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Energy recovery from heat produced during aerobic treatment of organic waste through exploitation by micro organic Rankine cycle (ORC).

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Introduction (1): EU directive and organic waste

- Directive of Council on landfills (1999/31/EC) to gradually reduce the transfer of organic waste to landfill sites.
- Directive of Council on organic waste recycling (Framework Directive 75/442/EEC on waste).
- Directive of Council on fertilizers quality parameters (2003/2003/EC).

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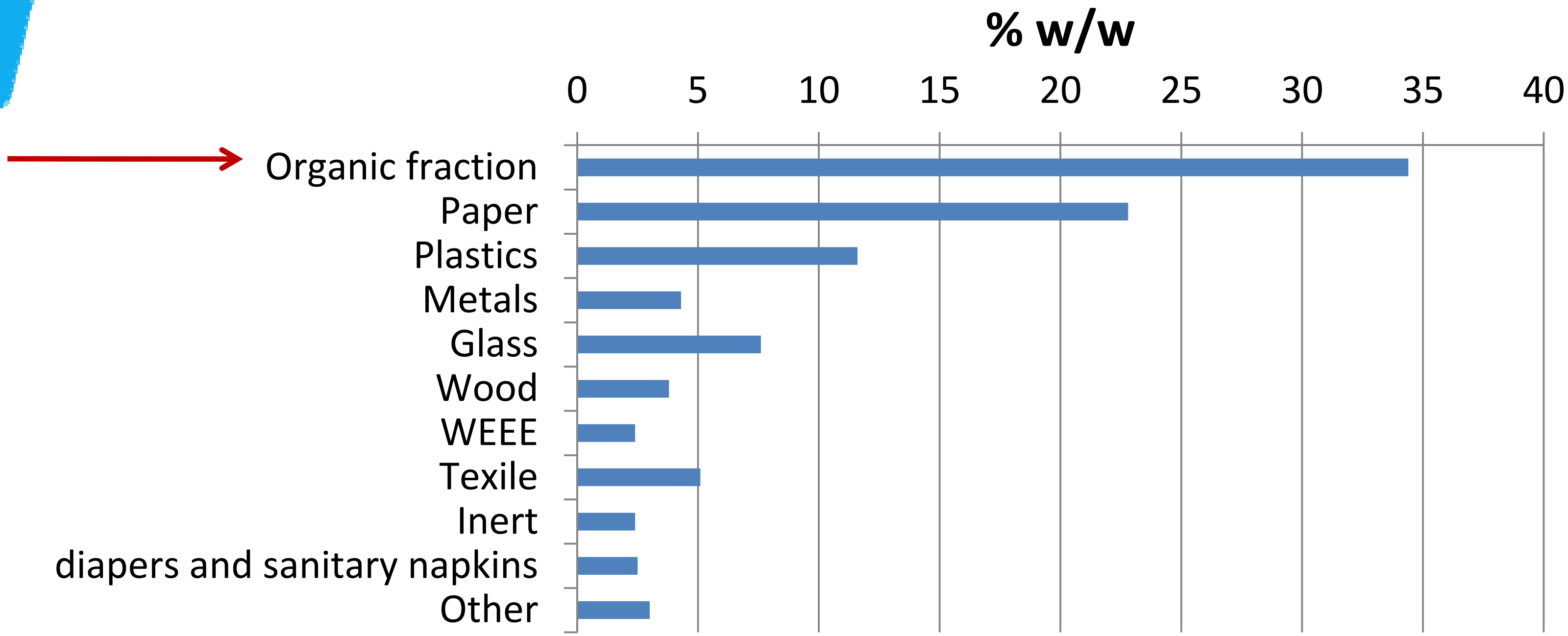
Introduction (2): average waste composition in Italy



