Comparison of Priority Service and Multilevel Demand Subscription for Mobilizing Residential Demand Response

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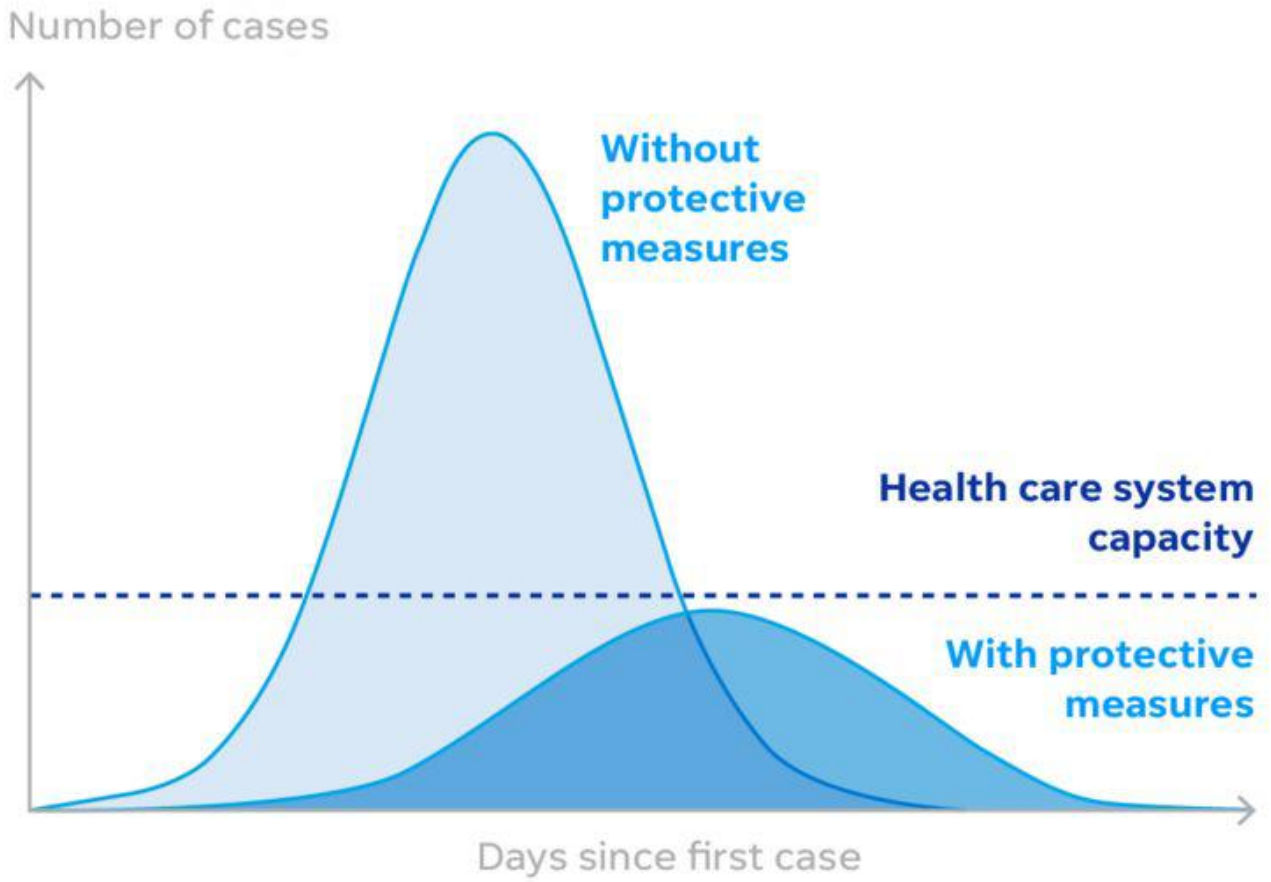
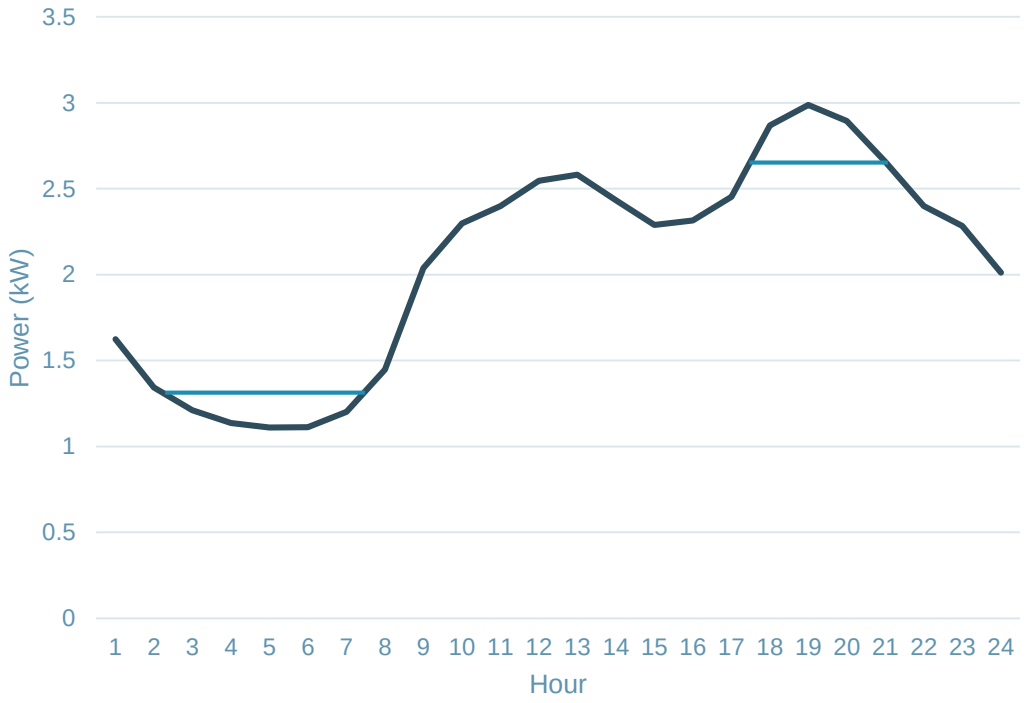
1. VITO/EnergyVille 2. UCLouvain

Flatten the Curve



Source: https://www.hln.be/

Peak-Shaving in Power Service



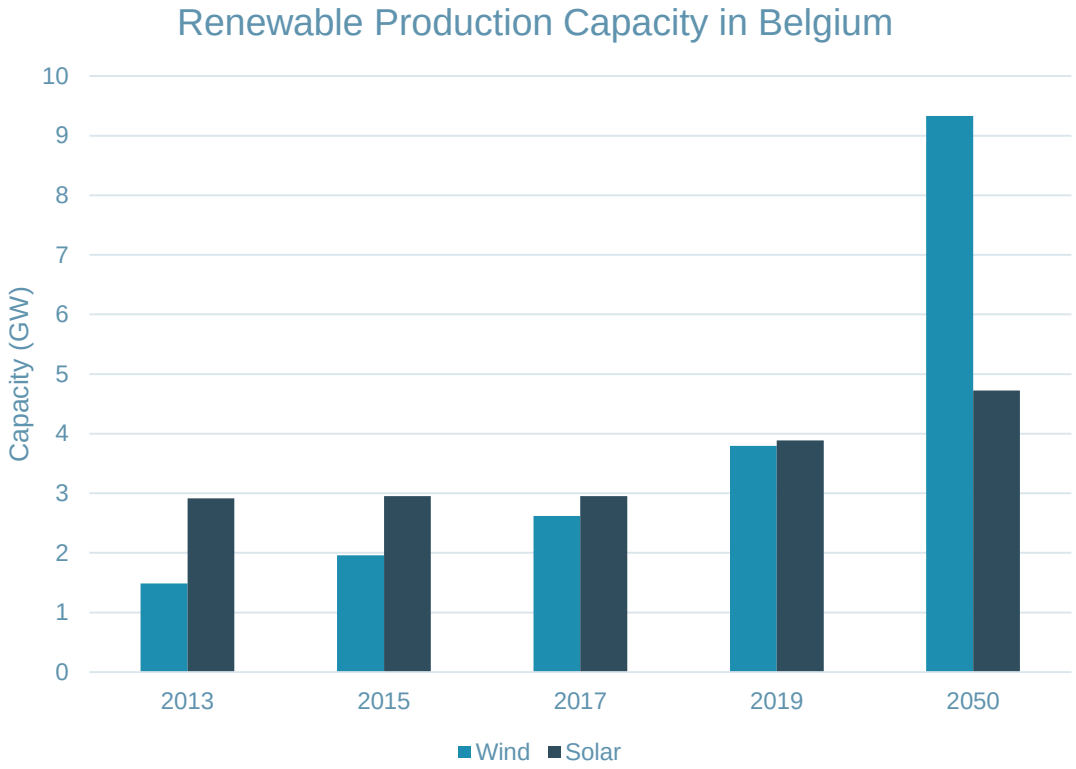
NORMAL	
Redevance fixe (€/an)	54,49
Prix par kWh (c€/kWh)	7,669
BIHORAIRE	
Redevance fixe (€/an)	54,49
Prix par kWh heures pleines (c€/kWh)	8,855
Prix par kWh heures creuses (c€/kWh)	6,546

