Tariff structure for distribution networks: a case study for European prosumers and stakeholders

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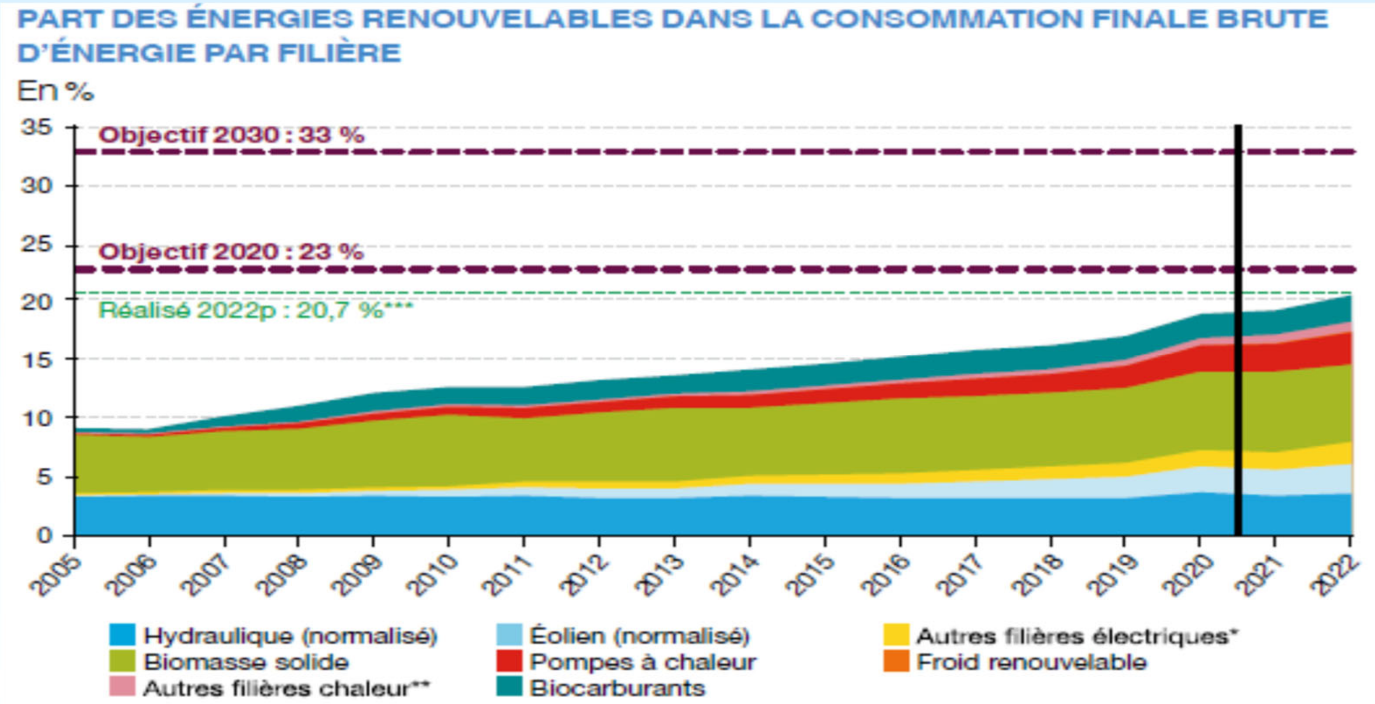
Introduction (1)

Energy transition in Europe:

- European directives and decisions give a pathway for a low carbon Economy.
- One of them is to integrate more renewables in the Energy System:



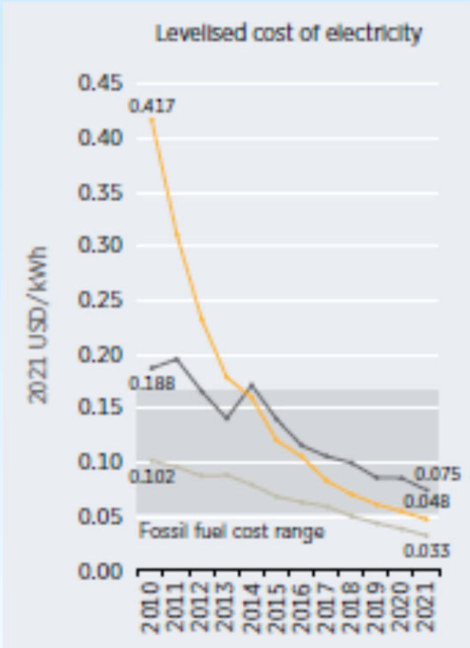
Share of renewables (Hydrolic, biomass, wind, heat pump, etc…) in final energy consumption (French ministry of Enegy Transition, 2023)

