reduction - SNCR) is needed for the 1 MW biomass boiler.
  → Additional investment and operation costs are needed, when OTP and VYP are utilised.

In order to evaluate the economic performance of a 1 MW biomass boiler fired with olive tree or vineyard pruning pellets a differential costs calculation has been performed. Thereby, a VDI 2067 cost calculation considering all cost categories influenced by the biomass fuel used (additional investment costs for the SNCR, consumption costs for the SNCR, additional building costs, …) has been performed in order to calculate the maximum fuel costs allowable to achieve the same heat generation costs as for wood chips or wood pellets.

For these calculations, the general framework conditions for Spain have been considered. For the wood chips a moisture content of 25 wt% w.b. has been considered. The investment costs and consumption costs for the SNCR system are based on calculations of the Umweltbundesamt in Austria (Beschreibung unterschiedlicher Techniken und deren Entwicklungspotentiale zur Minderung von Stickstoffoxiden im Abgas von Abfallverbrennungsanlagen 2011) and experience values of BIOS.

Table 5.2. Differential investment costs regarding building, fuel storage and SNCR as well as differential costs regarding labor costs and consumption costs

Application		**1 MW biomass boiler**		
Fuel type		**wood pellets**	**wood chips**	**VYP**
Nominal load				
Heating capacity	[kW]	1,000	1,000	1,000
Thermal efficiency	[%]	90	90	90
Fuel power input (related to NCV)	[kW]	1,111	1,111	1,111
Electricity demand	[kW]	3.8	5.6	3.8
Operating hours at full load	[h/a]	8,000	8,000	8,000
Bulk density biomass fuel	[kg w.b./m³]	625	220	625
Annual fuel demand	[m³/a]	2,738	10,855	3,048
Fuel delivery	[#/a]	20	20	20
Max. utilisation rate of the fuel storage	[%]	80	80	80
Space requirement fuel storage	[m³]	171	678	190
Space requirement SNCR	[m²]	-	-	10.0
Room height	[m]	3.5	3.5	3.5
Specific building costs	[€/m³]	170	170	170
Building costs	**[€]**	**29,100**	**115,300**	**38,300**
Additional investment costs for the SNCR	[€]	-	-	220,000
Maintenance costs SNCR	[% of invest/a]			2.0%
Maintenance costs SNCR	[€/a]			4,400
Total differencial investment costs	**[€]**	**29,100**	**115,300**	**258,300**
Expenditure of time for the SNCR	[h/a]	-	-	20
Labour costs	[€/h]	20	20	20
Labour costs	[€/a]	-	-	400
Consumption costs for the SNCR	[€/h]		-	0.23
Consumption costs for the SNCR	[€/a]		-	1,864

Based on the differential cost calculation the following specific maximum fuel costs for VYP result for the 1 MW boiler investigated in comparison to class A1 wood pellets and wood chips (see Table 5.3).

Table 5.3. Economic evaluation of a 1 MW biomass boiler: specific maximum fuel costs for VYP

Explanations: *) average fuel costs for the period under consideration base on the fuel price for the first year and a price index of 2%/a

Application		**1 MW biomass boiler**		**1 MW biomass boiler**	
Fuel type		wood pellets	VYP	wood chips	VYP
Capital bound costs	[€/a]	1,600	19,146	6,339	19,146
Maintenance costs	[€/a]	331	5,435	1,310	5,435
Operation based costs	[€/a]	-	455	-	455
Consumption based costs	[€/a]	-	2,119	-	2,119
Fuel costs	[€/a]	413,567	to be calculated	276,170	to be calculated
Total costs per year	**[€/a]**	**423,050**	**27,154**	**283,819**	**27,154**
Resulting costpotentail for VYP	**[€/a]**		**395,896**		**256,665**
Fuel demand	[MWh/a]	8,889	8,889	8,889	8,889
specific max. fuel costs for VYP (first year)	[€/MWh]	40.9	39.2	27.3	25.4
specific max. fuel costs for VYP (average *)	[€/MWh]	46.5	44.5	31.1	28.9
specific max. fuel costs for VYP (first year)	**[€/t]**	**213**	**179**	**102**	**120**
specific max. fuel costs for VYP (average *)	**[€/t]**	**242**	**203**	**116**	**136**

To compensate the additional costs needed for the SNCR compared to wood chips the maximum fuel costs for VYP are 256,665 €/a related to 28.9 €/MWh (7% lower than wood chips costs). Based on a heating value for VYP of 16.8 MJ/kg, fuel costs of 120 €/t would result to achieve the same specific heat generation costs as for wood chips with fuel costs of 102 €/t (at a water content of 25 wt% w.b.).

When comparing with class A1 wood pellets the maximum fuel costs for VYP to compensate the additional costs needed for the SNCR are 395,896 €/a related to 44.5 €/MWh (4% lower than wood pellets costs). Thus, fuel costs of 179 €/t would result to achieve the same specific heat generation costs as for wood pellets with fuel costs of 213 €/t.

