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Operational Volatility and Synergistic Value in Vertically Integrated Energy Systems

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I) Background

Renewable Energy
- Economics of renewable energy are changing rapidly: falling costs, rising market share.
- Intermittent nature challenges balancing of electricity supply and demand in real time.
- Opportunity to divert surplus energy to production of energy storing products like hydrogen.

Vertical Integration
- With market imperfection vertical integration is a central issue in the theory of the firm.
- Integration costs arise from further capacity investments and benefits from synergies.
- Synergies repeatedly face operational volatility in terms of price and output fluctuations.

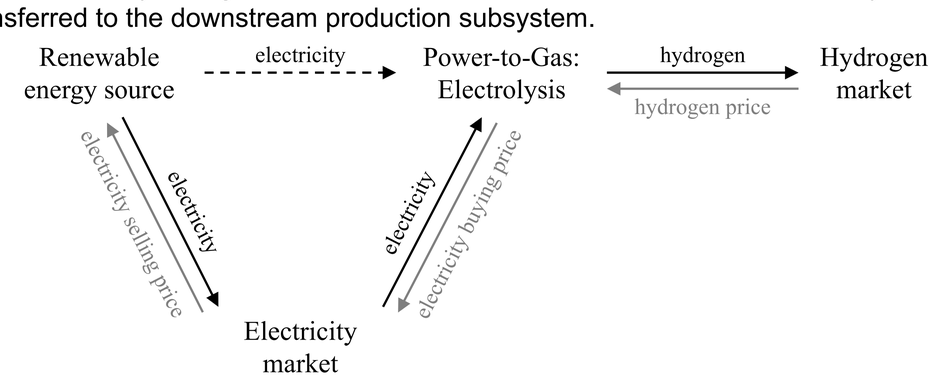
Research Question

? When does the investment in a combined renewable energy and Power-to-Gas (PtG) facility have synergistic value? ?

II) Economic Model

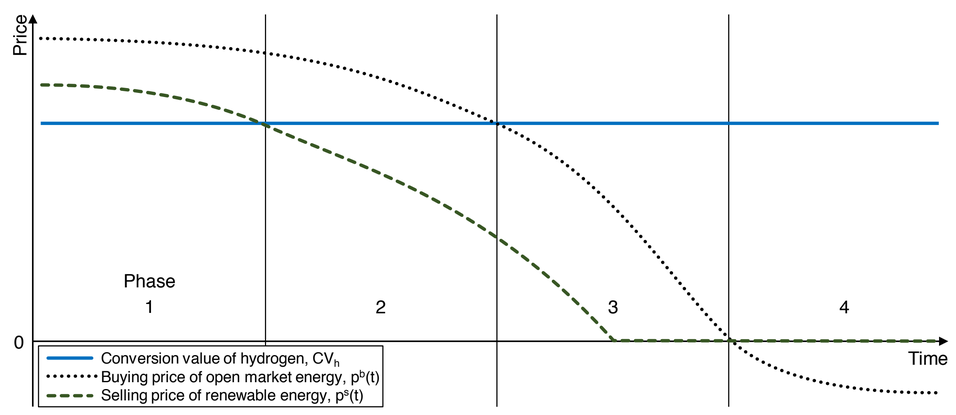
- Our model identifies when vertically integrated energy systems exhibit synergistic value.
- We provide necessary and sufficient conditions for the value (NPV) of the integrated system to exceed the sum of the maximized values of the subsystems on their own.

Setting
- A vertically integrated production system comprises two interacting subsystems.
- Upstream subsystem generates intermediate input that can be sold externally or transferred to the downstream production subsystem.



- In stand-alone operation, a renewable source generates and sells electricity on market.
- A stand-alone PtG facility can buy electricity from open market to produce hydrogen.
- Integration of both enables the transfer of generated electricity to the PtG facility.