Source:ISPRA 2012

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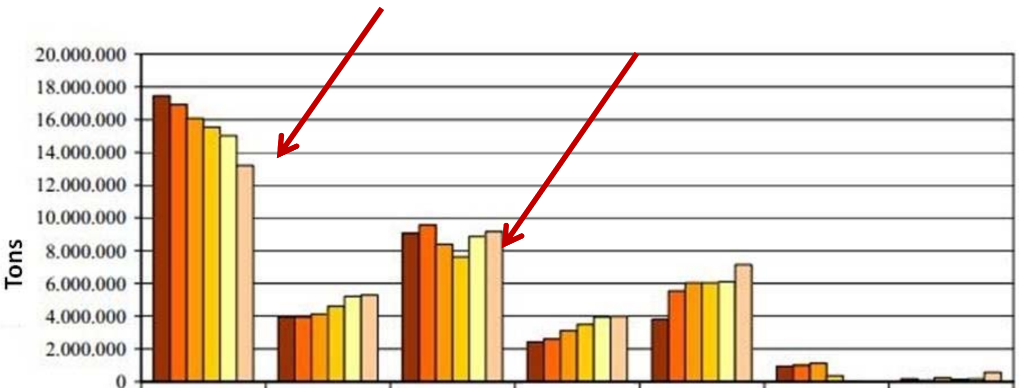
Introduction (3):waste treatment scenario in Italy



	Landfill	Incineration	MBT	Biological treatment OF	Others material recovery	Storage	Use as energy recovery source
2006	17.462.301	3.951.128	9.046.509	2.432.556	3.813.283	937.922	170.325
2007	16.911.545	3.955.297	9.572.120	2.599.039	5.536.316	1.005.374	73.764
2008	16.068.760	4.137.036	8.392.421	3.106.055	6.046.951	1.135.605	235.073
2009	15.537.822	4.605.192	7.628.156	3.489.958	6.041.572	358.349	139.000
2010	15.015.119	5.215.665	8.868.728	3.942.637	6.106.281	8.624	171.107
2011	13.205.749	5.290.454	9.160.839	3.980.723	7.149.082	0	560.373

Source:ISPRA 2012

Organic Waste Fraction inside **Residual Municipal Solid Waste (ROF)**

- Mechanical Biological Treatment (MBT) before final disposal

- Stabilization
- Pollutant emissions reduction
- Landfill volumes reduction

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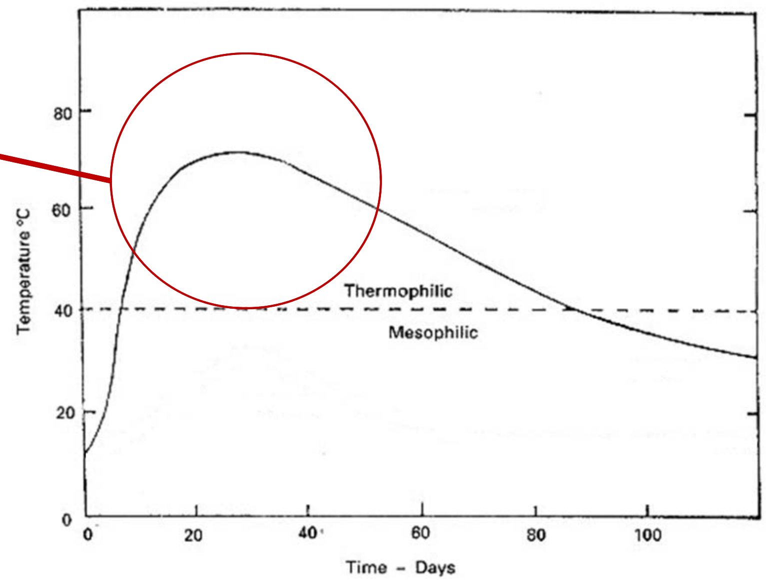
Introduction (4):aerobic treatment and low thermal renewable energy recovery

AEROBIC BIOLOGICAL STABILIZATON

- **Heat production from biological aerobic activity : 17,000-18,000 kJ/kg of Organic Matter**
- **Available renewable low thermal energy**
- **Possibility of recovering further renewable electrical energy by employing Organic Rankine Cycle**



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Summary:

- The case study
- Biological treatment section: experimental analysis
- ORC model
- Economic model
- Main results
- Conclusions

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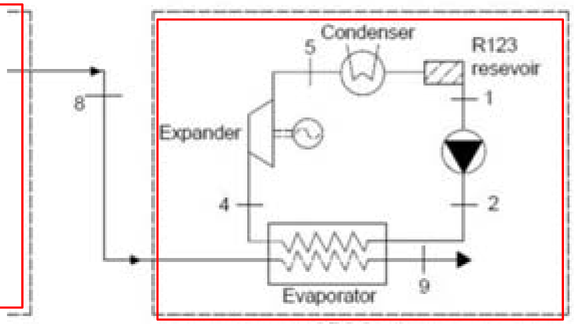
The case study (1): description of the proposed system

