Strategic capacity choice in renewable energy technologies under uncertainty

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Matthias Ondra, Thomas Dangl

Vienna University of Technology, Institute of Management Science

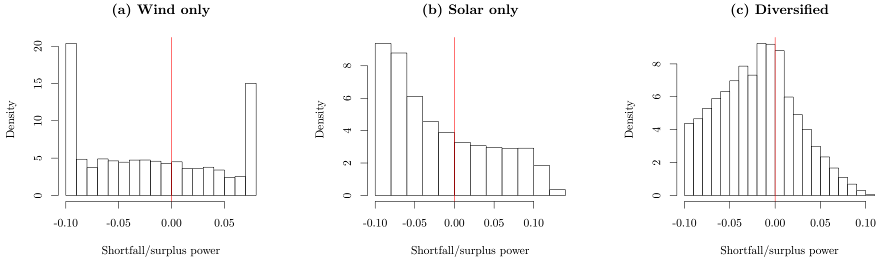
Introduction 1

- Analyze optimal investment decision in renewable energy sources (RES, primarily wind and solar) under uncertainty to cover demand d
- Various source of uncertainty in investment in power generation facilities [TPF16]. We consider:
    (i) Uncertain production volumes of RES [ODH21, OD21]
    (ii) Technological uncertainty (uncertain investment price of solar technology; price for wind technology is assumed to be constant) [BL84, GW97, SC20]
    (iii) Policy uncertainty (uncertain level of remuneration policy) [BMF12, RS16, DGH^{+}18, NHK21]
- Follow the approach of [SC20]: study the combined impact of (ii) and (iii) and include multiple energy sources (wind and solar) which introduces diversification benefits

Introduction 2

- Energy manager of a firm aims at minimizing the expected power procurement costs by choosing optimally installed capacities:
  (i) Investment costs
  (ii) Expected power shortfall costs
  (iii) Expected benefits from selling surplus power to the grid
- What is the optimally RES portfolio? What is the optimal timing of the investment? (Value of managerial flexibility)
- We propose a real options approach to investment problem and solve dynamic investment problem via Dynamic Programming in discrete time

Portfolio diversification: Uncertain production volumes of RES



- Distribution of hourly power output P_i[1]
- Idea: By choosing optimally installed capacities the energy manager can shape the risk distribution

[1] Empirical data available for a typical location in Central Europe: Schwechat, Austria, from 09:00 - 17:00.

Portfolio diversification: Optimal static portfolio decision 1

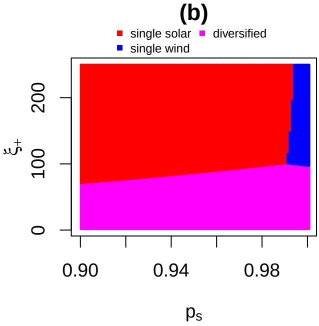
- Consider the "now-or-never" investment problem (no flexibility to defer investment)
- Optimal portfolio selection is given by solving:

$$\min_{x_w, x_s \geq 0} \underbrace{x_w p_w + x_s p_s}_{\text{Investment costs}} + \underbrace{\xi_- \mathbb{E}[\max\{d - \mathbf{x}'\mathbf{P}; 0\}]}_{\text{Expected shortfall costs}} - \underbrace{\xi_+ \mathbb{E}[\max\{\mathbf{x}'\mathbf{P} - d; 0\}]}_{\substack{\text{Expected benefits from} \\ \text{selling surplus power}}}$$

$$x_w p_w + x_s p_s \leq I_0$$

Portfolio diversification: Optimal static portfolio decision 1

- Simplification: we consider only pure investment choices (100 % wind or 100 % solar) and diversified portfolio (50 % wind and 50 % solar)
- Nonlinear costs introduces diversification effect



Technology and policy uncertainty

- Dynamic sources of uncertainty:
  (i) Exogenous innovation shocks occur randomly over time, each innovation decreases investment price by $\alpha \in (0, 1)$
  (ii) Assume that level of FIT follows Geometrical Brownian motion