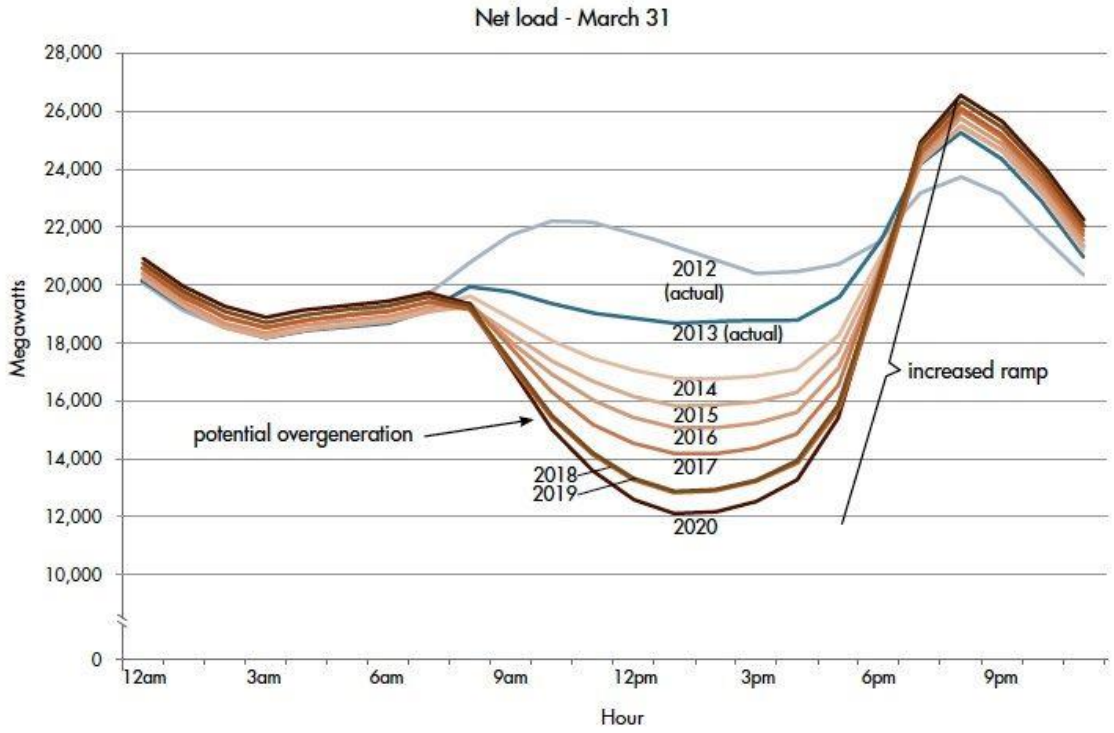
Heures creuses/ heures pleines

Les plages horaires des heures creuses du bi-horaire s'étendent **la nuit (de 22h à 7h le lendemain) et le week-end (du vendredi 22h au lundi 7h)**.
Dans quelques communes desservies par ORES, elles s'étendent de **21h à 6h** (week-end : du vendredi 21h au lundi à 6h).

Source: Electrabel; ORES

Is a Time-of-Use Tariff Future-Proof?





Source: ELIA; CAISO

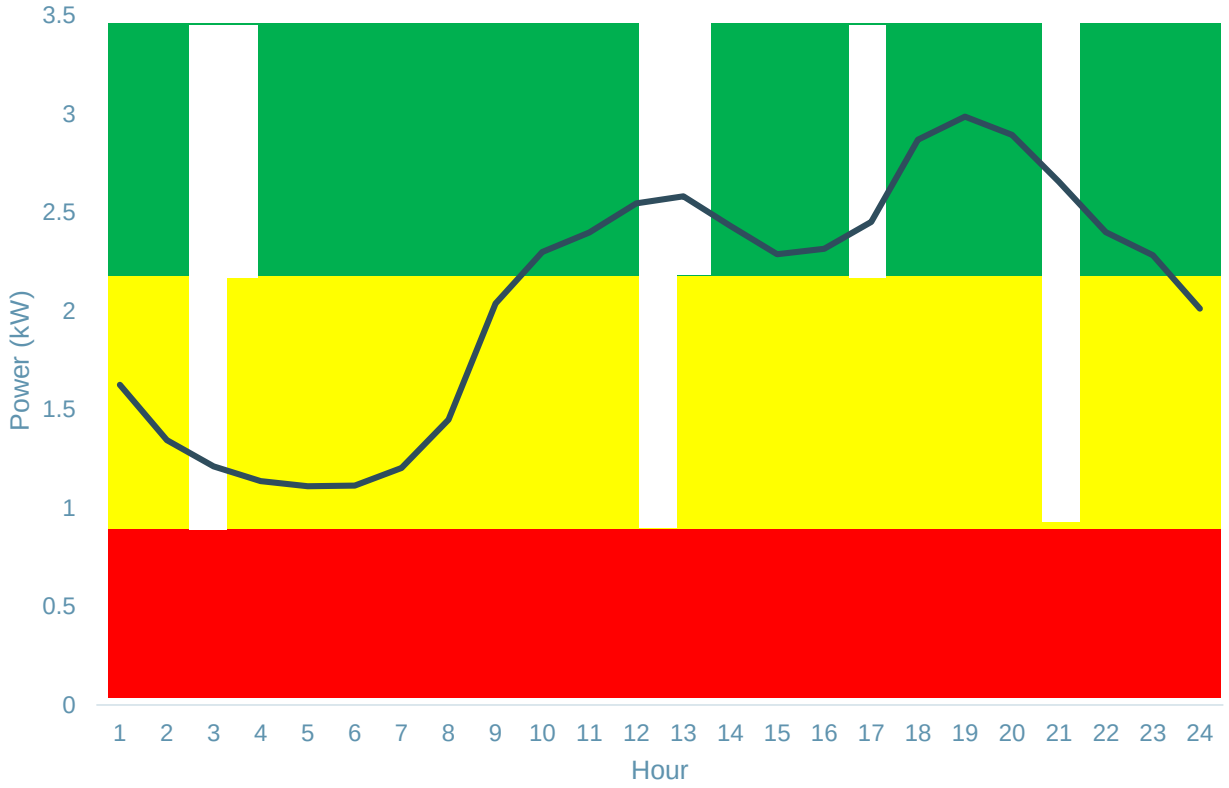
Outline

- Motivation
- A Bilevel Optimization Formulation of Priority Service and Multilevel Demand Subscription
- Performance Evaluation of Priority Service and Multilevel Demand Subscription
- Case Study on the Belgian Power System
- Conclusions and Perspectives

Motivation

- To deal with the increasing integration of renewable production, we investigate new pricing schemes for electricity retailers.
- We consider a future where households are equipped with PV panels, resulting in decreasing energy needs from the main grid, but where capacity needs remain or even increase due to electrification. This calls for a careful design of electricity tariffs.
- Power as a service with differentiated quality:
  - Deadline differentiated pricing policy for deferrable electric loads [Bitar & Low, 2012];
  - Duration differentiated energy service [Nayyar et al., 2016].
- We compare reliability-differentiated pricing (priority service) and reliability-duration-differentiated pricing (multilevel demand subscription) → Complexity versus Efficiency

Illustration of Priority Service



Reliability (%)	Price (€/kW-month)	Equivalent Price (¢/kWh)
75	30	5.6
87.5	40	7.4
100	50	9.3

- Strips of higher priority corresponding to higher price (simple).
- Consumers self-select how to allocate individual devices to strips (non-intrusive).

The Devices Obey “Traffic Signals”

