Energy Communities

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Part I

From « energy » to
« energy communities »

Back to the beginning:
why are we here?

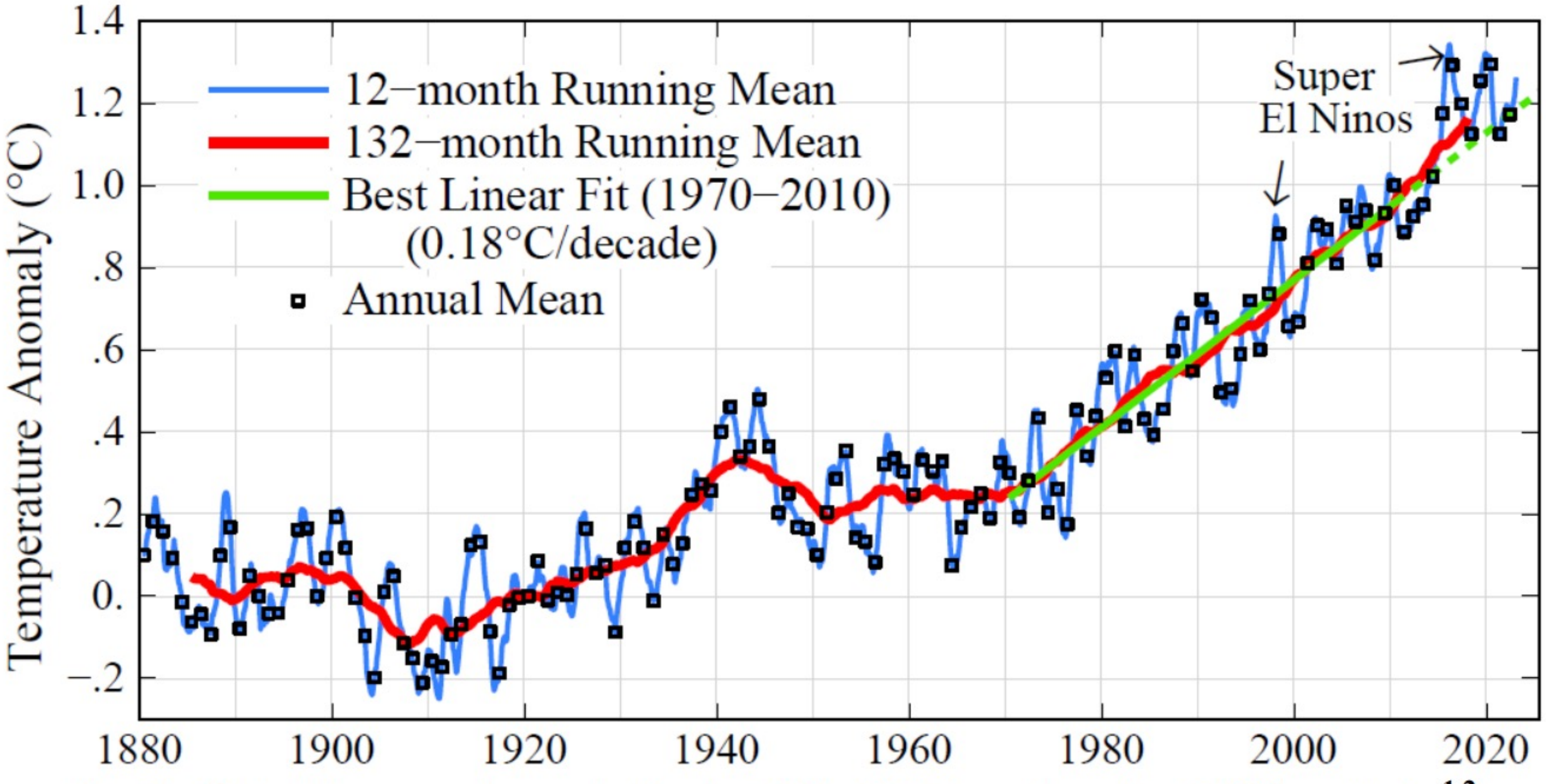


Fig. 2. Global temperature relative to 1880-1920 based on the GISS analysis.[1,2]

Source : Global Warming is Accelerating. Why? Will We Fly Blind? 14 September 2023. James Hansen, Makiko Sato, Reto Ruedy, and Leon Simons

EU Directive

⬇️

Wallon decrees

Directive 2009/28/CE du Parlement européen et du Conseil du 23 avril 2009 relative à la promotion de l'utilisation de l'énergie produite à partir de sources renouvelables et modifiant puis abrogeant les directives 2001/77/CE et 2003/30/CE (Texte présentant de l'intérêt pour l'EEE)

What happened in Wallonia?

Huge incentives to promote distributed solar PV: Solwatt, Qualiwatt, …

In particular, counter running backwards + « certificats verts ».

-> a situation very profitable pour people owning a house with a well-oriented rooftop.