Introduction (2)

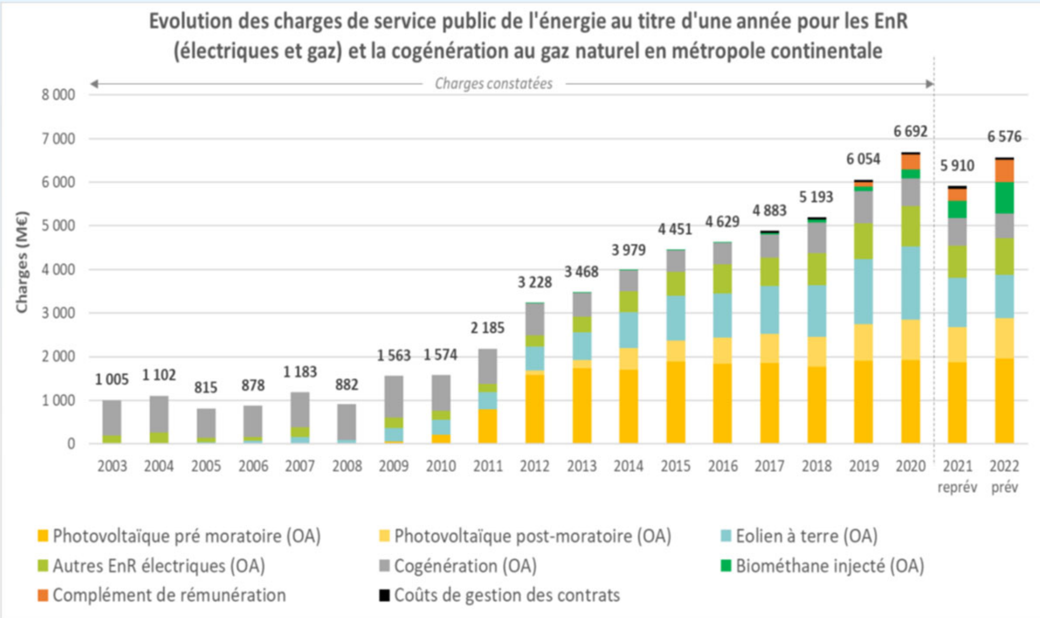
Increasing share of renewables in Europe:

- High energy prices;
- Preferences for green energies;
- Lower investment costs and LCOE=>
- Incentives and Public Services

Obligations increase to foster this deployment of renewables.



IRENA (2021)



<= Evolution of Public Service Obligations in France for Photovoltaic, Wind power, Biogas and Cogeneration

(CGCSPE, 2021)

Introduction (3)

Decentralisation of energy trades in Europe:

- Incentives to self-consumption to reduce renewables electricity fed into the grid and costs of renewables incentives:
  - Reduction of the feed-in-tariffs;
  - Fees to reward each self-consumed kwh.

- Energy Communities increase this self-consumption in a regulated area (Local Energy Markets);

- In Energy Communities, trades are organized on a peer-to-peer basis or by a centralized entity (called the Community Manager).

Introduction (4)

The risk of Utility Death Spiral:

- Increasing self-consumption reduces energy consumption from the grid (volumes or number of grid users);
- Situation where the network cost has to be recouped from a shrinking number of users.

Network tariffs play a central role in this phenomenon

- How to set regulated tariffs to recover Distribution System Operator's costs?
- Network tariffs should compensate the costs linked to the grid and to self-consumption's incentives while avoiding Utility Death Spiral effect.

Self-consumption and the sharing of distribution costs

Objectives

To study how to optimally share the distribution network costs between self-consumers/energy communities and ordinary consumers: a solution to the “utility death spiral”.

Approach

We use cooperative game theory with the core as a solution to compute optimal network tariffs, reducing incentives to by-pass the distribution network (i,e staying in the gran coalition).

