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Cost-Reflective Distribution Network Tariffs

Adapting Tariff Design to Changing Network Use

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IAEE European Conference, Milan
Date: 26-07-2023
Preliminary results

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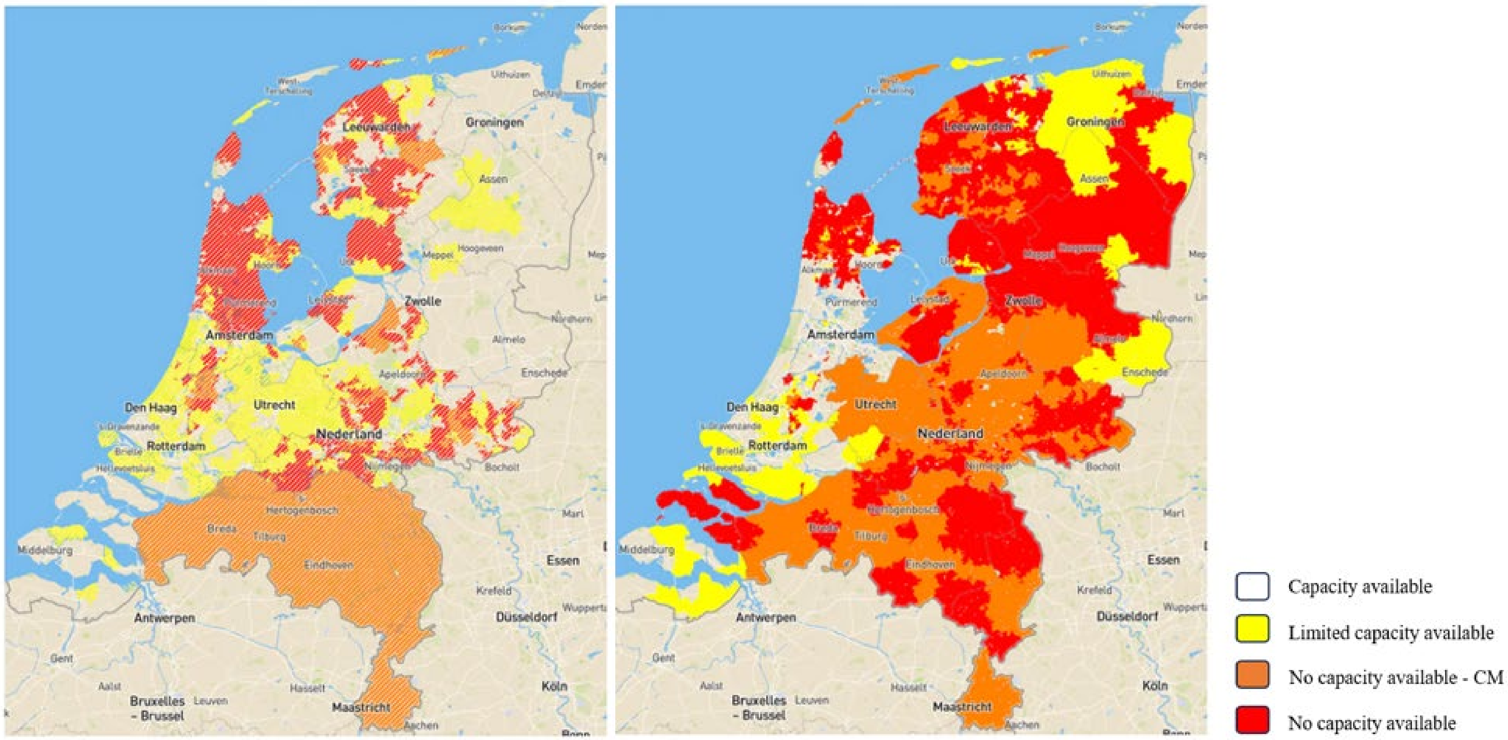
1. INTRODUCTION

Background: changing network use as a result of energy transition

- On the demand side: electrification of transport, heating and industry
  - Electrification is one of the key strategies to reduce CO2 emissions and reach net-zero targets
  - The share of electricity in the energy mix is expected to increase by 4 percent each year (IEA, 2023)

- On the supply side: electricity generation based on renewable energy sources (RES)

Network congestion in the Netherlands from both high load and high generation



(a) Load (b) Generation

Figure 1. Network congestion map of the Netherlands in September 2022, for both (a) generation and (b) load.

Note: Source: Netbeheer Nederland Capaciteitskaart, https://capaciteitskaart.netbeheernederland.nl/

Problem: tariffs are not cost-reflective

- Regulated distribution Use-of-System tariffs do not reflect individual users' impact on network costs:

(a) Flat tariffs do not contain **temporal** and/or **locational** components

(b) Tariffs are only levied on consumption, not on **generation**

Users do not fully internalize their impact on the electricity distribution network

- Coordination problem
- Users do not contribute according to the costs they impose on the system

Research questions

Research questions:

(a) How do current flat tariffs incentivize the provision of flexibility by network users?

(b) How can we differentiate tariffs w.r.t. time and location to be more cost-reflective, while being consistent with (other) regulatory tariff design principles?

2. TARIFF DESIGN PRINCIPLES

Components of tariff design

1. **Fixed component**
   - Fixed charge (€/connection)
2. **Energy component**
   - Energy withdrawal/injection (€/kWh)
3. **Capacity component**
   - Connected/fuse capacity (€/kW)
   - Individual peak use (€/kW-peak)

Remark: individual peak use tariffs can provide incentives to reduce peak load, even:

- When there is sufficient network capacity available
- When there is congestion due to local feed-in

Tariff design principles

1. **Cost-recovery:** DSO should be able to recover (efficient) network costs (CEER, 2020)
2. **Efficiency:** For efficient use and development of the network, tariffs should reflect the costs they impose on the system to coordinate network use
3. **Non-distortionary:** Do distort decisions on network connection and use, or (wholesale) market outcomes and offers
4. **Non-discrimination:** No undue discrimination between network users
5. **Transparency, simplicity and predictability**
6. **Fairness** (Neuteleers et al. 2017)

3. METHOD

(a) Medium-voltage grid model

(b) Distribution grid tariffs and evaluation criteria

Method: medium-voltage distribution grid

- We use a model developed in Ghaemi et al. (2023) to evaluate different grid tariff designs used to recover network costs of the DSO
- The model simulates the use of a medium-voltage (MV) grid with various types of network users:

(1) Electricity end-users

(2) Users with power-to-heat technologies

(3) Users with power-to-gas technologies

(4) Distributed electricity generation

Method: types of network users connected to the electricity grid

1. Distributed generation
(a) Wind turbines
(b) Solar PV
(c) Combined heat and power

2. Electricity end-users
(a) Price-elastic end-users
(b) Inelastic end-users

3. Power-to-heat
(a) Users with electric boilers
(b) Users with heat pumps

4. Power-to-gas
(a) Elektrolyzer

Method: objective of the DSO

- The DSO’s objective is to keep the system within technical and security constraints
- The DSO’s objective is to minimize the operating costs:

(a) Energy losses

(b) Curtailment of generation

(c) Shedding of consumption (i.e., load shedding)

- This is a short-term network operation model, which means that the capacity of network components is fixed