Wallonie énergie SPW

Particuliers

Inondations | Guichets Énergie Wallonie | Aides et primes | Construire et rénover | Acheter, vendre, louer
Economiser l'énergie au quotidien | Mon gaz, mon électricité | Energies renouvelables | Trimestriel Energie4

Accueil / Particuliers / Aides et primes / Soutien au photovoltaïque (Solwatt et Qualiwatt)

Soutien au photovoltaïque (Solwatt et Qualiwatt)

Solwatt

Entré en vigueur le 1er janvier 2008, Solwatt , qui a laissé la place à Qualiwatt le 1er mars 2014, avait été lancé pour inciter les particuliers à investir dans une installation photovoltaïque de puissance inférieure ou égale à 10 kw. Ce mécanisme de soutien avait pour but de récompenser la production d'électricité verte via des titres immatériels, les certificats verts.

Plus d'info

Qualiwatt

Qualiwatt est le mécanisme de soutien à la production d'électricité à partir de panneaux photovoltaïques qui était en vigueur pour les installations de moins de 10 kWc raccordées au réseau de distribution mises en service entre le 1er mars 2014 et le 30 juin 2018.

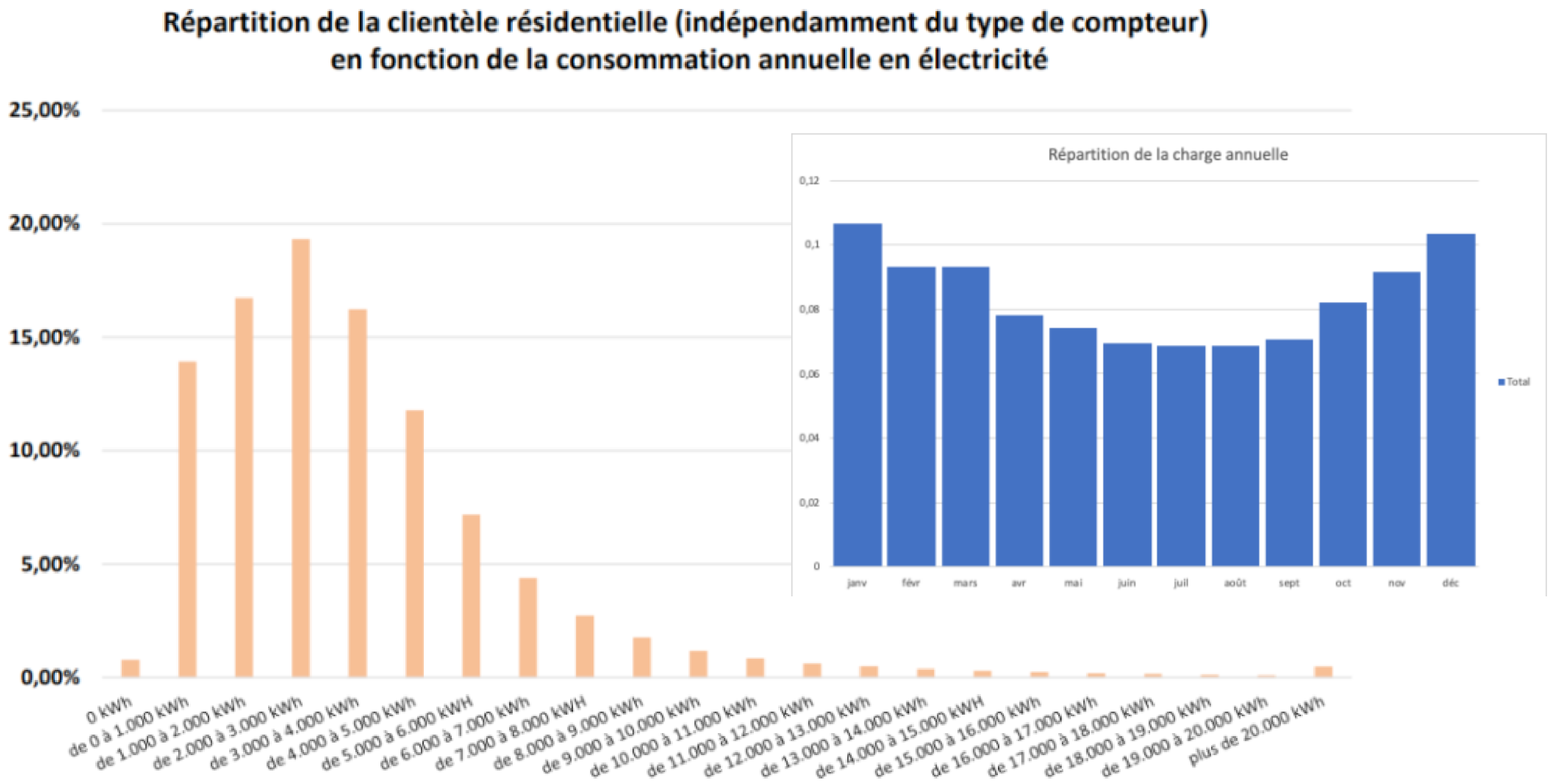
Plus d'info

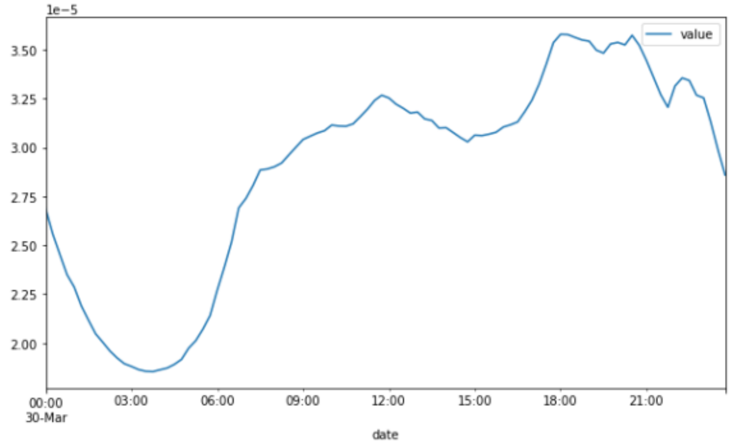
