Feasibility analysis of MSW mass burning in the Region of East Macedonia – Thrace in Greece

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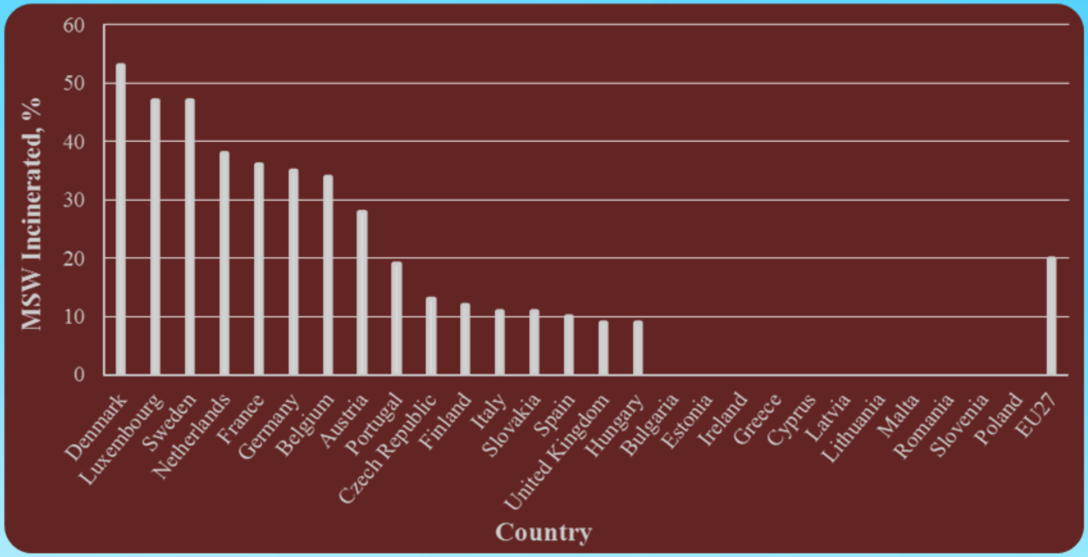
Introduction

MSW mass-burning with simultaneous energy production is a reliable and widespread practice

- more than 800 mass burning plants worldwide
- 460 plants in Europe
- at least 100 of these have been founded in the last 10 years



In 2009, 20 % of EU's MSW were incinerated, a share that exceeded:

- **50 % in Denmark,**
- **40 % in Sweden and**
- **30 % in Germany, France, Netherlands and other EU countries**