Operational Volatility
- Operational volatility stems from intermittency and fluctuations in electricity prices.
- For given investment, system seeks to optimize use of available capacity in real time.
- Integrated system exhibits four production phases: (1) sell renewable energy, (2) convert renewable energy, (3) convert renewable and grid energy, (4) convert grid energy.



Synergistic Value
- Synergies arise when the market for the intermediate input (electricity) is imperfect.
- A vertically integrated energy system is said to have synergistic value if for some combination of renewable energy capacity k_e and PtG capacity k_h:

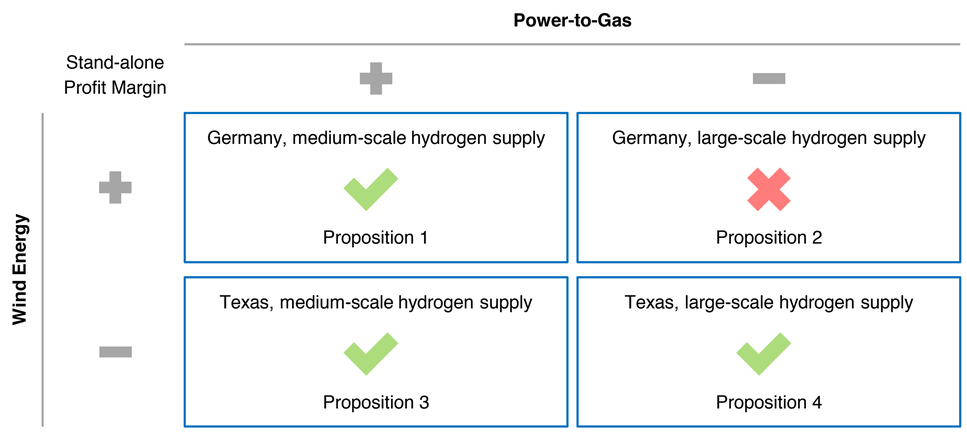
$$NPV(k_e,k_h) > \max\{ NPV(k_e,0), 0\} + \max\{ NPV(0,k_h), 0\}$$

Stand-alone profitability causes four alternative scenarios and analytical Propositions:
1. Both energy systems have positive profit margin stand-alone,
2. Renewable energy source has positive, but PtG has negative profit margin,
3. Renewable energy source has negative, but PtG has positive profit margin,
4. Both energy system have negative profit margin stand-alone.

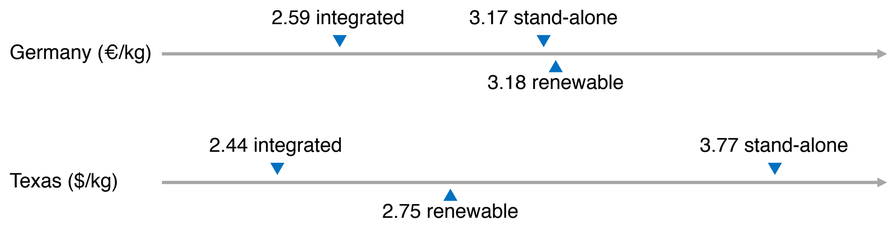
III) Application: Wind Energy and Power-to-Gas in Germany and Texas (US)

Stand-alone Wind Energy and Power-to-Gas
- Wind power is currently profitable in Germany (due to subsidies), but not in Texas.
- PtG profitability depends on attainable market prices for hydrogen: with higher medium-scale supply price, PtG is profitable; with lower large-scale supply price, PtG is not.

Vertically Integrated Energy System
- Intuitively, if both systems are profitable, integration has synergistic value (1: Germany).
- Conversely, if neither system is profitable stand-alone (4: Texas), synergies from vertical integration still more than compensate for stand-alone losses.



Magnitude of Synergistic Effect
- Break-even price of hydrogen production measures gains from vertical integration.
- Pronounced drop of 1.33$/kg illustrates significant synergies from integration in Texas.
- Restricting PtG to only convert renewable energy causes high “sustainability premium”.



Prospects for Future Synergistic Value

Multiple market trends suggest improving economics of integrated hydrogen production: