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Environomic Assessment of Industrial Surplus Heat Transportation

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4DH
4th Generation District Heating
Technologies and Systems

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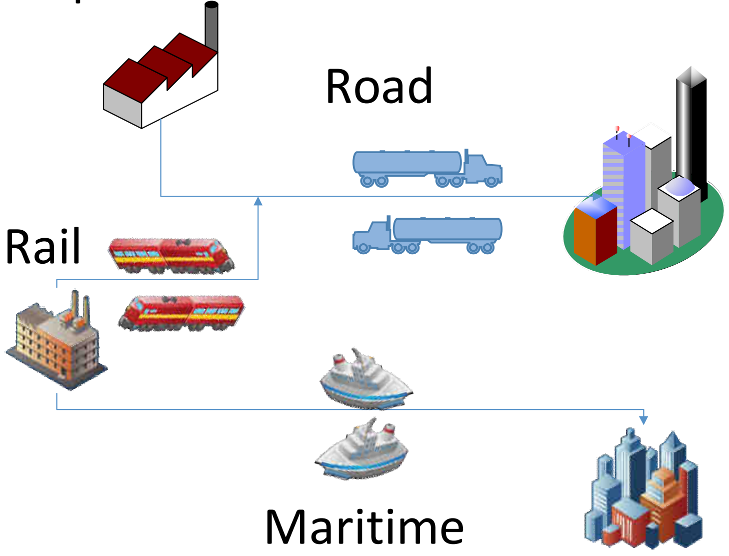
1. Introduction

Industrial sector: 20% - 50% energy released to the ambient

Building sector: represents 40% total energy use

Objective: Use industrial surplus heat in district heating via mobile thermal energy storage (M-TES)

→ load shift in space and time



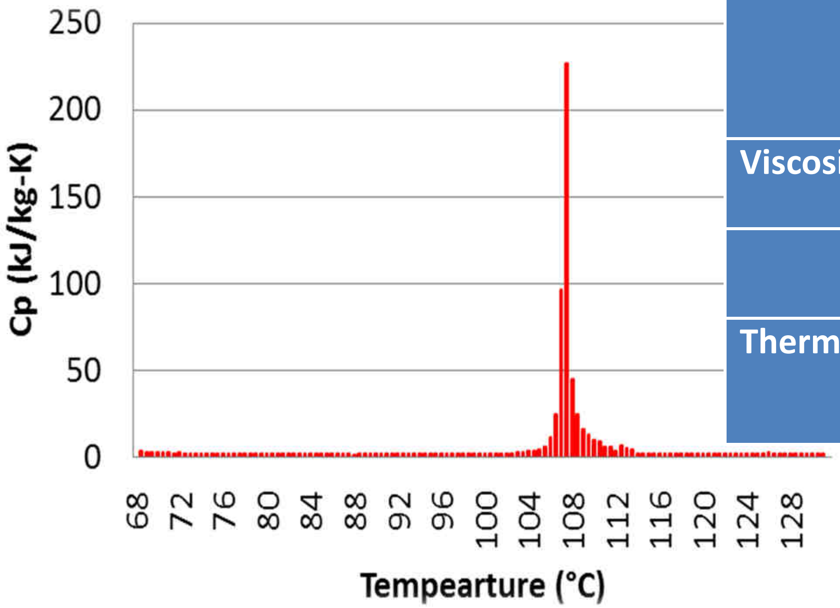
2. Methodology

- High energy storage density
- Sufficient thermal charge/discharge rate
- Transportation flexibility
- Cost effectiveness