Main primary results

1. The core exists thus solutions exist which are efficient for each profile of consumers to jointly remunerate the distribution network.
2. To set tariffs is more complex: tariffs based on the volume or fixed fees could be outside of the core; the Shapley-Value solution is inside it.
3. A (discriminatory) three-part tariff restores the stability of the equilibrium.

Literature

Perico E Santos and Massol (2022):

In case of a poorly adapted pricing, a DSO can stimulate the users' migration to off-grid solutions and initiate the so-called "Utility Death Spiral".

Schittekatte and Meeus (2018)

Their research builds upon existing studies and proposes the use of more sophisticated pricing mechanisms to optimize cost allocation.

Abada, Ehrenmann and Lambin (2020a, 2020b):

Using cooperative game theory models, they study conditions for the stability of Energy Communities (stability of coalitions) and network tariffs to internalize the "Utility Death Spiral" effect.

Morell-Dameto, Chaves-Avila, Gomez San Roman and Schittekatte (2023)

In real world (implementation for Slovenia), they recommand a complex tariff (forward-looking) based on peak energy charges, a variable part for energy losses and a fixed component to internalize flexibility of consumers (load-shifting and self-consumption).

Methodology to build a simple empirical network (1)

Four consumers'profiles with or without self-consumption (photovoltaic):

Cases	Baseline Case				Mixed Case (Self-Consumption/SC)			
Consumers profiles	Ent1	Ent2	Res1 (50 Crs)	Res2 (50 Crs)	Ent1	Ent2 with SC	Res1 (50 Crs)	Res2 with SC
Yearly consumption (MWh)	161	2 014	150	285	161	660	150	203
Subscribed power (kW)	74	450	240	240	74	364	240	120

Data come from Clastres, Percebois, Rebenaque and Solier (2019) for PV investments and consumers profiles.

Res1 are consumers with flat rate.

Res2 are consumers with time of use tariffs.

Methodology to build a simple empirical network (2)

The network cost function:

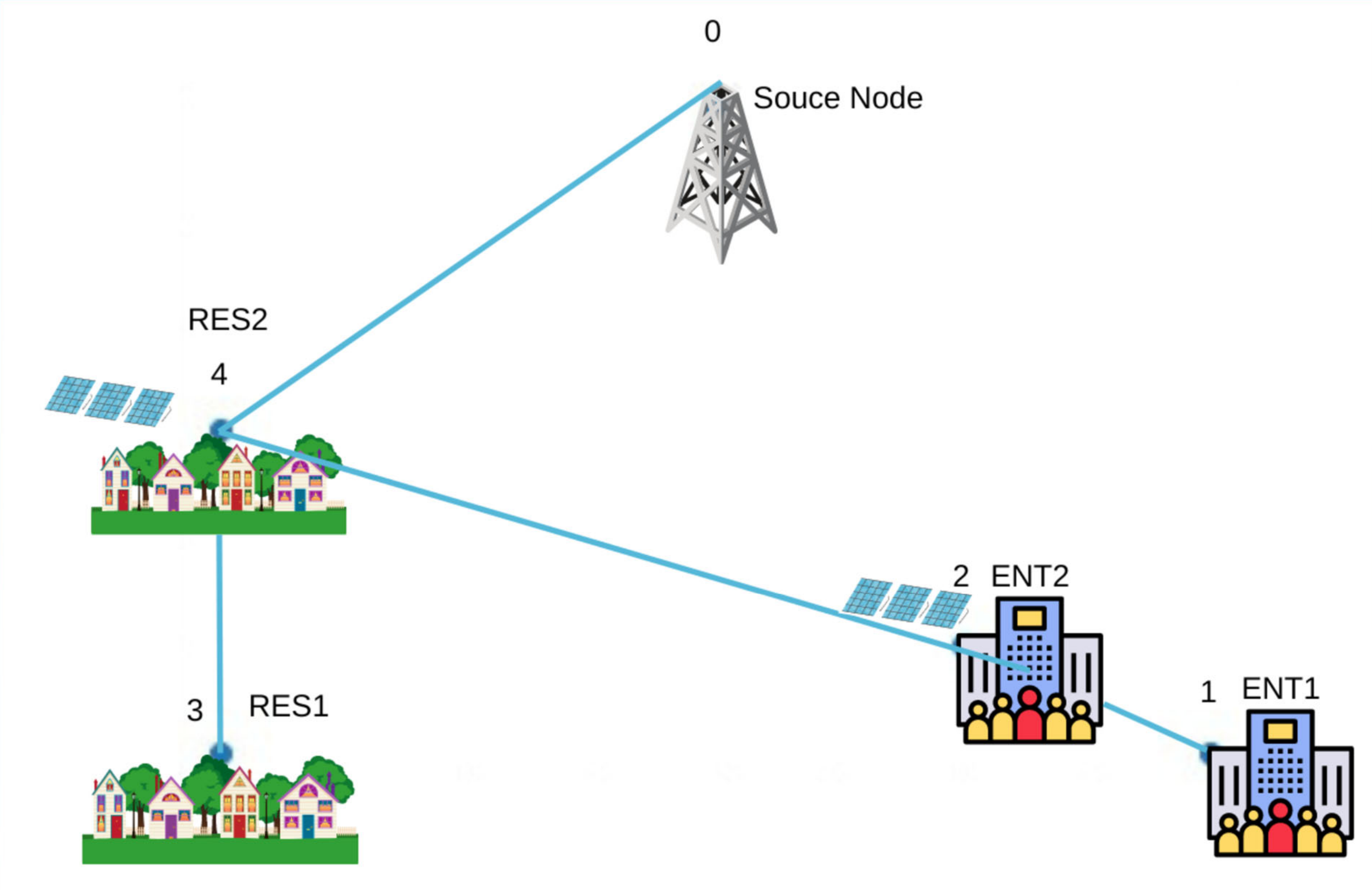
$$cost(D,P,n) = I(D) + \sum_{i=0}^{n} \frac{L(D,P)}{(1+r)^i} = K * \sum_{i=1}^{|V|} d_{0,i} + \sum_{i=0}^{n} \frac{k * \sum_{j=1}^{|V|} [d_{0,j} * p_j]}{(1+r)^i}$$