Electricity

Typical unit used to measure electrical energy :

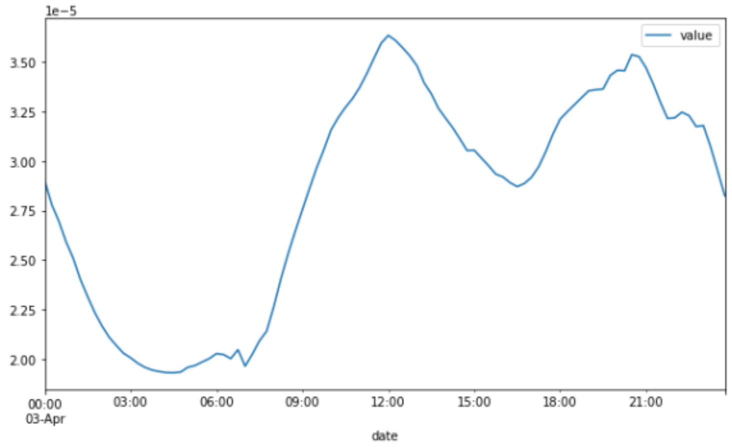
kWh : 1000 W power during 1h of time.

Average consumption in Wallonia: 3500kWh per year.

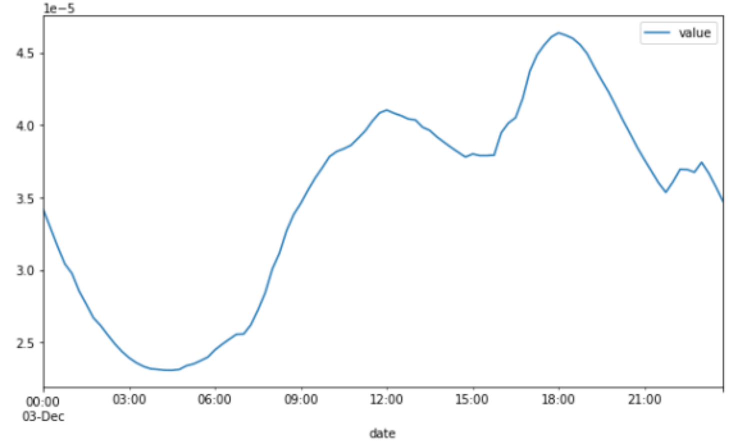




March 30th, 2022



April 3rd, 2022



December 3rd, 2022

The electricity bill

Data for **May 2023** for a **residential customer** located in the **Walloon Region, Belgium,** and connected to the **RESA** network

Prix fixes de l'énergie - 1 an

Redevance fixe [1]		Prix par kWh (€cent/kWh)						Coûts énergie verte [5]
61,48 €/an		Type d'usage	Normal	Bihoraire Heures pleines	Bihoraire Heures creuses	Exclusif Nuit		(€cent/kWh)
	+	Consommation [2]	23,513	24,764	20,247	20,247	+	2,996
	−	Injection [3]	7,802	9,468	3,576			

Coûts de réseaux (distribution et transport) [6]

Gestionnaire du réseau de distribution	Distribution						Transport
	Normal	Bihoraire		Exclusif Nuit	Activité de mesure Relevé annuel	Tarif prosumer [7]	
		Heures pleines	Heures creuses				
	€cent/kWh	**€cent/kWh**	**€cent/kWh**	**€cent/kWh**	**€/an**	**€/kWe/an**	**€cent/kWh**
TECTEO - RESA	9,34	10,37	5,87	5,16	24,90	67,62	2,61