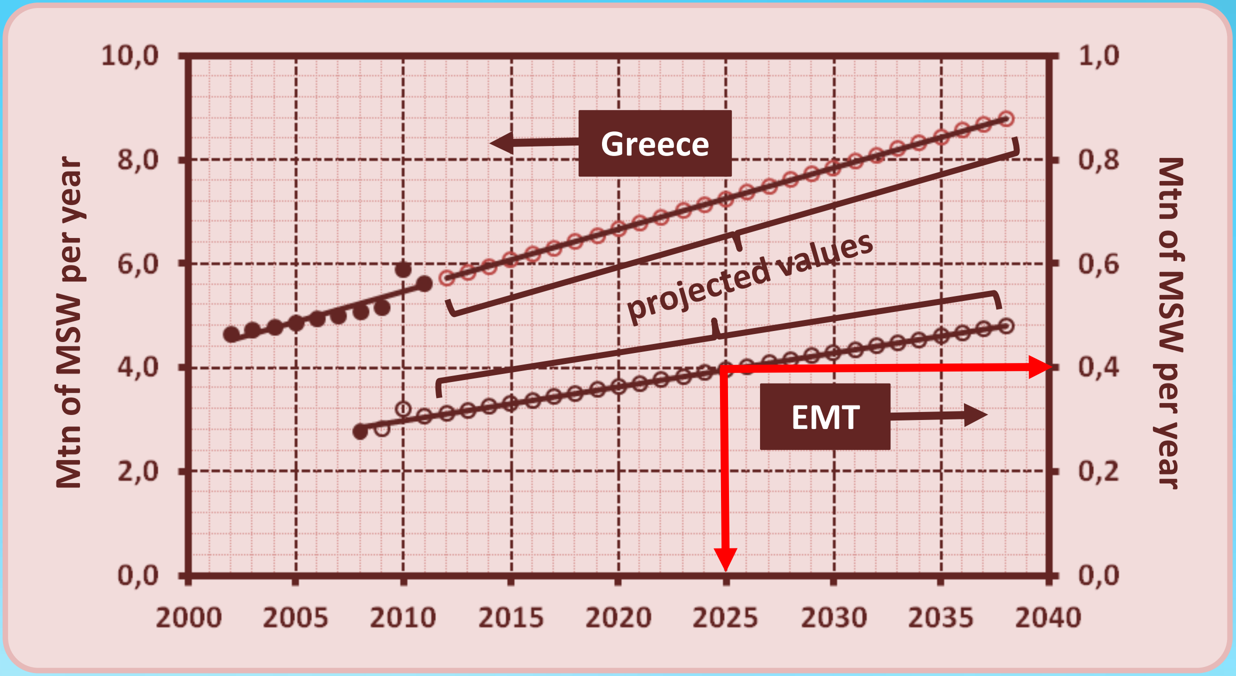
Objective

to evaluate feasibility of a single MSW mass burning to electricity plant in the Region of East Macedonia and Thrace (EMT) based on:

- a commercially available technology and plant design (e.g. 400.000 tn yr^{-1} MSW, 30 MWe/45.7 MWth in Brescia-Italy)
- qualitative/quantitative and the elemental analysis of the MSW for the thermodynamic analysis of the plant design
- the official data of MSW generation in Greece and in EMT Region
- basic economic features for the installation/operation costs

Evolution of MSW generation in EMT region

Based on the evolution of MSW generation in Greece and the MSW generation of EMT, we assumed a linear trend for both.



For 25 years life time:

- the design load was set at 400 ktn yr^{-1} (50 tn h^{-1})
- corresponds to a 20 % increase factor regarding the 2013 MSW generation, in EMT, and to the expected MSW generation in the mid of the plant's life time

MSW composition in the EMT region

	% w (wet)	% moisture	% w (dry)
Fermentable materials	45.80	71.20	20.27
Paper-Cardboard	15.30	5.93	22.12
Plastic	16.50	0.44	25.25
Leather-Wood-Fabric-Tires (LWFT)	5.20	10.50	7.15
Diapers-sanitary napkins-toilet paper (DSNTP)	6.20	5.93	8.96
Metal	3.40	2.50	5.10
Glass	4.30	2.00	6.48
Inert materials	2.00	8.00	2.83
Other	1.30	8.00	1.84
Total	100.00	34.94	100.00

