An economic analysis of a coupled LAES system utilizing the regasification cold energy of liquid ethylene

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Introduction

Liquid air energy storage (LAES), an emerging large-scale energy storage technology, stores electricity via the liquefaction of air. It is capable of grid peaking and mitigating the grid instability in fluctuating renewable power. However, the low efficiency of LAES systems restricts its application. The incorporation of external cold and heat sources presents an effective strategy to enhance performance. Building on the considerations, this study proposes a coupled LAES-LE system that recovers the regasification cold energy of liquefied ethylene (LE) and industrial waste heat. Besides, this study develops an economical model of the coupled LAES-LE system and investigates the influence of various parameters on the system's economic performance, including the temperature of the waste heat, the mass flow of the LE, and the varying peak-valley electricity prices.

Conclusions

- A LAES-LE system recovering liquid ethylene (LE) regasification cold energy and industrial waste heat is proposed.
- Greater electricity price difference and higher waste heat temperature could enhance system profitability, although excessive ethylene flow may not be beneficial.
- Under specific conditions—13.33 t/h ethylene flow, 345 °C waste heat, and Beijing's electricity price—the system could achieve profitability within 3 years, with the NPV30 reaching a high of 18.69 million USD.

The system layout

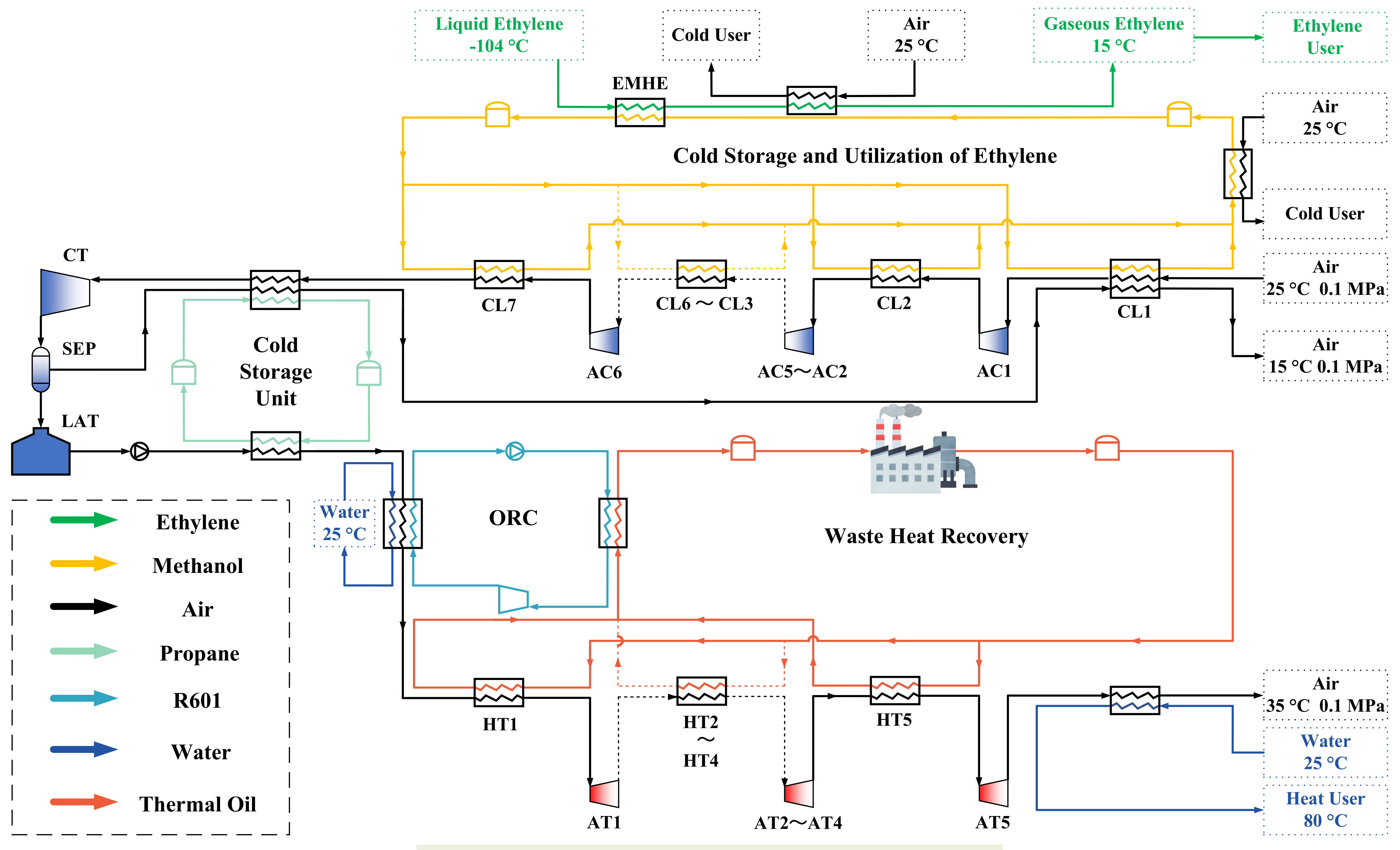

Fig 1. Layout of the LAES-LE system.

☐ Ethylene cold energy

- Conveyed and stored by methanol.
- High-grade cold energy: air cooling (CLs, -90 °C).
- Low-grade cold energy: cold users.

☐ Energy storage process

- The air is cooled and compressed in 6 stages to 9.0 MPa, then is liquefied to store electricity.
- Liquid air is stored at 0.105 MPa and -193.8 °C.

☐ Energy release process

- Liquid air is pressurized to 6.82 MPa.
