D3.2 – ROI Estimation (for use case 1,2, and 3)

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Heat pipE TECHnologies for INdustrial Applications.

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Summary

In this deliverable the return on investment (ROI) of the three of heat pipes-based heat exchangers (HPHE) designs that will be installed in three demonstration sites is presented. Each HPHE is specified in base of the available and required energy for each of the three use cases:

- Use Case 1 (UC1): representative of non-ferrous sector,
- Use Case 2 (UC2): representative of steel sector and
- Use Case 2 (UC3): representative of ceramic sector.

This report describes how the ROI was estimated considering the primary energy saving cost and the carbon reduction savings.

The estimated ROI of the final designs of the designed HPHEs varied between 6 months to 34 months among the three demo cases.

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Introduction

Heat pipe heat exchanger (HPHE) are very efficient technology for heat recovery in challenging applications. HPHEs can be upsized to maximise the heat recovery from waste stream, however sizing the HPHE reaches a limit where any further increasing in the scale of the system will slightly increase the duty of the unit in comparison to a great increment in the cost of the system. Based on the that HPHEs in this project are desired to be designed to recover 40% of the waste stream within back period less than three years.
The ROI of the final design for the three use cases was estimated to evaluate the designs from an economical point of view. The ROI was estimated based on the cost of the unit and the working hours per year and conversion factors reported in D2.1.
This document is an updated version of deliverable which corresponds to the final designs of the HPHEs.

1 ROI Estimation Methodology

Return on investment (ROI) measures the gain or loss generated on an investment relative to the amount of money invested. The ROI in this report is expressed as a payback period in months.

The general return on investment formula is:

$$ROI = (Net\ Profit\ /\ Cost\ of\ Investment)\ x\ 100$$

The net profit can be calculated as followed:

The Capital Cost is the cost of the unit delivered to the demo site.
Additional costs because of the HPHE installation can be summarised as follows:

- An additional cost can be the installation cost, In general, terms, the installation cost can be minimised when the HPHE is replacing a conventional recuperator or when it is connected in series after a conventional recuperator. While it increases significantly, when the installation requires installing additional pipelines and duct working for the heat source and heat sink and building a new installation platform and modifying the infrastructure of the plant. However, the ROI in this report is going to be calculated without considering the installation cost since it greatly differs between each demo case depending on the installation site and its complexity and cannot be estimated until the installation is performed.

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- Additional cost is the parasitic load which represents any power consumption on any electrical equipment that has been installed as a part of the recovery system. The parasitic load can be the power consumption of an additional fan or pump etc. In ETEKINA project, the HPHE is designed within the pressure drop allowed of the existing fans therefore there is no additional cost of the parasitic load except for Demo case 1 (Spain) where new fans will be installed on the primary and secondary streams. Therefore, the parasitic load for demo 1 will be included.
- Additional cost is the operating and maintenance cost (O&M) which the cost of the maintenance of the HPHE annually. This cost is a general term considered when the ROI is calculated. HPHE normally does not require any maintenance except cleaning the heat pipes from dust with a compressed air flow at the exhaust side. This applies as long the HPHE operates within the design parameters of the exhaust and heat sink flow rate and inlet temperatures. Furthermore, once the heat pipes are manufactured, they do not need any maintenance as individual parts until the end of their life expectancy, which normally exceeds 15 years.
- Cleaning the HPHE can be scheduled to be carried out during the regular maintenance period of the plant, which saves the timed and prevents any interruption to the operation of the plant.

The utilisation of the HPHE for waste heat recovery in industrial application includes saving in expenses at different points.
The main energy savings is due to energy recovered directly by the HPHE
An additional energy saving is saving in energy losses in the burner where the efficiency of the burner varies between 0.95 and 0.85 generally.
Further savings results from the reduction in the carbon emissions per annum.
The ROI in this report is represented by the payback period of the system which is calculated as follows:

$$\text{ROI} = \frac{Cumulative\ Cash\ flow}{Annual\ Net\ Benefit} \times 12\ (\text{months})$$

Where

$$Cumulative\ Cash\ flow\ at\ the\ beginning\ of\ year\ 1\ = HPHE\ Cost$$

$$Annual\ Net\ Benefit\ Excluding\ taxes = EC_{Sav\_NG} + C_{CO2\_emission\_saved} - E_{BOP} - C_{O\&M}$$

As highlighted before, there is not cost caused by the parasitic load or maintenance in ETEKINA project except for demo case 1 (Spain).
ROI is preferred in the industrial sector in the form of payback period in months more than a percentage. However, they are both calculated through the same formula.
The definitions of the symbols used to estimate the ROI in the above equation with their formulas are presented in Table 1.