MSW elemental analysis and HHV of MSW in the EMT region

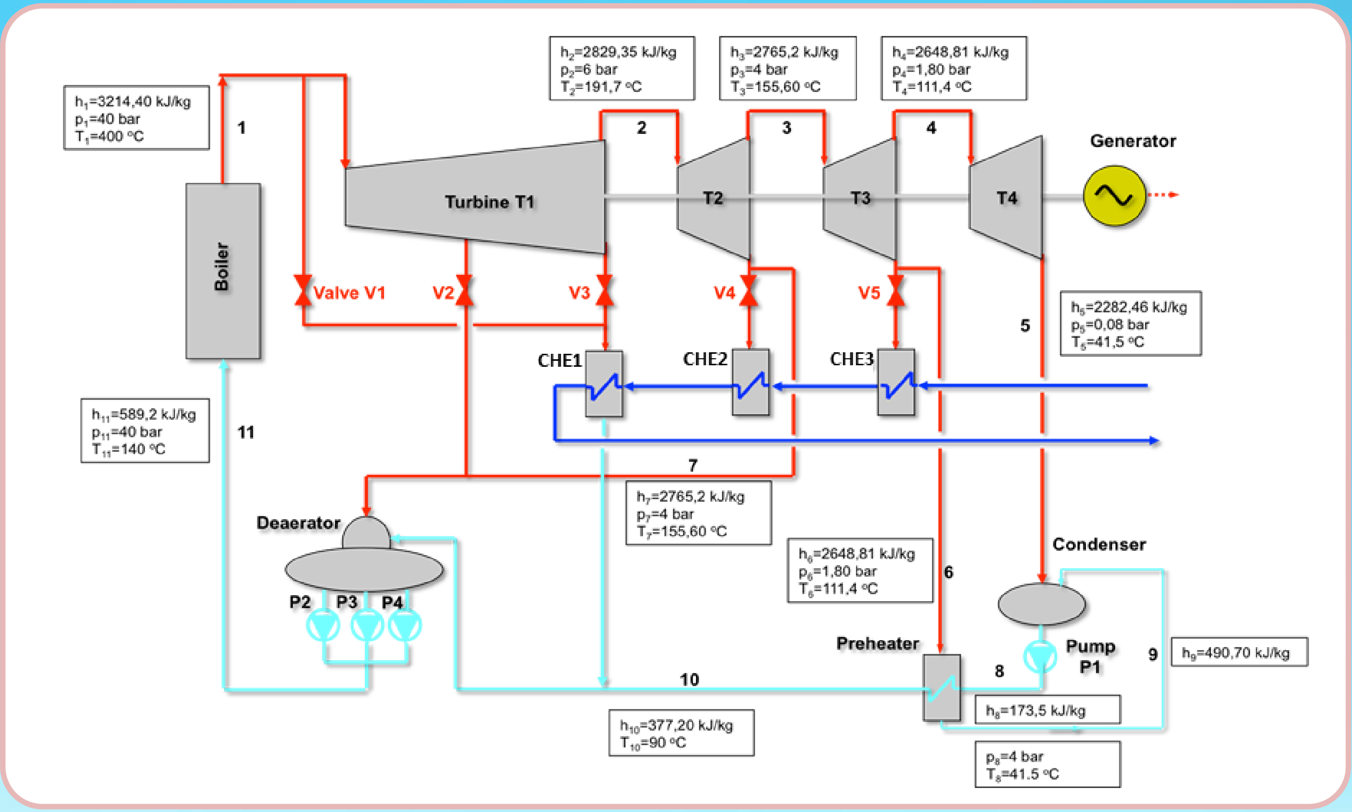
	%w (dry)						kJ/kg		
	C	**H**	**O**	**N**	**S**	**ash**	**HHV[1]**	**HHV[2]**	**LHV[2]**
Fermentable	48.00	7.66	32.70	5.75	0.52	5.37	20.761	5.979	3.756
Paper-Cardboard	39.40	5.99	42.20	0.11	0.00	12.30	14.427	13.572	12.189
Plastic	74.90	11.10	5.78	0.14	0.05	8.04	37.948	37.780	35.341
LWFT	60.63	7.65	21.38	4.20	0.16	5.99	26.619	23.824	22.063
DSNTP	39.40	5.99	42.20	0.11	0.00	12.30	14.427	13.572	12.189
Metal	4.50	0.60	4.30	0.10	0.00	90.50	1.619	1.579	1.389
Glass	0.50	0.10	0.40	0.10	0.00	98.90	233	228	158
Inert materials	26.30	3.00	2.00	0.50	0.20	68.00	12.215	11.238	10.436
Other	26.30	3.00	2.00	0.50	0.20	68.00	12.215	11.238	10.436
Total	46.72	6.94	23.07	1.57	0.14	21.56	**20.847**	**13.563**	**11.718**

1 dry basis **2 wet basis**

Higher Heating Values (HHV) were calculated by elemental compositions (dry weight), through the correlation (Komilis et al. 2012): HHV = 350,26C + 1241.74H-146.13O