- Cold-storage unit is set to recover cold energy of liquid air regasification.
- Heated and expansion in 5 stages to release electricity.
- An ORC is set for more power generation.

☐ Waste heat recovery

- Recovered from industry process, 245 °C.
- Conveyed by thermal oil.

Modeling and evaluation

☐Assumptions for modeling

- Physical properties were calculated by P-R equations of state.
- Composition of air: N2 (0.7812), O2 (0.2096), and Ar (0.0092).
- Heat leakage and pressure drop of flows is disregarded.
- Compression/expansion stages are in equal pressure ratios.

☐Basic parameters of system

Parameters	Value
Inlet pressure of liquefied ethylene	3.0 MPa
Inlet and outlet temperature of liquid ethylene	-104 °C ～ 15 °C
Energy storage period t_s, and energy release period t_r	8 h
Adiabatic efficiency of ACs, ATs and ORCT	0.85
Adiabatic efficiency of pumps and CT	0.80
Ambient temperature and pressure	25 °C, 0.1 MPa
Temperature and pressure of LAT	-193.8 °C, 0.105 MPa
Pinch-point temperature difference of cryogenic heat exchangers	2 °C
Pinch-point temperature difference of the other heat exchangers	10 °C
Pressure of air after compression	9.0 MPa
Pressure of air before expansion	6.82 MPa

☐ Economic indicators

- Initial Investment Cost (IIC): the sum of the costs of all the components.

$$IIC = \sum C_i$$

- Annual Electricity Cost (AEC): cost of off-peak electricity in one year.

$$AEC = W_{in,net} \cdot c_{e,valley} \cdot t_s \cdot 365$$

- Annual Total Income (ATI): revenues from electricity and hot water sales, but exclude the LE waste cold energy, which is free of charge.
- Annual Total Cost (ATC): includes annual O&M costs and AEC.
- Annual Total Profit (ATP): the difference between ATI and ATC.

$$ATP = ATI - ATC$$
$$= (W_{out,net} \cdot c_{e,peak} + Q_{hw} \cdot c_{hw}) \cdot t_r \cdot 365 - (\beta \cdot IIC + AEC)$$

- Net Present Value (NPV): the net inflow of cash over n years.

$$NPV_n = \Sigma_{j=1}^{n} \frac{ATP_j}{(1+\alpha)^j} - IIC$$

- Dynamic Payback Period (DPP): the time when the NPV is exactly 0.

