

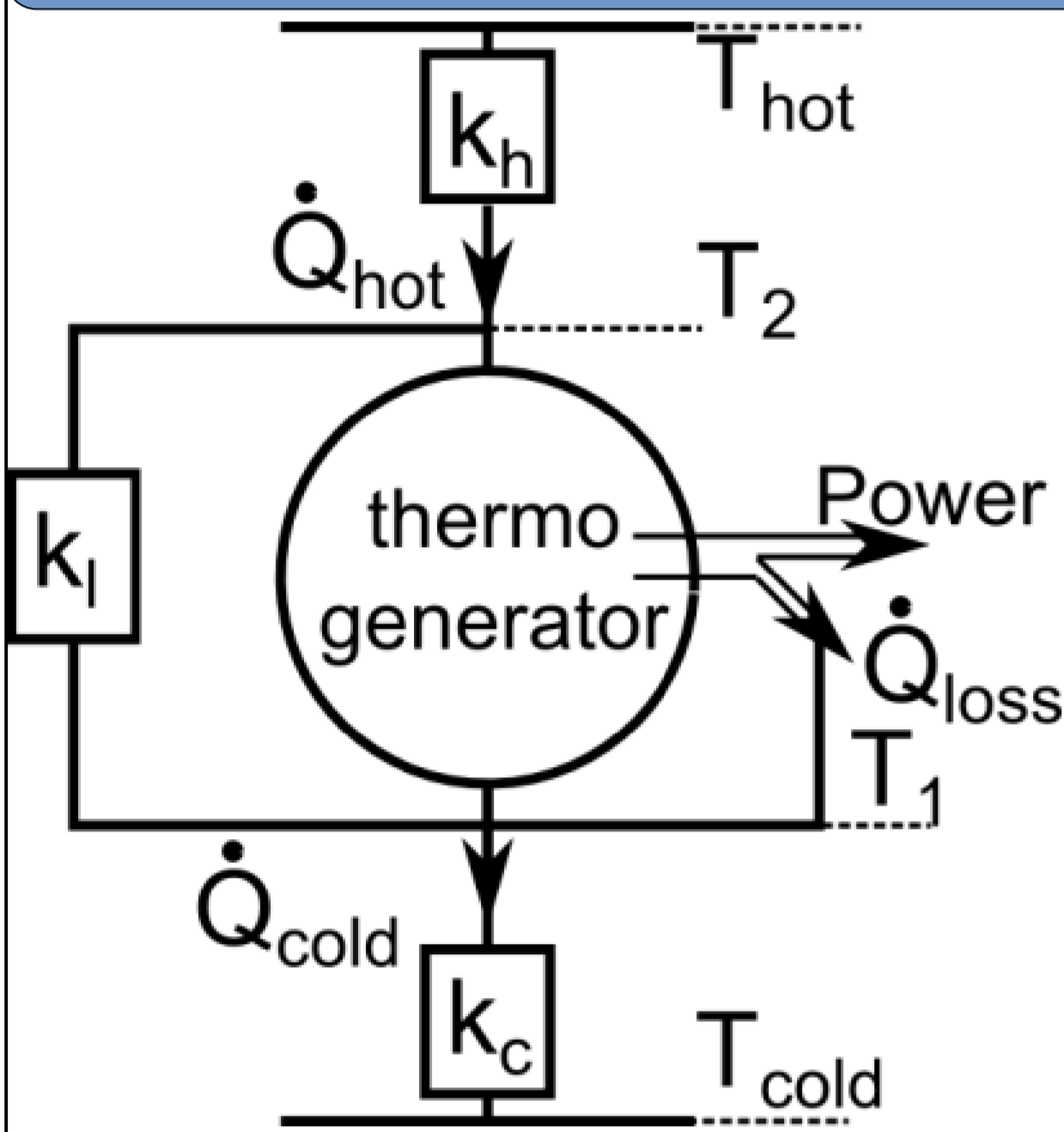
Thermal energy harvesting thermomagnetic versus thermoelectric generator

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Context

High and low grade waste heat are widespread, for example in the USA between 20% and 50% of the global industrial energy inputs, approximately 3 quadrillion Wh/yr, is lost as waste heat. This makes thermal energy harvesting at different scales a key research area. So far thermal energy harvesting is mainly oriented towards thermoelectric generation (TEG). However, recent advances on magnetocaloric materials (MCM), could pave the way for a new generation of thermomagnetic generators (TMG).