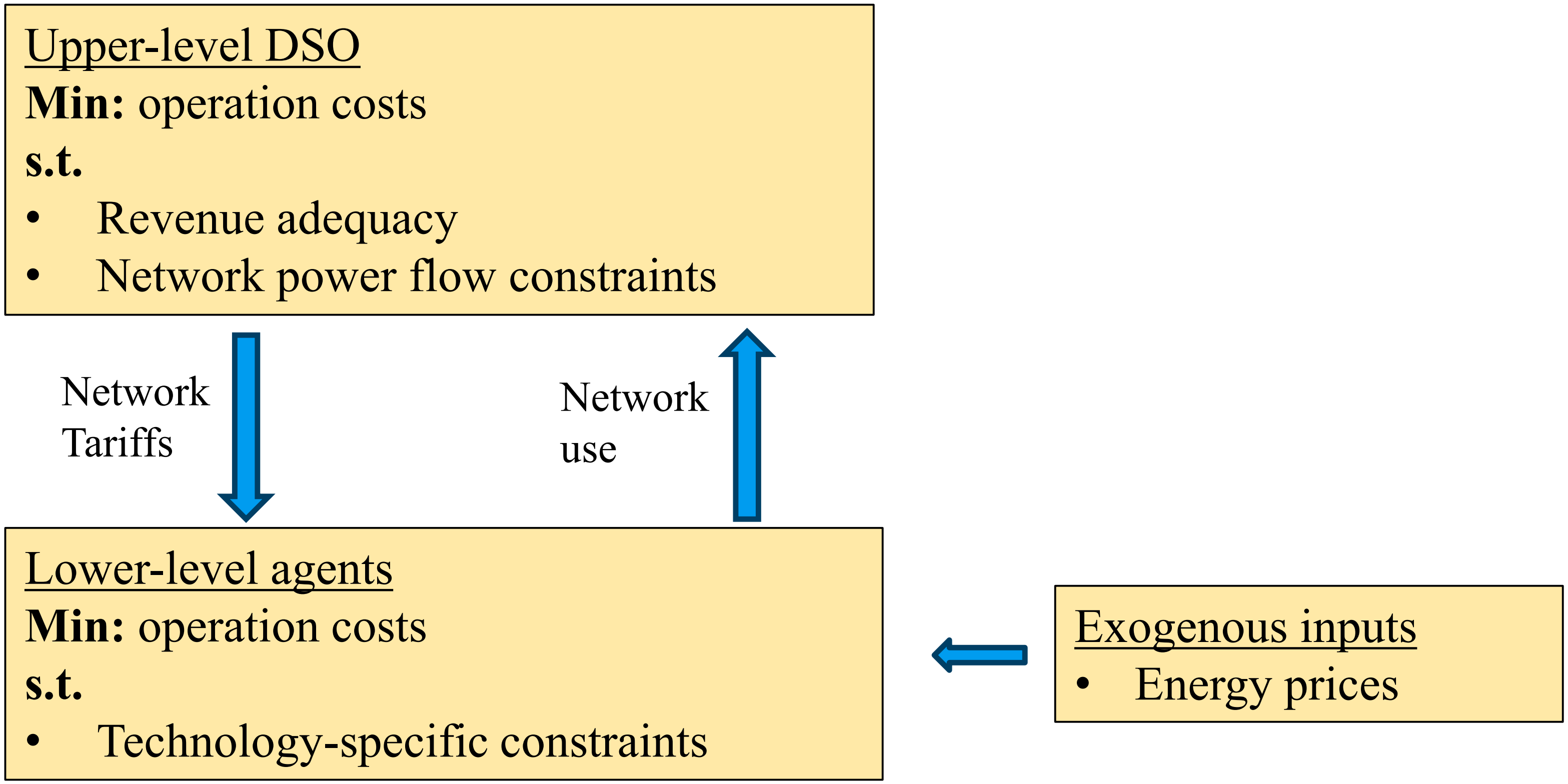
Method: objective of network users

- The objective of both heat and gas producers it to minimize the net costs of production

s.t. technology-specific constraints

- Price-inelastic end-users have a fixed load profile
- Price-responsive end-users have a fixed price-elasticity
- Electricity, hydrogen and gas prices are set exogenously
- Heat price and heat demand are determined endogenously in a local heat market

Method: overview of the model



Outcomes: (a) total revenues, (b) efficiency, (c) cost-allocation

Figure 2. Overview of the bi-level medium-volage distribution grid model

Method: overview of the MV-grid

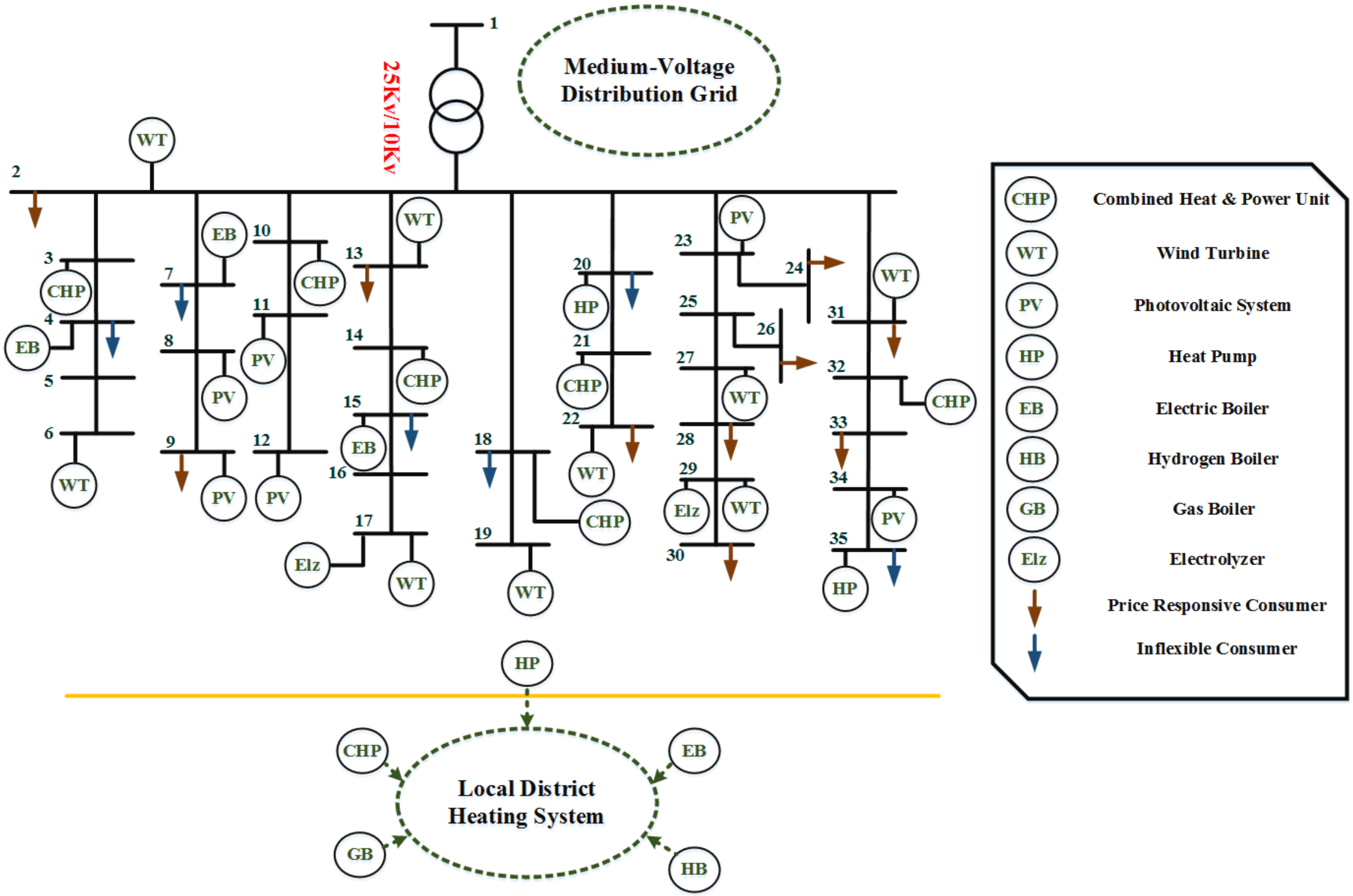


Figure 3. Dutch medium-voltage distribution grid in North-Holland with various types of network users and a coupled local heat market

