Direct investments in renewable energy portfolios: Stochastic NPV-based capacity budgeting

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Overview

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- Optimal renewable energy portfolio decision from an investor‘s point of view:
  - What is the optimal level of investment in renewables?
  - What is the optimal generation mix?
- Classical approach to capital budgeting problem: Markowitz (1952)
- We propose an alternative stochastic and data-driven modeling approach in the “minimum exceedance probability framework“
- Optimal renewable energy portfolio has the property:
  1. Minimizes capital expenditures
  2. Subject to probabilistic constraint on the profitability of the investment

Framework

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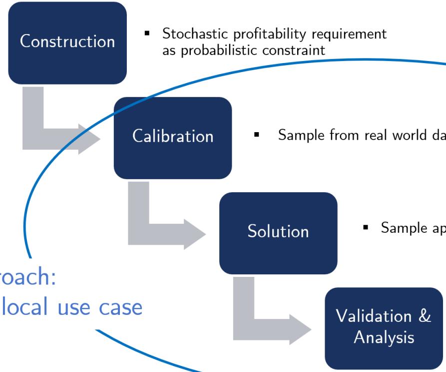
Construction
- Stochastic profitability requirement as probabilistic constraint

Calibration
- Sample from real world data

Solution
- Sample approach (Calafiore & Campi, 2005)

Validation & Analysis
- Ex-post validation of profitability constraint via resampled scenarios

Framework



- Stochastic profitability requirement as probabilistic constraint
- Sample from real world data
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Data driven approach:
Application to a local use case

Model construction

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- Optimal investment decision in the portfolio-theoretic context has been applied in the field of energy economics (Bar-Lev & Katz, 1976; Awerbuch & Berger 2003; Awerbuch & Young 2005)
- In direct investment domain size of investment is not fixed by investor's initial wealth but investment levels have to be determined explicitly
- Profitabiliy of investment by techno-economic assessment (Sommerfeldt & Madani, 2017) via NPV (Short et al., 1995)
- In our model we deal with two main sources of uncertainty:
  - Uncertain production volumes (wind and solar, e.g. Tietjen et al., 2016)
  - Profitability requirement via probabilistic constraint (Charnes & Cooper, 1959) on the NPV of the investment project

The Model 1/2

- Models with probabilistic constraints gaining increasing attention (Geng & Xie, 2019)
- Ondra et al. (2021) discuss investment problem from prosumer's point of view (stochastic hourly supply-demand constraint)
- We abstract from variable costs

$$\min_{x_1,\dots,x_n} \sum_{i=1}^{n} c_i x_i$$

$$s.t. \quad \Pr\{\mathrm{NPV}(\mathbf{x}) \geq \theta\} \geq \chi.$$

x_i ... capacity of i-th technology

c_i ... price per unit of installed x_i

θ ... threshold probability

χ ... confidence parameter

The Model 2/2

$$\Pi(\mathbf{x}) = \sum_{i=1}^{n} \sum_{t=1}^{y\Delta T} S_t p_{it} x_i \left(1 + \frac{r}{\Delta T}\right)^{-t} = \sum_{i=1}^{n} x_i \tilde{\pi}_i,$$

$$\mathrm{NPV}(\mathbf{x}) = \sum_{i=1}^{n} x_i \left(\tilde{\pi}_i - c_i\right) = \sum_{i=1}^{n} x_i \pi_i$$

x_i ... capacity of i-th technology

π_i ... NPV per unit of x_i

p_{it} ... power output per unit of x_i

$\tilde{\pi}_i$ ... revenue per unit of x_i

ΔT ... hours in one year (8760)

S_t ... spot market price

Model calibration

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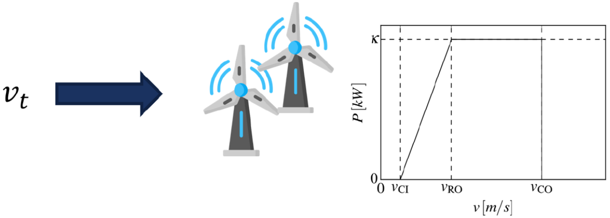
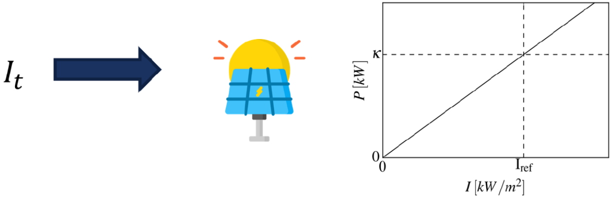
- CAPEX minimizing renewable energy portfolio (wind and solar) s.t probability to obtain NPV over the lifetime of the energy park $y = 25y$ larger than $\theta = 1\ Mio$ € is at least χ
- Prices of investment in renewables (wind and solar):

$$c_1 = 2.000€/kW,\ c_2 = 800€/kW$$

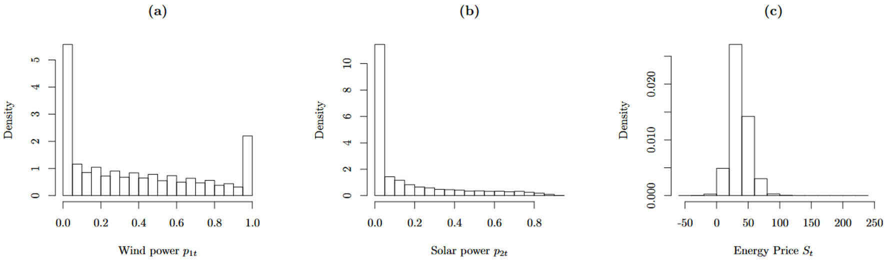
- Sample from real world data of solar irradiance and wind speed in Schwechat, Austria (*ASOS* and *CAMS solar radiation*, hourly data available from 2012-2018); hourly electricity spot market prices from EXAA