Finite time thermodynamics

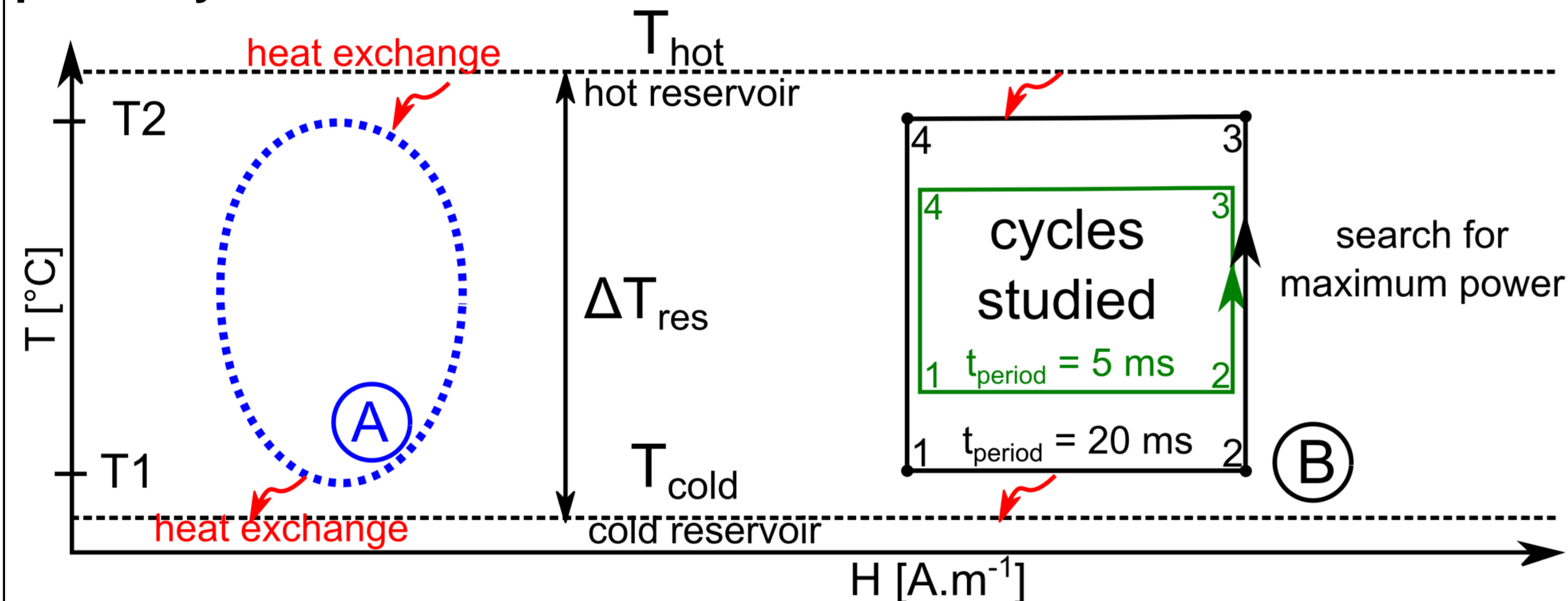


From the practical viewpoint, heat exchange in finite time and its irreversibility has to be considered, the main consequence is the introduction of a **tradeoff between efficiency and power**.