Inlet air to the Biological treatment section (BT) → During BT: air heating and increase on vapour content → Exhaust air coming from BT section at saturated vapour conditions. → Available heat from heated dry air and vapour's latent condensation heat

ORC section

Aerobic treatment section



Exploitation of exhaust air in an **Organic Rankine Cycle** for the production of renewable electrical energy

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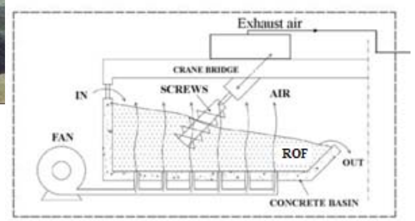
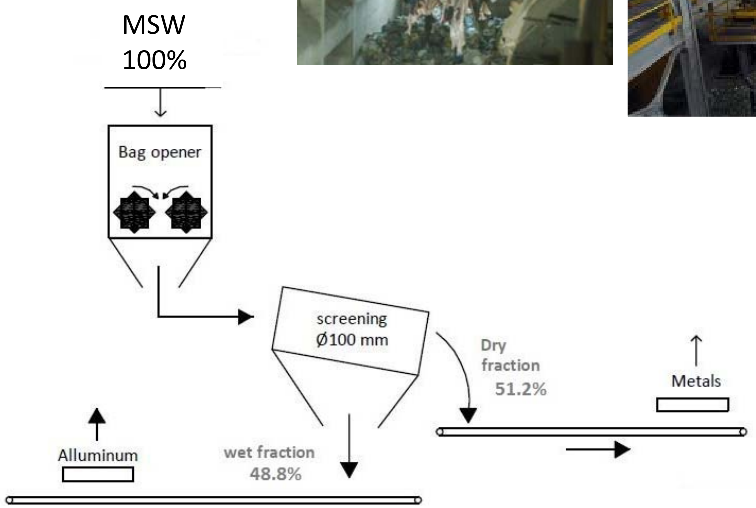
Biological treatment section(1): experimental analysis

Biological aerobic stabilization before landfilling



- concrete basin
- aerated floor
- crane bridge with screw
- humidity and temperature control
- 32,000 t/year



Landfill

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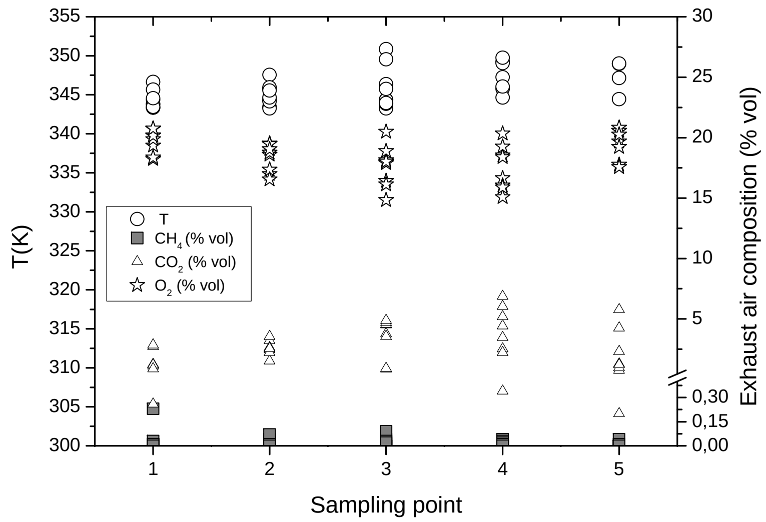
Biological treatment section(2): experimental analysis

In order to evaluate the features of the outlet exhaust air's temperature and composition some experimental investigations were performed at different times and points on the basin's surface.