Households

Control, Privacy

ColorPower Appliance Priorities

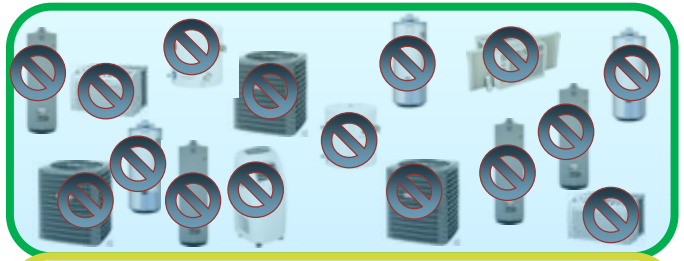
Obey consumers’ preferences

Obey grid traffic signals

Grid

Coordinates power access for flexible appliances

Flexible



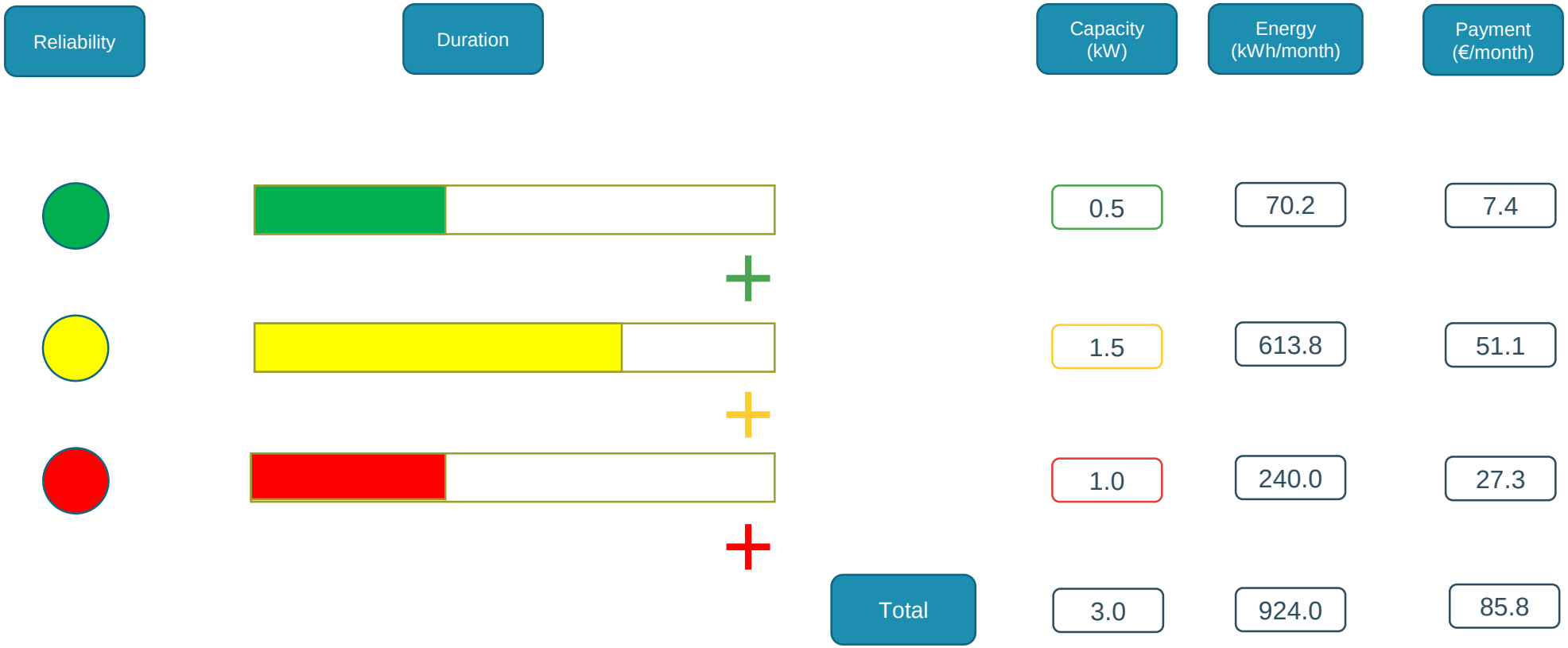
Emergency

Not Flexible

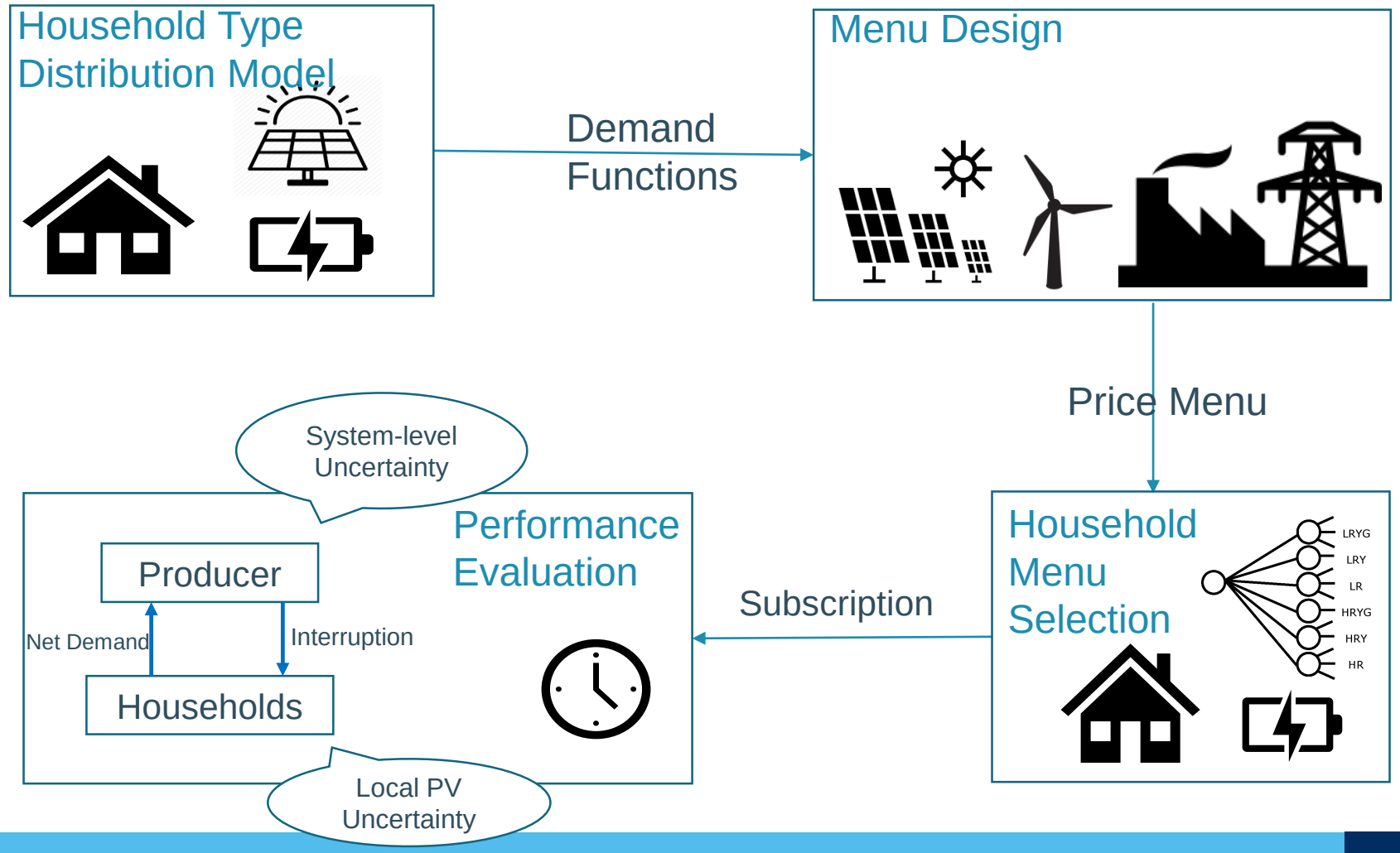
System operator tunes DR levels.

Source: Presentation of Dr. Alex Papalexopoulos

Implementation of Multilevel Demand Subscription



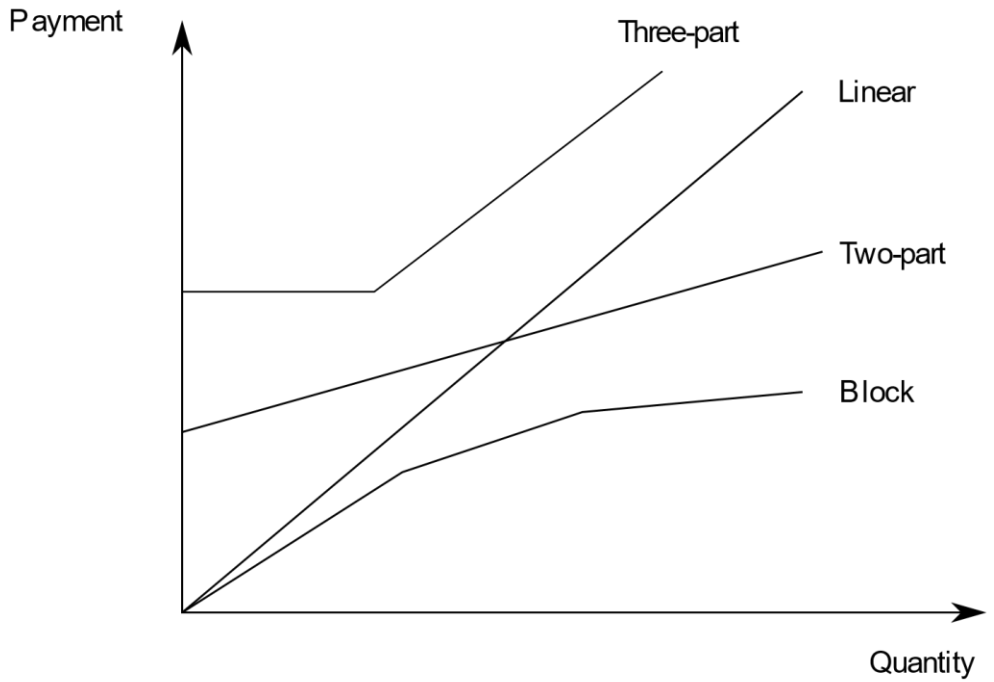
Research Overview



Menu Design

- Nonlinear Pricing Theory
- Information Asymmetry
- A Bilevel Optimization Formulation of Priority Service
- Extension to Multilevel Demand Subscription

Theory of Nonlinear Pricing



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- Hung-po Chao, Shmuel Oren, Stephen Smith, and Robert Wilson. Multilevel demand subscription pricing for electric power. Energy Economics 8, no. 4 (1986): 199-217.