Suppléments

Suppléments (€cent/kWh)	
Cotisation sur l'énergie	0,20417
Redevance raccordement [8]	0,07500

Accise fédérale [11] (€cent/kWh)	
Consommation entre 0 et 3.000 kWh	4,51300
Consommation entre 3.000 et 20.000 kWh	5,03288
Consommation entre 20.000 et 50.000 kWh	4,81876
Consommation entre 50.000 et 1.000.000 kWh	4,74668

More details about the “consumption” part…

Billing Item	(part)	Nature	Price (€c/kWh)
Fixed energy costs			
Consumption		Energy	23,513
Green energy cost		RES	2,996
Grid costs			
Distribution	RESA (DSO)	Réseau	9,340
Transport	Elia (TSO)	Réseau	1,573
	Fin. énergie ren.	RES	1,037
Supplements			
Energy cotisation		Taxes	0,204
Connexion fee		Taxes	0,075
Federal tax		Taxes	4,513
Subtotals		Energy	23,513
		RES	4,033
		Network	10,913
		Taxes	4,792
Total			**45,251**

Energy represents the price charged for the **production** of energy

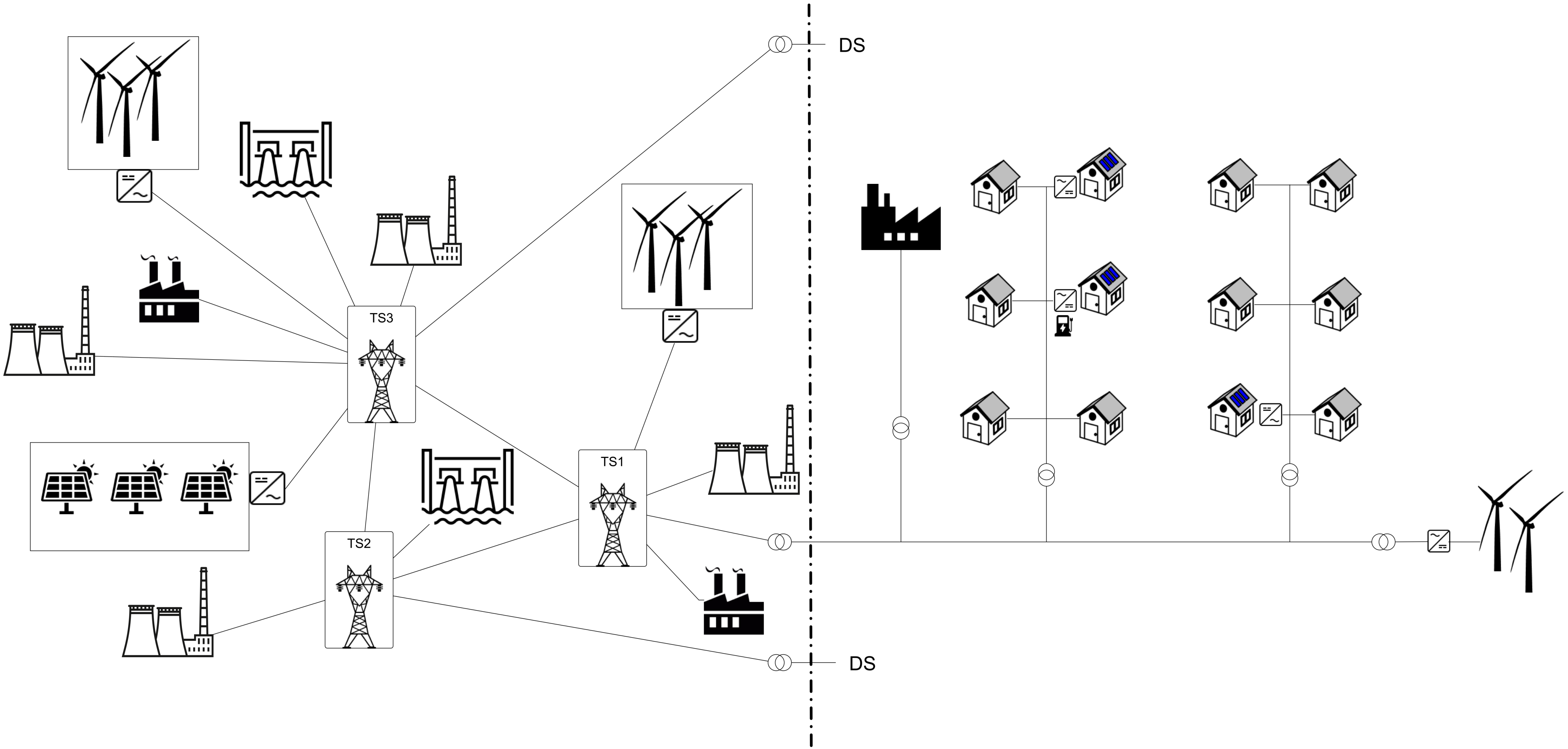
Renewable energy support (RES) covers the costs of policies to **encourage** the development of renewable energy (such as feed-in tariffs)

Network tariffs correspond to the costs required to operate the transmission and distribution networks, as well as certain public service obligations (OSP)

Some other expenses are not detailed because they are not relevant to the presentation.

