# Quantification of the energy consumption of entanglement distribution

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Inspired by environmental sciences, we develop a framework to quantify the energy needed to generate quantum entanglement via noisy quantum channels, focusing on the hardware-independent, i.e. fundamental cost. Within this framework, we define a measure of the minimal fundamental energy consumption rate per distributed entanglement (expressed in Joule per ebit). We then derive a lower bound on the energy cost of distributing a maximally entangled state via a quantum channel, which yields a quantitative estimate of energy investment per entangled bit for future quantum networks. We thereby show that irreversibility in entanglement theory implies a non-zero energy cost in standard entanglement distribution protocols. We further establish an upper bound on the fundamental energy consumption rate of entanglement distribution by determining the minimal energy required to implement quantum operations via classical control. To this end, we formulate the axioms for an energy cost measure and introduce a Hamiltonian model for classically-controlled quantum operations. The fundamental cost is then defined as the infimum energy over all such Hamiltonian protocols, with or without specific hardware constraints. The study of the energy cost of a quantum operation is general enough to be naturally applicable to quantum computing and is of independent interest. Finally, we evaluate the energy demands of three entanglement distillation protocols for photonic polarization qubits, finding that, due to entanglement irreversibility, their required energy exceeds the fundamental lower bound by many orders of magnitude. The introduced paradigm can be applied to other quantum resources, with appropriate changes depending on their nature.