The heat transfer rate between the heat reservoir and the engine are modeled with thermal conductance k_c and k_h which directly impact the efficiency and the power:

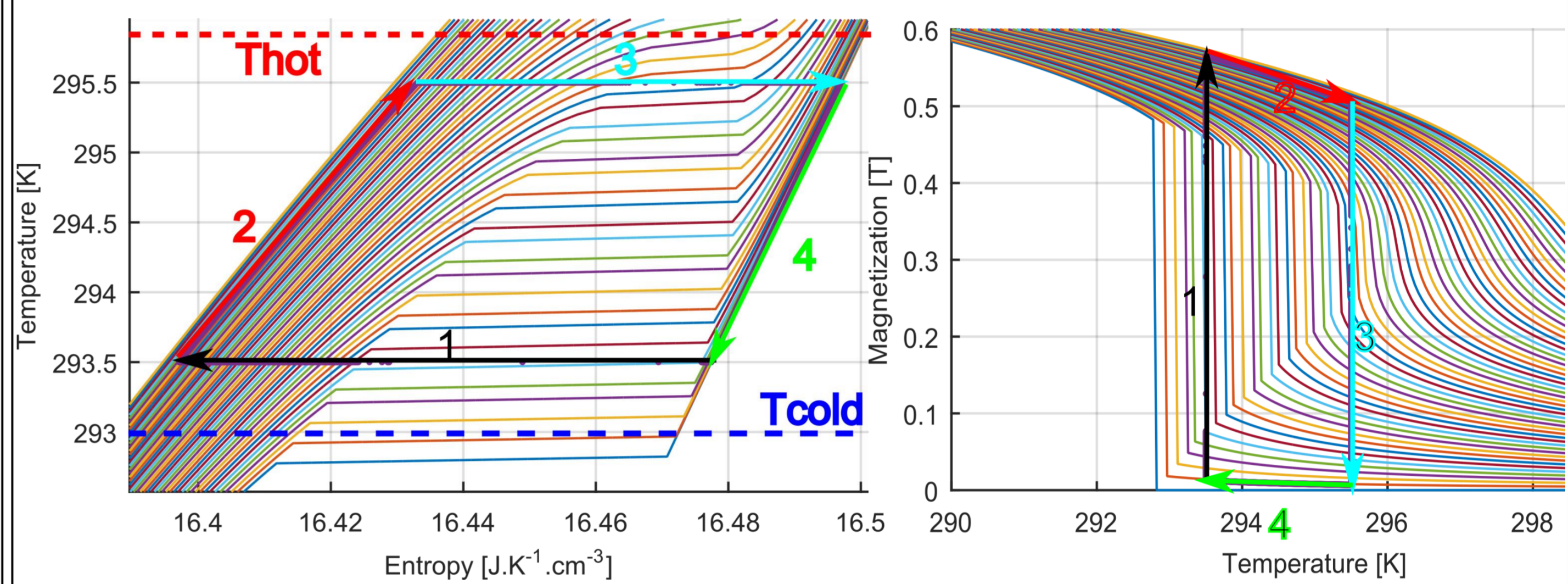
$$\begin{aligned} \delta Q_{hot} &= -k_h(T_2 - T_{hot})dt \\ \delta Q_{cold} &= k_c(T_1 - T_{cold})dt \\ k_h \text{ and } k_c &\in \{0; 1 \text{ W} \cdot \text{cm}^{-3} \cdot \text{K}^{-1}\} \end{aligned}$$

For a given ΔT_{res} and shape of the thermodynamic cycle, the **maximum power cycle** is found for TMG as well as TEG.