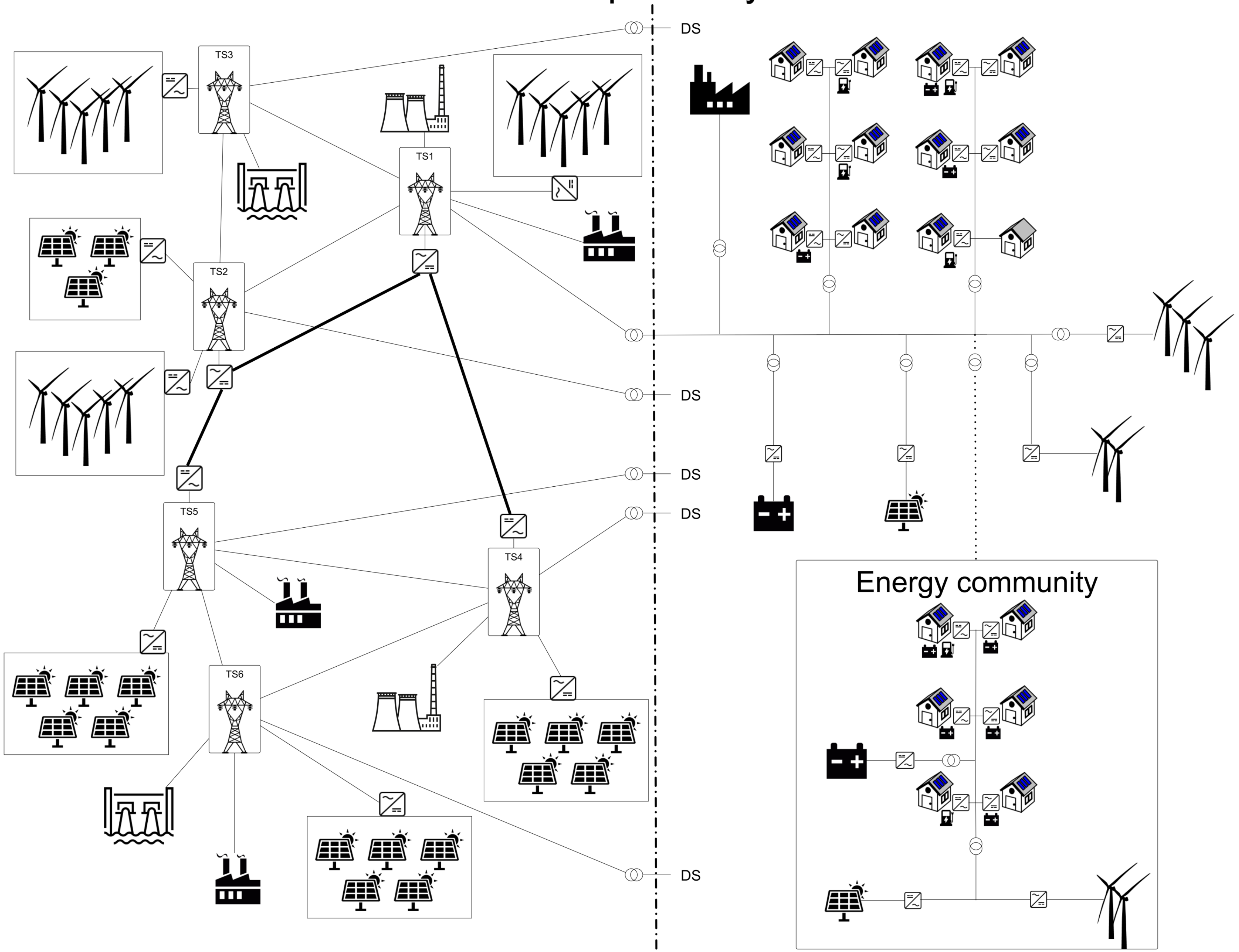
(Interlude)

From present...

