Agricultural residues in Greece: quantitative and qualitative characterization for assessing the most promising materials for biogas production

V.P. Aravani[1], M. Kornaros[2], V.G. Papadakis[1]

[1] Department of Environmental Engineering, University of Patras, Seferi 2, 30100, Agrinio, Greece

[2] Department of Chemical Engineering, University of Patras, Karatheodori 1, University Campus- Rio, 26504, Patras, Greece

INTRODUCTION

Greece:

- Strong agro-industrial sector
- Almost 70% of its total area is used for agricultural activities
- Only a small percentage of biomass is currently used to cover electrical energy needs
- Burning of residual biomass in the field
- The final electricity consumption for the year 2018 was 54,3TWh

Main categories of generated residues in Greece:

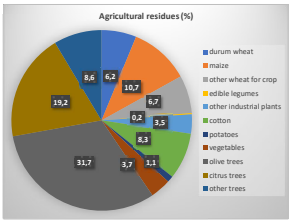


Figure 1: Agricultural residue percentage in Greece (2011-2018). The total average annual production of agricultural residues is 10Mt/y.

Main categories of agricultural residues in Greece:

- Wheat for crop
- Edible legumes
- Industrial plants
- Potatoes
- Vegetables
- Trees

From the Figure 1 olive tree residues seems to have the highest amount regarding the agriculture residues in Greece followed by citrus trees. Maize and durum wheat are the most abundant residues at the category of wheat for crop. From the industrial plants, the greatest production is related to cotton, followed by vegetables and potatoes, respectively.

The estimation formula of crop residues amount is:

$$\text{residues (tn)} = \text{crop production(tn)} * \text{Avi} * \text{Rtpi}$$

Table 1: Residue to product ratio, availability of the main crop residues in Greece, residue's production and estimated energy.

Cultivation species	Type of residue	Range of Residue to Product Ratio (RtPi)	Residue to Product Ratio (RtPi)	Availability (Avi)	Crop production (t/y)	Residue's production (t/y)	Estimated energy (MW)
Wheat for crop							
wheat	straw		1.28	0.40	440,235	225,400	290,708
durum wheat	straw		1.28	0.40	1,151,466	589,550	760,368
barley	straw		1.19	0.40	374,076	178,060	163,131
oat	straw, bran	1.36-1.60	1.48	0.40	100,674	59,599	48,251
rye	straw, bran	1.71-3.10	2.41	0.40	29,218	28,166	27,782
maize	straw	1.00-1.17	1.09	0.50	1,828,607	996,591	923,736
rice	straw, husk		1.70	0.40	247,074	168,010	332,660
Edible legumes							
beans	stem and leaves		1.42	0.40	19,293	10,958	2,625
chickpeas	hay		1.69	0.40	10,762	7,275	1,646
lentils	hay		1.49	0.40	9,338	5,565	1,259
Industrial plants							
tobacco	shoot	1.00-1.23	1.12	0.73	35,867	29,325	29,032
cotton	stalk		2.10	0.50	816,273	857,087	848,516
sunflower	straw		2.20	0.50	178,584	196,443	388,956
sugarbeet	leaves		0.42	0.70	410,438	120,669	26,203
Potatoes							
Potatoes	stalk and leaves	0.38-0.40	0.39	0.40	670,366	104,577	30,562
Vegetables							
Vegetables	sterm, leaves		0.40	0.40	1,991,925	318,708	315,521
Trees							
vineyard for wine	wood		0.65	0.80	492,137	255,911	191,197
vineyard for grapes	wood		0.65	0.80	149,586	77,785	58,115
citrus trees	prunings		2.30	0.80	1,036,055	1,906,341	2,909,553
apple trees	prunings		0.53	0.80	245,536	104,107	110,534
pear trees	prunings		0.54	0.80	88,970	38,435	40,808
peach trees	prunings		0.35	0.80	654,627	183,295	194,612
appricot trees	prunings		0.37	0.80	90,159	26,687	28,335
cherry trees	prunings		0.89	0.80	66,494	47,344	50,389
walnut trees	prunings		1.90	0.80	28,141	42,775	42,347
hazelnut trees	prunings		1.90	0.80	786	1,195	1,183
almond trees	prunings	1.90-2.74	2.32	0.80	40,268	74,738	104,745
chestnut trees	prunings		1.90	0.80	25,586	38,891	38,502
pistachio trees	prunings		1.90	0.80	-		
other fruit trees (fig, kiwi trees etc.)	prunings		2.00	0.80	-		
olive trees	prunings		1.55	0.80	2,631,091	3,262,553	3,229,927