With,

- D is the total length of the network.
- P is the sum of the yearly loads on each node.
- n is the lifespan of the investment. Its value is set as 40 years.
- r is the discount rate, fixed at 5%.
- K is the full infrastructure installation cost per km. We could set it as 100 000€/km (Verderi, 2022).
- k is the cost of the losses per km-kWh-an.

Our first program : ***Minimisation of the cost function to obtain a radial network (minimum spanning tree model, Golari, 2015).***

Exemple of a Simple Network Topology



The recovering of the network costs

A three-part network tariff

$$Inv(s,i) = x_1 \,.\, V^{s,i} + x_2 \,.\, P^{s,i} + x_3$$

With $V^{s,i}$ the yearly consumed volume for consumer i in coalition s, $P^{s,i}$ the subscribed power and $\{x_1, x_2, x_3\}$ respectively the tariff per volume, for subscribed power and a fixed fee.

The program to compute the core

Maximize e

Subject to $C(s)\text{-}Inv(s) \geq e$

$C(N)$=total grid cost

and

$$Inv(s) = \sum_{i=1}^{|s|} x_1 * V^{si} + x_2 * P^{si} + x_3$$

$x1 \geq 0$

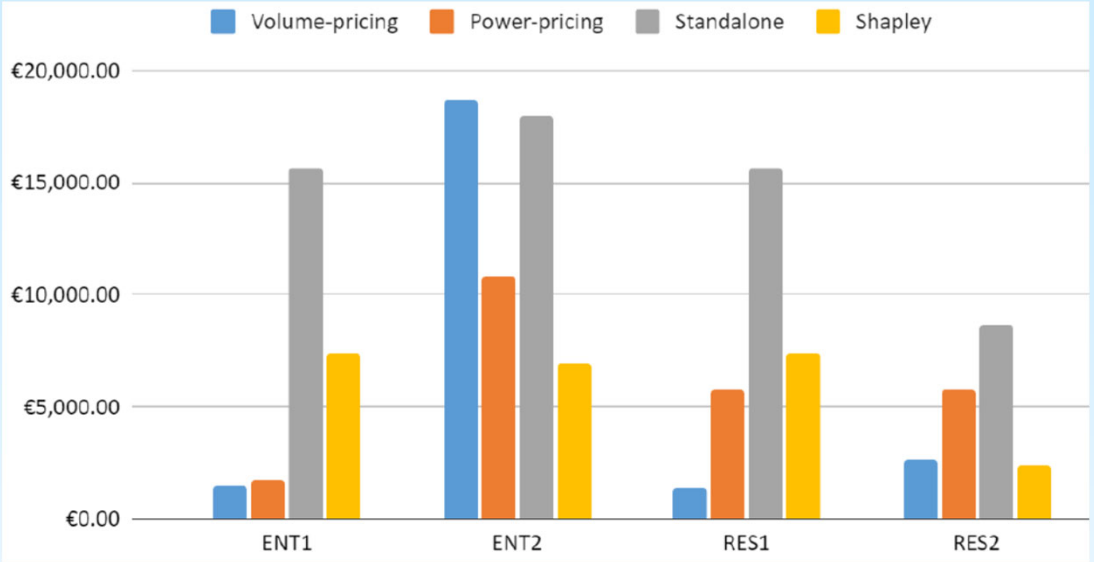
$x2 \geq 0$

$x3 \geq 0$

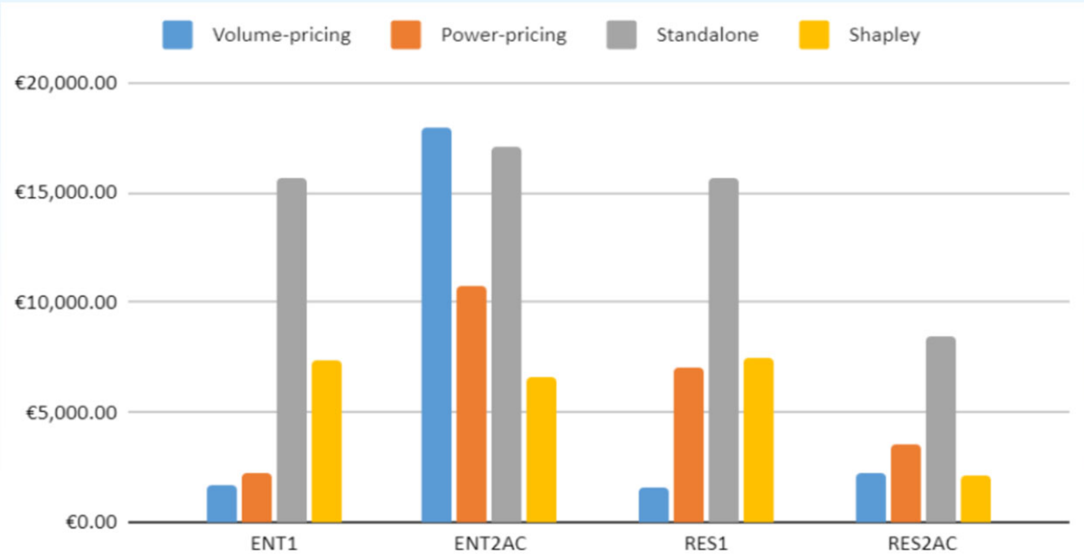
With C(s) the cost of building the network only for coalition s.