Temperature (K):

- K-termocouple at 1m deep

Exhaust air composition (%vol):

- portable gas analyzer and a storage volume on mass surface
  - **CH_4**(±1%) infrared sensor
  - **CO_2**(±1%) infrared sensor
  - **O_2**(±2%) electrochemical cells

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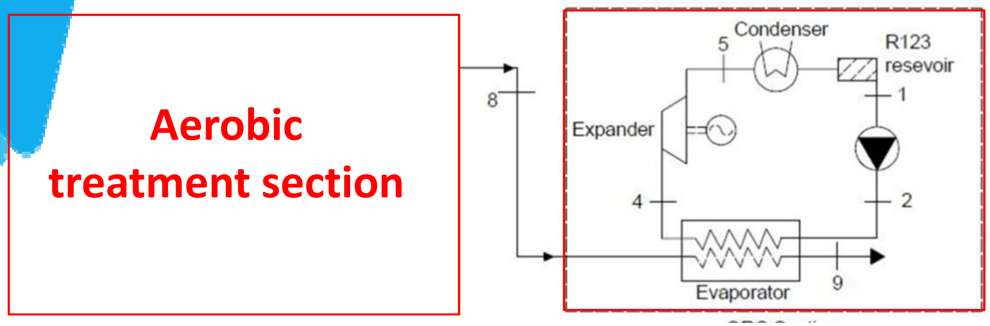
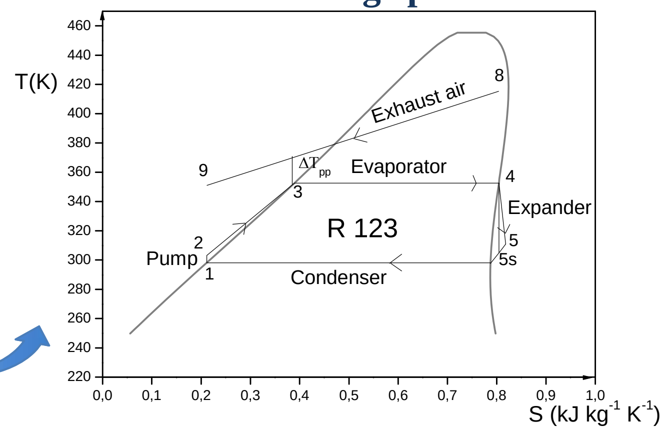
The ORC section model (1): main assumptions



ORC section

T-s diagram for the organic Rankine cycle (ORC) and of the heat exchange process.



- Outlet exhaust air 's temperature and composition (T_8) fixed and evaluated by experimental analysis
- Evaluation of ORC performances for different evaporator outlet section's temperature conditions (T_9).
- ORC working fluid: R-123
- Temperature at the condenser (T_1) and ambient temperature (T_{amb}) were imposed

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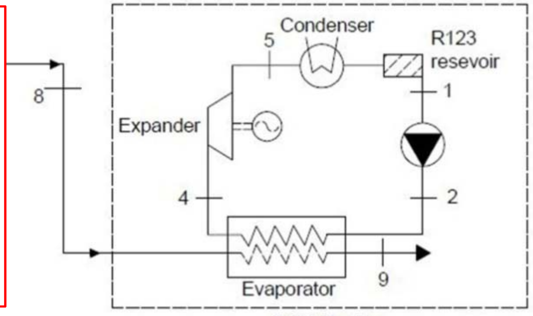
The ORC section model (2)

Aerobic treatment section



Exhaust air 's features assumed

Parameter	Value	Unit
Air flow rate	4,000	Nm^3h^{-1}
P8	101,325	Pa
T8	341	K
Φ	100	%
$\Delta T_{WOF\text{-}AIR}$	5	K
Exhaust air's mean composition		
CH_4	0.02	%vol
CO_2	2.70	%vol
O_2	18.5	%vol
N_2	78.7	%vol

- **Vapour content :**

$$x = \frac{M_{VAP}}{M_{AIR}} \quad (\text{kgkg}^{-1})$$

$$\dot{m}_{VAP} = x \cdot \dot{m}_{AIR} \quad (\text{kgs}^{-1})$$

- **Exhaust air's heat :**

$$Q_{BT} = Q_{AIR} + Q_{VAP} \quad (\text{kW})$$

$$Q_{AIR} = \dot{m}_{AIR} \cdot c_p^{AIR} \cdot (T_9 - T_8) \quad (\text{kW})$$

$$Q_{VAP} = (\Delta \dot{m}_{VAP} \cdot \Delta h_{VAP})_{T9-T8} \quad (\text{kW})$$