Method: evaluation criteria

- We evaluate different exogenous grid tariff designs using three criteria:

(1) **Total revenue** for the DSO

(2) **Efficiency** measured by congestion management costs

(3) **Contribution** of different network users to total revenue for the DSO

3. METHOD

(a) Medium-voltage grid model

(b) Distribution grid tariffs and evaluation criteria

Method: grid tariff designs

- We use this model to evaluate different distribution grid tariff designs
  1. Flat tariff
  2. Time-of-Use tariff
  3. Critical-Peak Pricing tariff
  4. Nodal tariff

Grid tariff design 1

Flat tariff design

- The flat tariff is based on current Dutch tariff
  A. Fixed part (€/connection)
  B. Energy part (€/kWh)
  C. Capacity part (€/kW-peak month)
  D. Capacity part (€/kW-peak year)

- Tariff components are only levied on load, and do not contain temporal or locational elements

Grid tariff design 2

Time-of-Use (TOU)

- Only the capacity components are weighted according to the hour of electricity consumption
- Three time blocks (peak, shoulder, off-peak hours)

Motivation:

- Users can shift peak-hour consumption to shoulder and non-peak hours
- Users could increase maximum load during shoulder and off-peak hours without facing additional charges
- In the case of congestion due to local RES feed-in, this could provide flexible users with more room to increase consumption

Grid tariff design 2

Determining the TOU blocks

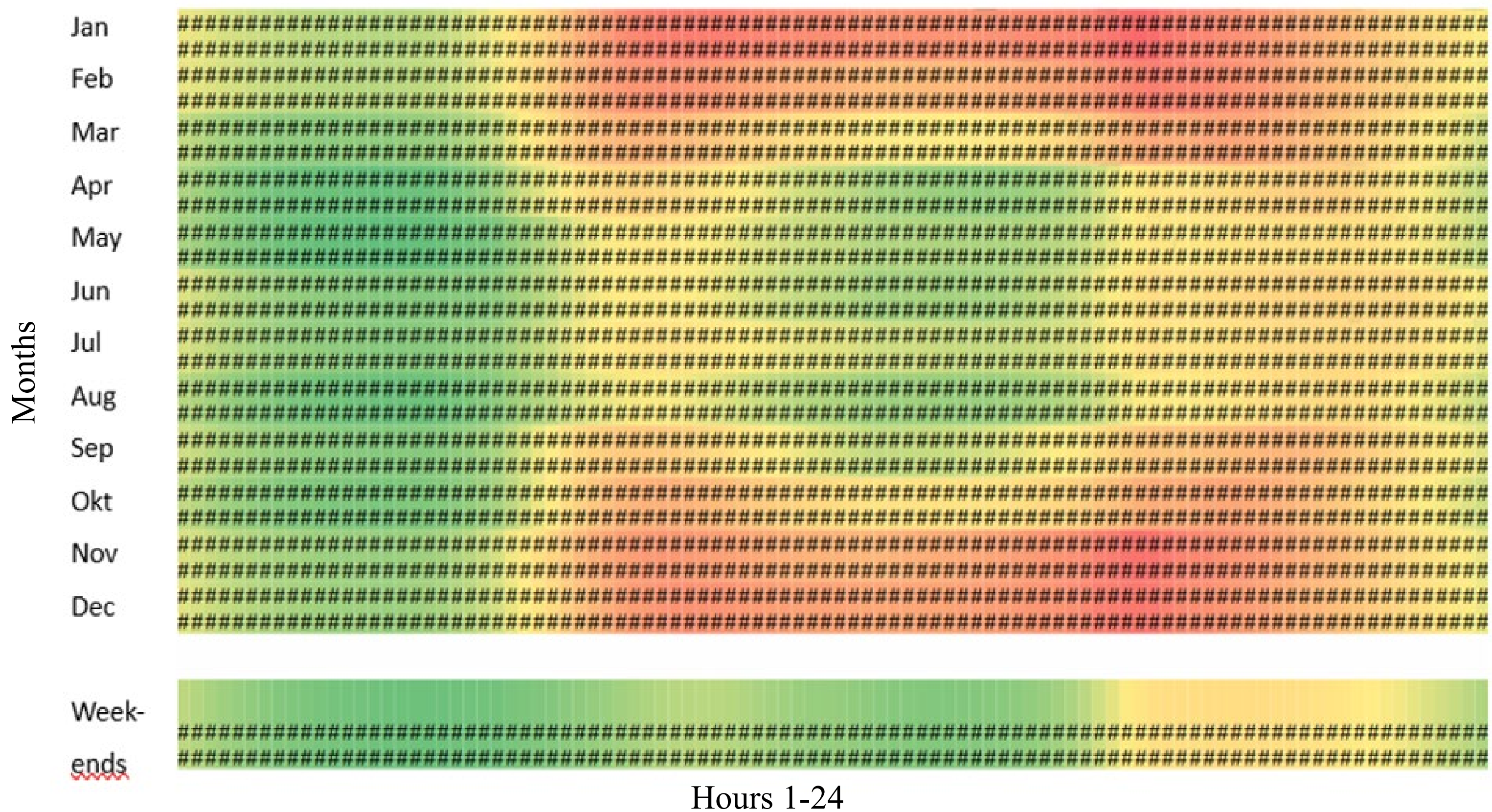


Figure 4. The average loading of the Dutch electricity network, used to divide the hours of the day into peak, shoulder and non-peak TOU blocks.

Note: Average loading for the entire Dutch electricity network, for the year 2021. Source: ENTSO-E data transparency platform.

Grid tariff design 2

TOU Weighting

Table 1. Example of a TOU weighted kW-month tariff component

Time block	Weighting factor	Month peak	Weighted month peak	€ / weighted month peak	Charge
1	100%	100 kW	100 kW	€5,-	€500,-
2	75%	110 kW	82,5 kW	€5,-	€412,50
3	50%	180 kW	90 kW	€5,-	€450,-

Note: The DSO charges users for their single highest weighted individual peak per month. The individual peaks are weighted according to the time block during which a peak takes place. For example, a individual peak during off-peak hours are weighted by 50 percent.