Preliminary results of cost allocations

Baseline Case



Mixed Case

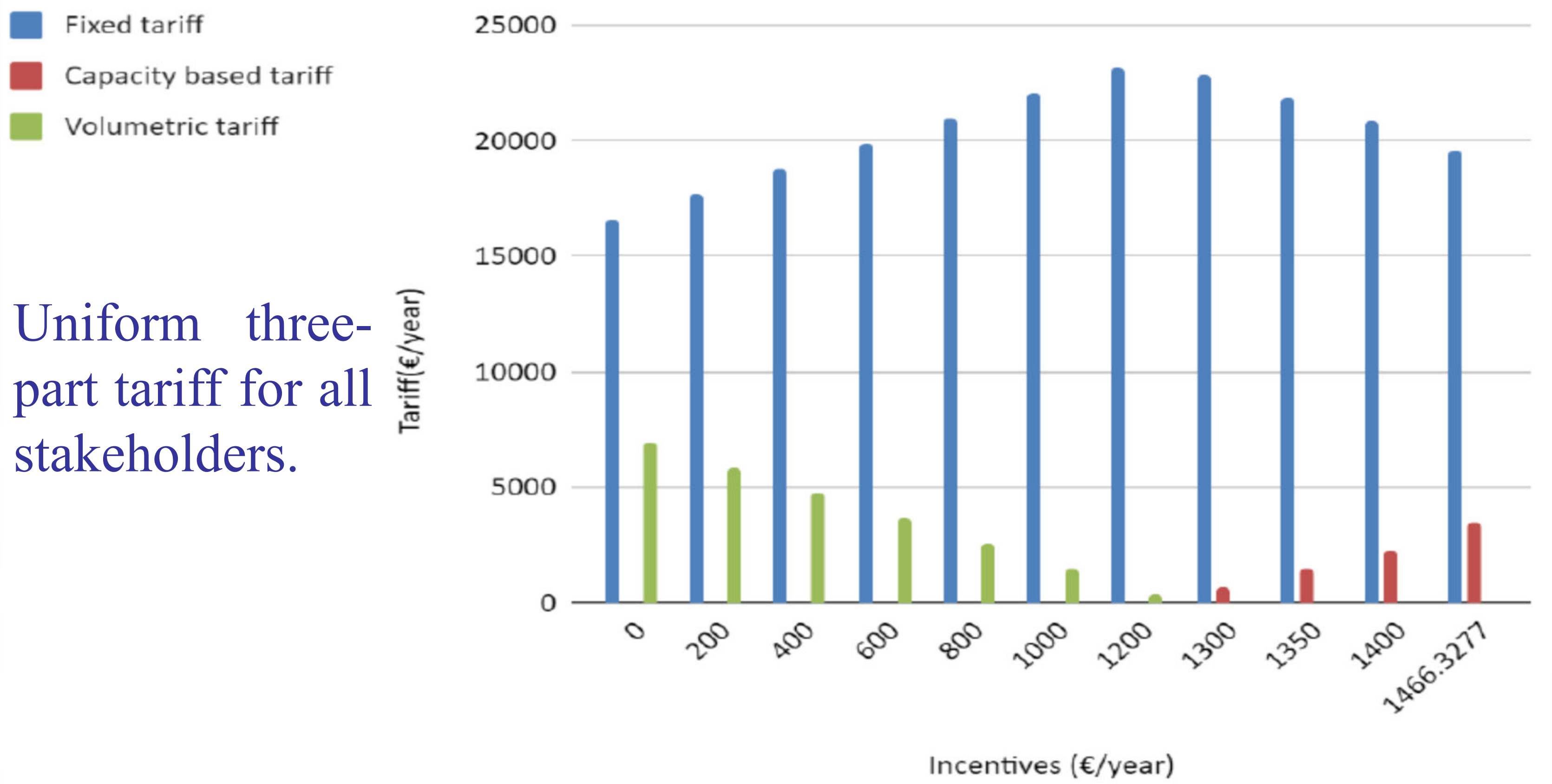


As in the literature, we found that the core is not-empty but volume and power pricing can lead to unstable coalitions.

The Shapley value is in the core and avoid cross-subsidies between stakeholders.

A decrease in losses reduces the level of cross-subsidies in mixed case.