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Table 1 Variables, Expression, and factors used to estimate the ROI

Expression	Symbol	Formula	unit
Total CO_2 cost saving	$C_{CO2\_emission\_saved}$	$m_{CO2saved} \times C_{CO2\_emission}$	€/y
CO_2 emission cost	$C_{CO2\_emission}$		€/tCO_2e
Total CO_2 quantity saving	$m_{CO2\_NG\_sav}$	$\dot{Q}_{HSNG,sav}$ x $ConvF_{NG}$	tCO_2e/y
Parasitic Load energy cost	E_{BOP}	$EC_E \times \dot{E}_{BOP} \times R_{time,HPHE}$	€/y
Electrical energy cost	EC_E		€/MWh
Working hours of the system per year	$R_{time,HPHE}$		hr/y
Reduction in fuel Cost	EC_{Sav_NG}	$\dot{Q}_{HSNG,sav} \times EC_{NG} \times R_{time,HPHE}$	€/y
Natural Gas Cost	EC_{NG}		€/MWh
Primary energy savings	$PEQ_{NG,sav}$	$\dot{Q}_{SSt} * Eff_{NG}$	MWh
Thermal power recovered by the HPHE	$\dot{Q}_{SSt}$	$\dot{m}_{sst} \times Cp \times (T_{sst,out} - T_{sst,in})$	kW,MW
Conversion factor for natural gas	Eff_{PEN}		
Cost of Mintinance	$C_{O\&M}$		€/y

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2 UC1 (Spain): ROI Estimations

Thermal design of the HPHE for Use Case 1 is based on the data provided in D2.2
The thermal design of the HPHE which recovers the heat from an exhaust stream to an air flow for use case 1 is presented in Table 2. The HPHE duty is 88.6 kW, which corresponds to heat recovery of 512 MWh/y considering the working hours of the HPHE and the furnace.

Table 2 Thermal Design of Use Case 1 (Spain)

Flow rates		
Exhaust	1,791	kg/hr
Air	1,802	kg/hr
Specific Heat		
Exhaust average specific heat capacity	1113	J/kg.°C
Air average specific heat capacity	1033	J/kg.°C
Temperatures		
Exhaust entry	400	°C
Exhaust exit	240	°C
Air entry	145	°C
Air exit	316.5	°C
Heat recovered		
Total Duty of the Unit	**88.6**	**kW**

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Based on the methodology presented in the section 1, the ROI of Use Case 1 and the corresponding savings are presented in Table 3. Cash flows for the investment in Use Case 1 is presented in Figure 1. Where the corresponding saving are based on the thermal performance of the HPHE i.e the maximum heat recovery of the HPHE, which represents 43% of the waste heat rejected to the ambient. The payback period of the HPHE of demo site 1 is around three years. Considering the total working hours of the furnace during the year, which represents 66% of hours per year and the potential energy in the exhaust flow, the ROI of the HPHE has a considerable payback period.
The fans are not installed yet but and estimation of the fans power is 3 kW. Hence, the parasitic load cost per year is as follows:

$$E_{BOP} = EC_E \times \dot{E}_{BOP} \times R_{time,HPHE}$$
$$E_{BOP} = 0.0904 \times 3 \times 5784 = 1568.6 \text{ €/y}$$

Table 3 ROI estimation for Use Case 1 (Spain)

Variable	Value
Unit Duty, Thermal energy transferred to secondary streams	88.6 kW
Working hours	5784 hr/y
Thermal energy transferred to secondary streams per year	512 MWh/y
Eff_{PEN}	1
Natural gas Energy saving $Q_{HSNG,sav}$ (LHV)	512 MWh/y
Primary energy savings $PEQ_{NG,sav}$ (HHV)	567MWh/y *@HHV, 512.4 MWh/y @ LHV
EC_{NG} (LHV)	29.609 €/MWh [(1)]
EC_{Sav_NG}	15173 €/y
E_{BOP}	1569 €/y
$Conv_{FNG}$	215.86 $kgCO_2$/MWh(LHV) [(2)]
$m_{CO2saved}$	111 t/y
$C_{CO2\_emission}$	21.75 €/t [(3)]
$C_{CO2\_emission\_saved}$	2406 €/y
Total Saving per year (€/y)	**17580**
Unit Cost [(4)]	**49342 €**
ROI (payback in months)	**36 months**
ROI (%)	**33.3%**