2.1. Latent Heat Storage

PCMs have

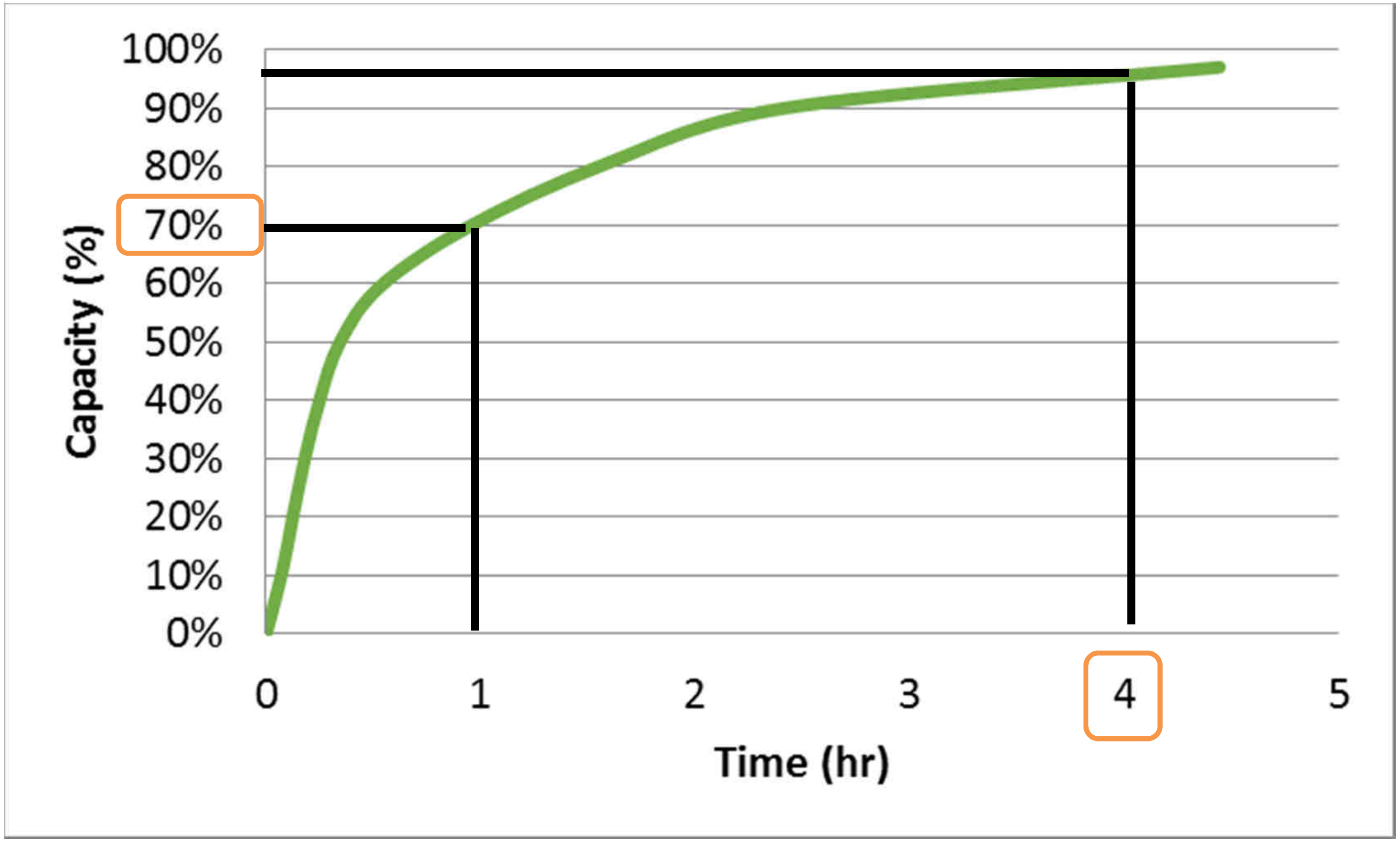
- small temperature swing
- large enthalpy
- application-suited working temperature range