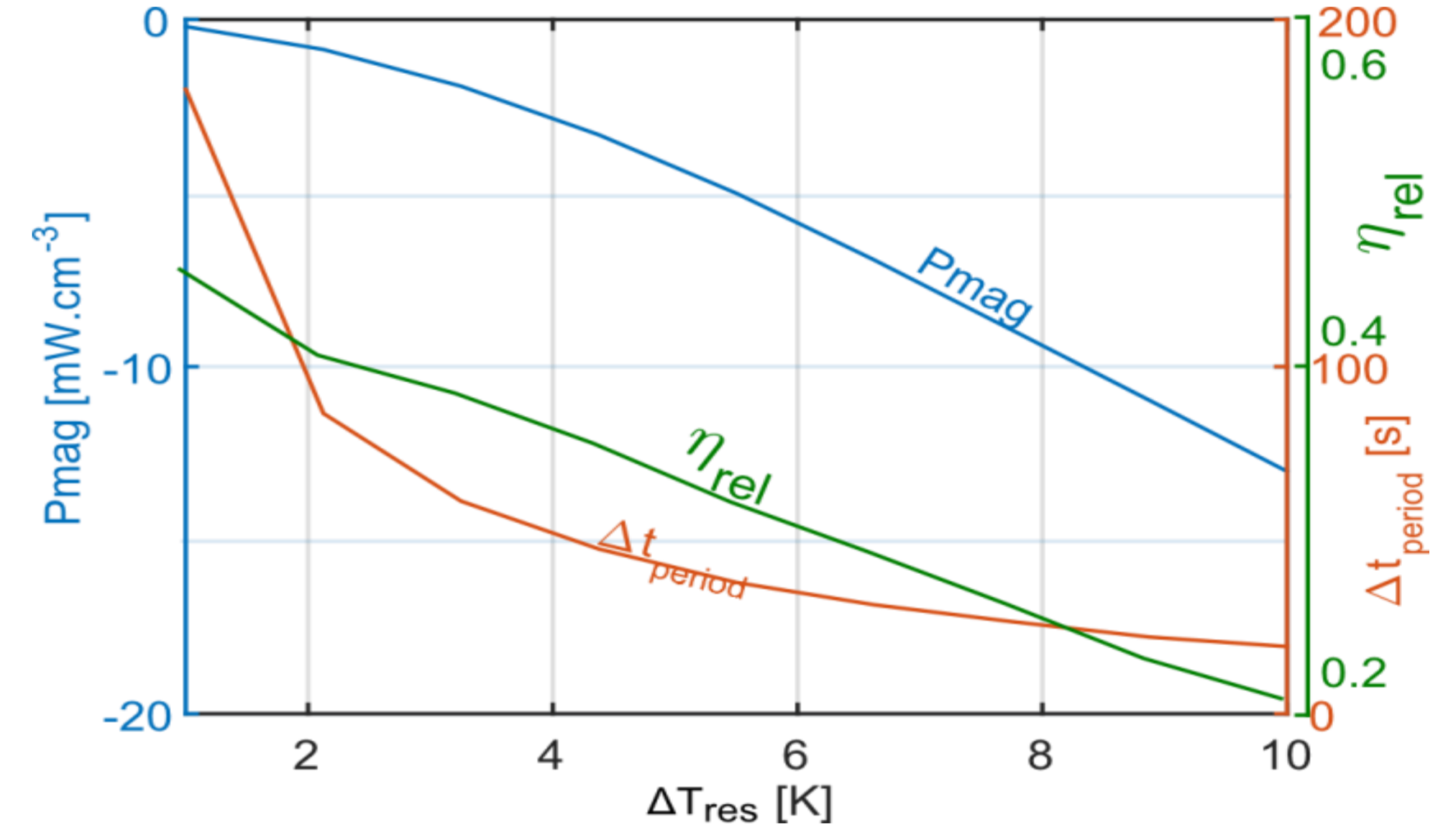


Thermodynamic cycle in TMG

Equation of state of $Mn_{1.3}Fe_{0.65}P_{0.5}Si_{0.5}$ from Landau model where the transition is driven by magneto-elastic coupling with an example of thermomagnetic cycle corresponding to cycle (B):



Maximum power and relative efficiency η_{rel} for different ΔT_{res} for cycle (B) with $\mu_0 H = 1T$ and 1st order $Mn_{1.3}Fe_{0.65}P_{0.5}Si_{0.5}$

