

Sustainability Promotion Assessment – Proof of Economic and Environmental Viability

The computational models for both case-studies 1 and 2 approached in the work titled “Methodology to assess the integrity of Water and Energy Integration Systems (WEIS) models using the ThermWatt computational tool” have been developed with the ultimate aim to assist on the project of the installation of WEIS, having the inherent capacity to estimate the values associated to all stream allocation and equipment sizing-related variables to systems which are set to promote overall eco-efficiency through recirculation. These have been primarily developed to minimize the input of energy and water in the system, while respecting the most basic constraints related to physical phenomena occurrence and operational constraints associated to plant maintenance. The project of the WEIS also required the project of the implementation of several technologies, which overall entail investment costs which are in all cases additional costs to the plant. These costs are overall related to the installation of the new machinery, maintenance of the installation and acquisition of new utilities.

The reduction of water and energy inputs in the water system is a guarantee that the environmental burden (resulting from the use of both these resources) is diminished in absolute values, as it is the case for the operational costs associated to these. With the aim to ensure that the project satisfies the requirements for it to be considered viable in respect to sustainability (economically and environmentally viable), it is necessary to proceed with both an economic evaluation and an environmental impact reduction assessment so to effectively ensure the simultaneous economic and environmental viability associated to the WEIS project. In the sequence of Tables A1 and A2, it is presented the determination of the required indicators that lead to the effective economic evaluation and environmental impact reduction assessment of the previously presented WEIS projects for both case-studies 1 and 2. In respect to the performance of the presented assessments, the following assumptions and determination aspects are considered:

- The considered unitary water and energy prices are the ones that have already been used for the development of the optimisation models (23.66 €/GJ for natural gas, 0.1459 €/kWh for electricity and about 1.85 €/m³ for freshwater);
- The considered unitary equivalent carbon dioxide emissions factors are the ones covenanted for the energy system of Portugal.

Table A1. Economic Evaluation and Environmental Impact Reduction Assessment for Case-study 1

Natural gas consumption (kg/h)				
Process	Initial	Improved	Savings Share	Savings (€/h)
Kiln 1	196.5	156.53	20.34%	42.65
Kiln 2	103.5	78.80	23.87%	26.36
Hot utilities consumption (GJ/h)				
Unit	Initial	Improved	Savings Share	Savings (€/h)

Heater 1	0.175	0.003	97.88%	4.05
Heater 2	0.183	0.003	97.83%	4.24
Heater 3	0.133	0.004	97.97%	3.08
Heater 4	0.023		100.00%	0.54
Cold utilities consumption (GJ/h)				
Unit	Initial	Improved	Savings Share	Savings (€/h)
Cooler	0.396		100.00%	16.05
Water consumption (m³/h)				
Initial	Improved	Relative Savings Share	Savings (€/h)	
1.378	1.051	23.71%	0.60	
Electricity Balances (kWh/h)				
Net Electricity Generation (kWh/h)				Savings (€/h)
81.91				11.95
Final assessment				
Investment Cost (k€)	Savings (k€/year)		Payback Time (Years)	
1538.32	856.94		1.80	
Total CO_{2,eq} Emissions Reduction (kton CO_{2,eq}/year)				
2.42				

Table A2. Economic Evaluation and Environmental Impact Reduction Assessment for Case-study 2