According to CIEMAT the current price for VYP in Spain is with 145 €/t higher than the maximum fuel price to reach an economical feasible result for the 1 MW boiler (120 €/t) when compared with wood chips and lower than the maximum fuel price for VYP (179 €/t) to reach an economical feasible result compared to class A1 wood pellets.

6. Conclusions

Currently BiomasudPlus fuels like OS, OTP and VYP are scarcely used as fuels, but they represent a significant, untapped biomass potential in Mediterranean regions of increasing interest for the market. The market prices for the BiomasudPlus fuels in Mediterranean regions are expected to be lower than the prices for wood pellets. In this Report, the technical and economic performance of current residential heating boilers and stoves operated with BiomasudPlus fuels has been evaluated.

6.1. Technical evaluation

Olive stone (OS) combustion in residential stoves and boilers

When utilizing OS in the stoves and boilers tested no problems regarding fuel feeding, ash melting and de-ashing occurred and no shortening of the cleaning intervals was necessary.

The tests with OS resulted in emissions below or slightly above the current and upcoming emission limits. It is expected that, for those technologies, which have not reached the emission limits during the test runs with OS, minor adaptations of the combustion conditions (air flows, air staging settings, grate movement) would lead to sufficiently low emissions. Thus, OS should be suitable for the utilization in residential biomass boilers and stoves with appropriate combustion technologies.

Vineyard and olive tree pruning pellets (OTP and VYP) combustion in residential stoves and boilers

The test runs pointed out, that OTP and VYP (in the quality used for the test runs – class B according to D3.3) should only be used in boilers that are designed for ash rich fuels. Otherwise, problems with ash deposit formation and the de-ashing system result.

Furthermore, the combustion of OTP and VYP lead to high emissions regarding CO, NO_x and TSP exceeding the respective emission limits. Thus, the fuel qualities tested are not suitable for common residential biomass boilers and stoves. However, based on the limits regarding ash and N content defined for OTP within D3.3 the utilization of OTP class A1 and A2 in residential stoves and boilers by complying the emission limits regarding NO_x and TSP seems realistic.

Vineyard and olive tree pruning pellets (OTP and VYP) combustion in larger biomass boilers

For larger-scale biomass boilers (in the range of 1 MW_{th}), the utilization of pruning pellets with high ash contents (OTP and VYP of the quality used during the test runs – class B according to D3.3) should be possible due to the more robust combustion technology. It is expected, that the CO emissions can be reduced down to the level of wood chips. To reach the emission limits for TSP an adequate filter system is obligatory (similarly to wood chips and wood pellets). However, to reach the emission limits for NO_x secondary measures are needed for OTP and VYP in contrast to the utilization of wood chips and wood pellets.

6.2. Economic evaluation

A detailed economic evaluation of the utilisation of BiomasudPlus fuels in the stoves and boilers tested within the project has been performed for the framework conditions in Spain and Greece. Thereby, the utilization of OS has been compared with the utilization of class A1 wood pellets and with state-of-the art liquid gas and natural gas boilers and stoves.

The economic evaluation pointed out that, due to the lower fuel costs of OS the specific heat generation costs of the stoves and boilers investigated are 4 to 36% lower compared to the operation with wood pellets. Thus, from an economic point of view the utilization of OS instead of wood pellets can be recommended for residential stoves and boilers in Spain and Greece.

Furthermore, the economic evaluations revealed that the specific heat generation costs for state-of-the-art liquid gas boilers and stoves are higher than for the biomass boilers and stoves fired with OS (due to the comparably high costs for liquid gas and the additional investment costs for the liquid gas tank). However, compared to state-of-the-art natural gas boilers and stoves the specific heat generation costs of some systems fired with OS (Stove III, Boiler I and Boiler III in Spain and Boiler II and Boiler III in Greece) are higher and thus, these systems are not economically competitive. In this case, subsidies for the utilization of BiomasudPlus fuels would be necessary to be competitive with state-of-the-art natural gas boilers and stoves.

In addition, the utilization of VYP in a 1 MW_{th} biomass boiler has been evaluated. Due to the high N content in the fuel resulting in high NO_x emissions, secondary measures for the reduction of NO_x (selective non-catalytic reduction – SNCR) are necessary. Thus, compared to a wood chips or wood pellets fired boiler increased investment, operation and consumption costs for the SNCR have to be considered. Based on a differential cost calculation the specific maximum fuel costs for VYP where calculated. These calculations have revealed that, based on the current price for VYP in Spain of 145 €/t, the operation with VYP would lead to lower specific heat generation costs than for the operation with wood pellets. To be competitive with wood chips a reduction of the VYP costs down to 120 €/t would be necessary.