$$DPP = t - 1 + \frac{|NPV_{t-1}|}{ATP_t}$$

Parametric analysis

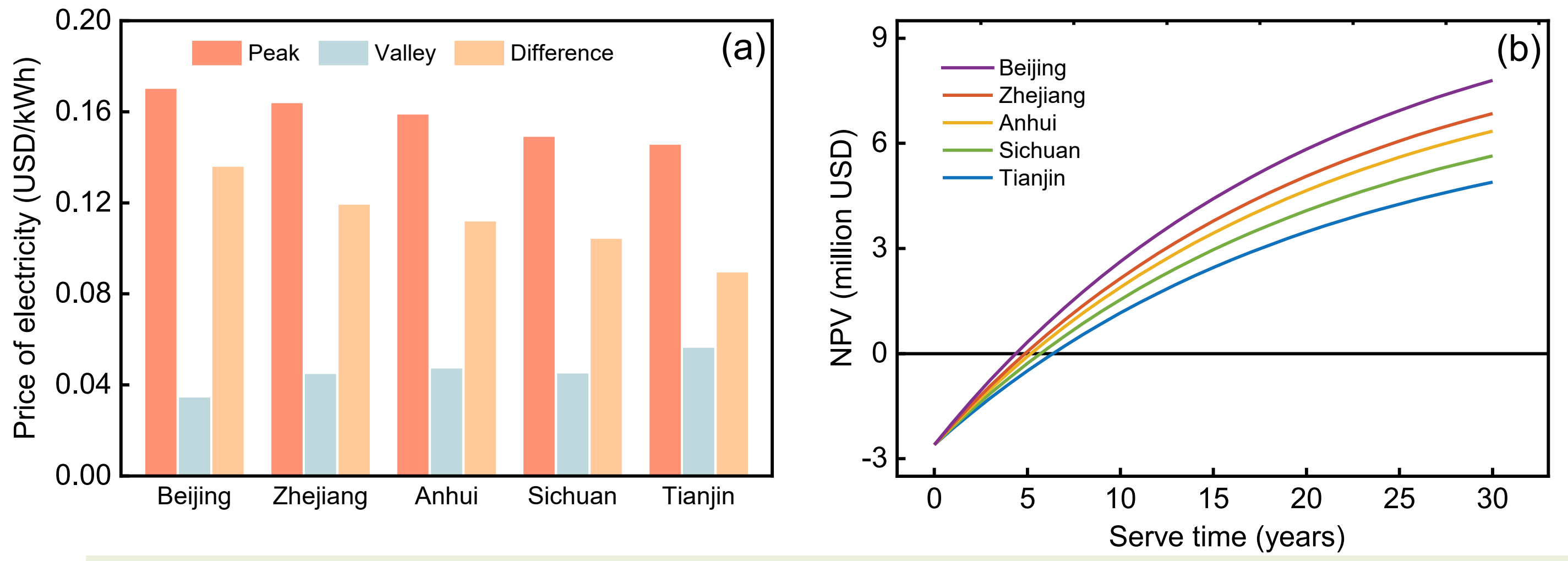

Fig 2. System economics at different regional electricity prices.

- ➢ Peak/valley electricity price, as well as economics, exhibit regional variations.
- ➢ Beijing, with the most significant electricity price difference, demonstrates the shortest DPP at 4.38 years and the highest NPV30 at 7.80 million USD.