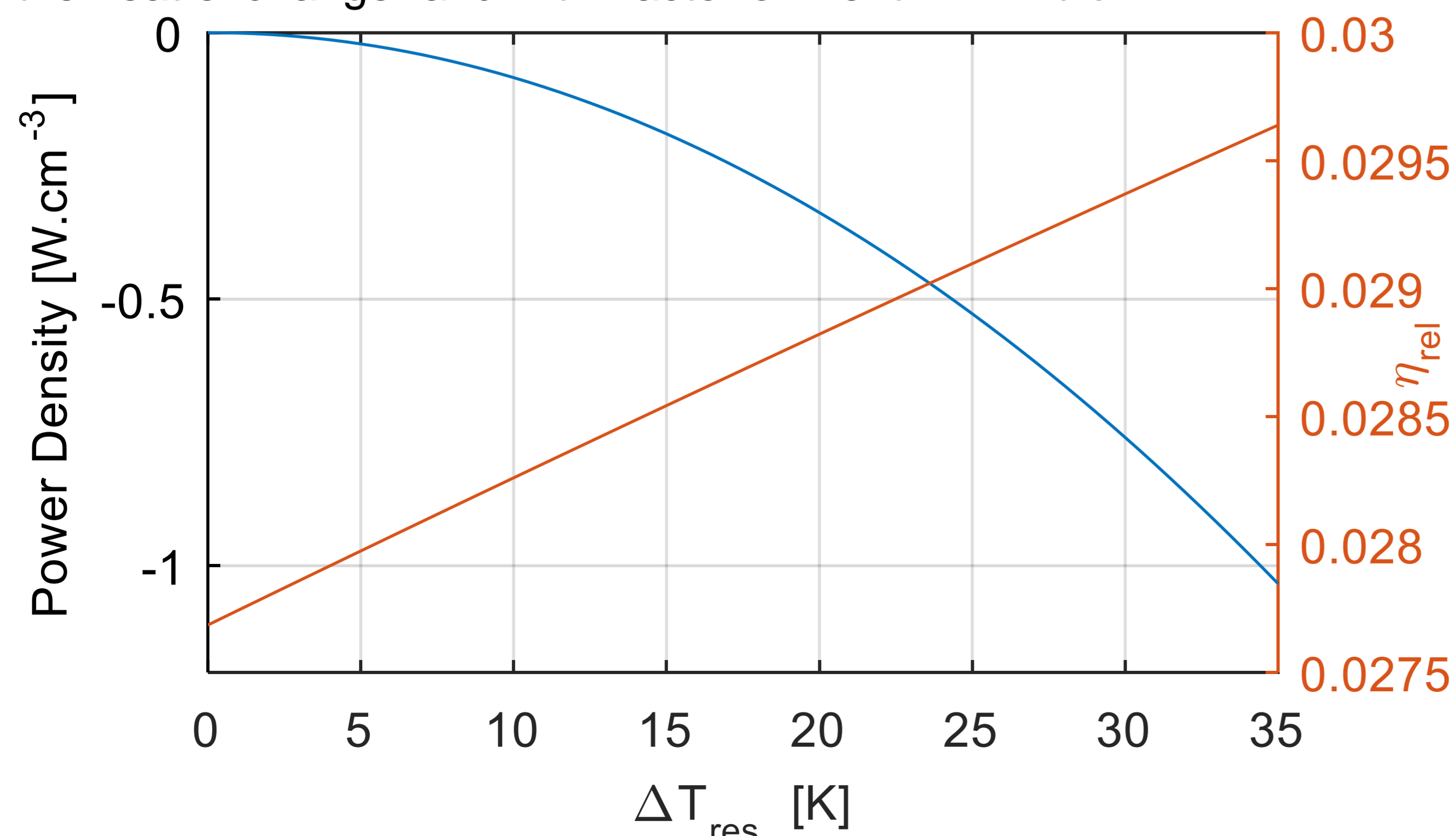


Thermoelectric generator

The use of Onsager model allows a description of the internal dissipation and of the heat leakage between reservoirs and thus puts forward the irreversibility due to thermal exchanges. For different ΔT_{res} , the length of the TEG is optimized, giving a realistic estimate of the efficiency at the maximum power.