Design parameters (of Brescia plant)

- the cogeneration option was not considered
- operation temperature above 850 °C (effluent gasses at 130 °C)
- 1 kg of diesel per ton of MSW, as supplementary fuel



- 60 % air excess
- operate on 5 – 15 MJ kg^{-1} LHV of MSW
- “moving griddle” burner

Cost elements

Initial investment and annual operating costs of MSW mass-burning-to-electricity plants exhibit a considerable heterogeneity

The investment (I) and operating cost (OC) functions used herein was estimated according to the correlations (Tsilemou and Panagiotakopoulos 2006):

$$I = 5000 \times C^{0.8} \quad \Leftrightarrow \quad I_{2003} = 5000 \times C^{0.8} = 5{,}000 \times (400{,}000)^{0.8} = 151.57 \text{ x } 10^{6}\text{ €}$$

$$OC = 700 \times C^{-0.3} \quad \Leftrightarrow \quad OC_{2013} = 700 \times C^{-0.3} = 700 \times (400{,}000)^{-0.3} = 14.60 \text{ €/tn of wet MSW}$$

where C the nominal plant capacity in tn yr^{-1}.

These correlations refer to 2003, and they were inflated to 2013 using an average annual inflation of 2.7 %:.

$$I_{2013} = I_{2003}(1.027)^{(2013-2003)} = 197.8\text{x}10^{6}\text{€}$$

$$OC_{2013} = OC_{2003}(1.027)^{(2013-2003)} = 19.06 \text{ €/tn MSW}$$

Burner losses and efficiency

Product	mol wkg^{-1} MSW	sensible heat losses
CO_2	25.383	10.47
H_2O	44.920	160.88
O_2	24.823	78.25
N_2	197.105	605.67
NO_2	0.054	0.22
SO_2	0.028	0.12
Total	**292.312**	**949.83**

NO_2, the data was taken from data referring to similar existing mass burning plants

- exhaust gas composition (mol kg^{-1} of MSW) in 60% air excess and losses due to exhaust gas sensible heat (kJ wkg^{-1} of MSW)

Burner losses and efficiency

- total losses due to exhaust gas sensible heat: 949.83 kJ kg^{-1}, i.e. the 8.1 % of LHV at the inlet*
- specific latent heat of steam condensation : 40,7 kJ mol^{-1}
- latent heat losses: 1828.22 kJ kg^{-1}, i.e the 15.6 % of LHV at the inlet*
- specific heat capacity of ash: 1,047 kJ kg^{-1} $^{o}C^{-1}$
- ash outgoing temperature : 425 ^{o}C
- heat losses due to ash removal: 58.74 kJ kg^{-1}, i.e the 0.5 % of LHV at the inlet*
- heat losses due to unburned carbon and radiation: negligible
- total heat losses: 2830,79 kj kg^{-1} of wet MSW
- useful heat: 10772.89 kJ kg^{-1} (129.30 MJ s^{-1})*
- boiler efficiency : 10772,89/13609,68 = 79.16 %*

*** taking into account the 1 kg of diesel per wet tn of MSW**

electrical power output

gross electrical power[1]:	41.39 MW (full load operation)
in-plant electricity consumption[2]:	19 %
net electrical energy (available to grid):	33.52 MW
overall efficiency[3]:	20.53 % LHV

R_1 coefficient (Directive EU2008/98):

$$R_1 = \frac{E_P - E_F - E_I}{0.97 \times (E_F + E_W)}$$

where:

- E_P — 2.6 times the produced electricity (including the electricity consumed by the plant - 41.39 MW for 8,000 hr yr^{-1}) plus 1.1 times the produced heat (zero - cogeneration option was taken into account)
- Ef — fossil LHV induced to the system (auxiliary diesel, i.e. 43.4 MJ kg^{-1} regarding 1 kg of diesel per tn of wet MSW)
- Ew — LHV of the wet MSW (400 ktn per yr multiplied by 11718 Mj tn^{-1})
- Ei — all other (except Ef and Ew) energy supplied to the system (2 % of gross electricity)[2]