The theoretical estimated energy of agricultural residues in Greece is 11TWh. The estimation formula of the theoretical energy potential of agricultural residues is:

$$\text{energy} = \text{residues} * \text{VS} * \text{BMP} * \text{CH4} * \text{LHV}$$

AGRICULTURAL RESIDUES

According to Table 1, olive trees and followed by citrus trees present the highest estimated energy.

The residues of wheat for crop, edible legumes and trees could be classified as non-biodegradable and suitable for thermochemical treatment (moisture content: below 50- 55%, C: N ratio: above 30), in contrast to the residues of tobacco, sugar beet, potatoes and vegetables which could be classified as biodegradable and suitable for biostabilization and particularly anaerobic digestion (moisture content: above 50-55%, C: N ratio: below 30).

Table 2: Mean values of the physicochemical characteristics of agricultural residues in Greece.

Cultivation species	Type of residue	TS (%)	VS (%)	BMP (m³/kg VS)	CH_4 content (%)	C:N ratio	Retention time (days)	Moisture (wt.%)	Ash (wt.%)	C (%w/w)	H (%w/w)	O (%w/w)	N (%w/w)	S (%w/w)
Wheat for crop														
wheat	straw	70	81	0.30	53	90	30	15	13.70	45.74	6.27			
durum wheat	straw	70	81	0.30	53	90	30	40		44.84	6.23			
barley	straw, bran	70	31	0.51	59	90	30	15	4.90 dry	46.80	5.53	41.90	0.41	0.06
oat	straw, bran	70	70	0.20	58	90	30	15	4.90	46.00	5.91	43.50	1.13	0.02
rye	straw, bran	70	41	0.41	59	90	30							
maize	straw	70	37	0.44	57	90	30	3,55	5.34	45.04	6.01	41.65	0.68	0.06
rice	staw, husk	70	90	0.40	55	90	30	25	13.4	39.88	5.01	36.60	0.70	0.08
Edible legumes														
beans	sterm, leaves	70	13	0.30	60	90	30							
chickpeas	hay	70	13	0.29	60	90	30							
lentils	hay	70	13	0.29	60	90	30							
Industrial plants														
tobacco	shoot, stems	80	90	0.20	55			85		27.27	3.82			
cotton	stalk, lint hull	80	90	0.20	55			6	13.30	40.85	5.11	34.00	2.63	0.00
sunflower	straw	80	90	0.40	55	90	30	40	3.00	47.67	6.24	35.90	1.38	0.15
sugarbeet	leaves	80	12	0.31	56	55	14	75	4.80dry	44.50	5.90	42.80	1.84	0.13
Potatoes														
Potatoes	stalk, leaves	80	13	0.38	58	55	14							
Vegetables														
Vegetables	stem, leaves	80	90	0.20	55	55	14							
Trees														
vineyard for wine	wood	65	96	0.13	60	617		40	3.80	46.29	5.74	41.10	1.80	0.08
vineyard for grapes	wood	65	96	0.13	60	617		40	3.80	46.29	5.74	41.10	1.80	0.08
citrus trees	prunings	70	75	0.37	55	617		40	2.80	45.25	5.84	43.20	1.00	0.03
apple trees	prunings		74	0.25	58	617		40		48.09	6.34			
pear trees	prunings		74	0.25	58	617		40		48.68	6.70			
peach trees	prunings		74	0.25	58	617		40	1.00	48.34	5.64	39.10	0.32	0.05
appricot trees	prunings		74	0.25	58	617		40	0.20	50.06	6.40	41.20	0.80	0.10
cherry trees	prunings		74	0.25	58	617		40	1.00	46.50	6.12			
walnut trees	prunings	80	90	0.20	55	617								
hazelnut trees	prunings	80	90	0.20	55	617								
almond trees	prunings	80	74	0.33	58	617		40		46.08	6.31			
chestnut trees	prunings	80	90	0.20	55	617								
olive trees	prunings	80	90	0.20	55	617		7.10	4.75	48.59	6.21	43.40	0.70	

ANIMAL MANURE

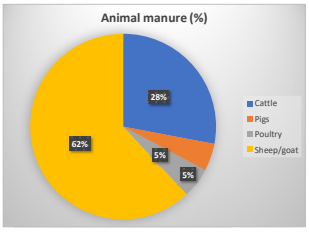


Figure 2: Percentage of animal manure production in Greece (2000-2018). The total average annual production of animal manure is 26Mt/y.

