Combined Heat and Power Units

Scope

The scope of this exercise was to produce the calculations required to be able to quantify the Return of Investment resulting from replacing boilers with Combined Heat and Power units (CHPs). The CHPs would be used to supply hot water for space heating and/or domestic hot water and generate electrical power.

Overview

The calculation is modular, based on a number of boilers. It is assumed that the proposed CHP unit will replace the boiler(s) meeting the same thermal load. It is further assumed that three types of fuel can be used: Liquefied Petroleum Gas (LPG), Light Fuel Oil (LFO) and Diesel.

The user inputs the variables listed in Table 1 for each boiler or number of similar boilers. Variables i1 to i7 describe the current system. The user selects whether the boiler runs on diesel, LFO or LPG. The volume of diesel, LFO or LPG is specified in variables i2 to i4.

The efficiency of the boilers is inputted in variables i5 to i7. The boiler efficiency value should be based on the Gross (Higher) Calorific Value of the fuel used and should only be related to the boiler itself. Losses such as thermal losses along the pipework should not be included. Such an efficiency is also called Fuel-to-steam efficiency.

The proposed CHP units are described using variables i8 to i13. The thermal efficiency values (based on the Gross (Higher) Calorific Value of the fuel) are inputted in variables i8 to i10 and the electrical generation efficiency values are defined in variables i11 to i13.

Input variables i1 to i13 are inputted for the different boilers (numbered 1 to n).

Variable No	Input Variable	Symbol	Unit
i1	No of similar boilers	N	No
i2	Current Annual Fuel Consumption per boiler - Diesel	$V_{CN.D}$	litres/year
i3	Current Annual Fuel Consumption per boiler - LFO	$V_{CN.LFO}$	litres/year
i4	Current Annual Fuel Consumption per boiler - LPG	$V_{CN.LPG}$	litres/year
i5	Boiler Efficiency - Diesel	$B_{eff.D}$	%
i6	Boiler Efficiency - LFO	$B_{eff.LFO}$	%
i7	Boiler Efficiency - LPG	$B_{eff.LPG}$	%

i8	Proposed CHP Thermal Efficiency - Diesel	$CHP.T_{eff.D}$	%
i9	Proposed CHP Thermal Efficiency - LFO	$CHP.T_{eff.LFO}$	%
i10	Proposed CHP Thermal Efficiency - LPG	$CHP.T_{eff.LPG}$	%
i11	Proposed CHP Electrical Efficiency - Diesel	$CHP.E_{eff.D}$	%
i12	Proposed CHP Electrical Efficiency - LFO	$CHP.E_{eff.LFO}$	%
i13	Proposed CHP Electrical Efficiency - LPG	$CHP.E_{eff.LPG}$	%

Table 1: Required Inputs – Technical

The unit fuel costs for diesel, LFO and LPG are specified in financial inputs fi1 to fi3 (listed in Table 2).

The user inputs the CHP costs in financial variables fi4 to fi7 and defines the discount rate and the required Return of Investment (ROI) period in variables fi8 and fi9 respectively. The electricity generated by the CHP unit can either be used on site or else fed to the grid. The appropriate electricity tariff is defined in variable fi10. Enemalta consumption tariffs are shown in Appendix 1.

Variable No	Input Variable	Symbol	Unit
fi1	Unit Fuel Cost - Diesel	U_D	€/litre
fi2	Unit Fuel Cost - LFO	U_{LFO}	€/litre
fi3	Unit Fuel Cost - LPG	U_{LPG}	€/litre
fi4	Dismantling Cost	C_1	€
fi5	Disposal Cost	C_2	€
fi6	Capital Cost	C_3	€
fi7	Installation Cost	C_4	€
fi8	Discount Rate	i	%
fi9	ROI period	R	Years
fi10	Electricity Tariff	r	€/kWh

Table 2: Required Inputs – Financial

The algorithm calculates and presents the outputs listed in Table 3 and Table 4.

The current, proposed, generated and saved energy consumption and the corresponding costs are calculated in variables o1 to o45 and fo1.

The Return of Investment and the Payback period (variables fo3 to fo6) are calculated based on the savings (variable fo1) and the total investment cost (variable fo2).