R1, for full load operation, is 0.67 (> 0.65, the official EU limit)

1 calculated by mass and energy balances and the thermodynamics of the steam-turbine unit
2 according to data regarding similar units already in operation
3 of the MSW and the auxiliary diesel fuel

electricity price

renewable fraction 87.85 € MWh^{-1}

the fossil fraction "System Marginal Price" (SMP)

in 2013, the monthly average SMP varied between 62.81 € MWh^{-1} in December and 32.30 € MWh^{-1}, in June, forming a year average of 41.47 € MWh^{-1}

Despite its expected variations, the SMP for the analysis herein was considered equal to 32 € MWh^{-1}, i.e. slightly below the minimum of 2013.

The renewable fraction of total MSW: fermentable materials (food waste)
paper/cardboard and
75 %ww of the TWRL fraction (by assumption)

renewable LHV: 4.45 kJ/kg (37.8 % LHV at inlet)

selling price: 37.8% x 87.85 + 62.2% x 32 = **53.19 € MWh^{-1}**

economic feasibility estimation

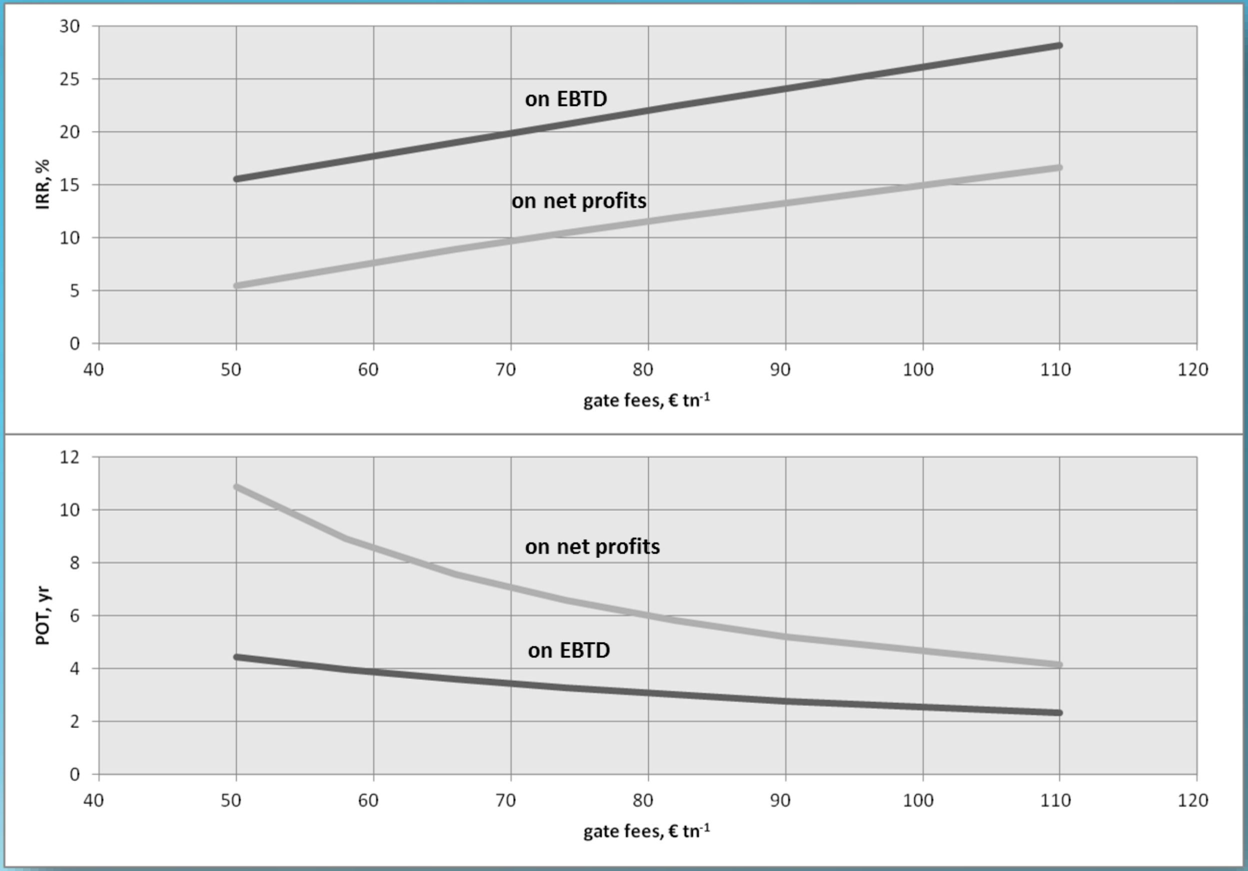
Based on: investment costs and annual operation costs correlations
calculated selling electricity price
and for 40 % investment subsidization