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Robert B. Wilson
The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 2020

Born: 16 May 1937, Geneva, NE, USA

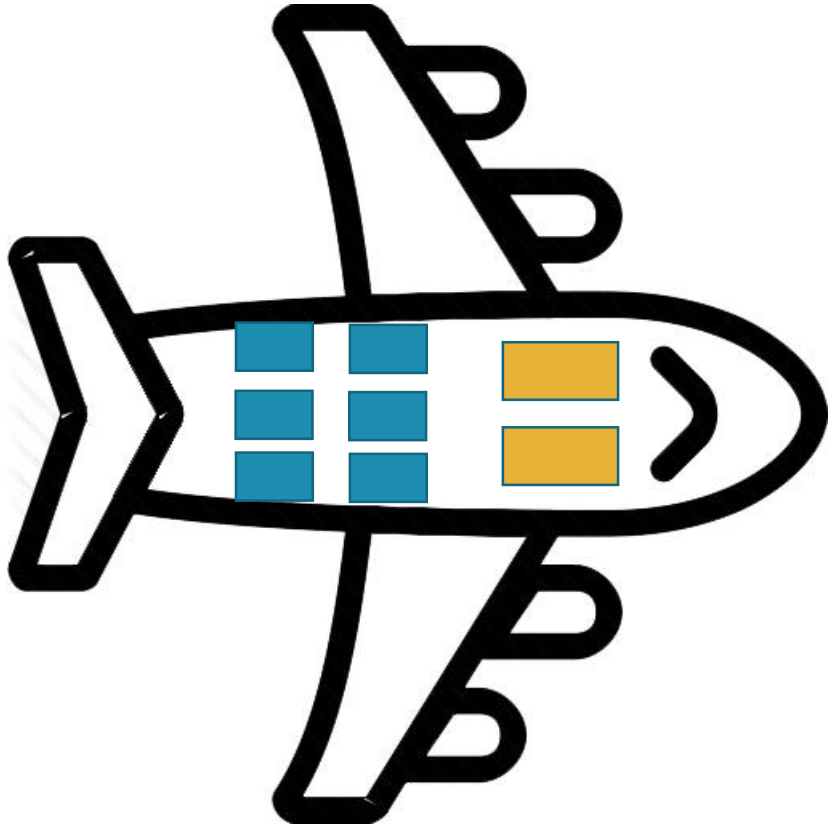
Affiliation at the time of the award: Stanford University, Stanford, CA, USA

Prize motivation: "for improvements to auction theory and inventions of new auction formats."

Prize share: 1/2

Source: https://www.nobelprize.org/prizes/economics/2020/wilson/facts/

Information Asymmetry



- Flight from Brussels to Shanghai
  - Jessie, business, 4000 €
  - Yuting, holiday, 1000 €
- Pricing schemes:
  - Uniform price: 800 €
  - Business class: 2000 €; economic class: 600 €
- Electricity service:
  - Time-of-use tariff: when to consume
  - Priority service: reliability

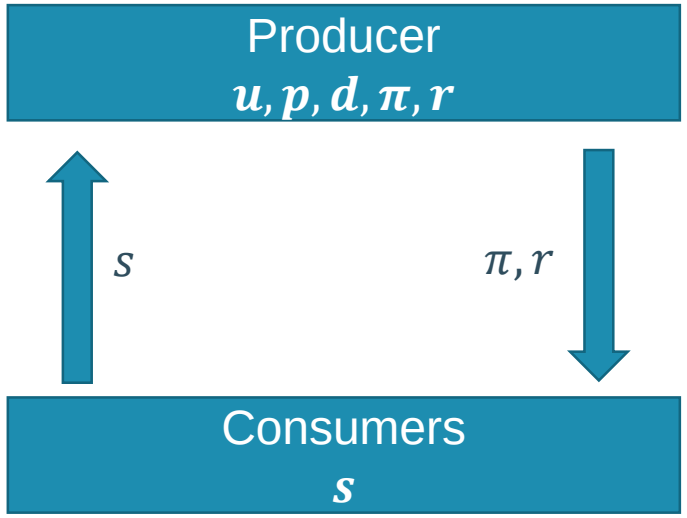
private

Shortcomings of Traditional Theory and Our Proposition

- The cost function is assumed be to convex, so non-convex production costs, such as start-up and min-load costs, cannot be handled.
- The presented model is static, in the sense that there is no coupling over time periods (e.g. due to minimum up and down times, ramp constraints).

- We incorporate unit commitment into the menu design problem and model it as a Stackelberg game, which is reformulated as a bilevel optimization problem.
- Non-convex costs are captured directly. The time-coupling constraints of generators and the pumped hydro storage are modeled explicitly.

Priority Service Bilevel Model



$$\max_{\boldsymbol{u,p,d,\pi,r}} \quad SW(\boldsymbol{u, p, d, \pi, r})$$

subject to:

$$(\boldsymbol{u, p, d}) \in \mathcal{X}$$

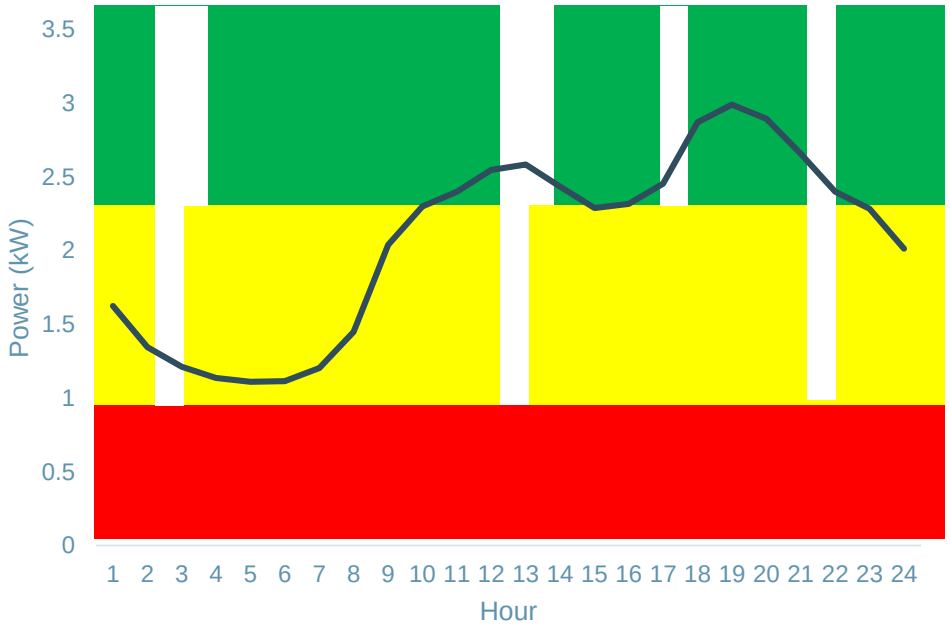
$$\boldsymbol{r} = \phi(\boldsymbol{d}, \boldsymbol{s}^\star)$$

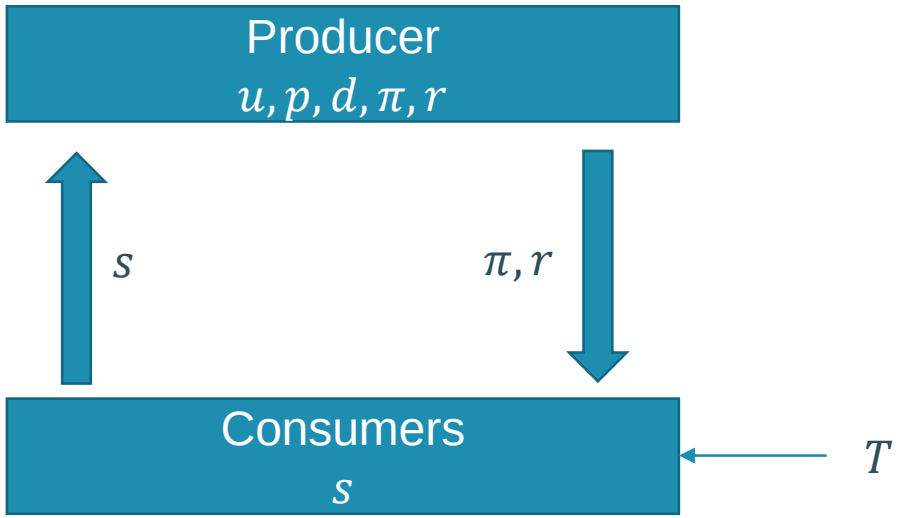
$$\Pi_\star = \psi(\boldsymbol{u, p}, \boldsymbol{s}^\star, \boldsymbol{\pi})$$

$$\boldsymbol{s}^\star \in \operatorname{argmax}_s\{CS(\boldsymbol{r}, \boldsymbol{\pi}) : \boldsymbol{s} \in S\}$$

$\boldsymbol{u, p}$	unit commitment and production decisions
$\boldsymbol{d}$	power supply to different options
$\boldsymbol{r, \pi}$	reliability and price
$\boldsymbol{s}$	subscription decision
$\Pi_\star$	profit target

Extension to Multilevel Demand Subscription



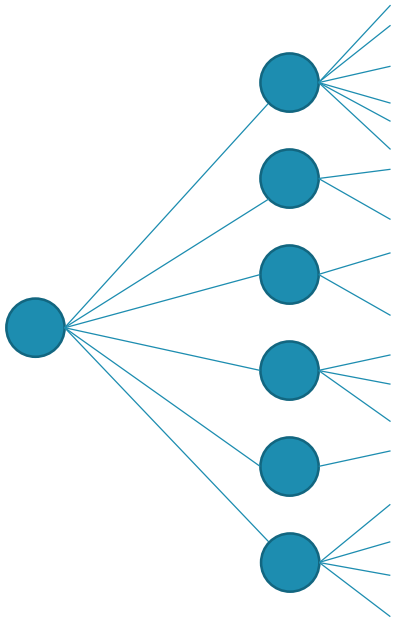


- Consumers: reduce un-utilized subscription.
- Producer: better estimation of the valuation of consumers.