Erythritol	
Phase Change Energy Storage Capacity	330 [kJ/kg] / 92 [kWh/ton]
Peak melting point	~110 [°C]
Density	1480 [kg/m³] in solid state 1300 [kg/m³] in liquid state
Viscosity	2.90×10^{-2} [Pa s] (Solid)
	1.60×10^{-2} [Pa s] (Liquid)
Thermal Conductivity	0.326 [W/m-K]

Source: Gunasekara et al. Applied Energy, 2015

2.2. Performance Mapping



Source: Chiu et al, Applied Energy, 2013

2.3. Techno-Economic Optimization

- Objective Functions:

1. Minimize CAPEX
2. For the minimum CAPEX, minimize OPEX

- Constraints:

1. User load profile
2. Case specific boundaries

- Variables:

1. Operating conditions
2. Logistics/ Operating mode

3. Results

3.1. Case Study Hedesunda

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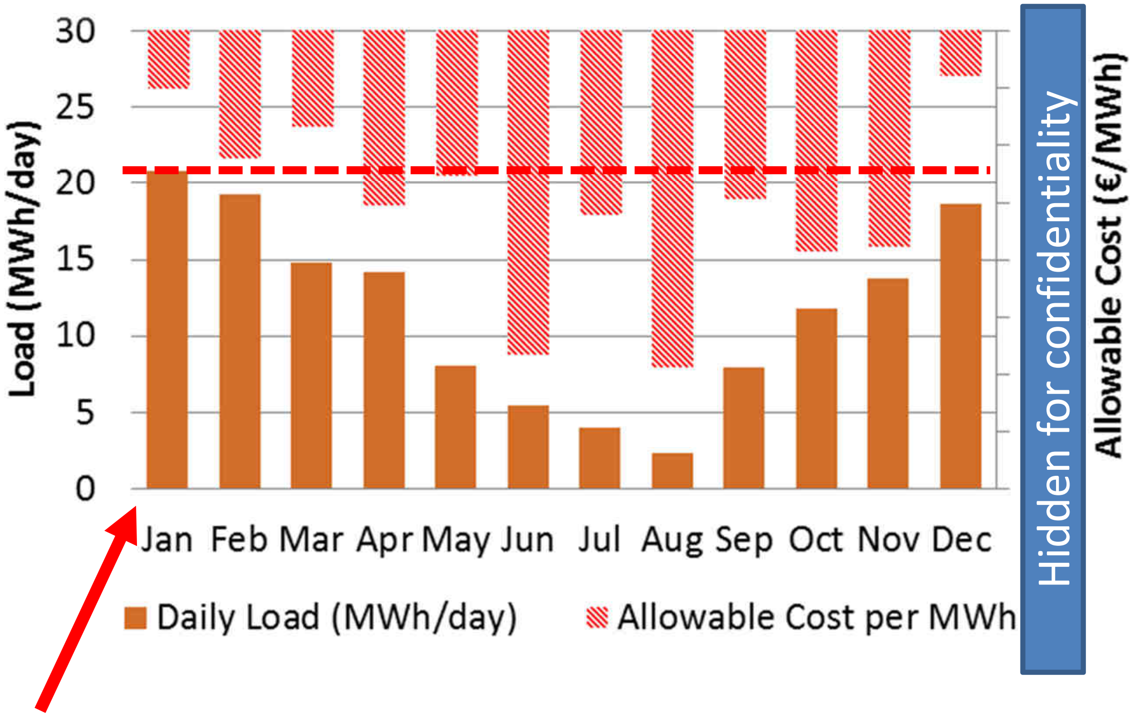
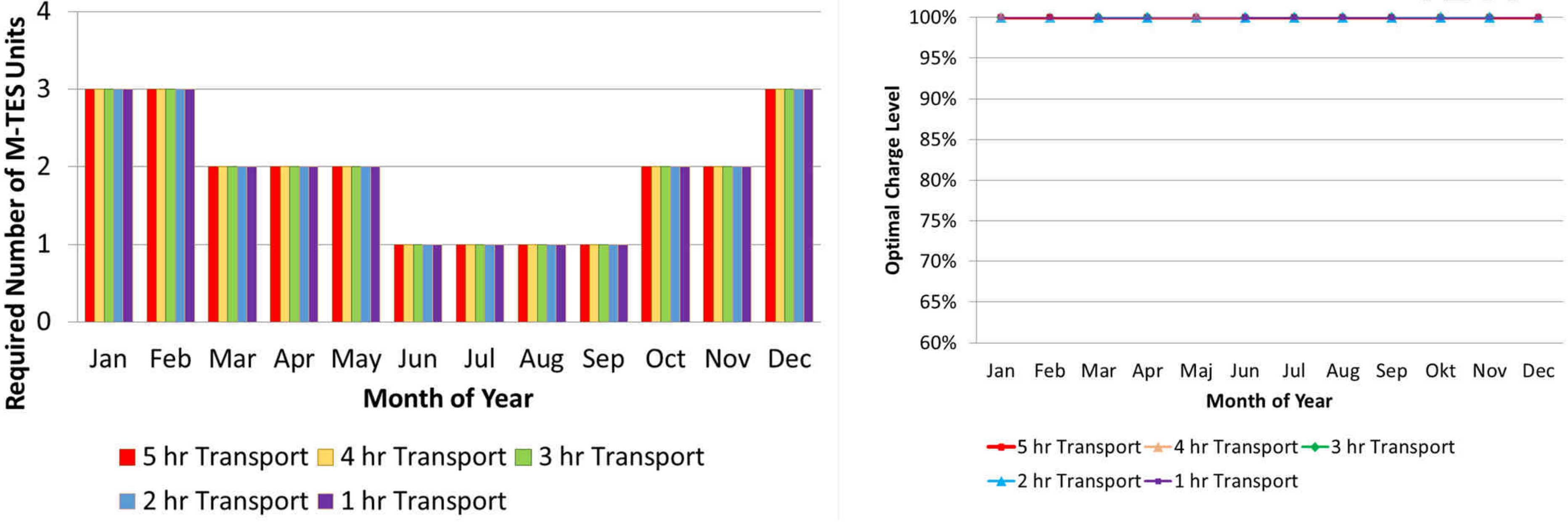