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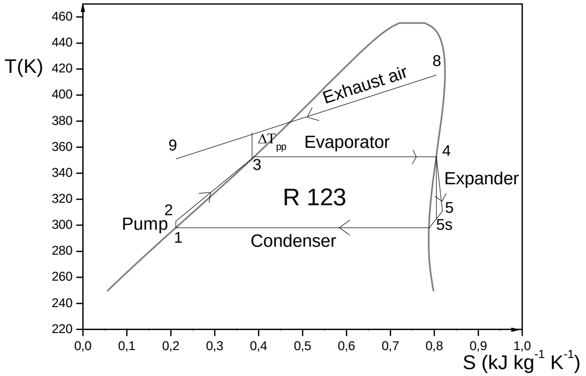
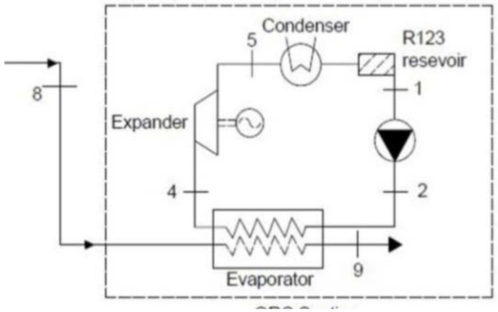
The ORC section model (3): thermodynamic analysis





ORC features		
Parameter	**Value**	**Unit**
η_p	80	%
η_{ex}	55	%
ΔT_{pp}	10	K
T_c	293	K
$\Delta T_{9,2min}$	10	K
Working fluid R123		
Molecular mass	152.93	g mol^{-1}
Boiling point	300.97	K
Critical Pressure	3.662	MPa

- **Power pump** *(kW):* $$W_p = \dot{m}_{ORC}(h_2 - h_1) = \frac{\dot{m}_{ORC}(h_{2s} - h_1)}{\eta_p}$$
- **Heat supplied to R-123** *(kW):* $$Q_{IN} = \dot{m}_{ORC}(h_4 - h_2)$$
- **Generated power** *(kW):* $$W_{ex} = \dot{m}_{ORC}(h_4 - h_5) = \dot{m}_{ORC}(h_4 - h_{5s})\eta_{ex}$$
- **Heat ejected at condenser** *(kW):* $$Q_C = \dot{m}_{ORC}(h_5 - h_1)$$

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The ORC section model (4): ORC performances evaluation

- **Net power** *(kW)*:

$$W_{net} = \eta_{eg}(W_{ex} - W_p)$$

- **Net efficiency** *(%)*:

$$\eta_{net} = \frac{W_{net}}{Q_{IN}} \cdot 100$$

- **Exergetic efficiency** *(%)*:

$$\eta_{EXE} = \frac{W_{net}}{EX_{IN}} \cdot 100$$

- **Inlet Exergy** *(kW)*:

$$EX_{IN} = EX_{AIR} + EX_{VAP}$$

$$EX_{IN} = [(ex_8^{AIR} - ex_{amb}^{AIR}) \cdot \dot{m}_{AIR}] + [(ex_8^{VAP} \cdot \dot{m}_8^{VAP}) - (ex_{amb}^{VAP} \cdot \dot{m}_{amb}^{VAP})]$$

- **Pressure ratio:**

$$\beta = \frac{p_2}{p_1}$$

ORC features

Parameter	Value	Unit
η_{eg}	90	%
T_{amb}	288	K
p_{amb}	101,325	Pa

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The economic model

Plant's lifetime: 10 years

Working time : 7,500 h/year

Component	Dependent variable	Cost correlation
Expander (€kW^{-1})	Volume flow rate V_{exp} $(m^3 s^{-1})$	$1{,}5 \cdot (225 + 170 \cdot V_{exp})$
Heat exchangers (€)	Heat exchange area A (m^2)	$190+(310 \cdot A)$
Working fluid pump(€)	Electrical power W_p (W)	$900 \cdot (W_p \cdot 300^{-1})^{0.25}$
HTF pump(€)	Electrical power W_{HTFp} (W)	$500 \cdot (W_{HTFp} \cdot 300^{-1})^{0.25}$
Liquid receiver(€)	Volume V (l)	31,5+16 V
Piping(€)	Pipe diameter d_{pipe} (mm) and lenght L_{pipe} (m)	$(0{,}897 + 0{,}21\, d_{pipe})L_{pipe}$
Working fluid(€)	Working fluid mass M_{ORC} (kg)	$20 \cdot M_{ORC}$
Hardware and control system(€)	-	800
Labour(€)	Total investment cost	30%
O&M(€year^{-1})	Total investment cost	15%