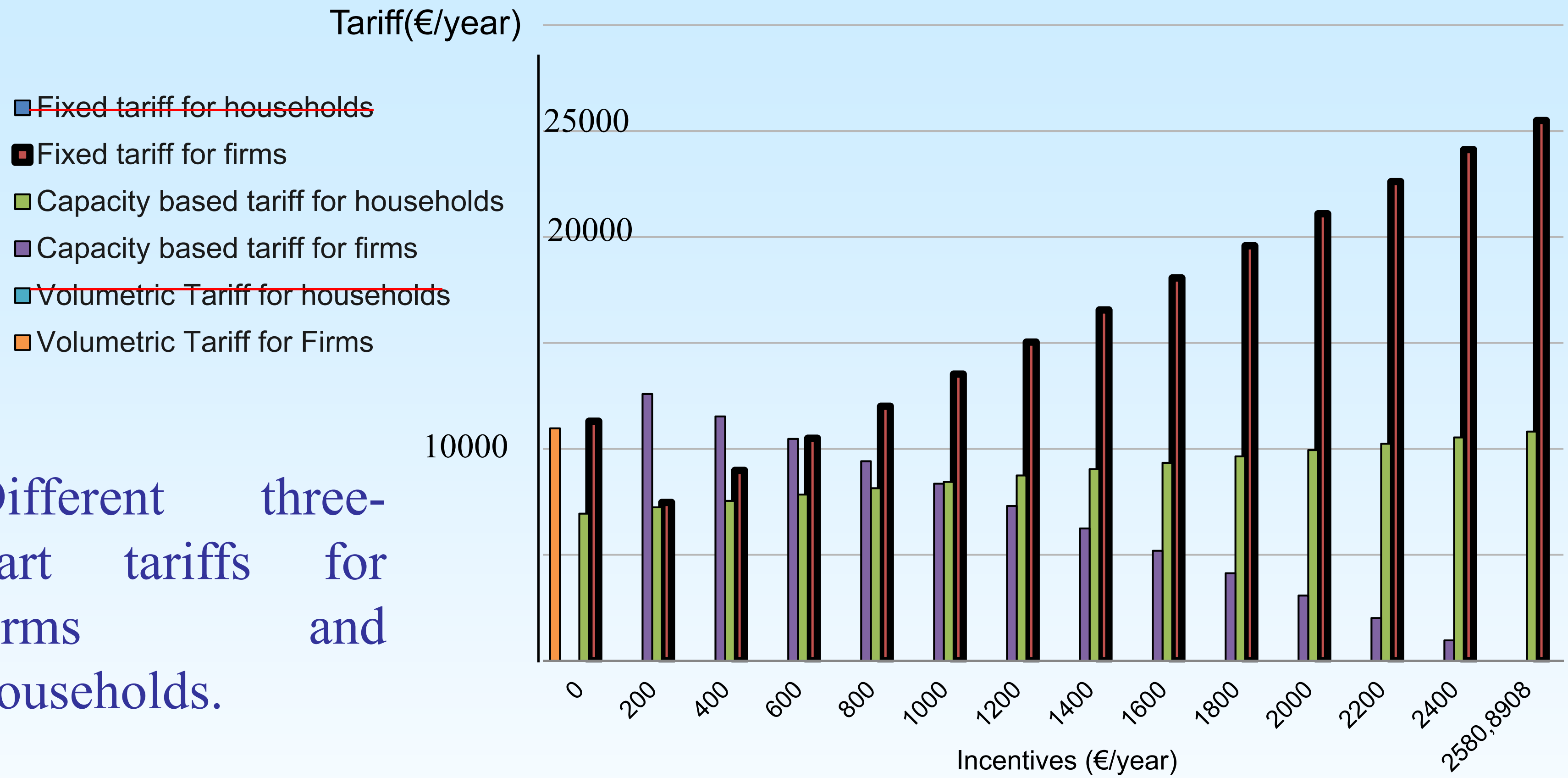
Preliminary results of three part tariffs (1)



Uniform three-part tariff for all stakeholders.

The connection fee (x_3) and volume part (x_1) are used if incentives for being in the gran coalition is weak (incentives near 0). More differenciation with a positive x_1 is needed, replaced by a x_2 positive for stronger incentives (less differenciation).

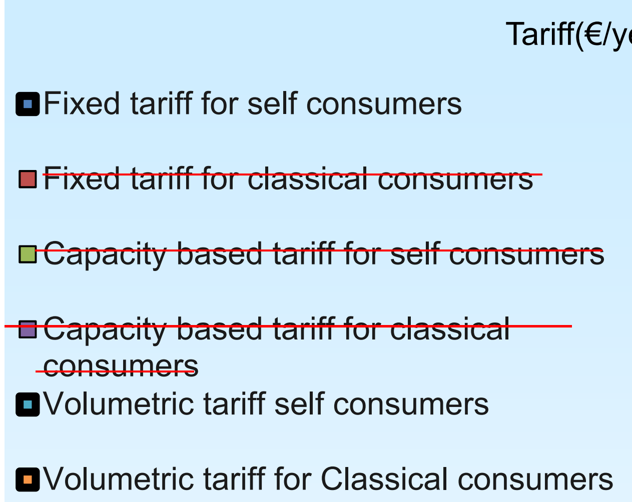
Preliminary results of three part tariffs (2)