(*) caused by natural gas consumption reduction; the influence of electricity consumption variation is not included yet
(1) (LHV) Gas price obtained from Eurostat data for medium size industries of Spain prices in 2017 (26.744 €/MWh at HHV). Taxes not included.
(http://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=ten00118&language=en)
(2) Values based on "Well to tank Report, version 4.0" of Joint Research Institute, 237,239 $kgCO_2$/MWh(HHV)

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(3) $C_{CO2\_emission}$ (€/t)=21.75 (average of price during from 01/09/2018 to 25/04/2019, https://sandbag.org.uk/carbon-price-viewer/)
(4) Based on currency exchange GBP to EUR conversion: 1 £=1.12 €

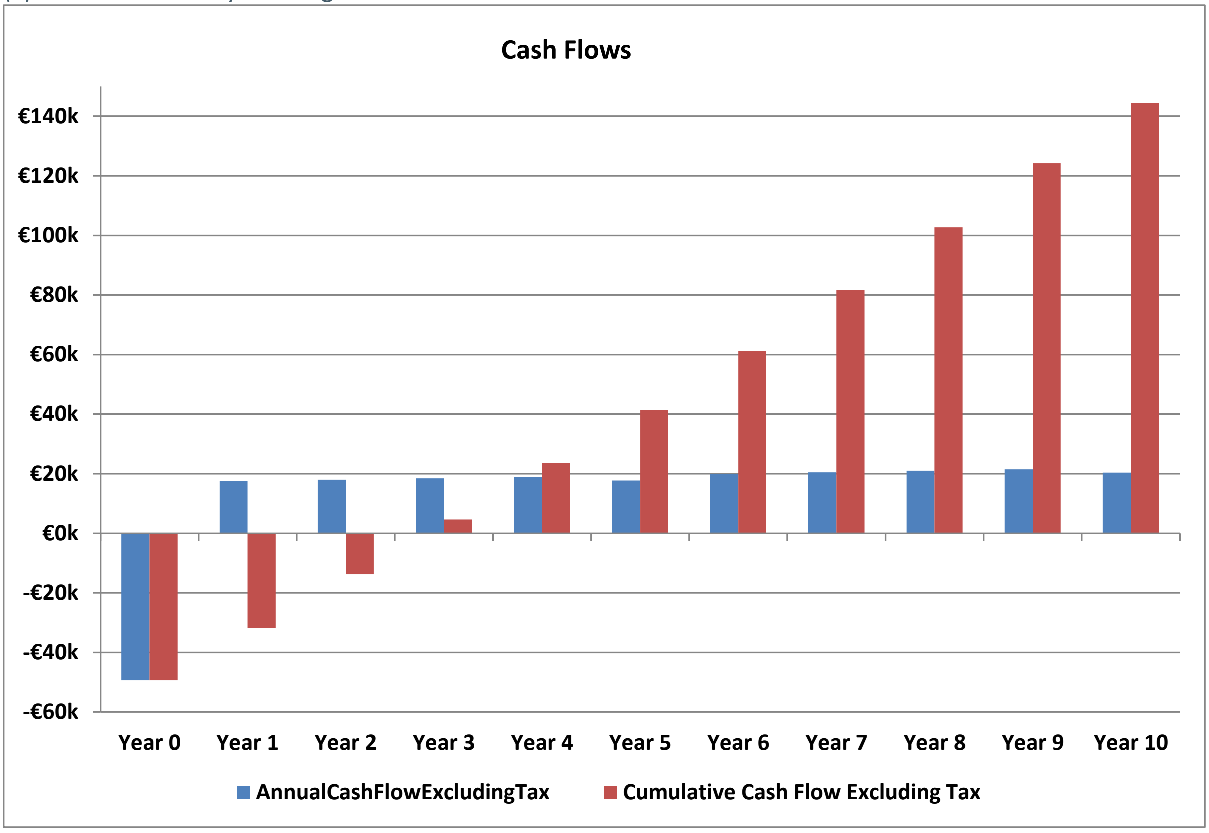

Figure 1 Cash Flow for Use Case 1 (Spain)

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3 UC2 (Slovenia): ROI Estimations

The HPHE for use case 2 was designed on the average values of the flow rates and temperatures in the exhaust stream where the temperature of exhaust after the HPHE is designed to be 178.5 °C. As a result, the designed HPHE recovers 350 kW which represents 53 % of the waste stream. The thermal design of the HPHE is presented in Table 4. The presented thermal design and ROI correspond to the final design of the HPHE.