Winter time → 10X higher thermal power demand

3.1. Case Study: Hedesunda

Non Optimized Operating Strategy with full Storage



Reduced number of MTES by 33% if control strategy is optimized for high thermal power demand period

High thermal power demand→ Partial storage for minimum number of MTES

Low thermal power demand→ Full storage for maximum capacity per trip, min number of trips

Source: Chiu et al. Greenstock 2015.

3.1. Case Study: Hedesunda

Component	Cost
PCM	20 €/kWh
Heat Exchanger and Tank	160 €/m² heat transfer area for 40 foot container
Auxiliary Components	20% of MTES unit cost
Substations	45 k€ for the considered case
Transportation Cost	1€/km, 0.4€/km and 0.1€/km for road, rail and maritime
Operation and Maintenance	Replacement of PCM after 5’000 cycles
Transportation CO_2 emission	Maritime: 9 g/km Rail: 20 g/km Road: 900 g/km

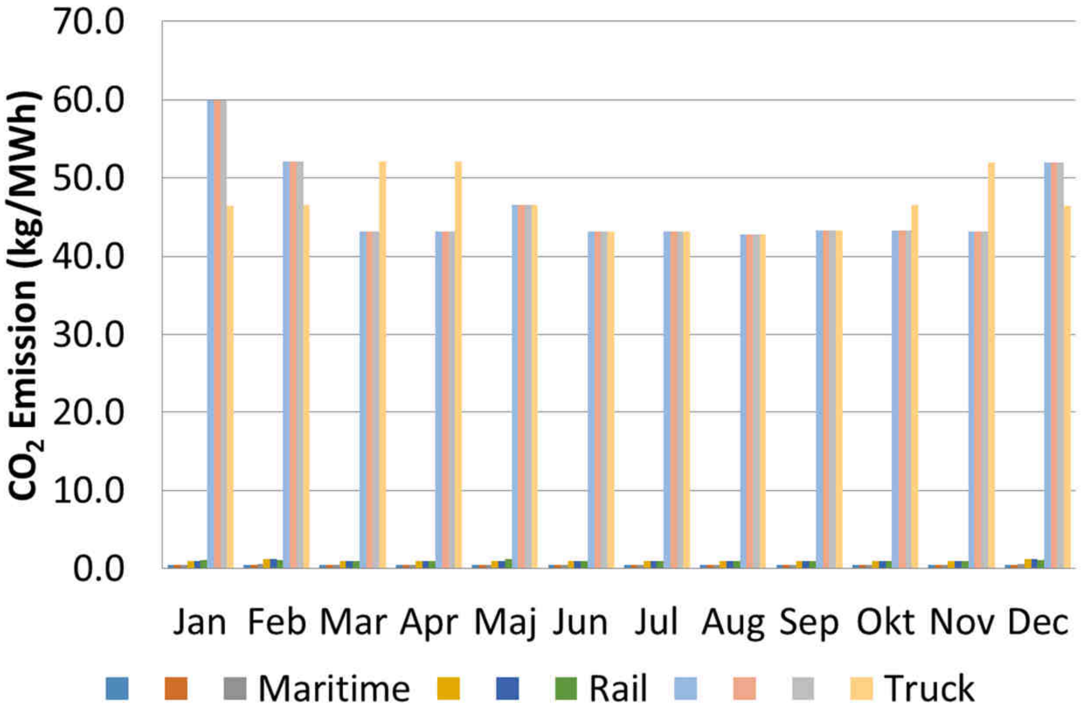
Goal	
Discount Rate	4%
Pay Back Time	12 years

	Maritime	Rail	Road
Optimal Cost Scenario	49 €/MWh	62 €/MWh	86 €/MWh

Source: Chiu et al., ASME Power and Energy 2015.

Source: AP Møller-Maersk, 2014.
IEA and UIC, 2014.
Na et al, Atmospheric Environment, 2015.

3.2. CO$_2$ Emission in Cost Optimized Scenarios



In comparison with boiler:

