Entropy, pricing and macroeconomics of pumped-storage systems

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Abstract

We propose a pricing scheme for the optimization of macroeconomic performance of pumped-storage systems, based on the statistical properties of both geophysical and economic processes. The argument consists in the need for identification of economic values concerning the fuel-energy system, which in terms could be a reference energy economy for all involved macroeconomic energy sectors (RES) and dissipated related insecurity. In the case of pumped-storage, the inherent storage of the reservoir is a means to achieve this objective (ranked determinate RES). The necessity of related multi-valued storage capacity models in terms of real-time elastic controls and regional derivative systems is a key of the valuation process as a need to examine the economic scenario as well, and not only the stability of wind derived generation primarily, but also the efficiency of macroeconomic processes as a need to examine the economic scenario at a higher amplitude of macroeconomic events and be increasingly depended on hydrological uncertainty (entropy) related to reservoir recharge.

1. Entropy and hydro-economic adaptability

Shannon (1948) postulated a statistical mechanical definition of entropy, concerning the propagation of information. This means that a communication signal as a random variable X1 within a specific time-frame. We conceptualize processes of hydrological supply as signals that incorporate uncertainty; statistically quantified by entropy. Uncertainty may very well comprise a function of complexity. The connection of entropy to order economic lies in the effort of the economic system to reconfigure its internal structure towards higher resistance against natural variability, via (a) charting an internal probability space of higher resolution (wider amplitude of statistical capabilities to adequately meet a wider amplitude of natural events) and (b) the use of an interpretation language of higher complexity (more options). Considering that for the economic system Shannon’s formula H(X1) comprises a function of its own language complexity as well, we may write:

\[ H(X_1) = - \sum p(x_1) \log_2 p(x_1) \]

for a discrete-time random variable

The main difference of H(X1) from the conventional conceptualization of H(X) is that it further comprises a function of the economic system’s language complexity to interpret hydrological processes with a better encoding than the dual (U). For pumped-storage deployment this is equivalent to more alternative options (strategies) – thus reduction of dependence from natural uncertainty (Fig. 1). The sophistication of each of the strategies affects the entropy risk (Fig. 2) as it makes them feasible towards a wider amplitude of uncertainty.

Entropy, the complexity language and the economic macrostate (macroeconomics)

Primary efforts by economist Paul Samuelson (1960) - followed by Edward Jaynes (1991) concerned the identification of how an economic system’s macrostate may be shaped by its internal microstate (microeconomic framework). Following this, a more classical approach, Roeger (1971) argued that the utility of a resource is reverse proportional to its entropy, as high entropy signifies a higher cost (in terms of production factors’ sacrifice) for its economic utilization.

2. Entropy of geophysical series and pumped-storage

The optimization of a pumped-storage system primarily depends on its geophysical variables, the natural inputs of each connected renewable energy source (RES), as their coordination or independence will affect the pumped-storage cycle (i.e., a heavy rainfall event that fills the reservoir, with high wind energy output and low demand energy is probable to lead to lower utility of the system’s main purpose due to failure to store wind energy excesses). Mutual Information is a scale-free measure of entropy decrease based on conditional probability of the two events’ joint frequency.

3. Entropy and energy systems integration: Efficiency increase

Optimal integration consists in increasing the statistical efficiency (subsets A4, B4) of the system’s components (i.e., A5, B5) by: (a) minimizing the supply uncertainty of interconnected sources (i.e., wind, and B6) minimizing excess energy output, via storage to a full reservoir (water in the reservoir).

A wits problem for Hermes...

A man in economics and trade god asks himself: How to put into cooperation Acesius (symbolizing the god of winds) with Achilleus (symbolizing the rivers as the most famous ancient Greek river-god) and tame their variability in order to conserve the Earth’s energy resources for as long as possible?

3.1 Energy and entropy systems integration: Efficiency increase due to system integration

The energy strategy of the system consists in avoiding electricity demand by minimizing the repositioning of required resources (i.e., the prevention of total previous exceeding 80% of total fuel excesses – that contributed by 80-92% to total excesses and 69.1% of wind – that contributed by 19.08% to total excesses (middle figures). Resource use optimization occurs for minimum depletion ratio and maximum efficiency increase due to the system integration of the energy resources. For each reservoir: P5 hydropower reduces the fuel depletion ratio by 48.9% (lower figures) – with fuel exhaustion occurring at 100% and a constant pump storage reserve volume.

4. Entropy and energy systems pricing: The scarcity rent

The scarcity rent derives as a shade price imposed on the depletion of a biophysical surplus and has a strong link to the 2nd Law of Thermodynamics (Karakatsanis, 2012). According to Roeger (1971), macroeconomics exhibit an energy unavailability for further production of thermomechanical work. The scarcity rent was primary developed for fossil fuels depletion in order to represent rising scarcity due to the monotonic irreversibility of fuel degradation to heat, as an imposed cost on future availability and need for a transition to new technologies (left figures) with price (P7). The notion of scarcity rent can be well expanded to any kind of surplus, such as reservoir capacity and available water electricity output. Scarcity rents for renewable-surpluses such as water represent only immediate unavailability (Karakatsanis et al. 2013) thus are fluctuating. For pumped-storage – with fluctuating water scarcity - the optimal pricing path is defined from the minimum price per unit time.

5. Simulation of a simple pumped-storage system

We model a simplified version of the Italian island pumped-storage system (Birippi 2013) that consists of (1) a diesel fuel power station, (2) a wind park and (B) a hydro power station with a lower tank (by 400MW) that gathers water after hydroelectricity output in order to store it for pumping. The basic energy deficit and excess characteristics of this system are now:

The derivation of scarcity rent from an optimization problem

The scarcity rent derives from the problem of optimizing a resource’s pricing path, whether it is a fossil resource or a biophysical capacity (i.e., the free capacity of a reservoir or the available water from the minimum volume) as a X1 related to the optimal order quantity costonatic:

6. Pumped-storage for optimal energy resource composition

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7. Conclusions

- Pumped-storage is equivalent to an increase of the economic system’s complexity language towards a more sophisticated management of intermittent energy inputs.
- Maximization of intermittent renewables’ penetration and conservation of fuel reserves for future availability can lead to an optimal use path of non-renewable resources.
- Minimization of the scarcity rent may comprise a macroeconomic pricing target that is also in accordance to the 2nd Law (via the imposing of shadow prices across fuel depletions).

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