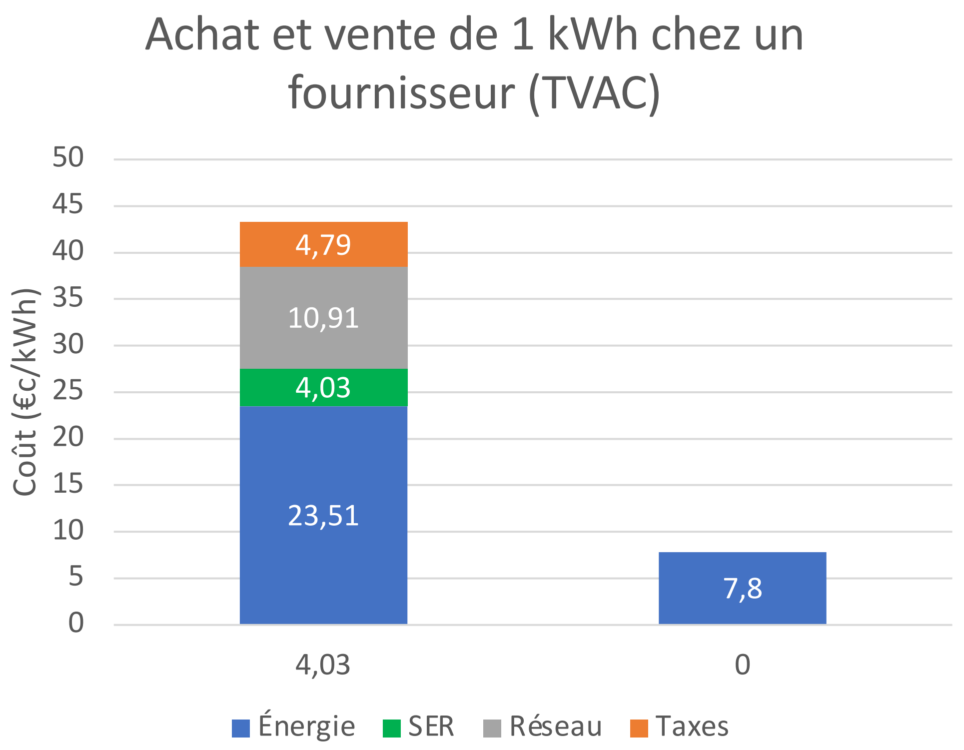


(Interlude)

... to future power systems.



… before adding the "prosumer" part

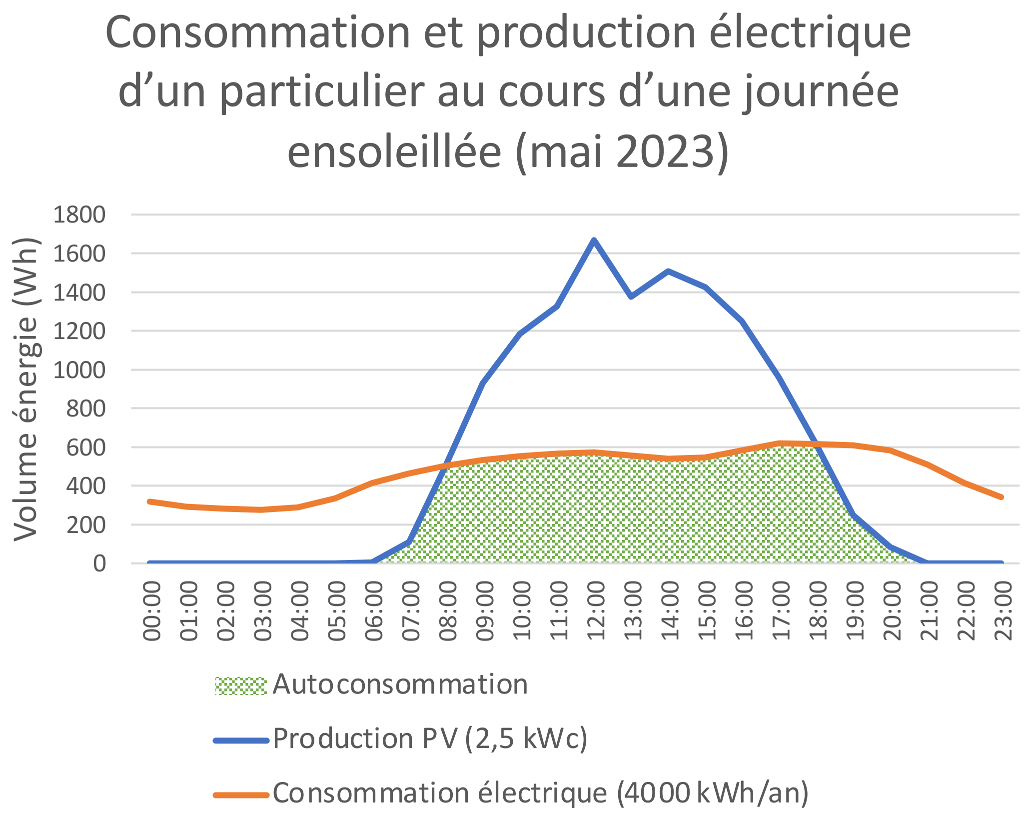


A prosumer buys its energy from a supplier: it pays for the energy, network fees, RES, and taxes.

The PV production is first used for self-consumption, behind their meter, the surplus is sold to their supplier.