Performance Evaluation

- Scenario Tree of Interruption Patterns and Local Uncertainty
- Interaction between System-Level Uncertainty and Local Uncertainty

Scenario Tree



LRYG

LRY

LR

HRYG

HRY

HR

H, L	high or low PV production
R, Y, G	Red, yellow or green color is served

Probability of each path can be calculated according to the probability of high/low PV production and the reliability of each option.

Reliability (%)	Price (€/kW-month)
75	30
87.5	40
100	50

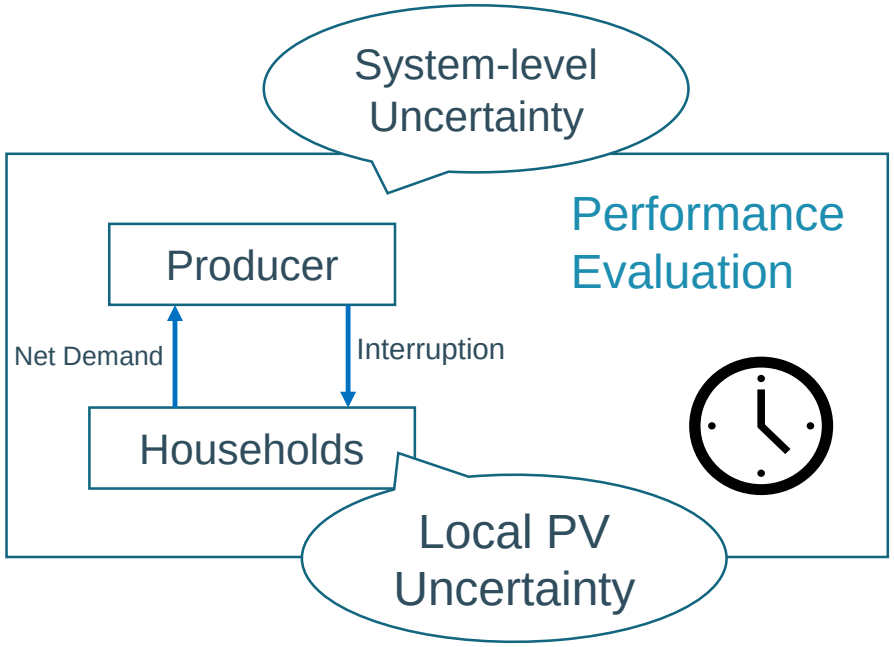
$$P_{\mathrm{RYG}} = r_1$$

$$P_{\mathrm{RYG}} + P_{\mathrm{RY}} = r_2$$

$$P_{\mathrm{RYG}} + P_{\mathrm{RY}} + P_R = r_3$$

$$P_{\mathrm{LRYG}} = P_{\mathrm{L}} \times P_{\mathrm{RYG}}$$

Interaction between System-Level Uncertainty and Local Uncertainty



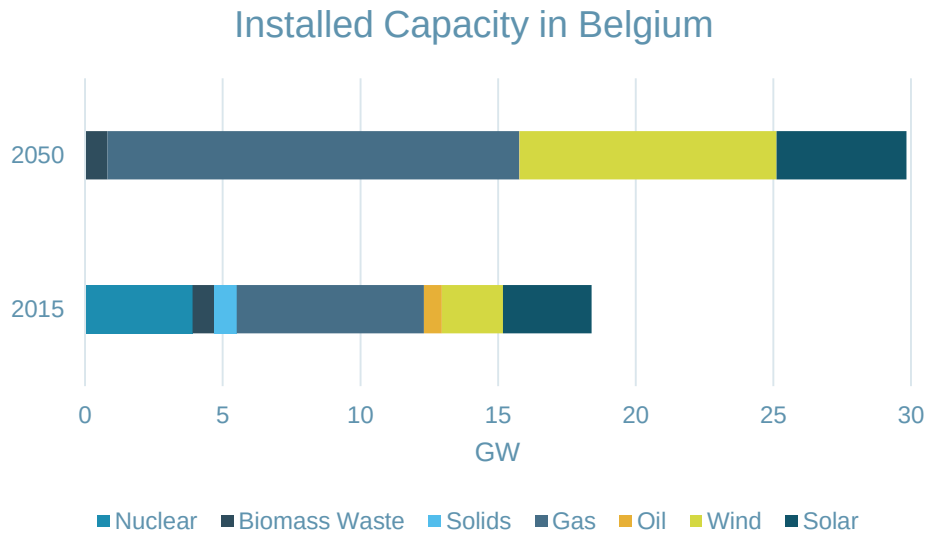
- The interface between the producer and the household is the service contract.
- The producer meters and reacts to net demand.
- Household faces rooftop solar power supply as well as the interruption of different service options.
- The simulation adopts a rolling horizon approach.

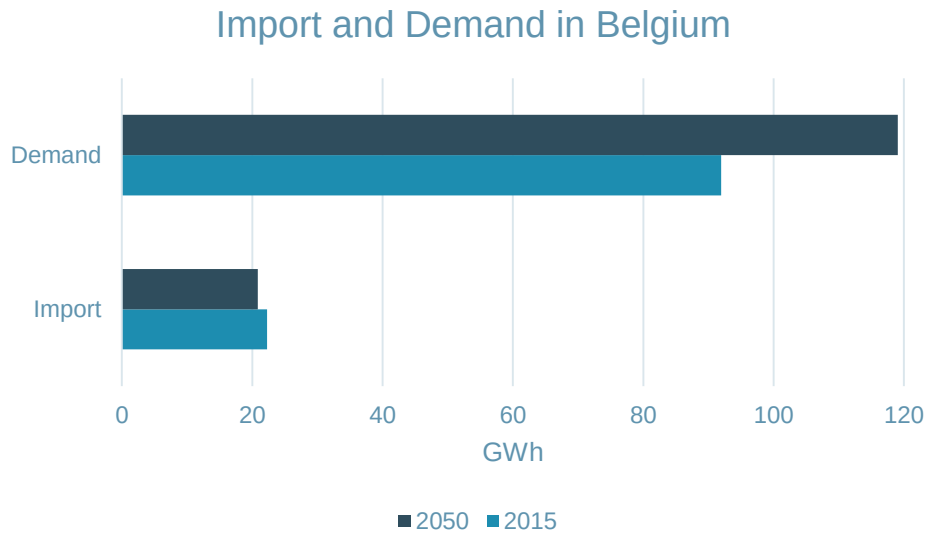
Case Study

- System settings
- Price menus
- Policy analysis

System Settings

We consider a forward-looking scenario of the year 2050, and work with eight representative days, each of which is split into six 4-hour blocks.





Source: the European Commission

System Settings (Cont'd)

Battery Type	Energy Limit (kWh)	Power Limit (kW)	Efficiency (%)	Overnight Cost (€)
Large (Tesla)	13.5	5	95	11,100
Small (Moixa)	3.84	0.85	95	5,120

Household Type	1	2	3	4	5	6	7	8
Peak	Day	Night	Day	Night	Day	Night	Day	Night
PV Panel	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Battery	Large	Large	Small	Small	No	No	No	No
Proportion (%)	6.83	1.5	6.83	1.5	6.83	1.5	61.5	13.5