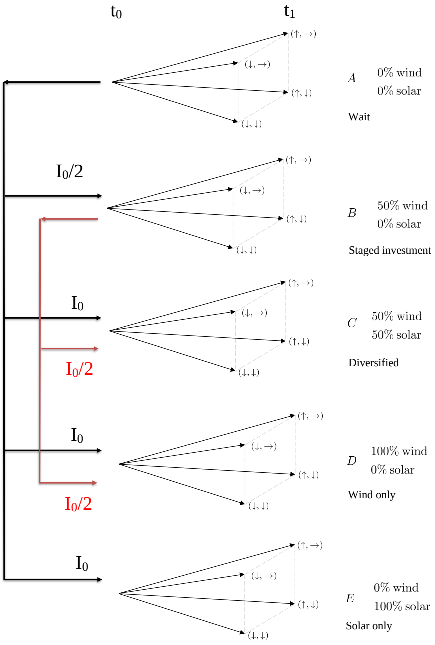
$$\mathrm{d}\xi_+ = \mu\xi_+\mathrm{d}t + \xi_+\sigma\mathrm{d}w,$$

  $\mathrm{d}w$ is increment to a Wiener process, $\mu < 0$, $\sigma > 0$

- Determine optimal timing of the investment and optimal RES portfolio simultaneously (pure investment in wind / solar or diversified portfolio?)

Assumptions

- The timing of the investment is not exogenously fixed! This allows for a lumpy or a staged investment strategy (split the investment I_0 in equal parts)
- Staged investment strategy: invest early $I_0/2$ in wind technology and keep the option to expand the energy park alive
- Technologies have finite lifetime. We assume re-investment in the chosen renewable energy portfolio (modeled via higher interest rate r)
- Budget I_0 is such that no surplus power is generated in case of staged investment
- Level of the FIT is fixed over the expected useful lifetime of the energy park. Level of the FIT of the second stage investment decision overwrites the level of the FIT of the first stage investment decision



t_0
t_1
(↑, →)
(↓, →)
(↑, ↓)
(↓, ↓)
A
0% wind
0% solar
Wait
$I_0/2$
B
50% wind
0% solar
Staged investment
I_0
$I_0/2$
C
50% wind
50% solar
Diversified
I_0
$I_0/2$
D
100% wind
0% solar
Wind only
I_0
E
0% wind
100% solar
Solar only

Use case: Minor technological innovations

single solar; single wind; diversified; staged; wait

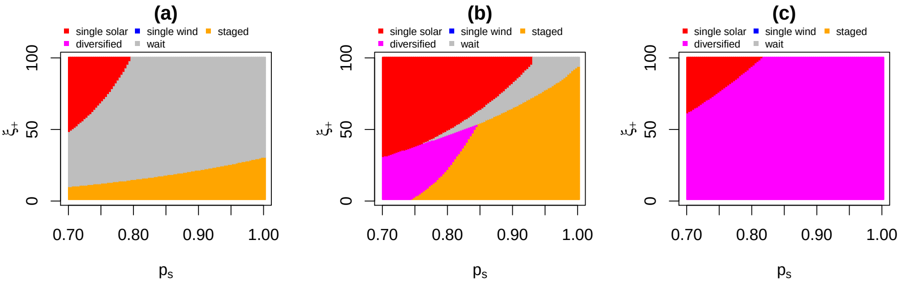


Figure 2: (a) low $\xi_- = 50€/MWh$, (b) mid $\xi_- = 100€/MWh$ and (c) high $\xi_- = 200€/MWh$ energy price regime , $\alpha = 0.1$, $p_w = 1.4M€/MW$, $\pi_{\uparrow}^{\text{Inv}} = 0.5$, $\mu = -0.1$, $\sigma = 0.2$.