Natural gas consumption (kg/cycle)				
Process	Initial	Improved	Relative Savings Share	Savings (€/cycle)
Kiln 1	5355.00	4530.38	15.40%	879.92
Kiln 2	5044.20	3529.69	30.02%	1616.08
Kiln 3	334.29	318.18	4.82%	17.19
Kiln 4	1266.05	1230.65	2.80%	37.78
Hot utilities consumption (GJ/h)				
Unit	Initial	Improved	Relative Savings Share	Savings (€/h)
Heater 1	0.125		100.00%	2.958
Heater 2	0.180		100.00%	4.259
Heater 3	0.033		100.00%	0.781
Cold utilities consumption (GJ/h)				
Cooler 1	0.085		100.00%	3.439
Cooler 2	0.133		100.00%	5.374
Cooler 3	0.017		100.00%	0.689
Water consumption (m³/h)				
Initial	Improved	Relative Savings Share	Savings (€/h)	
0.861	0.529	38.57%	0.61	
Electricity Balances (kWh/cycle)				
Net Electricity Generation (kWh/cycle)				Savings (€/cycle)
771.89				112.62
Final assessment				
Investment Cost (k€)	Savings (k€/year)		Payback Time (Years)	
1802.81	637.91		2.83	
Total CO_{2,eq} Emissions Reduction (kton CO_{2,eq}/year)				
1.76				

The assessment of both WEIS projects converges on the determination of the economic and environmental viability associated to these. In the context of the present analysis, such determination has as a basis the analysis of the payback period and the absolute $\text{CO}_{2,\text{eq}}$ emissions reduction respectively, which have been obtained taking into account the optimal configurations obtained for each case-study. In relation to the estimated payback period values (about 22 months for case-study 1 and 34 months for case-study 2), two benchmarks values may be used: a 2 – 3 years (24 – 36 months) reasonable payback period interval for energy efficiency improvement measures within the industry of the European Union [388] and a 5 years (60 months) limit for a technology to be considered viable for industry in general [389]. For both case-studies 1 and 2, it is possible to verify that the obtained payback period is considerably lesser than the first mentioned benchmark interval. In this prospect, it is possible to affirm that the WEIS projects of both case-studies are securely favourable in comparison to the strictest benchmark (24 – 36 months).

The determination of the environmental impact reduction-associated viability for both installations depends in its turn on the comparison of the estimated reductions of $\text{CO}_{2,\text{eq}}$ emissions on benchmark values obtained for the approached industrial sector (in this case the European Union ceramic industry). Considering the obtained values (2.42 and 1.76 kton $\text{CO}_{2,\text{eq}}$ /year, respectively for case-studies 1 and 2) and taking into account different values for energy efficiency improvement measures implementation within the analysed sector (corresponding to a maximum value of 0.722 kton $\text{CO}_{2,\text{eq}}$ /year), it may be considered that the conceptualized WEIS project is effective in terms of the reduction of the environmental impact brought by the operation of the plant-level energy systems. The total ecological footprint reduction potential associated to the project is enforced by the zero-water discharge level obtained for each one of the case-studies, in which the only discharged streams of the water systems correspond to the brine streams from wastewater treatment (in this case the Multi-effect distillation units).

Sustainability Promotion Assessment – Proof of Social Benefits Achievement

The social-related benefits that are assumed to be promoted are based on the following aspects (which are prominently delineated in Roadmap for Carbon Neutrality 2050 (RNC2050) developed by the Portuguese government):

- **Promotion of a socially fair and efficient energy transition:** the conceptualized WEIS installations do not require additional investment on land except the one that is already used for plants to be installed and it requires investment costs that are assumed to be allocated from the industrial stakeholders, with the existence of government incentives;
- **Reinforcement of the competitiveness of the regional and industrial economies:** for both case-studies, payback periods of less than the most favourable and acceptable limit of

3 years and maximum acceptable limit of 5 years are obtained, which is significant that a considerable margin of total savings is possible to be allocated to the promotion of other benefits and the limits to which the commissioned installations are considered to be economic viable are nevertheless not surpassed;

- **Promotion of the creation of work positions:** this may be regarded as one of the aforementioned benefits;
- **Improvement of air quality and overall human health:** while the improvement of air quality is secured by the reduction of waste gas emissions (as evidenced by the final simulation results obtained for the case-studies), the improvement of human health may be secured by the combination of this benefit and the improvement of the quality of discharge water (which may be evidenced by the null level of the discharge water obtained for the case-studies), as well as the relative increase of water availability.

The insurance of the existence of these benefits is thus a necessary and sufficient condition to ensure the sustainability promotion character of the conceptualized WEIS installations.