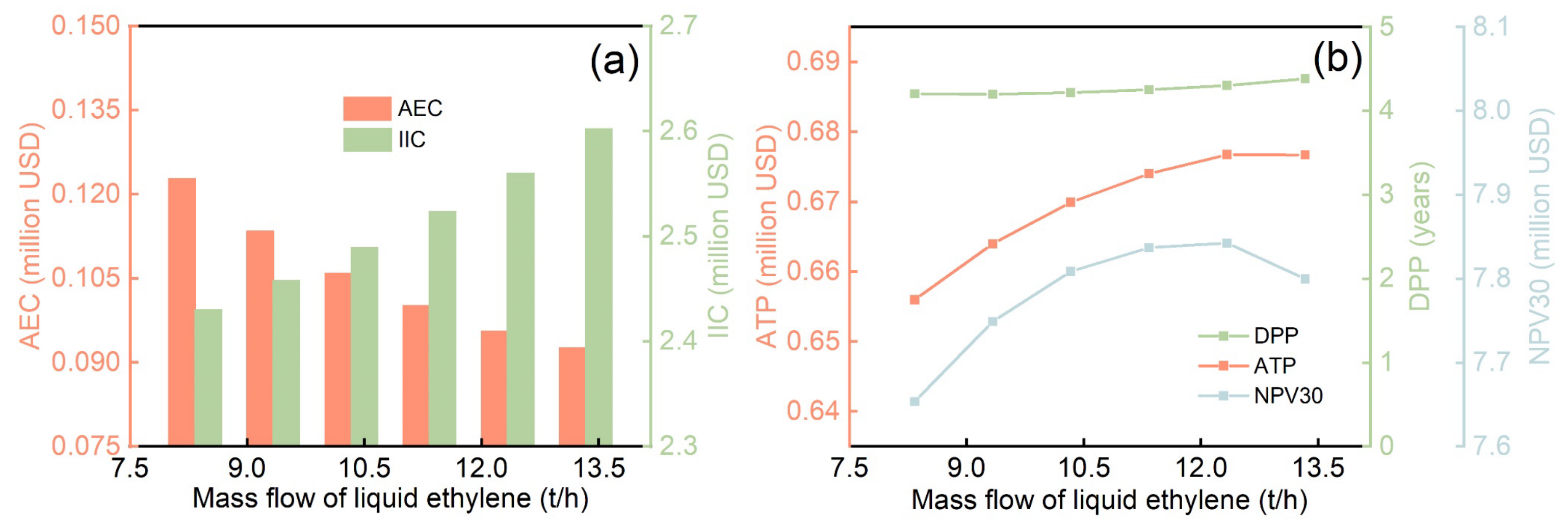

Fig 3. System economics at different ethylene flow.

- ➢ A more ethylene flow results in a less compression power consumption, thereby decreasing the AEC, but an increasing IIC with more components.
- ➢ The DPP slightly increases with ethylene flow. But ATP and NPV30 increase initially then mildly decrease, due to decreasing AEC but increasing IIC.

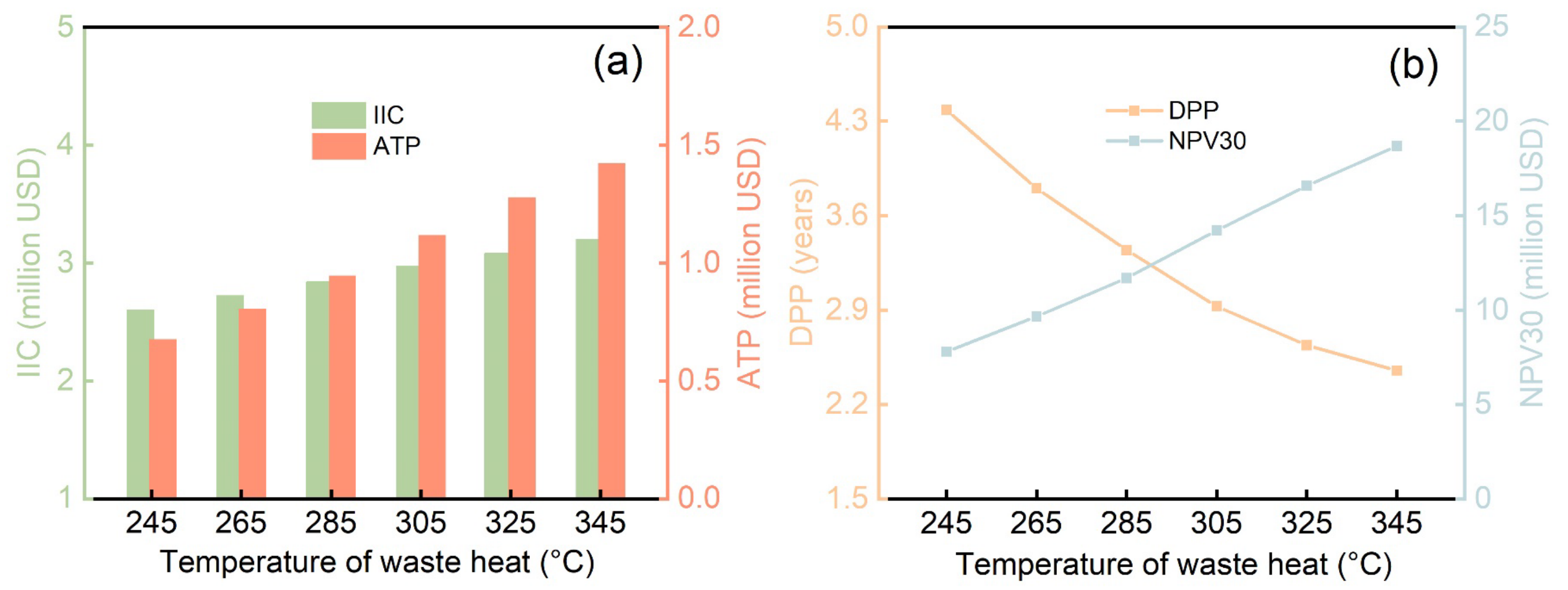

Fig 4. System economics at different temperatures of waste heat.

- ➢ An increase in the temperature of waste heat promotes enhancing profitability.
- ➢ Temperature of waste heat increase from 245 to 345 °C: ATP, 0.678 to 1.424 million USD; NPV30, 7.80 to 18.69 million USD; DPP, 4.38 to 2.45 years.