Price Menus

Priority service

Reliability (%)	Price (€/kW-month)
58.5	26.4
85.3	39.3
100.0	48.5

Multilevel demand subscription

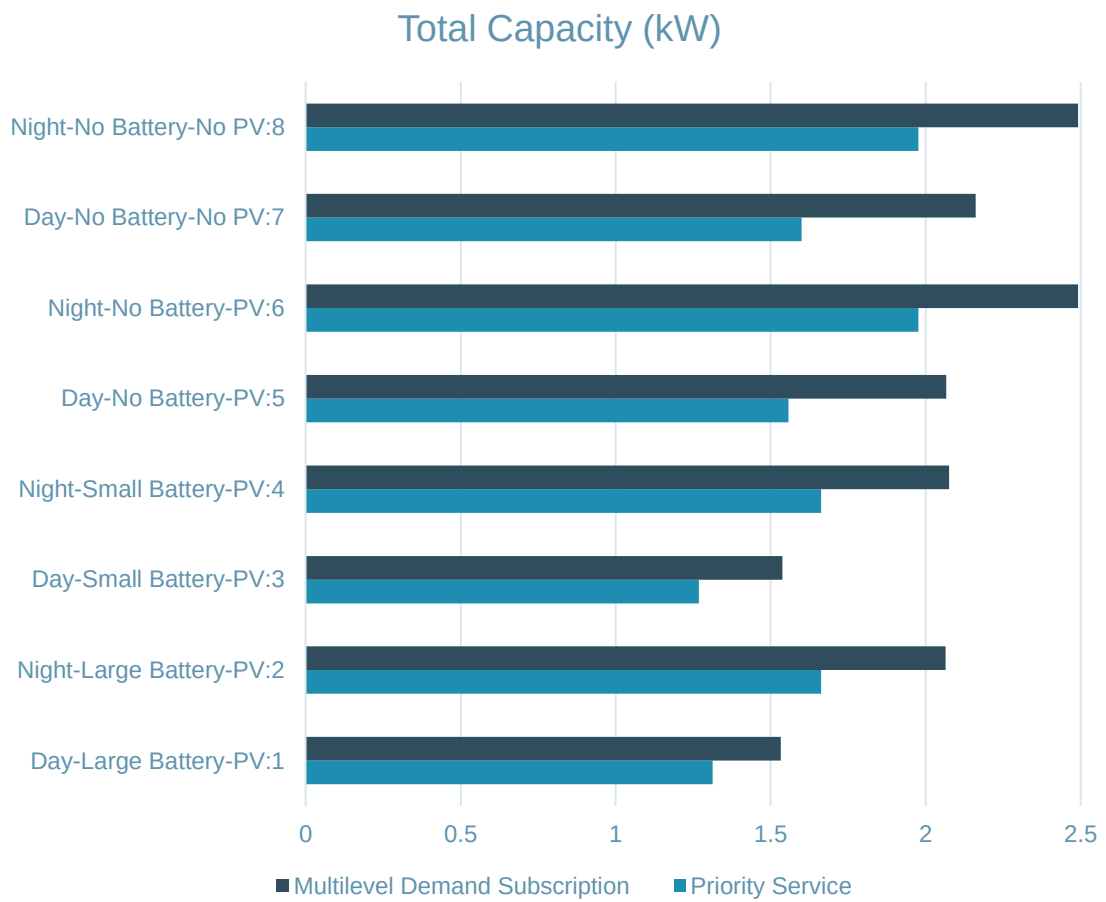
Reliability (%)	Duration (%)	Price (€/kW-month)
58.5	33.3	14.9
	66.7	22.9
	100.0	**26.4**
85.3	33.3	22.1
	66.7	34.1
	100.0	**39.3**
100.0	33.3	27.3
	66.7	42.1
	100.0	**48.5**

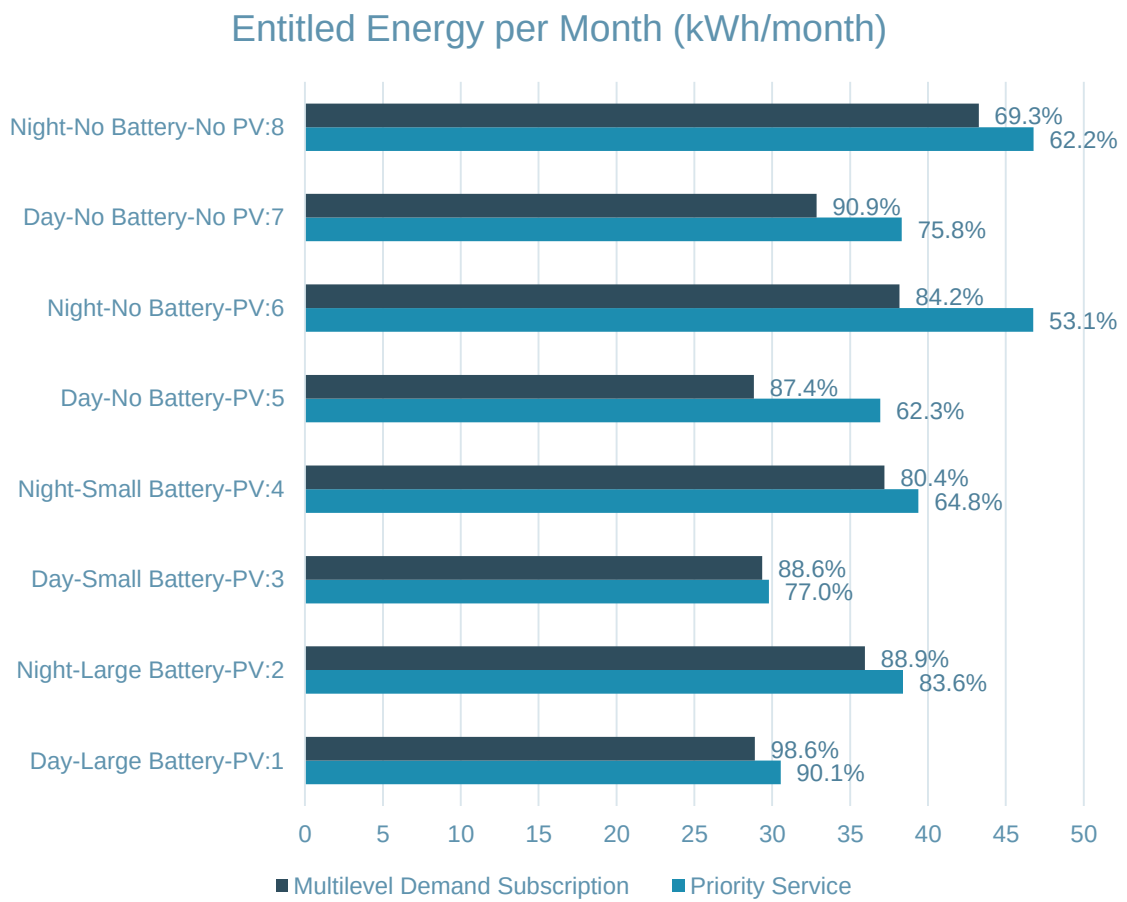
Operational Efficiency

Policy	Production Cost (M €/month)	Shortage Cost (M €/month)	Producer Revenue (M €/month)	Supplied Energy (GWh/month)
Priority Service	42.1	22.7	139.3	1514.4
Multilevel Demand	41.1	4.4	140.5	1534.3

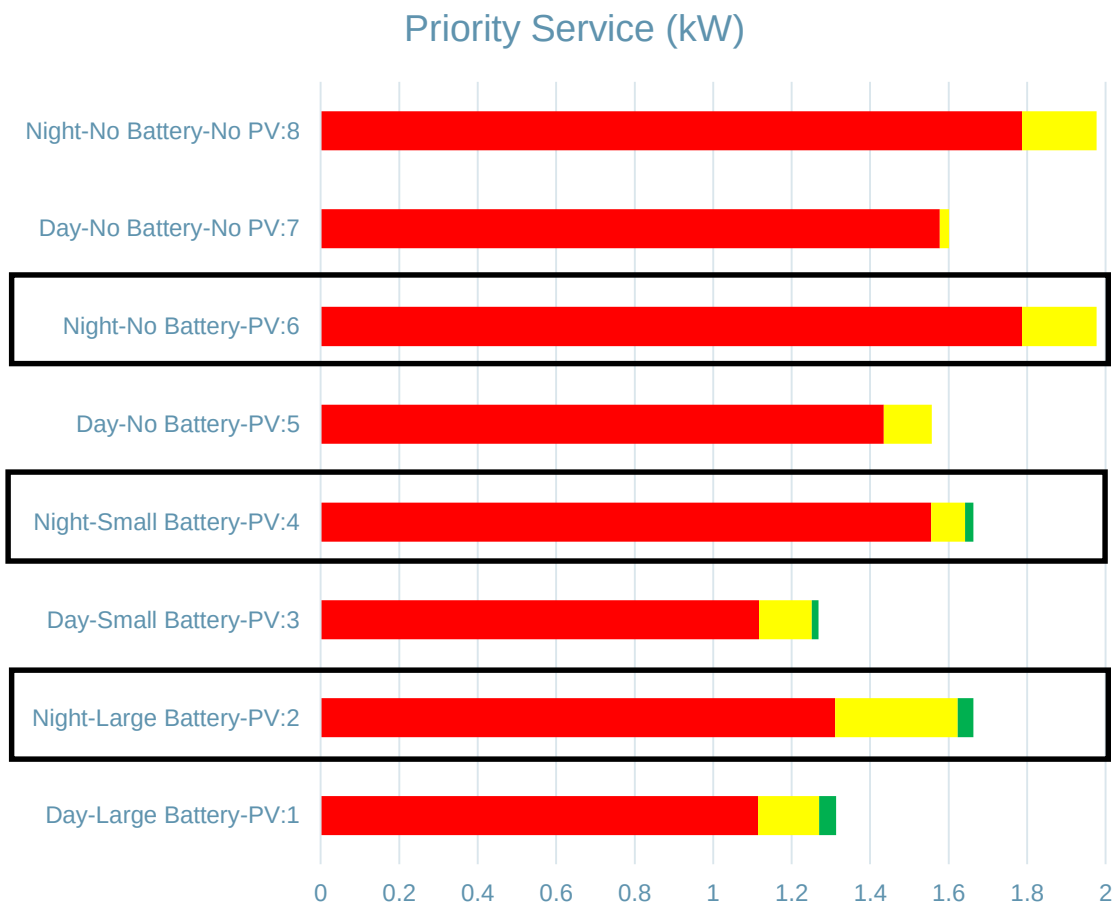
- Multilevel demand subscription supplies slightly more power to the households at a slightly lower cost and reduces discomfort of households significantly.
- The revenue of the producer increases slightly.
- Multilevel demand subscription proves to be beneficial for both the producer and households because of better differentiation.