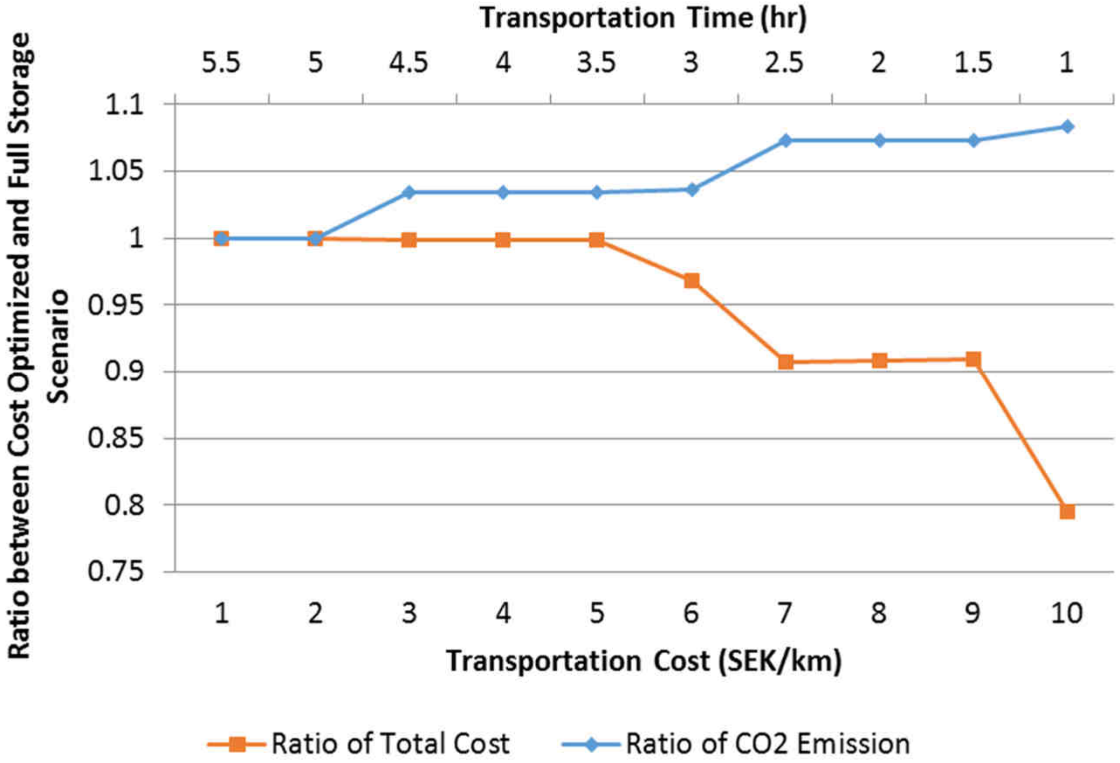
Diesel: 216 kg/MWh

LPG: 136 kg/MWh

Biomass: carbon neutral?

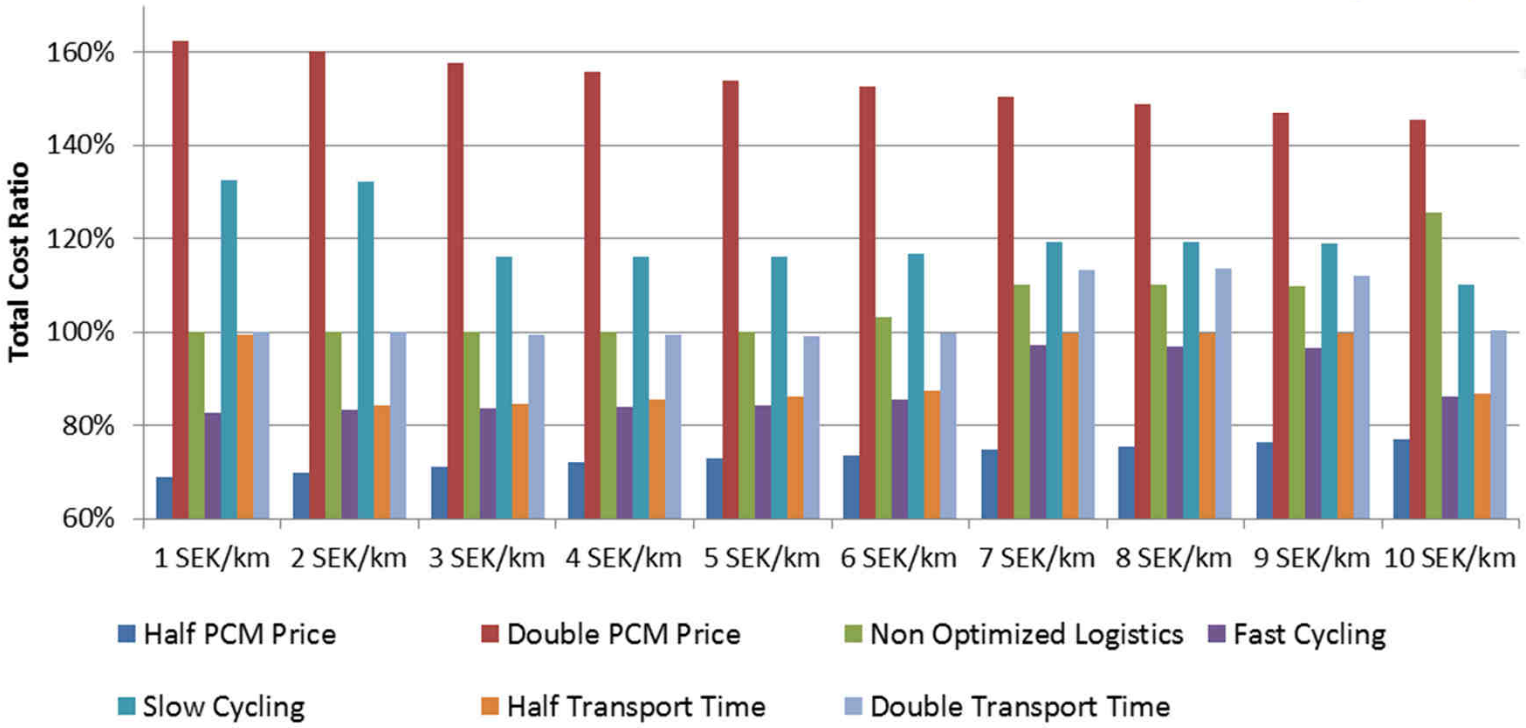
- Lower CO$_2$ emission with Martime (100X) and Rail (50X) as compared to Road
- Lower user load demand → lower CO$_2$