Variable No	Output Variables	Symbol	Unit
o1	Fuel Energy Consumption – Boiler N - Diesel	$E_{CN.D}$	kWh/year
o2	Fuel Energy Consumption – Boiler N - LFO	$E_{CN.LFO}$	kWh/year
o3	Fuel Energy Consumption – Boiler N - LPG	$E_{CN.LPG}$	kWh/year
o4	Total Current Fuel Energy Consumption – Diesel	$E_{C.D}$	kWh/year
o5	Total Current Fuel Energy Consumption – LFO	$E_{C.LFO}$	kWh/year
o6	Total Current Fuel Energy Consumption – LPG	$E_{C.LPG}$	kWh/year
o7	Total Current Fuel Energy Consumption	E_C	kWh/year
o8	Water Heating Requirement – Heater N	Q_N	kWh/year
o9	Proposed Fuel Energy Electricity Consumption – CHP N - Diesel	$E_{PN.D}$	kWh/year
o10	Proposed Fuel Energy Electricity Consumption – CHP N – LFO	$E_{PN.LFO}$	kWh/year
o11	Proposed Fuel Energy Electricity Consumption – CHP N - LPG	$E_{PN.LPG}$	kWh/year
o12	Proposed Fuel Energy Consumption – Diesel	$E_{P.D}$	kWh/year
o13	Proposed Fuel Energy Consumption – LFO	$E_{P.LFO}$	kWh/year
o14	Proposed Fuel Energy Consumption - LPG	$E_{P.LPG}$	kWh/year
o15	Total Proposed Fuel Energy Consumption	E_P	kWh/year
o16	Electrical Energy Generated – CHP N - Diesel	$E_{GN.D}$	kWh/year
o17	Electrical Energy Generated – CHP N - LFO	$E_{GN.LFO}$	kWh/year
o18	Electrical Energy Generated – CHP N - LPG	$E_{GN.LPG}$	kWh/year
o19	Electrical Energy Generated – Diesel	$E_{G.D}$	kWh/year
o20	Electrical Energy Generated – LFO	$E_{G.LFO}$	kWh/year
o21	Electrical Energy Generated – LPG	$E_{G.LPG}$	kWh/year
o22	Total Electrical Energy Generated	E_G	kWh/year
o23	Annual Energy Savings – CHP N	E_{SN}	kWh/year
o24	Total Annual Energy Savings	E_S	kWh/year
o25	Percentage Energy Savings – CHP N	S_N	%
o26	Current Annual Fuel Consumption - Diesel	$V_{C.D}$	litres/year
o27	Current Annual Fuel Consumption - LFO	$V_{C.LFO}$	litres/year
o28	Current Annual Fuel Consumption - LPG	$V_{C.LPG}$	litres/year

o29	Proposed Annual Fuel Consumption – CHP N - Diesel	$V_{PN.D}$	litres/year
o30	Proposed Annual Fuel Consumption – CHP N - LFO	$V_{PN.LFO}$	litres/year
o31	Proposed Annual Fuel Consumption – CHP N - LPG	$V_{PN.LPG}$	litres/year
o32	Proposed Annual Fuel Consumption – Diesel	$V_{P.D}$	litres/year
o33	Proposed Annual Fuel Consumption – LFO	$V_{P.LFO}$	litres/year
o34	Proposed Annual Fuel Consumption – LPG	$V_{P.LPG}$	litres/year
o35	Current Annual Diesel Cost	$C_{C.D}$	€/year
o36	Current Annual LFO Cost	$C_{C.LFO}$	€/year
o37	Current Annual LPG Cost	$C_{C.LPG}$	€/year
o38	Proposed Annual Diesel Cost	$C_{P.D}$	€/year
o39	Proposed Annual LFO Cost	$C_{P.LFO}$	€/year
o40	Proposed Annual LPG Cost	$C_{P.LPG}$	€/year
o41	Total Current Annual Fuel Cost	C_C	€/year
o42	Total Proposed Annual Fuel Cost	C_P	€/year
o43	Revenue from Generated Electrical Energy	C_G	€/year
o44	Percentage Energy Savings	S_E	%
o45	Percentage Cost Savings	S_C	%

Table 3: Calculated Outputs

Variable No	**Output Variables**	**Symbol**	**Unit**
fo1	Total Annual Energy Cost Savings	C_S	€/year
fo2	Total Investment Cost	C_t	€
fo3	Pay Back Period - Simple	t_{SPB}	years
fo4	Pay Back Period - NPV	T_{NPV}	years
fo5	ROI after R years	ROI_R	€
fo6	Percentage ROI after R years	$ROI_{R\%}$	%

Table 4: Calculated Outputs - ROI

Negative E_S, C_S, S_E, S_C, t_{SPB}, and t_{NPV} values imply that the investment is not profitable.

Conclusion

A preview with three units and dummy values is shown in Appendix 2. The three options shown are for (i) diesel fired boiler, (ii) LFO fired boiler, and (iii) LPG fired boiler. The number of units can be increased accordingly.