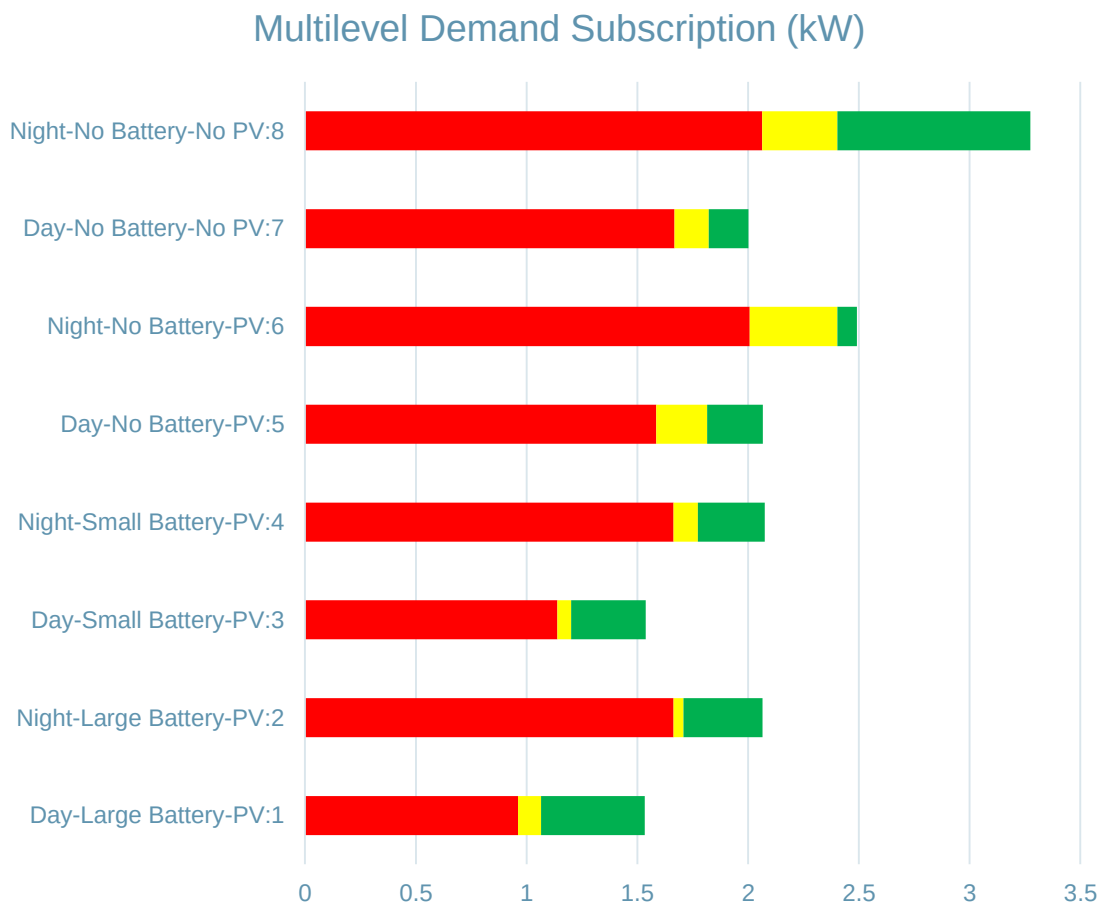
Service Comparison under Different Policies