Grid tariff design 3

Critical-Peak Pricing (CPP)

- DSO can signal critical periods during which the capacity components are increased
  - 2 critical periods of 2 hours per month
- Capacity tariff components are increased with 500% during a critical period
- The critical periods are determined based on the endogenous network loading across all nodes of the MV-grid

Motivation:

- Critical periods are determined endogenously and can target critical peaks in overall network loading

Grid tariff design 4

Nodal energy pricing

- DSO calculates a nodal congestion price, which is levied on top of day-ahead wholesale electricity prices (€/kWh)
- The DSO increases/decreases the nodal congestion price until the congestion is solved

Motivation:

- Nodal price can provide flexible users at congested nodes with an incentive to adjust consumption patterns

Grid tariffs - Evaluation criteria

1. **Cost recovery (i.e., revenue adequacy)**
   - We compare the total revenues of different tariff designs
   - Tariffs should generate (at least) the same amount as current tariffs
2. **Efficiency**
   - Proxied by congestion management costs
3. **Cost allocation**
   - The contribution of various types of network users to cost-recovery

4. CASE STUDY

Case: scenarios

1. Medium RES scenario:

- Medium levels of RES installed capacity
- Congestion is (mainly) caused by load
- This type of congestion is solved through load shedding

2. High RES scenario:

- High levels of RES installed capacity
- Congestion is caused by both load and generation

Case: exogenous prices

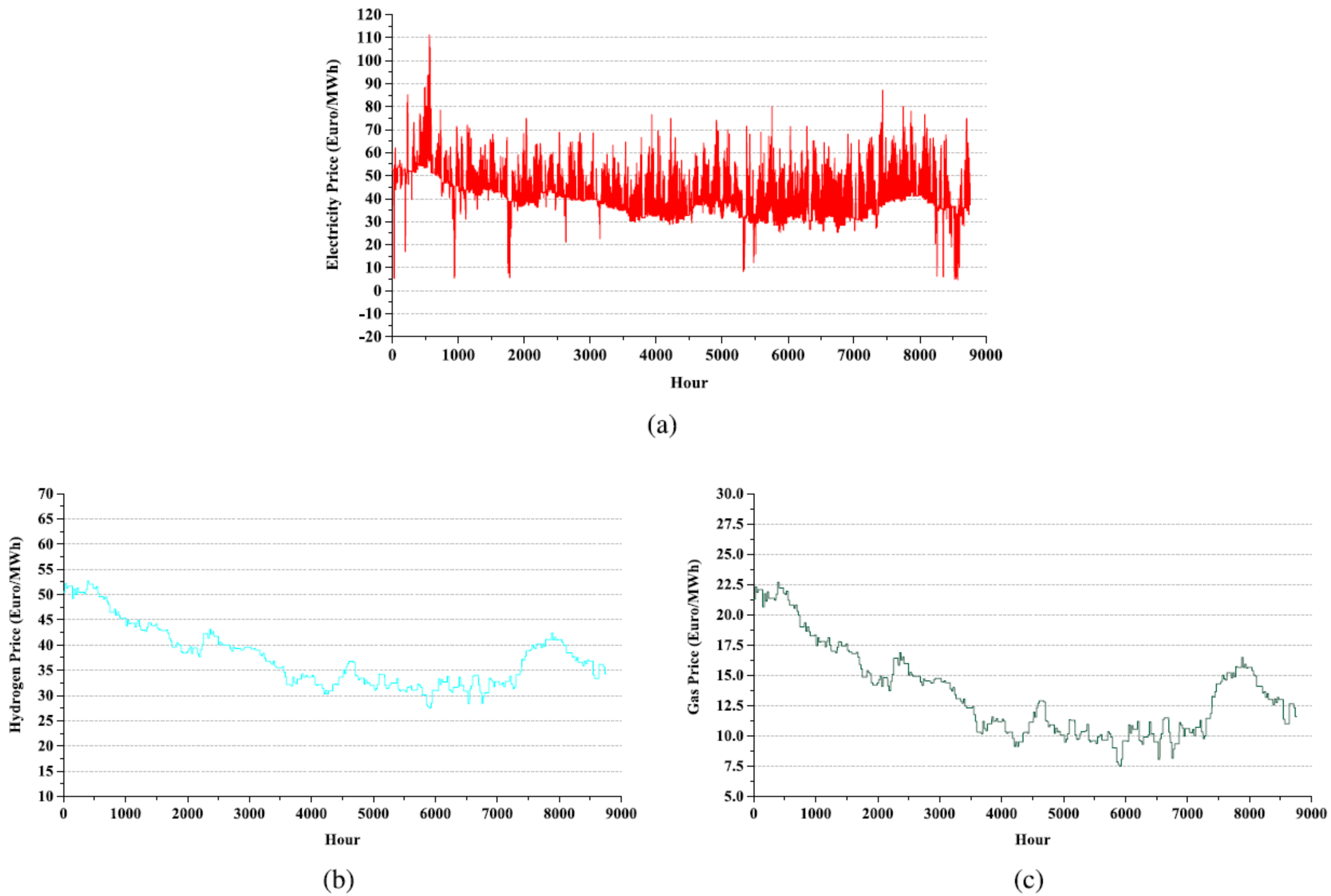


Figure 5. Exogenous prices for (a) electricity, (b) hydrogen, and (c) gas based on Dutch prices in 2019.

Note: From Ghaemi et al. (2023)