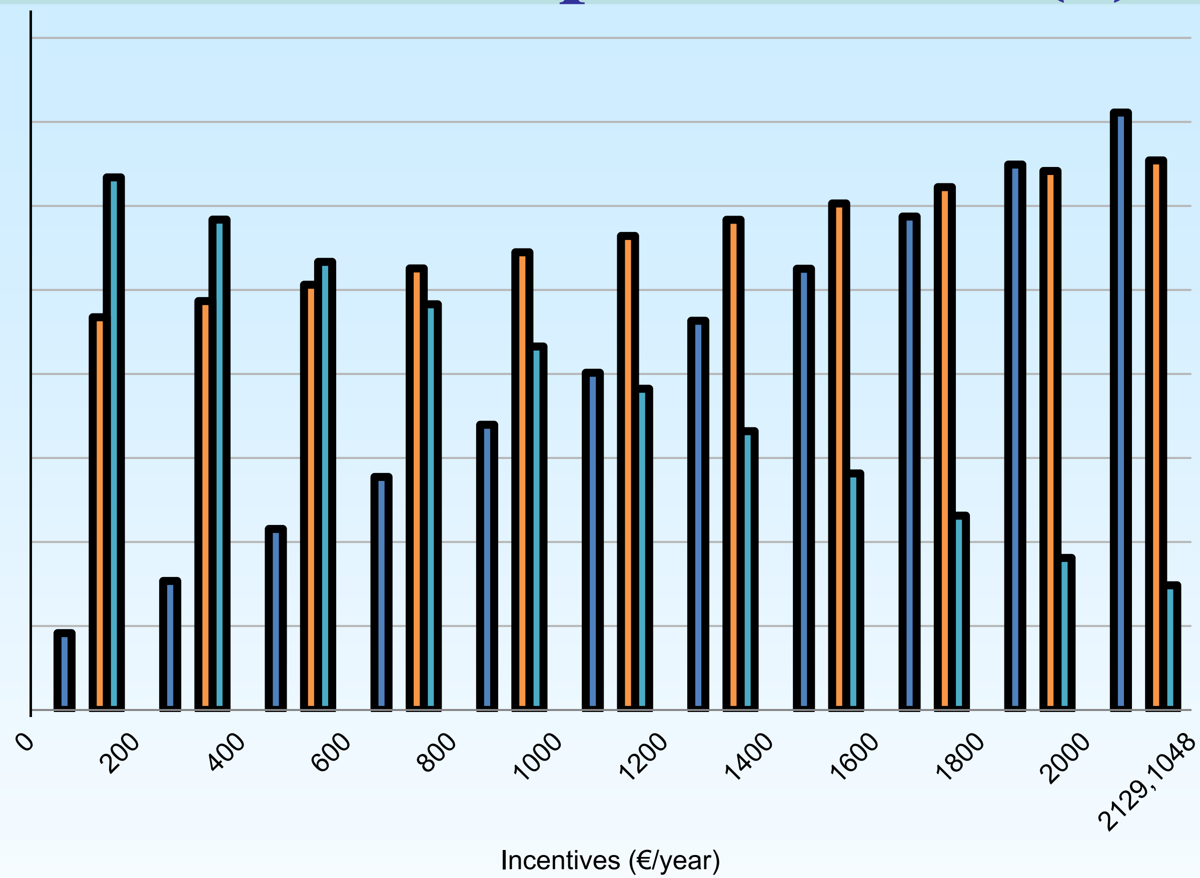


Different three-part tariffs for firms and households.

Only fixed fees (x_2 and x_3) are used to recover network costs and being in the core. Volumetric part is only used for lower incentives for firms. The proportion of firms payments decreases with incentives (no incentive to by-pass the gran coalition).

Preliminary results of three part tariffs (3)





Different three-part tarifs for self-consumers and « classic » ones

Self-consumers must be charged a differenciate tariff (x_1 and x_3 positives) to stay in the gran coalition. Classical consumers pay a volumetric part. Cross-subsidies exist as the share of the bill paid by self-consumers decrease with incentives.

Conclusions

- ✓ There exist network tariffs to internalize the Utility Death Spiral effect.
- ✓ These tariffs are in the core; thus the gran coalition is often stable.
- ✓ All parts of the tariffs are implemented to recover network costs, but not alltoghether as the literature with cooperative game theory could show it.
- ✓ The volumetric and capacity parts are used when the need to differenciate customers exists to keep incentives in being in the gran coalition.

- ✓ An ongoing research to precise as our cost function relies more on fixed costs, to compare with more fair allocations (Shapley values) and to add analysis on surpluses and cross-subsidies between stakeholders.

Thank you for your attention