Energy bought is about 5x more expensive than it is sold.

About self-consumption

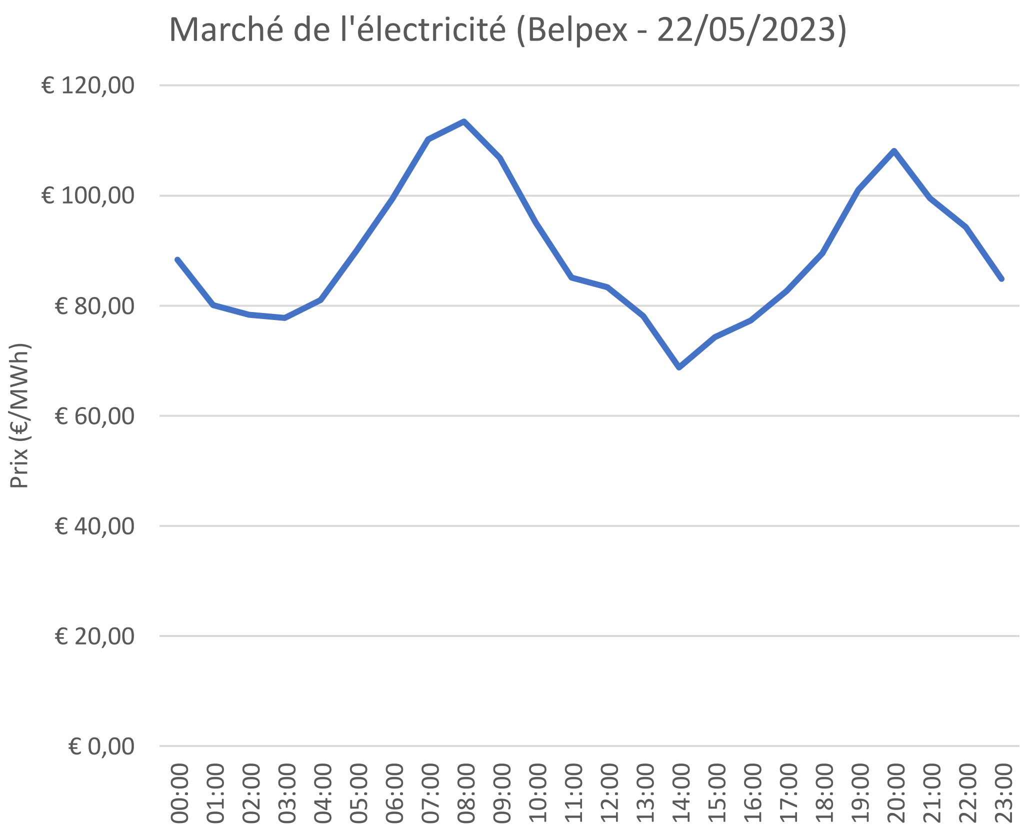


Self-consumption is for a customer supporting part of his electricity needs with energy that he has produced himself.

Self-consumed energy does not “circulate” on the network, it is totally free.

Regulation (network tariffs, taxes) promotes self-consumption.

About this – low - injection tariff



On the wholesale market, the price varies **every 15 minutes** according to supply and demand.

The injection tariff (generally fixed for a whole month/year) is low because the PV is injected when market prices are **low** and retailers must ensure their margins.

This results in the fact that self-consumption is much more interesting than selling your PV production.