Appendix 1: Enemalta Tariffs

Band	Cumulative Consumption (kWh)	Tariff (€/kWh)
1	0 - 2,000	0.1215
2	2,001 - 6,000	0.1275
3	6,001 - 10,000	0.1373
4	10,001 - 20,000	0.1485
5	20,001 - 60,000	0.1613
6	60,001 - 100,000	0.1500
7	100,001 - 1,000,000	0.1403
8	1,000,001 - 5,000,000	0.1275
9	5,000,000 & over	0.1080

Appendix 2: Excel version of Calculations

Boiler Number				1	2	3	TOTAL
Similar Heaters		N	No	1	1	1	
Current Annual Fuel Consumptiopn - per boiler	Diesel	$V_{CN.D}$	litres/year	6000			6,000
	LFO	$V_{CN.LFO}$	litres/year		6000		6,000
	LPG	$V_{CN.LPG}$	litres/year			9000	9,000
Boiler Efficiency	Diesel	$B_{eff.D}$	%	90			
	LFO	$B_{eff.LFO}$	%		90		
	LPG	$B_{eff.LPG}$	%			90	
Current Fuel Energy Consumption	Diesel	$E_{CN.D}$	kWh/year	64,109	0	0	64,109
	LFO	$E_{CN.LFO}$	kWh/year	0	66,323	0	66,323
	LPG	$E_{CN.LPG}$	kWh/year	0	0	65,448	65,448
Water Heating Requirement		Q_N	kWh/year	57,698	59,690	58,904	176,292
Proposed CHP Thermal Efficiency	Diesel	$CHPT_{eff.D}$	%	65			
	LFO	$CHPT_{eff.LFO}$	%		65		
	LPG	$CHPT_{eff.LPG}$	%			65	
Proposed CHP Electrical Efficiency	Diesel	$CHPE_{eff.D}$	%	25			
	LFO	$CHPE_{eff.LFO}$	%		25		
	LPG	$CHPE_{eff.LPG}$	%			25	
Proposed Fuel Energy Consumption	Diesel	$E_{PN.D}$	kWh/year	88,766	0	0	88,766
	LFO	$E_{PN.LFO}$	kWh/year	0	91,831	0	91,831
	LPG	$E_{PN.LPG}$	kWh/year	0	0	90,621	90,621
Proposed Annual Fuel Consumption	Diesel	$V_{PN.D}$	litres/year	8,308	0	0	8,308
	LFO	$V_{PN.LFO}$	litres/year	0	8,308	0	8,308
	LPG	$V_{PN.LPG}$	litres/year	0	0	12,462	12,462
Electrical Energy Generated	Diesel	$E_{GN.D}$	kWh/year	22,192	0	0	22,192
	LFO	$E_{GN.LFO}$	kWh/year	0	22,958	0	22,958
	LPG	$E_{GN.LPG}$	kWh/year	0	0	22,655	22,655
Energy Savings		E_{SN}	kWh/year	-2,466	-2,551	-2,517	-7,534
		S_N	%	-3.8	-3.8	-3.8	

INPUTS

Cost Item	Symbol	Value	Unit
Unit Fuel Cost - Diesel	U_D	1.50	EUR/litre
Unit Fuel Cost - LFO	U_{LFO}	1.50	EUR/litre
Unit Fuel Cost - LPG	U_{LPG}	1.50	EUR/litre
Dismantling Cost	C_1	2,000	EUR
Disposal Cost	C_2	500	EUR
Capital Cost	C_3	20,000	EUR
Installation Cost	C_4	2,500	EUR
Discount Rate	i	2.00	%
ROI period	R	4	years
Electricity Tariff	r	0	EUR/kWh

OUTPUTS

Cost Item		Symbol	Value	Unit
Total Investment Cost		C_t	25,000	EUR
Current Annual Diesel Cost		$C_{C.D}$	9,000	EUR/year
Current Annual LFO Cost		$C_{C.LFO}$	9,000	EUR/year
Current Annual LPG Cost		$C_{C.LPG}$	13,500	EUR/year
Total Current Fuel Energy Consumption		E_C	195,880	kWh/year
		C_C	31,500	EUR/year
Proposed Annual Diesel Cost		$C_{P.D}$	12,462	EUR/year
Proposed Annual LFO Cost		$C_{P.LFO}$	12,462	EUR/year
Proposed Annual LPG Cost		$C_{P.LPG}$	18,692	EUR/year
Proposed Fuel Energy Consumption		E_P	271,218	kWh/year
		C_P	43,615	EUR/year
Total Electricity Generation		E_G	67,805	kWh/year
		C_G	0	EUR/year
Energy Consumption (savings)		E_S	-7,534	kWh/year
		C_S	-12,115	EUR/year
		S_E	-3.8	%
		S_C	-38.5	%
Pay Back Period	Simple	t_{SPB}	-2.06	years
			-24.8	months
	NPV	t_{NPV}	-2.04	years
			-24.5	months
Return of Investment after year no. R (using NPV)		ROI_R	-71,132	EUR
		$ROI_{R\%}$	-284.5	%