3.2. CO_2 Emission in Cost Optimized Scenarios



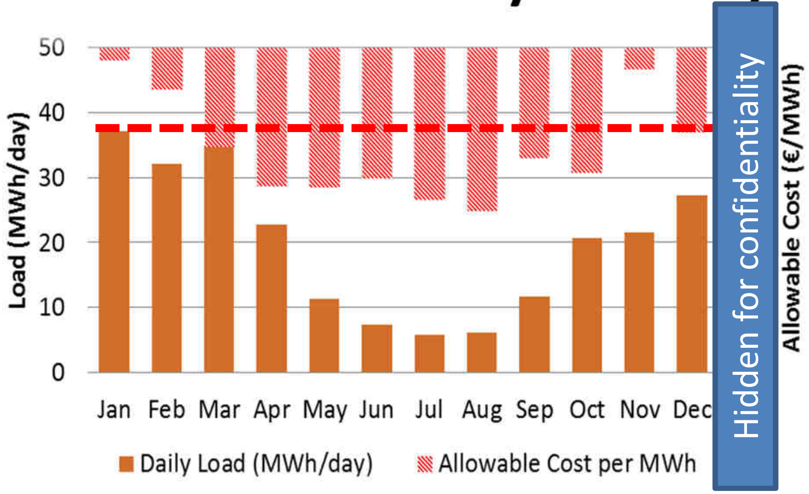
Cost optimized scenarios lead to 20% cost reduction but brings 3% - 8% of CO_2 increase due to operating mode with more frequent transport.

3.3. Sensitivity Analysis



- **PCM price** and **storage performance** have a preponderant impact on **low cost slower transportation** scenarios
- **Operation** optimization and **logistics** is reflected more on **high cost fast transportation** scenarios

3.3. Sensitivity Analysis- Söderfors



	Maritime	Rail	Road
Optimal Cost Scenario	**57 €/MWh**	**76 €/MWh**	**123 €/MWh**

	Site H	Site S
PER	181 mth^{-1}	191 mth^{-1}
Distance	48 km	58 km
Annual Demand	4.3 GWh	7.2 GWh
Average CO2 by Road	550 kg/MWh/yr	600 kg/MWh/yr

PER= Peak power to average load ratio

4. Conclusion

- Approved concept
- PCM selection ➔ M-TES setup ➔ Logistics modeling ➔ Economic Optimization ➔ Environomic performance
- Economic viability with fast and cheap transportation, optimized operating strategy, enhanced storage performance and low material/component cost
- Economic optimum as trade off to environmental benignity

5. Future Work

- Experimental and pilot plant validation
- Complete environomic scenario mapping of full range end-user power to energy profiles

Thank You for Your Attention

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