

Limitations of optimization models for longterm planning - representing market designs, policy interventions and agent behavior

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Long-term energy-system or power-system optimization models: two perspectives

- E.g., MARKAL/TIMES, ReEDS, etc.
- Social perspective:
 - Normative/prescriptive
 - Maximize welfare/minimize cost
 - Private agents' perspective
 - Descriptive
 - ↑ Maximize total surplus/minimize cost
 - Market equilibrium

Research question

What are the limitations of optimization models in representing the market equilibrium?

- Policy interventions
- * Market designs
- Agent behavior

Optimization models - what can be done

Optimization Problem

$$\min_{cap_{i},gen_{i,t}} \quad \sum_{t} \sum_{i} \left(cap_{i}FC_{i} + \sum_{t} (gen_{i,t}MC_{i}\Delta_{t}) \right)$$

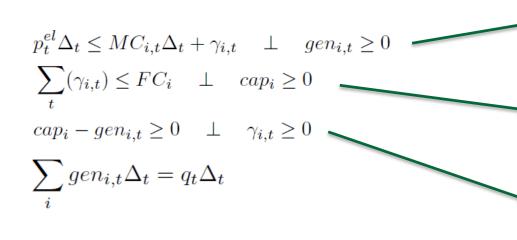
$$s.t. \quad cap_{i} - gen_{i,t} \geq 0 \quad (\gamma_{i,t}) \quad \forall i, t$$

$$gen_{i,t} \geq 0 \quad \forall i, t$$

$$cap_{i} \geq 0 \quad \forall i$$

$$\sum_{i} gen_{i,t}\Delta_{t} = q_{t}\Delta_{t} \quad (p_{t}^{el}) \quad \forall t$$

KKT Conditions



Only generate electricity if the price for electricity covers variable costs

Only invest if infra-marginal rents cover fixed costs

Infra-marginal rents can only be positive when generating at rated capacity

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Optimization models - what can be done

Optimization Problem

$$\min_{cap_{i},gen_{i,t}} \quad \sum_{t} \sum_{i} \left(cap_{i}FC_{i} + \sum_{t} (gen_{i,t}MC_{i}\Delta_{t}) - \sum_{t} (gen_{i,t}S_{i}\Delta_{t}) \right)$$

$$s.t. \quad cap_{i} - gen_{i,t} \geq 0 \quad (\gamma_{i,t}) \quad \forall i, t$$

$$gen_{i,t} \geq 0 \quad \forall i, t$$

$$cap_{i} \geq 0 \quad \forall i$$

$$\sum_{i} gen_{i,t}\Delta_{t} = q_{t}\Delta_{t} \quad (p_{t}^{el}) \quad \forall t$$

KKT Conditions

$$p_t^{el} \Delta_t + S_i \Delta_t \leq MC_{i,t} \Delta_t + \gamma_{i,t} \quad \perp \quad gen_{i,t} \geq 0$$

$$\sum_t (\gamma_{i,t}) \leq FC_i \quad \perp \quad cap_i \geq 0$$

$$cap_i - gen_{i,t} \geq 0 \quad \perp \quad \gamma_{i,t} \geq 0$$

$$\sum_i gen_{i,t} \Delta_t = q_t \Delta_t$$

Only generate electricity if the price for electricity + feed-in premium covers variable costs

Only invest if infra-marginal rents cover fixed costs

Infra-marginal rents can only be positive when generating at rated capacity

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Optimization models - what can be done

Policy interventions

- RES support schemes: e.g., feedin premium
- Carbon tax
- Technology acceptance
- Etc.

Market design/ imperfections

- Capacity payment, capacity market
- Emission trading markets, green certificate markets
- Non-level playing field: eligibility criteria, product definition, market access
- Incomplete markets:
 e.g., zonal pricing
- Etc.

Agent behavior

 Rational, perfect information (risk neutral), pricetakers

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Optimization models - what cannot be done

Policy interventions

- RES support
 schemes: e.g., feed in tariff, minimum
 price for green
 certificates
- Grandfathering of emission allowances

Market design/ imperfections

- Net metering
- Average price contracts

Agent behavior

- Strategic behavior
- Risk-averse behavior
- Heterogeneous costs of capital (hurdle rate)

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Duality

- Role of linking constraints in optimization models
 - Enforce physical/political constraints
 - Represent markets (dual variable reflects the price)
- **Examples**:
 - * Supply-demand balance: $\sum_{i} gen_{i,t} = q_t \ (p_t^{el}) \ \forall t$
- Implication: no decoupling possible between the physical/political constraint and the corresponding market
 - * All variables appearing in physical/political constraints valued according to the dual variable of that constraint (+ a constant)
 - * Variables not appearing in a physical/political constraint cannot be valued according to the endogenously determined price

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Example: minimum price for green certificates

- Suppliers have obligation
- Generators can decide to sell their certificates:
 - st To the market (suppliers): q_i^{SUP} @ p^{GC}
 - st To the DSO: at guaranteed minimum price: q_i^{DSO} @ $P^{GC,DSO}$
- Issue: in an optimization model: every green certificate generated will be implicitly valued at the market price

$$\sum_{i} \sum_{t} (q_i^{DSO} + q_i^{SUP}) \ge D^{GC} \quad (p^{GC})$$

Alternative models

- Mixed Complementarity Problems (MCP)
 - + + more flexible
 - + Computation time increases
- Parametrized optimization problems (iteratively solving optimization problems)
 - ★ + Small barrier for implementation
 - ★ Computation time, convergence
- Dedicated solution techniques
 - * + reduce computation time
 - → low flexibility

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Optimization models – relevance of what cannot be done

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Conclusions and further research

- Optimization models cannot distinguish between physical/political constraints and the corresponding markets
- Certain market designs, policy interventions and behavioral elements cannot be represented
- Particularly the impact of behavioral elements (heterogeneous cost of capital, risk averseness) deserves further attention in long-term optimization models