(Quoilin et al., 2011)

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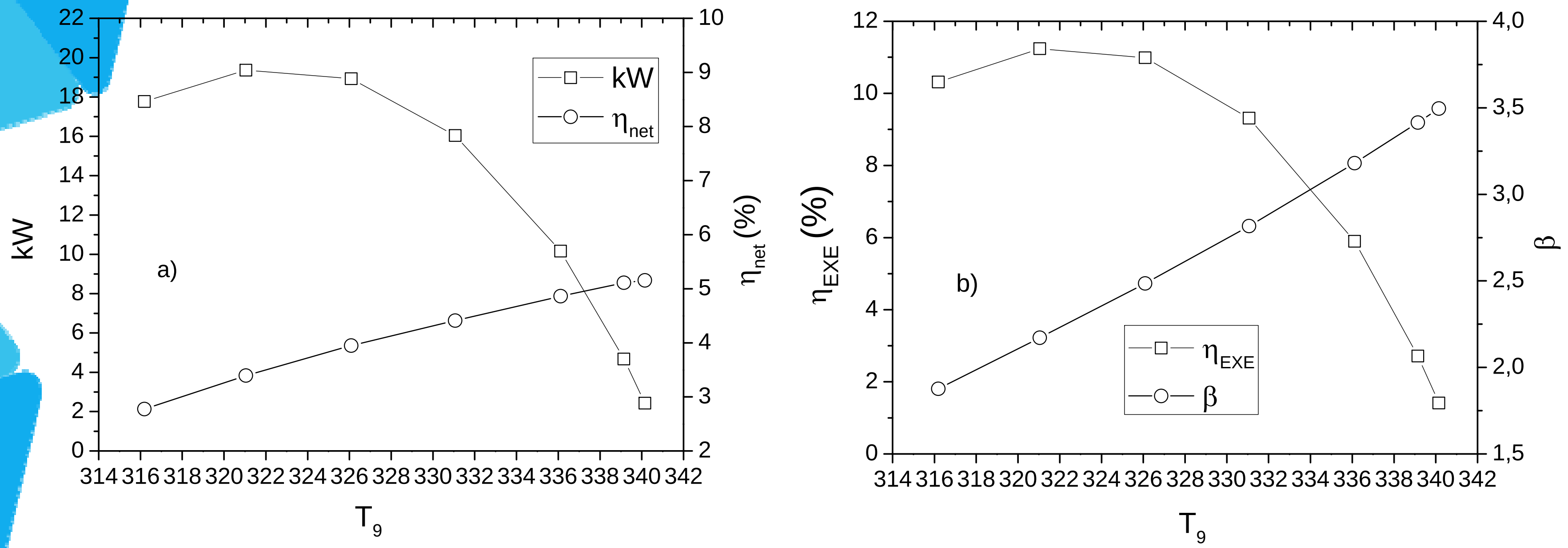
Main results (1) : energetic analysis



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Main results (2): economic feasibility

Reference scenario:

T9=321K

Net power output 19.4 kW

Component	Cost
Expander (€)	16,206
Heat exchangers (€)	21,671
Working fluid pump and HTF pump (€)	2,498
Liquid receiver and piping (€)	1,271
Working fluid (€)	427
Control system and hardware (€)	800
Labour (€)	12,862
Investment cost (€kW^{-1})	**2,873**
O&M (€$year^{-1}$)	8,360
Total cost (€kWh^{-1})	**0.096**

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Conclusions

- The micro Organic Rankine Cycle is a suitable way to exploit the low grade heat available from the exhaust air of the biological treatment section of the MBT facility

- Thanks to the high presence of vapour, even if the temperature is quite low, the heat available and exploitable inside the ORC is satisfactory.

- The energetic analysis shows an increase of the power output and exergetic efficiency for lower pressure ratio

- Even if the power output is quite limited, the analyzed system seems to be an interesting solution for the production of renewable energy and is compatible with other micro-ORC similar applications.

- The micro-ORC proposed solution turn out to be economically sustainable, and it is possible to compare it with other similar technologies.

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