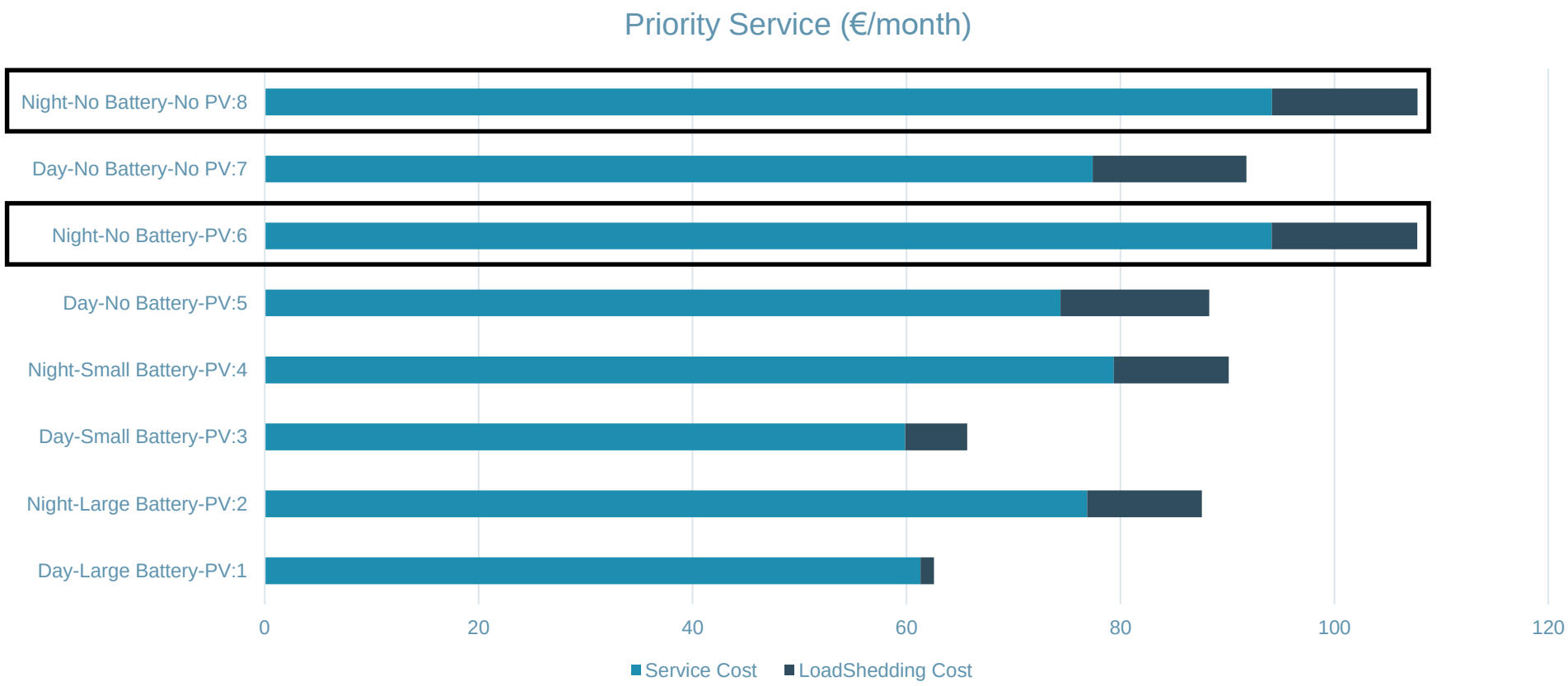


Impact of Storage on the Demand for Capacity

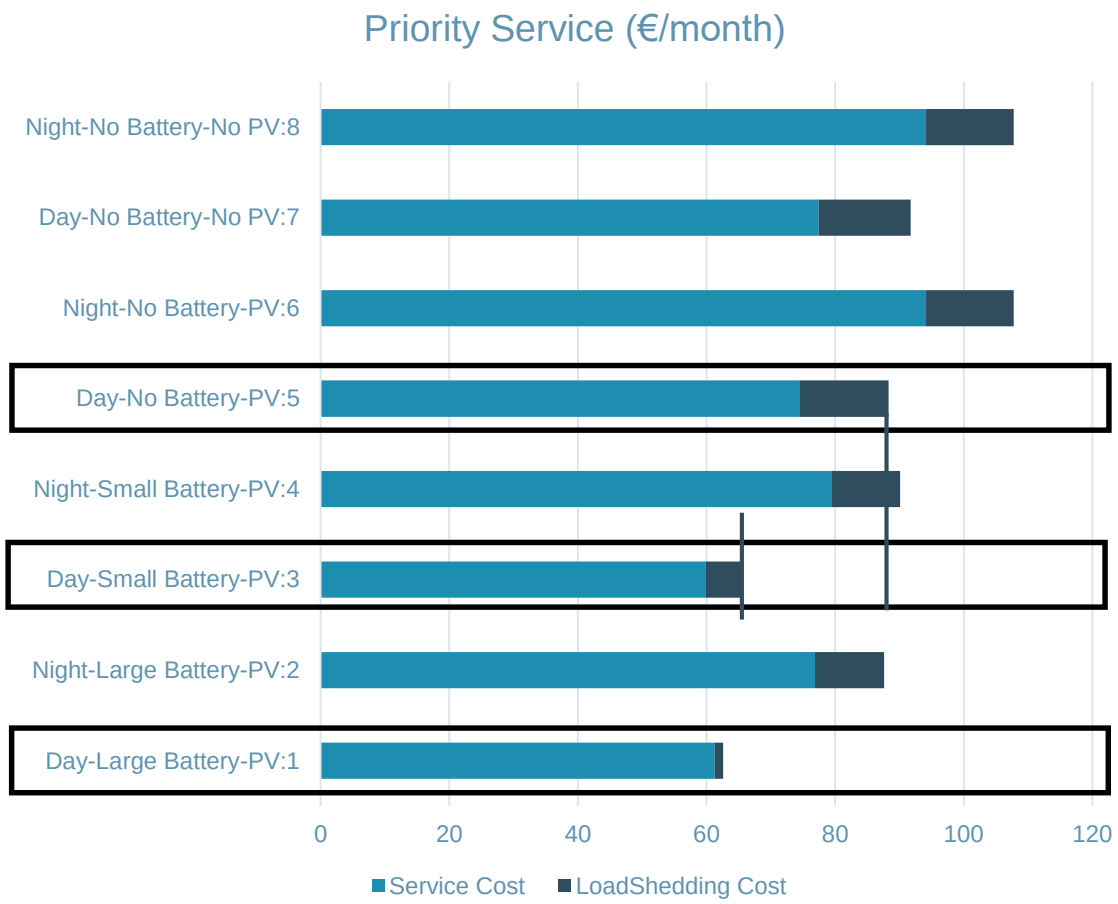


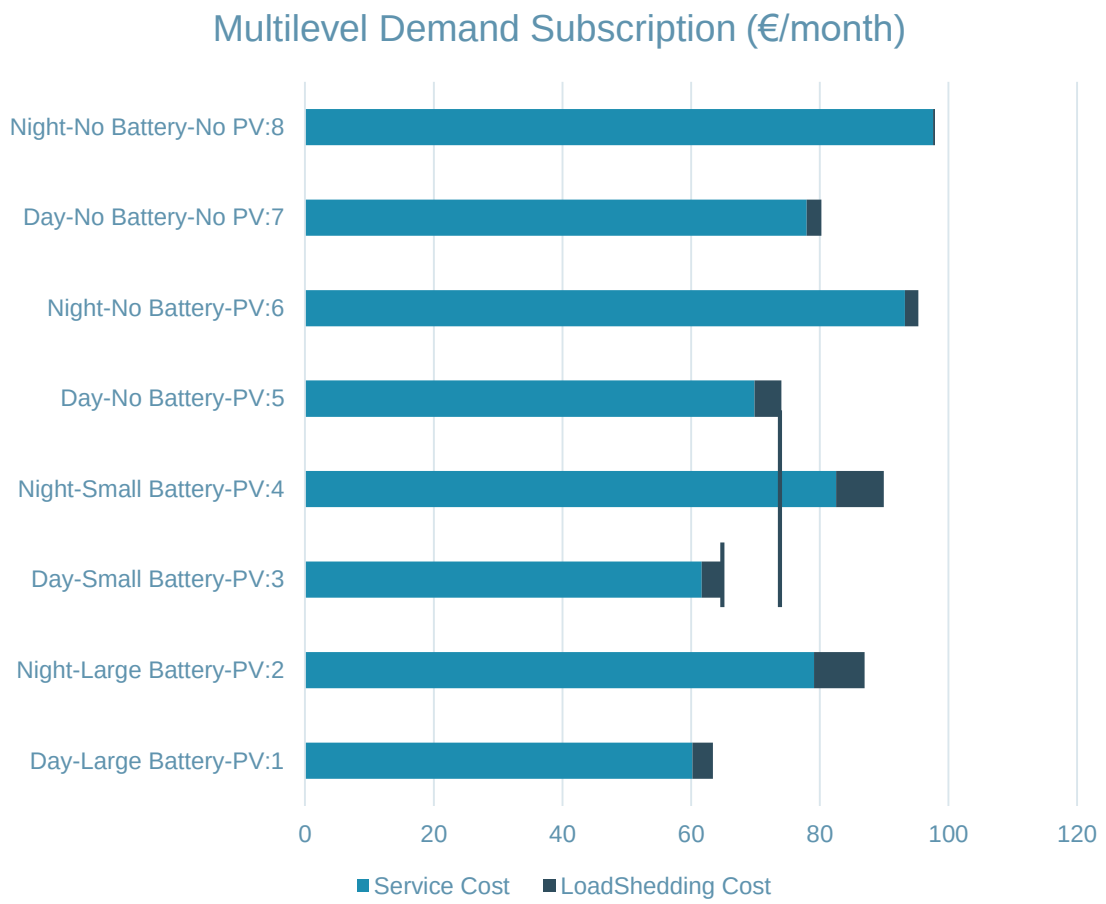


Benefits of PV Panels

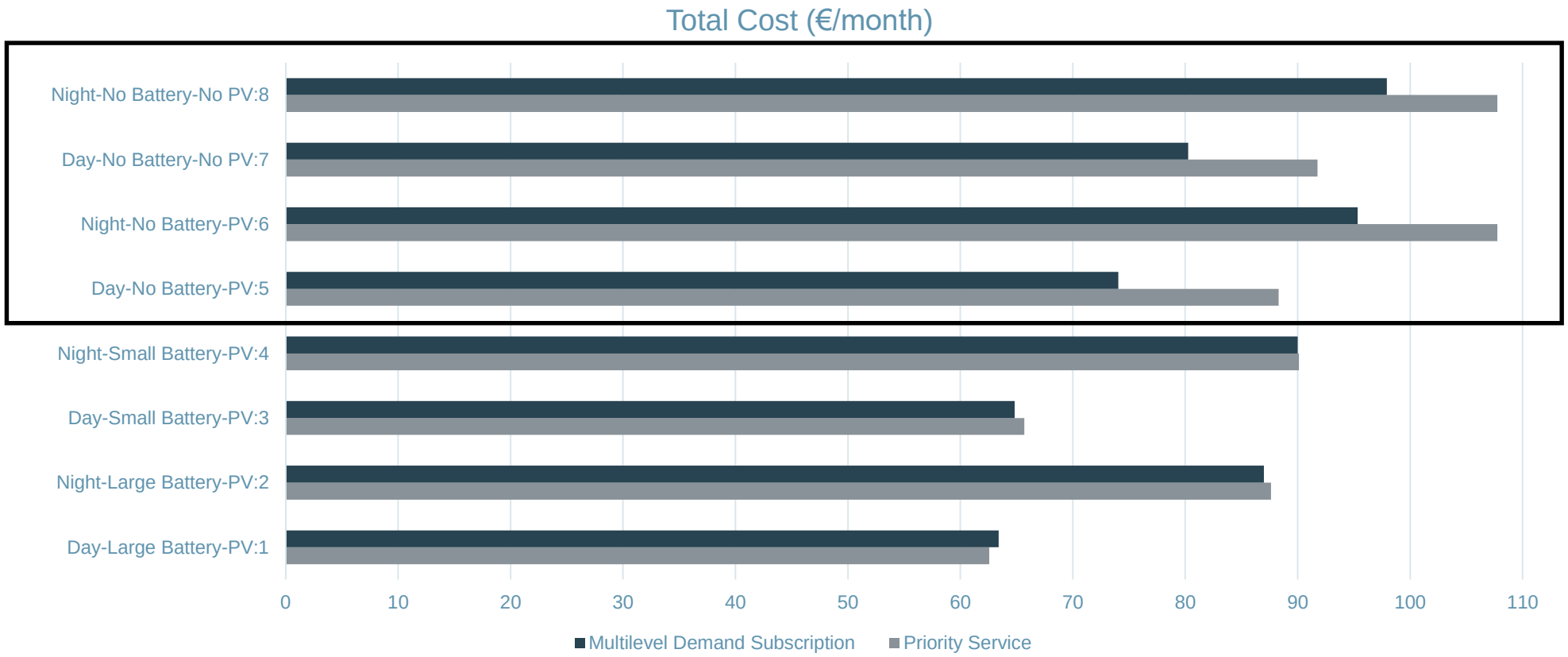


Benefits of Local Storage under Different Policies





Cost Comparison of Households under Different Policies



Conclusions and Perspectives

- A summary of conclusions
- Future areas of research

A Summary of Conclusions

- **Operational efficiency:**
  - Under multilevel demand subscription, the utility is able to supply more energy to households at a lower cost.
  - The service inconvenience of households is also reduced.
- **Service comparison:**
  - The total subscribed capacity of each household under multilevel demand subscription is higher than that under priority service.
  - The subscribed energy is less.
  - Under multilevel demand subscription, the utilization ratio of the subscribed energy improves.

A Summary of Conclusions (Cont'd)

- **Cost comparison of households under different policies:**
  - The total cost of a household equipped with a battery under multilevel demand subscription is almost identical to that under priority service.
  - If the household does not own a battery, the savings achieved by multilevel demand subscription are more significant.

Future Areas of Research

- **Improved representation of the household model:** We are working on further improving the household models by considering more diverse household types, flexible appliances, a longer horizon, a more detailed model of uncertainty and sizing of batteries.
- **Development of home energy management systems:** HEM assists households with managing electricity consumption based on machine learning techniques or optimization models [Gérard et al., 2019].

Ongoing Priority Service Research Projects

ICEBERG - Scalable Optimization of Power Systems with Flexible Demand and Renewable Supply

SMARTS - Stochastic Market Auction Redesigned Trading System

European Research Council

Established by the European Commission

Advanced Research Projects Agency • ENERGY

U.S. DEPARTMENT OF ENERGY

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- Yuting Mou. **Nonlinear Pricing Schemes for Mobilizing Residential Flexibility in Power Systems**. *PhD thesis, Université Catholique de Louvain, 2020.*


Gratias ago
Matondi
Merci
감사합니다
Grazie
Dankie
Eskerrik Asko
Hvala
Dziękuję
Dank u wel
Dankon
Thank you
Tak
Shukran
мерси
谢谢
Gracias
Obrigado
Danke
ευχαριστώ
ありがとうございました