- Wind speed and solar irradiance are translated into power output via the physical energy model





Model calibration



Hourly values for: (a) wind power output per installed MW (b) solar power output per installed MW and (c) energy price (€/MWh)

Model calibration

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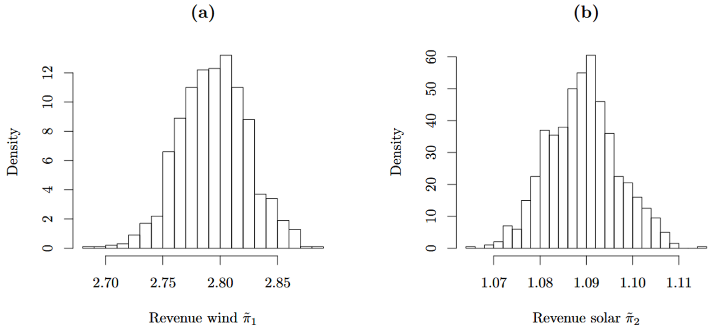
- Create sample to simulate NPV over expected useful lifetime of the energy park via block-bootstrapping
- Block size of 3 days to incorporate short and long term weather trends

Model calibration



Aggregated data over lifetime of the energy park: (a) revenues (M€/MW) per MW installed capacity of wind technology (b) revenues (M€/MW) per MW installed capacity of wind technology

Model solution

- Replace probabilistic constraint by deterministic sample:

$$\Pr\{\text{NPV}(\mathbf{x}, \boldsymbol{\xi}) \geq \theta\} \geq \chi \quad \Longleftrightarrow \quad \text{NPV}(\mathbf{x}, \boldsymbol{\xi}^{(i)}) \geq \theta, \qquad i = 1, \ldots, N$$

$$\boldsymbol{\xi} = (\text{spot price, production volume}, \ldots)$$

set of all uncertain parameters

- Sample approximation introduced in Calafiore & Campi (2005)
- Sample & Discard algorithm (Campi & Garatti, 2011): Remove (reliability dependent) number of constraints according to any algorithm
- Solution is robustly feasible with reliability level χ

The model applied to Schwechat

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$$\min_{x_1,x_2} c_1x_1 + c_2x_2 \quad s.t.$$

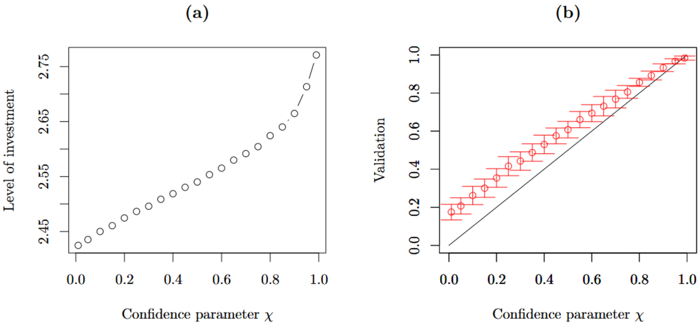
$$x_1(\tilde{\pi}_1^{(1)} - c_1) + x_2(\tilde{\pi}_2^{(1)} - c_2) \geq \theta$$

$$\vdots$$

$$x_1(\tilde{\pi}_1^{(N)} - c_1) + x_2(\tilde{\pi}_2^{(N)} - c_2) \geq \theta$$

$$x_1, x_2 \geq 0, N = 1000.$$

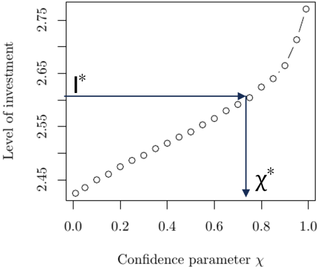
Model validation



(a) Optimal level of investment in the energy park (b) validation to assess the quality of the solution based on resampled scenarios

Minimum level of risk

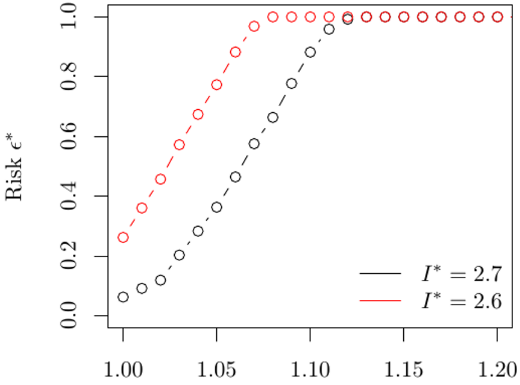
- Introducing a budget constraint I^* endogenizes maximum reliability χ^* (or equivalently minimum level of risk $\epsilon^* = 1 - \chi^*$)



$$\max_{\chi \in [0,1)} \chi, \qquad \text{s.t.}$$
$$I(\theta, \chi) \leq I^*$$

Minimum level of risk

- Optimization problem can be solved iteratively via a bi-sectioning approach
- Endogenized level of risk corresponds to minimum level of project failure (probabilistic constraint is not fulfilled) that the investor has to accept



Conclusion

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- Probabilistic modelling approach to the MEP using empirical distributions
- Decision-support tool for investment decisions in the energy sector
- Determine optimal level of investment in RES subject to probabilistic constraint
- Quantify the minimum level of risk that investor has to accept in case of a budget constraint

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Thank you for your attention!