In Greece, animals produce significant amount of manure due to the high animal breeding activity.

Main categories of animal manure in Greece:

- Cattle manure
- Pig manure
- Poultry manure
- Sheep/goat manure

The estimation formula of animal manure is:

$$\text{manure (tn)} = \text{number of heads} * \text{residue/animal}$$

Table 3: Main characteristics of animal waste in Greece.

Animal wastes	Residue/ animal (tn/head/year)	Number of heads	TS (%)	VS (%)	C:N ratio	Biogas yield (m³/kg VS)	Retention time (days)	CH_4 content (%)	Specific weight (kg/L)	BOD_5	COD	COD/BOD_5
cattle	11.16	673,289	9.50	80	13	0.29	25	65	0.99	2.50	11.90	4.85
pig	1.34	952,124	5.50	75	6.50	0.37	30	73.41	0.97	3.10	9.60	3
poultry	0.04	34,108,317	20	75	6.50	0.47	>30	70	1.06	6.80	25.10	3.70
sheep/ goat	1.20	13,604,095	18.33	87		0.53		64.70	0.98	2.30	29.50	13.10

The largest amount of manure is produced by sheep & goats (gathering difficulty).

Livestock manure is considered suitable for biostabilization due to its high moisture percentage (above 70%) and its low C/N ratio (below 30).

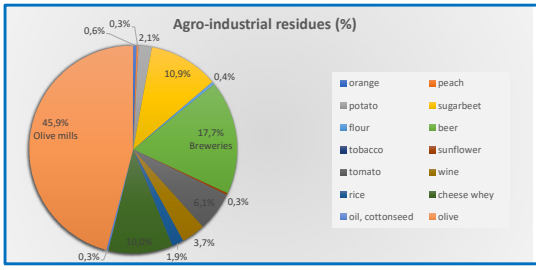
The estimation formula used to calculate the theoretical energy potential of animal manure is:

$$\text{energy} = \text{manure} * \text{VS} * \text{BMP} * \text{CH4} * \text{LHV}$$

Sheep/ goat manure standing out as the most promising energy feedstock.

Table 4: Estimated energy of animal manures (66TWh).

Animal species	Mean value of residues (t/year)	VS (%)	Biogas yield (m³/kg VS)	CH_4 content (%)	Calorific value of biogas (kWh/m³)	Estimated energy (MWh)
cattle	7,382,925	80	0,29	65	10	11,330,976
pig	1,206,215	75	0,37	73	10	2,619,470
poultry	1,395,232	75	0,47	70	10	3,402,305
sheep/ goat	16,120,718	87	0,53	65	10	49,389,803



The main industries that use agricultural or livestock products as raw material in Greece are the orange, peach, tomato, olive, wine, beer, tomato, sunflower, sugar, potato, flour, cotton, tobacco and cheese industries.

Figure 3: Main agro-industrial residue percentage in Greece. The total average production of agro-industrial residues is approximately 13.2Mt/y.

AGRO-INDUSTRIAL RESIDUES

- Most abundant: agro-industrial residues of olive mills followed by agro-industrial residues of breweries, sugar industry, cheese industry, tomato processing and wineries.
- Some could be or are already being used as animal feed: e.g. cheese whey.
- Agro-industrial waste are mostly suitable for biological treatment (anaerobic digestion in particular) as they contain high percentage of moisture and organic matter.

CONCLUSIONS

- Greece could cover its own electric energy needs with only the utilization of agricultural and livestock residues.
- For the needs of this study, Greece was divided into a Northern and a Southern part and relevant proposals were made for residues that can be used for energy production through anaerobic digestion.

Suitable substrates for anaerobic digestion:

✓ Humidity> 50-55%

✓ 15<C:N<30

Northern Greece	Southern Greece
Summer 	Summer 
Winter 	Winter 

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