Use case: Major technological innovations

single solar; single wind; diversified; staged; wait

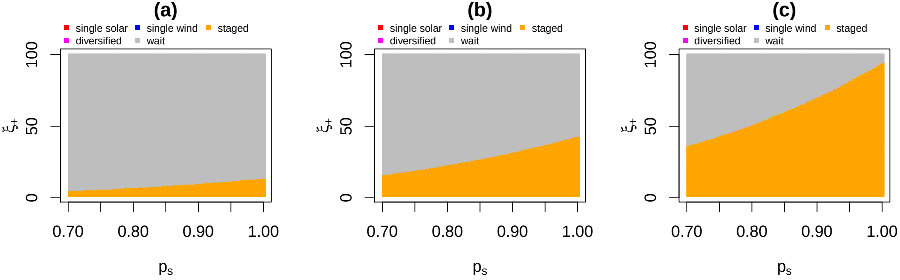
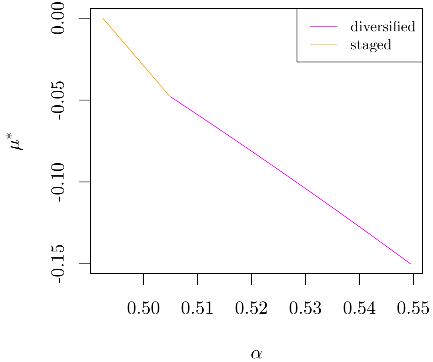


Figure 3: (a) low $\xi_- = 50€/MWh$, (b) mid $\xi_- = 100€/MWh$ and (c) high $\xi_- = 200€/MWh$ energy price regime, $\alpha = 0.3$, $p_w = 1.4M€/MW$, $\pi_\uparrow^{\text{Inv}} = 0.5$, $\mu = -0.1$, $\sigma = 0.2$.

Policy implications: Optimal subsidy-retraction

- Consider a regulator who is responsible for setting the appropriate long-term subsidy retraction rate $\mu < 0$
- To prevent overcompensation for the investment or underinvestment: choose μ^* s.t. decision maker is indifferent in investing now or postponing the decision



Conclusion

- Determined the optimal investment decision and timing simultaneously
- Staged investment strategy: Early partial investment in wind technology decreases ongoing costs of supplying the demand via outside power and keeps the option to invest alive
- Based on optimal decision of the energy manager we infer the optimal subsidy retraction rate from the social planner's point of view

Literature i

Yves Balcer and Steven A Lippman.
Technological expectations and adoption of improved technology.
Journal of Economic Theory, 34(2):292–318, 1984.

Trine Krogh Boomsma, Nigel Meade, and Stein-Erik Fleten.
Renewable energy investments under different support schemes: A real options approach.
European Journal of Operational Research, 220(1):225–237, 2012.

Peder AO Dalby, Gisle R Gillerhaugen, Verena Hagspiel, Tord Leth-Olsen, and Jacco JJ Thijssen.
Green investment under policy uncertainty and bayesian learning.
Energy, 161:1262–1281, 2018.

Steven R Grenadier and Allen M Weiss.
Investment in technological innovations: An option pricing approach.
Journal of financial Economics, 44(3):397–416, 1997.

Roel LG Nagy, Verena Hagspiel, and Peter M Kort.
Green capacity investment under subsidy withdrawal risk.
Energy Economics, 98:105259, 2021.

Literature ii

Matthias Ondra and Thomas Dangl.
Optimal investment strategy in renewable energy technologies.
Available at SSRN 3742080, 2021.

Matthias Ondra, Thomas Dangl, and Christoph Hilscher.
A probabilistically constrained extension to the generation expansion problem.
Available at SSRN 3771789, 2021.

Ingmar Ritzenhofen and Stefan Spinler.
Optimal design of feed-in-tariffs to stimulate renewable energy investments under regulatory uncertainty – a real options analysis.
Energy Economics, 53:76–89, 2016.

Lars Hegnes Sendstad and Michail Chronopoulos.
Sequential investment in renewable energy technologies under policy uncertainty.
Energy Policy, 137:111152, 2020.

Oliver Tietjen, Michael Pahle, and Sabine Fuss.
Investment risks in power generation: A comparison of fossil fuel and renewable energy dominated markets.
Energy Economics, 58:174–185, 2016.