Table 4 Thermal design of HPHE for use case 2 (Slovenia)

Flow rates		
Exhaust mass flow rate	6150	kg/h
Air mass flow rate	6590	kg/h
Water mass flow rate	3000	kg/h
Specific Heat		
Exhaust average specific heat capacity	1133	J/kg.°C
Air average specific heat capacity	1011	J/kg.°C
Water average specific heat capacity	4202	J/kg.°C
Temperatures		
Exhaust inlet temperature	360	°C
Exhaust outlet temperature	178.5	°C
Air inlet temperature	30	°C
Air outlet temperature	180	°C
Water inlet temperature	70	°C
Water outlet temperature	90	°C
Heat recovery		
Recovered heat (air side)	277	kW
Recovered heat (water side)	73	kW
Total heat recovery	**350**	**kW**

The ROI of Use Case 2 and the corresponding savings are presented in Table 5. The cash flow of Use Case 2 is presented in Figure 2. Where the corresponding saving are based on the

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thermal performance of the HPHE i.e the maximum heat recovery of the HPHE. The payback period of the HPHE for demo site 2 is 6.3 months, which accounts for ROI of 190% per year.

Table 5 ROI estimation for Use Case 2 (Slovenia)

Variable	Value
Unit Duty, Thermal energy transferred to secondary stream1 (Air)	277 kW
Unit Duty, Thermal energy transferred to secondary stream2 (water)	73 kW
Unit Duty, Thermal energy transferred to secondary streams	**350 kW**
Working hours per year (for the Air stage)	8050 hr/y
Working hours per year (for the water stage)	5050 hr/y
Equivalent working hours	7424 hr/y
Thermal energy transferred to secondary streams per year	2599 MWh/y
Eff_{PEN}	1.18
Natural gas Energy saving $Q_{HSNG,sav}$ (LHV)	3066 MWh/y
Primary energy savings $PEQ_{NG,sav}$ (LHV)	3066 MWh/y *
EC_{NG}	24.925 €/MWh **
EC_{Sav_NG}	76420 €/y
$ConvF_{NG}$	199 kgCO_2/MWh
$m_{CO2saved}$	610 t/y
$C_{CO2\_emission}$	21.75 €/t (1)
$C_{CO2\_emission\_saved}$	13270 €/y
Total Saving per year (€/y)	89693
Unit Cost (2)	**46938 €**
ROI (months)	**6.3 months**
ROI (%)	**190%**

(*) caused by natural gas consumption reduction; the influence of electricity consumption variation is not included yet
(**) gas price obtained from the Statistical Office of the Republic of Slovenia data for medium size industries (I4: 100 000 do 1 000 000 GJ) for 2017.
(http://pxweb.stat.si/pxweb/Dialog/varval.asp?ma=1817502S&ti=&path=../Database/Repozitorij_SLO/&lang=2)
(1) $C_{CO2\_emission}$ (€/t) = 21.75 (average of price during from 01/09/2018 to 25/04/2019, https://sandbag.org.uk/carbon-price-viewer/)
(2) Based on currency exchange GBP to EUR conversion: 1 £=1.12 €

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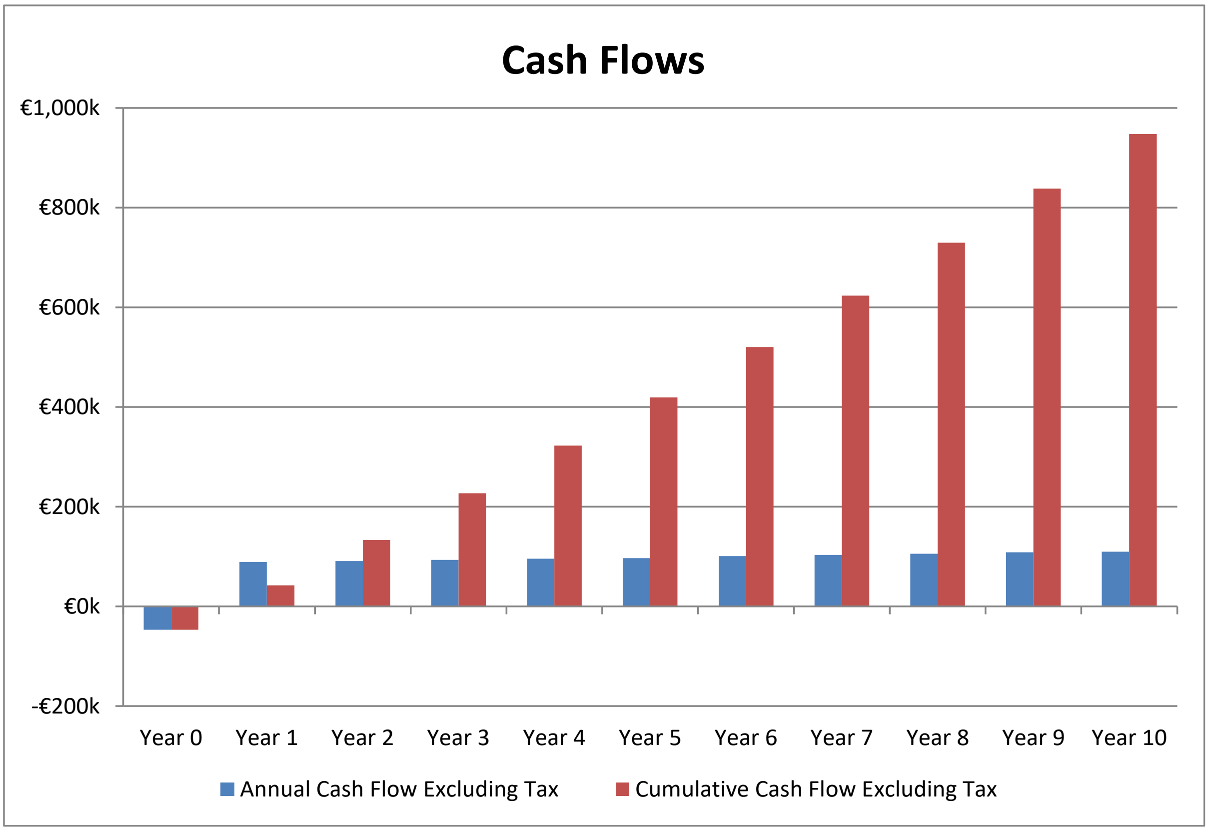

Figure 2 Cash Flow in Use Case 2 (Slovenia)

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4 UC3 (Italy): ROI Estimations

The thermal design of the HPHE is presented in Table 6 based on the data obtained from measurements in demo site 3 (Italy). The HPHE recovers 700 kW which represents 40 % of the waste heat rejected to the ambient.

Table 6 Thermal design of the HPHE for use case 3

Flow rates		
Exhaust mass flow rate	26000	kg/h
Water mass flow rate	11280	kg/h
Specific Heat		
Exhaust average specific heat capacity	1076.5	J/kg.°C
Water average specific heat capacity	4288	J/kg.°C
Temperatures		
Exhaust inlet temperature	245	°C
Exhaust outlet temperature	155	°C
Water inlet temperature	115	°C
Water outlet temperature	167	°C
Heat recovery		
Recovered heat	**700**	**kW**

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Based on the methodology presented in the section 1, the ROI of Use Case 3 and the corresponding savings are presented in Table 7. The cash flow of Use Case 3 is presented in Figure 3. Where the corresponding saving are based on the thermal performance of the HPHE i.e the maximum heat recovery of the HPHE. The payback period of the HPHE is 15 months which accounts for ROI of 78.3% per year. Although that the installation cost was not considered for the ROI, there is still a large potential of the HPHE investment even if the installation cost was equal to the cost of the HPHE cost, which keeps the ROI above 34% per year or in other words, a payback less than three years.

Table 7 ROI estimation in Use Case 3

Variable	Value
Unit Duty, Thermal energy transferred to secondary streams	**700 kW**
Working hours	6300 hr/y
Thermal energy transferred to secondary streams per year	4410 MWh/y
Eff_{PEN}	1.01
Natural gas Energy saving $Q_{HSNG,sav}$ (LHV)	4274 MWh/y(1)
Primary energy savings $PEQ_{NG,sav}$ (LHV)	4274 MWh/y
EC_{NG}	32 €/MWh (2)
EC_{Sav_NG}	136776 €/y
$ConvF_{NG}$	199 $kgCO_2$/MWh
$m_{CO2saved}$	850 t/y
$C_{CO2\_emission}$	21.75 €/t (4)
$C_{CO2\_emission\_saved}$	18500 €/y
Total Saving per year (€/y)	**155276 €/y**
Unit Cost (3)	**198363 €**
ROI (months)	**15 months**
ROI (%)	**78.3%**

(1)The primary energy saving is lower than the thermal energy transferred to the secondary stream since 4% of thermal losses are considered along the heat transfer circuit; the piping length between the HPHE and the heat sink will be 280 meters long (one way)
(2)"ec.europa.eu/eurostat/statistics-explained/images/2/29/Electricity_and_gas_prices%2C_second_half_of_year%2C_2013%E2%80%9315_%28EUR_per_kWh%29_YB16.png
(3) $C_{CO2\_emission}$ (€/t)=21.75 (average of price during from 01/09/2018 to 25/04/2019, https://sandbag.org.uk/carbon-price-viewer/)
(4) GBP to EUR conversion: 1 £=1.12 €

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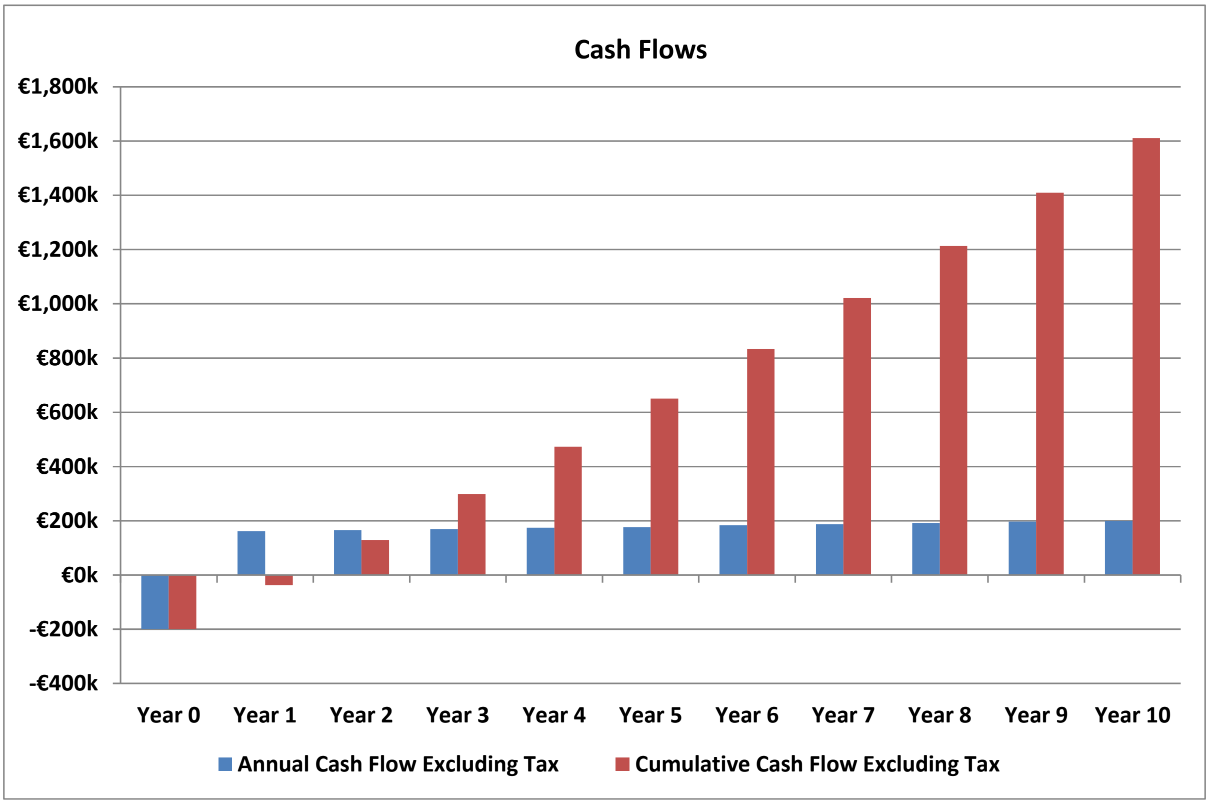

Figure 3 Cash Flow in Use Case 3 (Italy)

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Conclusion

The ROI estimation of the HPHEs for the three demo cases (Spain, Slovenia, and Italy) was presented. The pay-back period of the HPHE is estimated to be 36, 6, and 15 months for the demo sites 1, 2, and 3, respectively. The HPHEs were designed to achieve ETEKINA targets of recovering 40% or more of the waste heat with a payback period less than three years.

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