Case: potential congestion in the medium-voltage grid

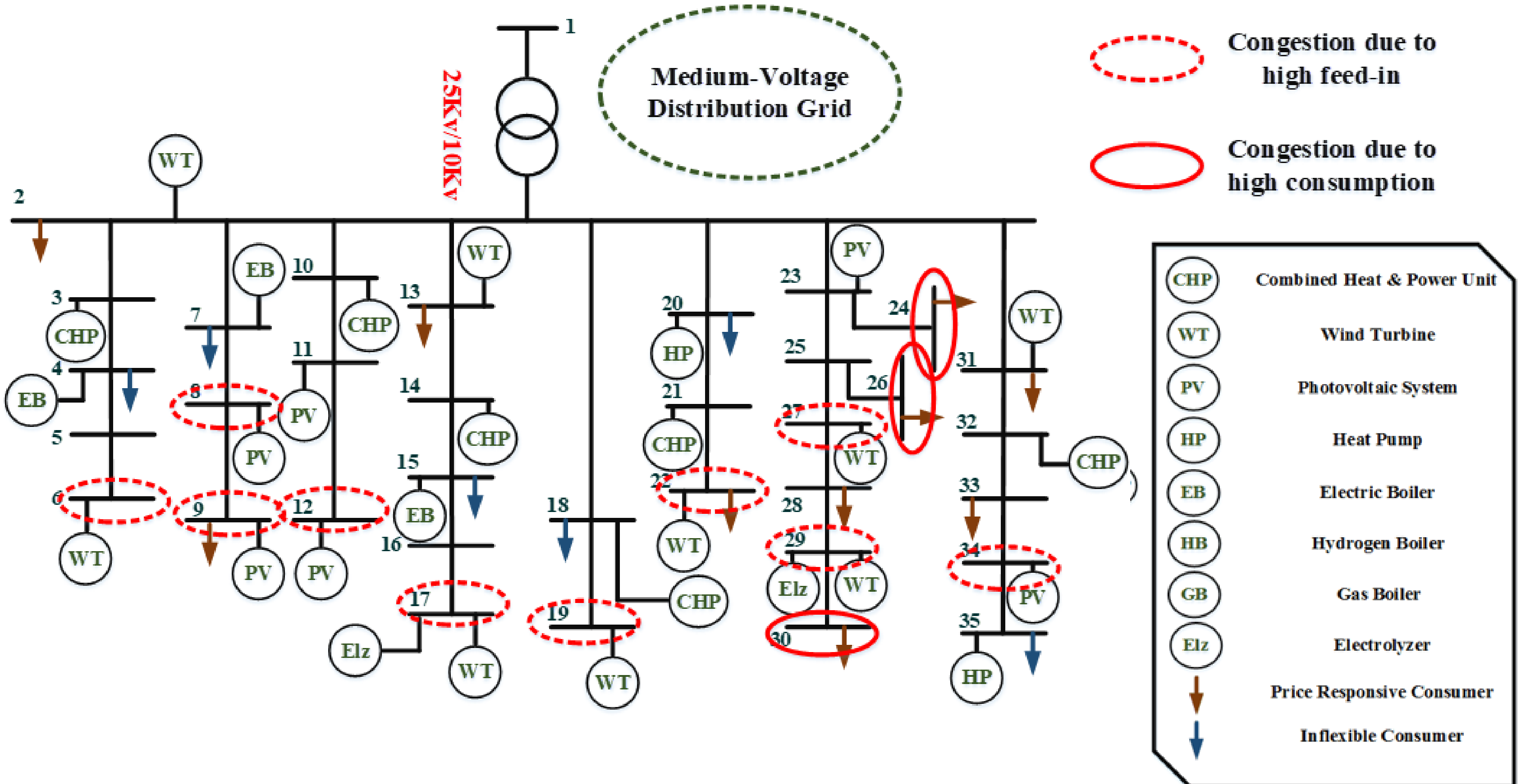


Figure 6. Potentially congested lines in the Dutch medium-voltage distribution _ types of network users and a coupled local heat market

5. RESULTS

Results: total DSO revenue

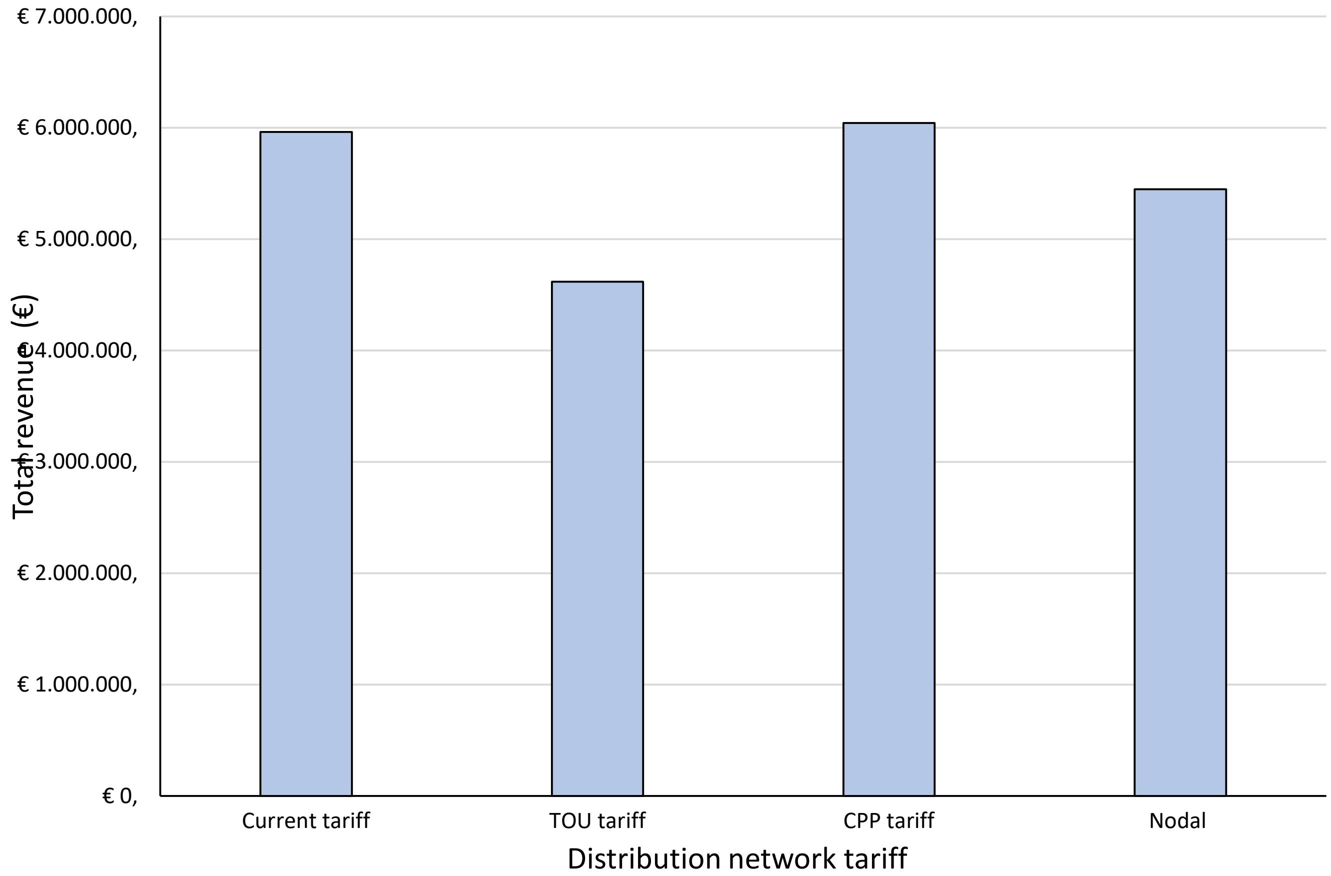


Figure 7. Total revenue for DSO generated from various distribution network tariffs

Note: Model run for a scenario with medium penetration of RES generation and medium consumption levels.