feasibility analysis for gate fees set at 90 € tn^{-1}

Initial investment(10^6€)	197,843.79		
Subsidy (10^3 €/year)	79,137.52		
Equity capitals(10^3 €/ year)	118,706.28		
Operating cost (10^3 €/ year)	7,625.08		
Depreciation (10^3 €/ year)	11,870.63		
Electricity revenues (10^3 €/ year)	14,266.30	IRR on EBTD	24.10%
Gate fees (10^3 €/ year)	36,000.00	IRR on net profit	13.32%
EBTD* (10^3 €/ year)	42,641.21	POT on EBTD	2.78
Net profit (10^3 €/ year)	22,770.23	POT on net profit	5.21

gate Fees for MSW mass-burning WTE plants, in EU vary from below 70 to above 130 € tn^{-1}

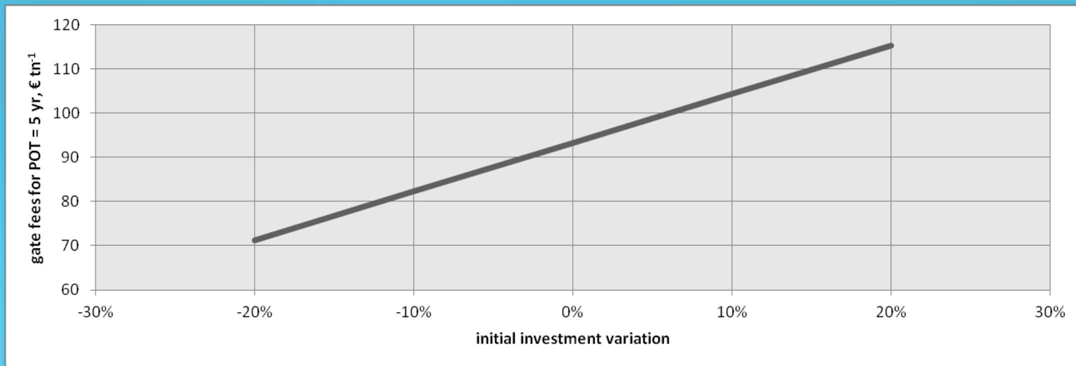
IRR and POT dependence on gate fees

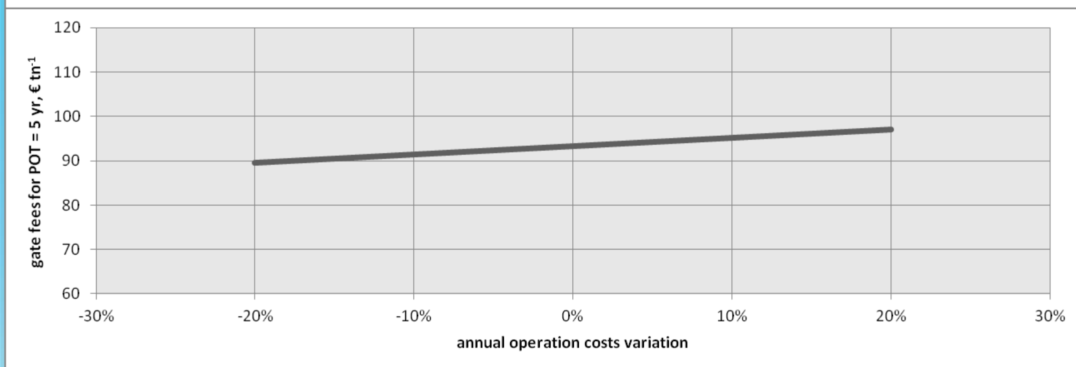


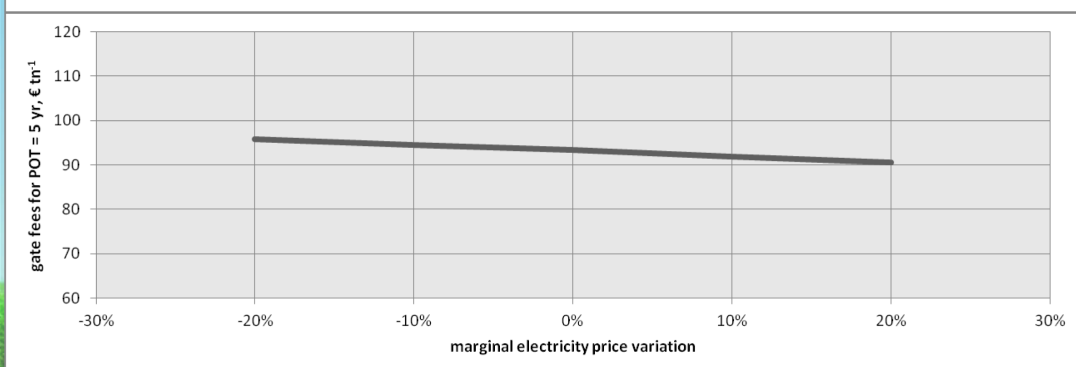
- POT on net profits can still be below 6 years (a limit that can be considered to denote an investment opportunity, in the Greek economic environment), for imposed gate fees as low as 80 € tn^{-1}
- For 80 € tn^{-1} gate fee value, IRR on net profits is above 10 % (exceeds 20 % if calculated on EBTD)

sensitivity analysis

- Gate fee variation, in order the POT on net profits to be equal to 5 years for 80 € tn^{-1} gate fee value, IRR on net profits is above 10 % (exceeds 20 % if calculated on EBTD)