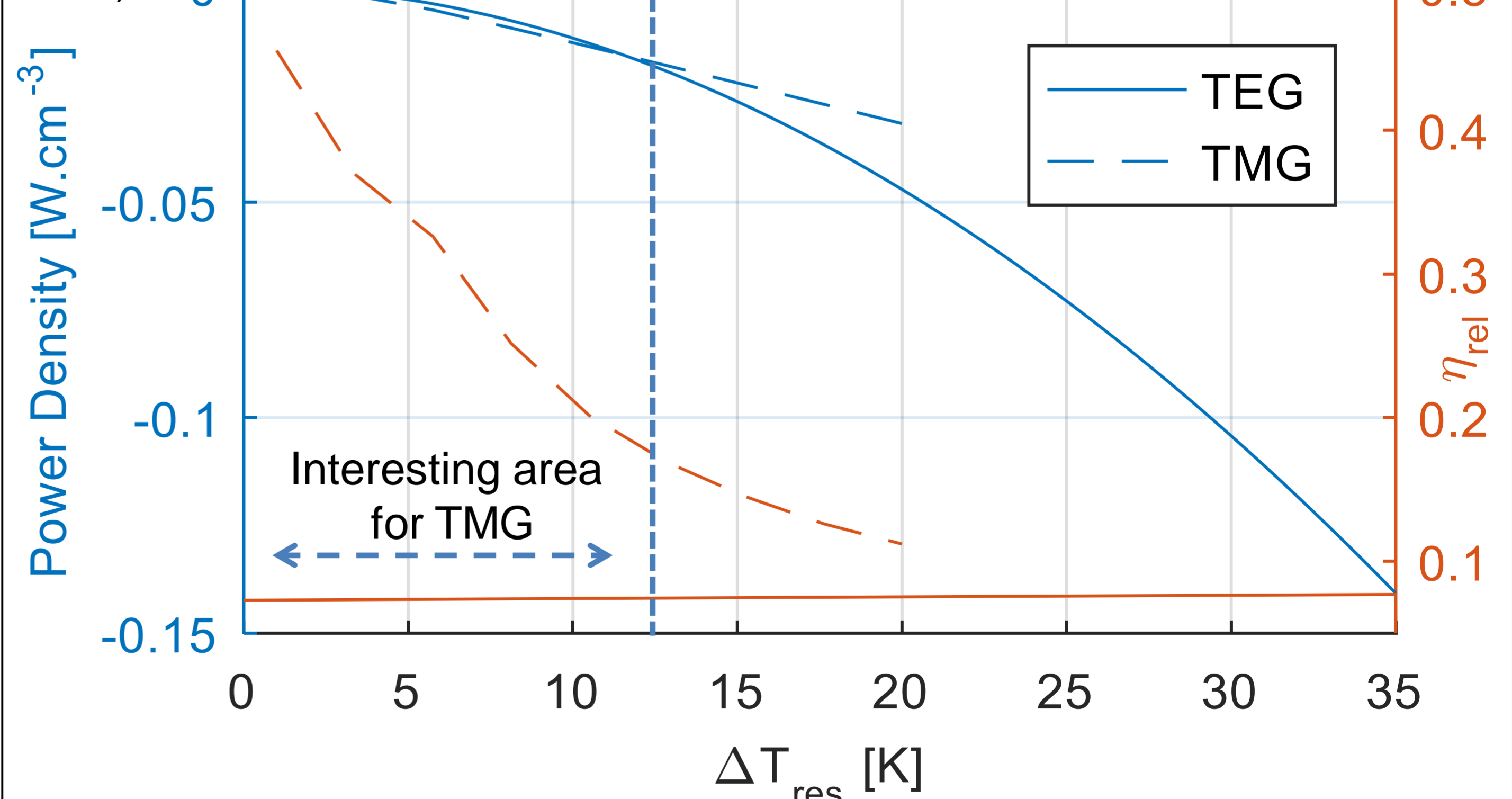
$$\begin{aligned} Q_{hot} &= \alpha N T_1 - \frac{1}{2} R_{in} I^2 + k_l (T_1 - T_2) \\ Q_{cold} &= \alpha N T_2 + \frac{1}{2} R_{in} I^2 + k_l (T_1 - T_2) \end{aligned}$$

Maximum power and relative efficiency function of ΔT_{res} for TEG without the heat exchanger and with Factor of merit $ZT = 0.8$



Thermomagnetic versus thermoelectric

Maximum power for different ΔT_{res} and relative efficiency η_{rel} for TEG with the heat exchanger (solid lines) and TMG with 1st order MCM (dashed lines).



For large ΔT_{res} the power density is higher for TEG, however for small ΔT_{res} , lower than 12 K, the power density is equal while the efficiency is always much higher for TMG with first order phase transition MCM.

Although the weight of the magnetic circuit and the efficiency of conversion of the magnetic energy into electricity are not included, improvement on the shape of the thermodynamic cycle could be expected. Further studies are needed to have better estimation of the coefficient used in the heat exchange conductance.