Results: congestion management costs

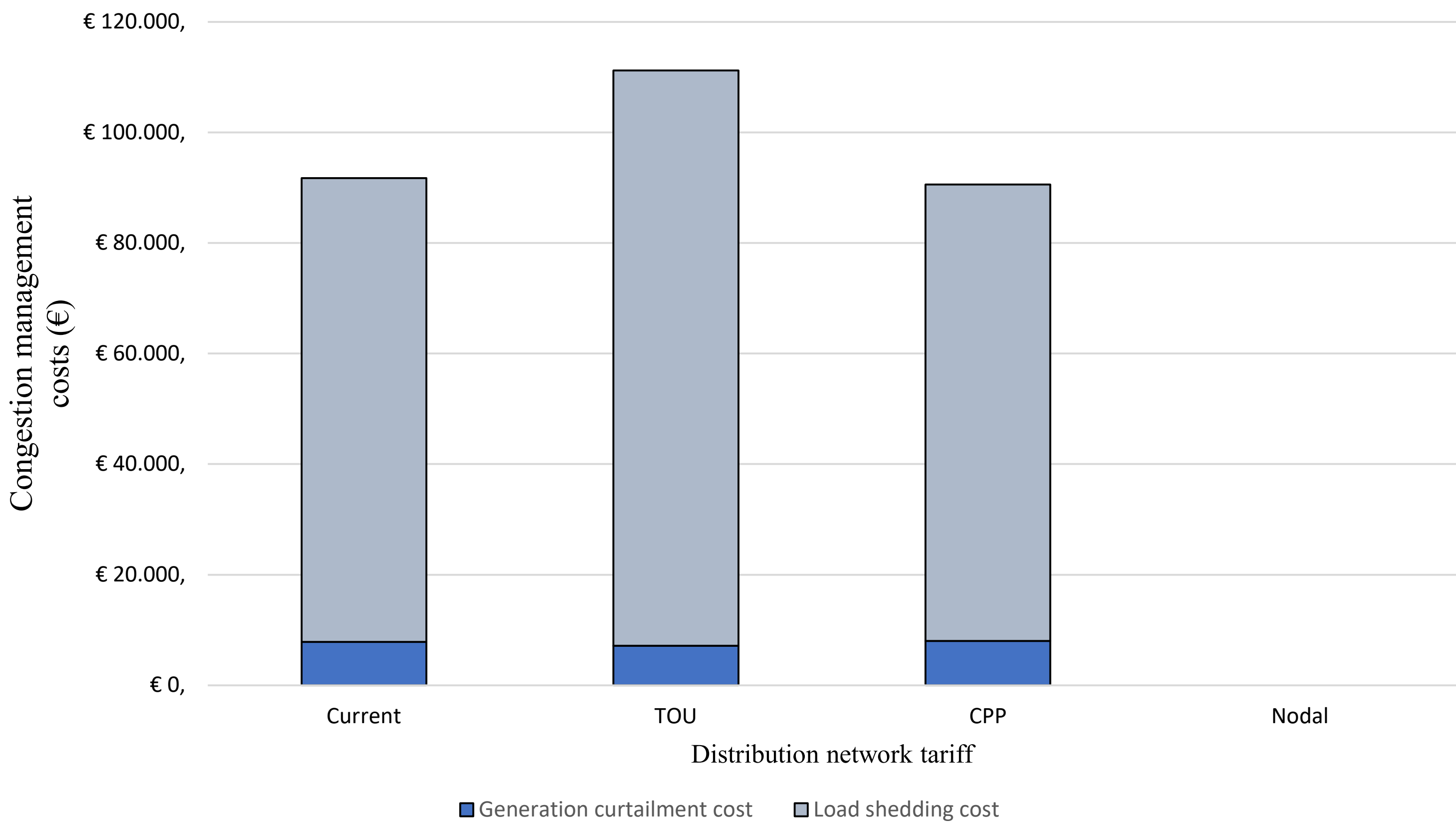


Figure 8. Congestion management costs

Note: Model run for a scenario with medium penetration of RES generation and medium consumption levels.

Results: cost allocation between users

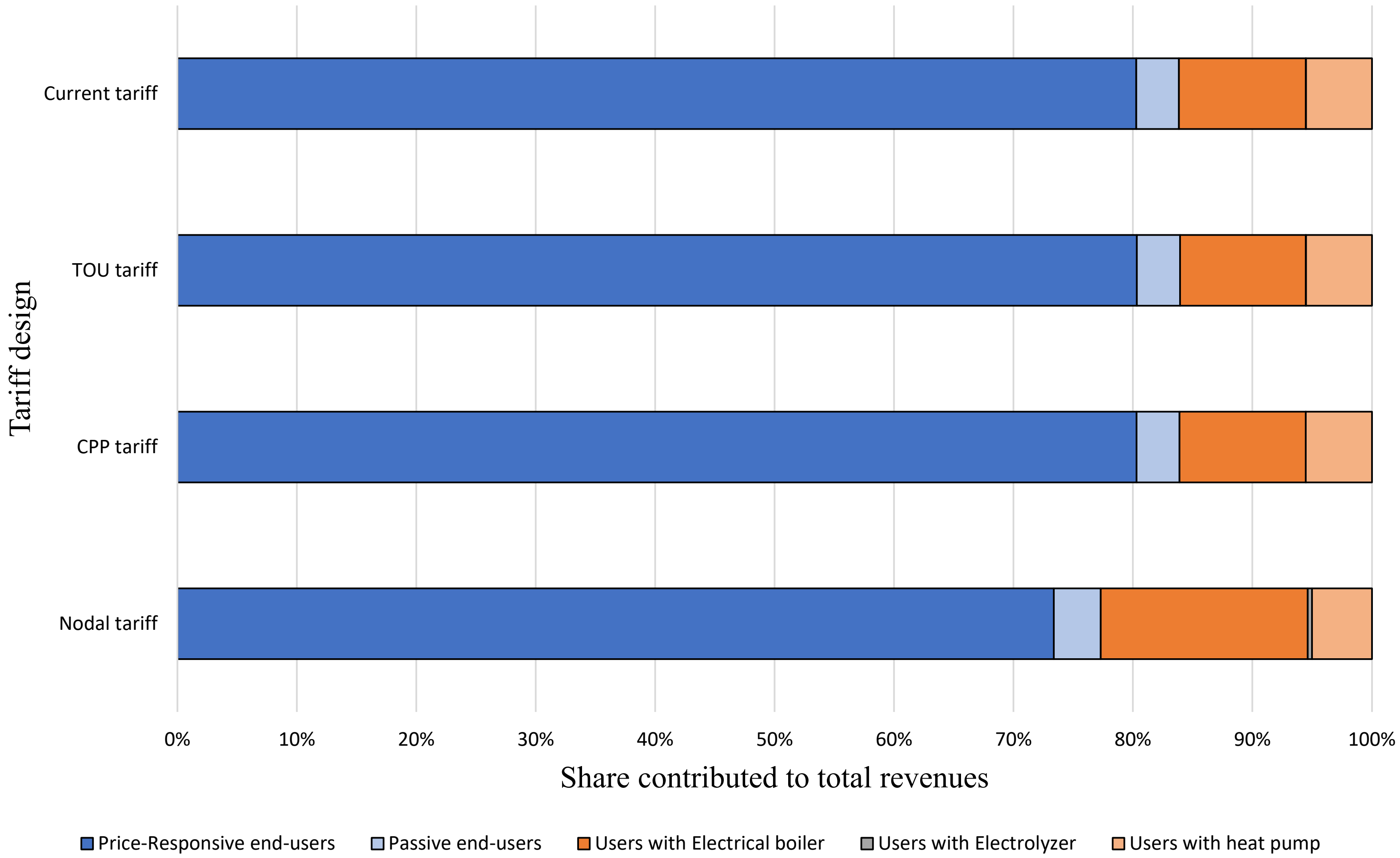


Figure 9. The cost allocation among different types of network users

Note: Model run for a scenario with medium penetration of RES generation and medium consumption levels.