- sensitive against initial investment - a 20 % increase results 30 % increase of gate fees

- much less sensitive to the variation of annual operation costs and on the SMP

conclusions

- mass burning to electricity of the total potential of MSW in the region of EMT (the option of heat cogeneration was not examined).
- nominal capacity: 0.4 Mtn yr^{-1} of wet MSW (50tn hr^{-1}, for 8000 hours annual operation) (expected to operate at ± 20 % of its nominal capacity, in its total lifetime)
- nominal power output : 32.5 MW (as in Brescia similar plant)
- annual production: 260 GWh
- overall efficiency : 20.5 % LHV
- R1 coefficient : 0.67 (above the EU Directive 2008/98 limit)
- Renewable LHV fraction: 37.9 % LHV inlet
- electricity price: 53.2 € MWh^{-1} (for MSP =32 € MWh^{-1})
- initial investment: 190 M€
- annual operation costs: 20 € tn^{-1} of wet MSW
- POT: 6 years (40 % subsidization, and 90 € tn^{-1} of wet MSW gate fees)

- **clear economic viability of a MSW mass burning to electricity solution in EMT**
- **the expected considerable increase of SMP in the forthcoming years further enforces this viability, even at gate fees as low as 75 € tn^{-1} (among the lowest for mass burning in EU-27)**

thank you all for your attention