Results: total DSO revenue – high RES

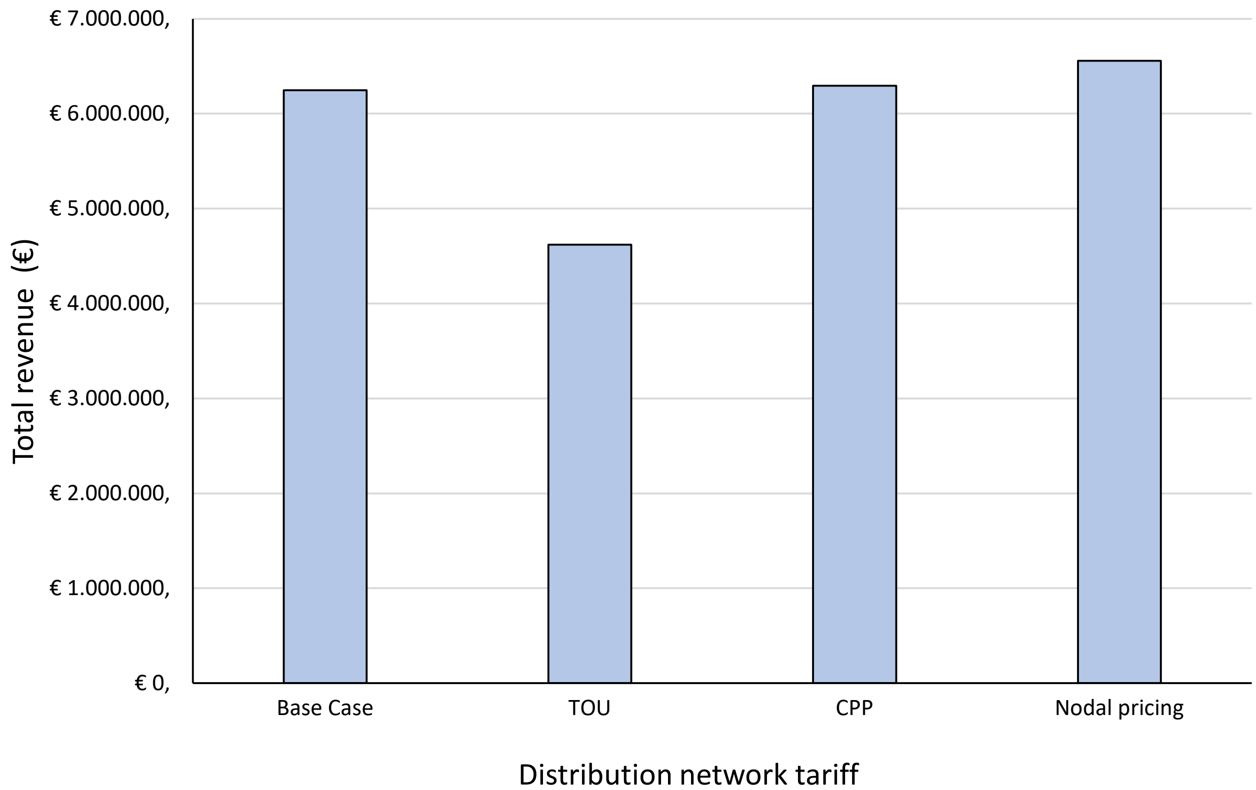


Figure 10. Total revenue from various distribution network tariffs

Results: congestion management costs – high RES

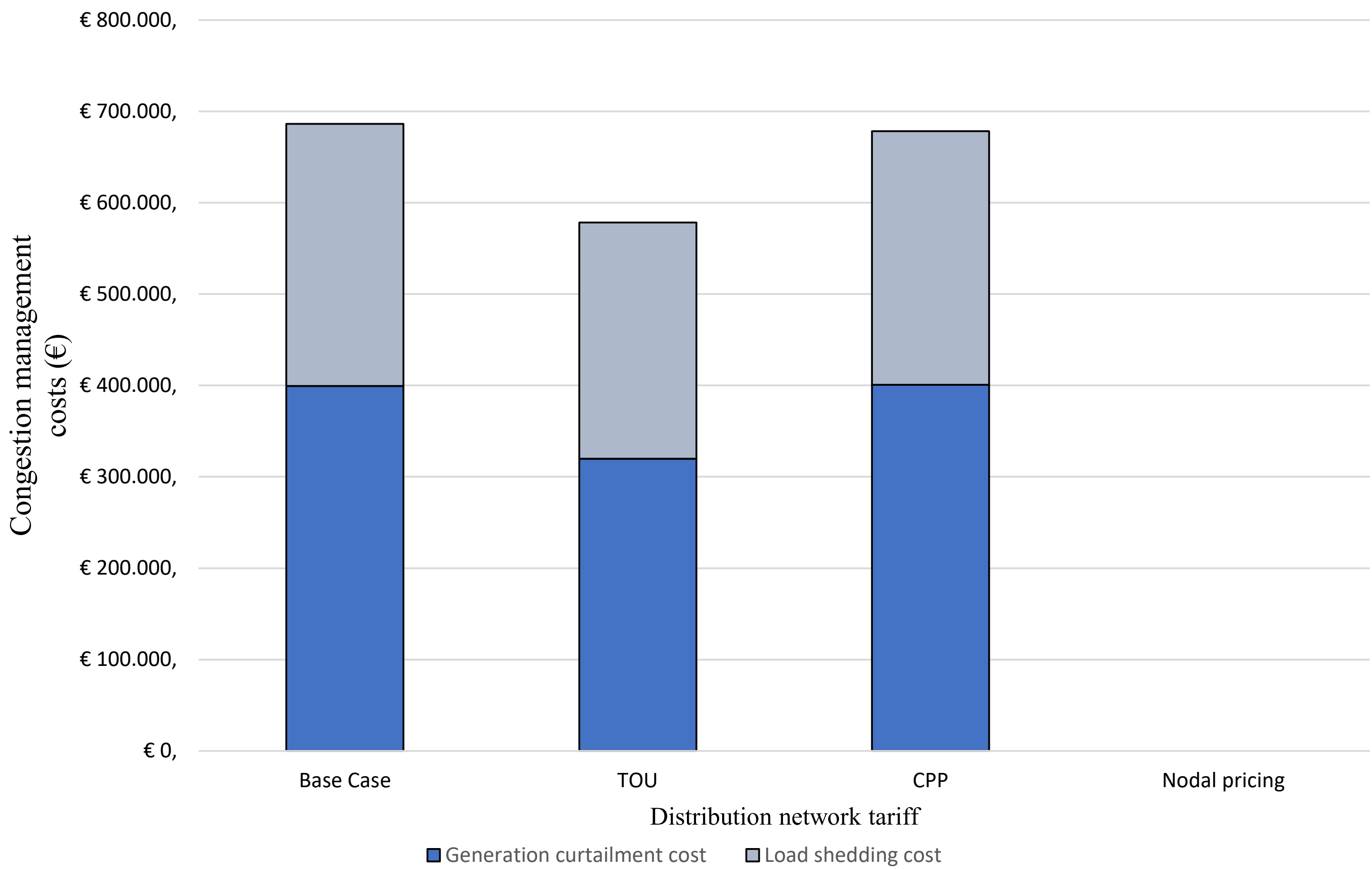


Figure 11. Congestion management costs

Note: Model run for a scenario with medium penetration of RES generation and medium consumption levels.

Results: cost allocation – high RES

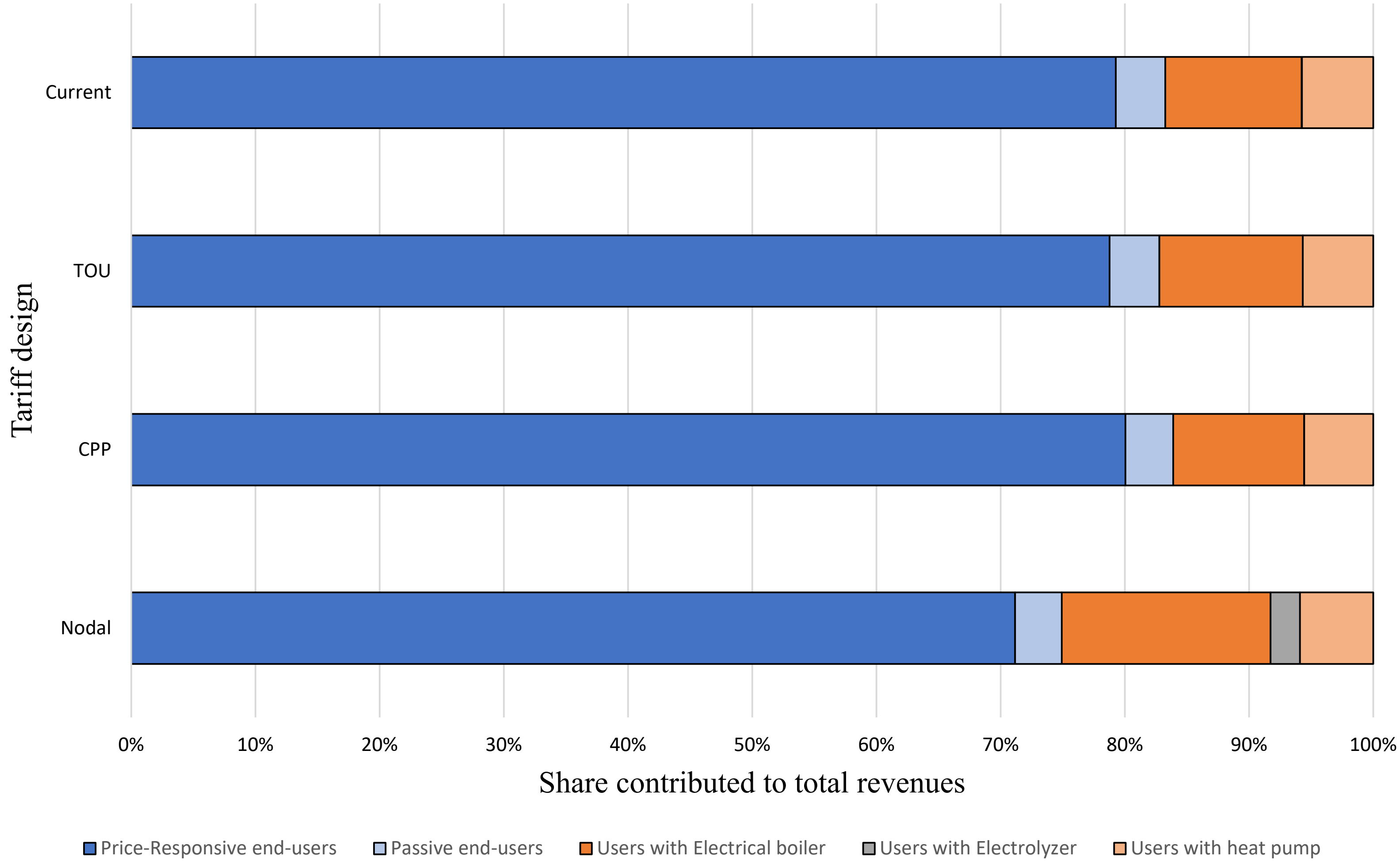


Figure 12. The cost allocation among different types of network users

Note: Model run for a scenario with medium penetration of RES generation and medium consumption levels.

Conclusions

- Different tariff designs result in different total revenues
- TOU increases congestion in a scenario with medium RES, but decreases congestion in a scenario with high RES
  - This indicates peak-load shifting
- Time differentation through TOU and CPP does not fundamentally alter the allocation of costs among network users
- Nodal pricing alters the allocation of costs among network users (through the locational component)

Next steps

- Impose a cost-recovery constraint in the tariff design problem
- Include other temporal and locational tariff designs, including tariffs with a generation component:
  - Long-term marginal cost component, reflecting the contribution to critical power flows in overloaded locational network components (in both directions)

References

- Ghaemi, S., Li, X., & Mulder, M. (2023). Economic feasibility of green hydrogen in providing flexibility to medium-voltage distribution grids in the presence of local-heat systems. *Applied Energy*, *331*, 120408.
- Neuteleers, S., Mulder, M., & Hindriks, F. (2017). Assessing fairness of dynamic grid tariffs. *Energy Policy*, *108*, 111-120.

Overview

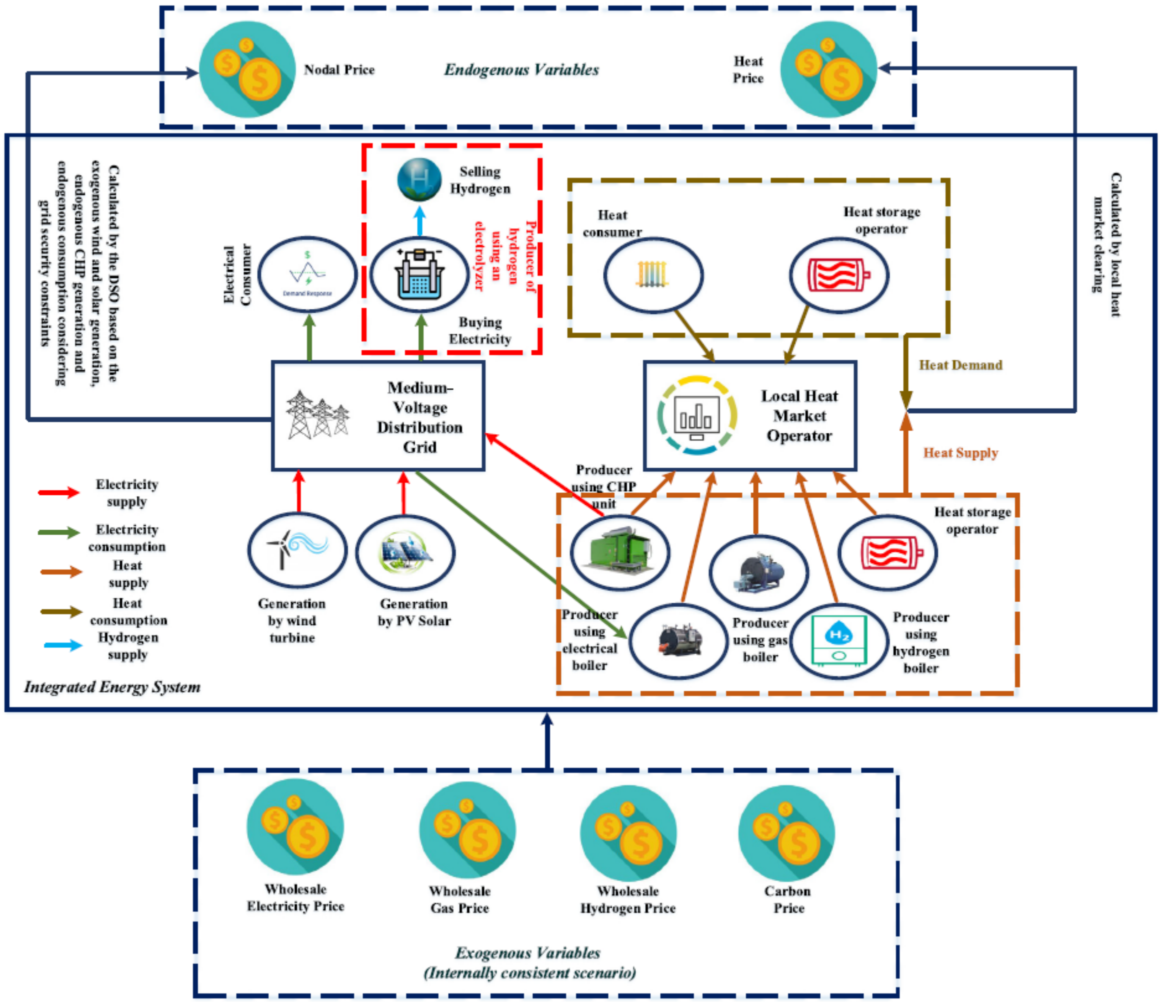


Figure 13. A schematic overview of the model

Note: Source is Ghaemi et al. (2023).

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