And what is proposed to other people…

… who live in a house without PV, close to house(s) with PV…

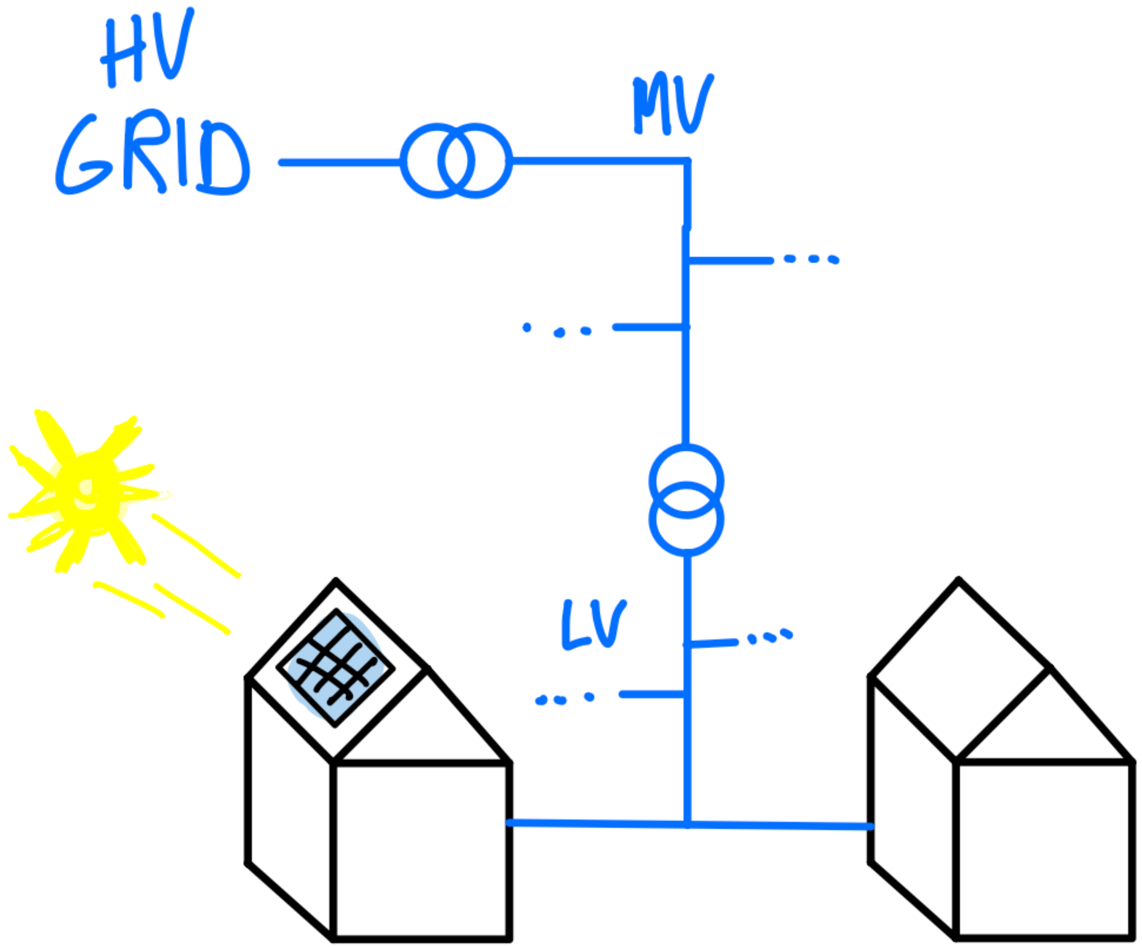
… share a house with PV with others…

… live in a flat, sharing a rooftop with PV with others…

?

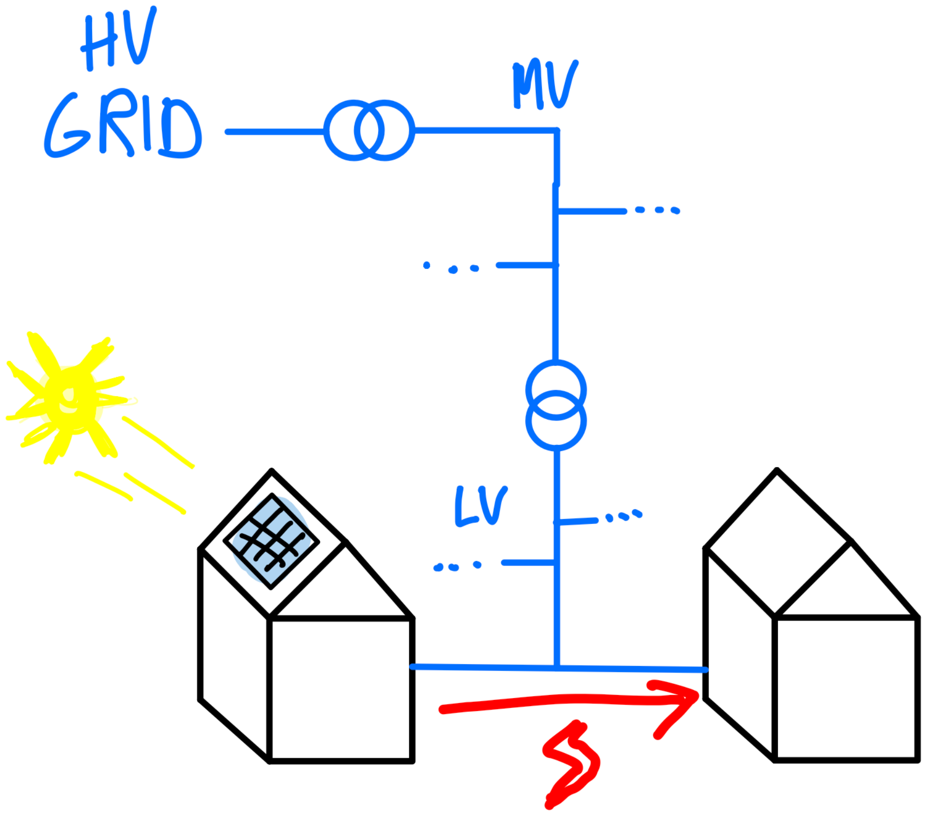
Currently, in a neighborhood

Currently, in a neighborhood



(backup – we draw this on the blackboard :-))

Currently, in a neighborhood



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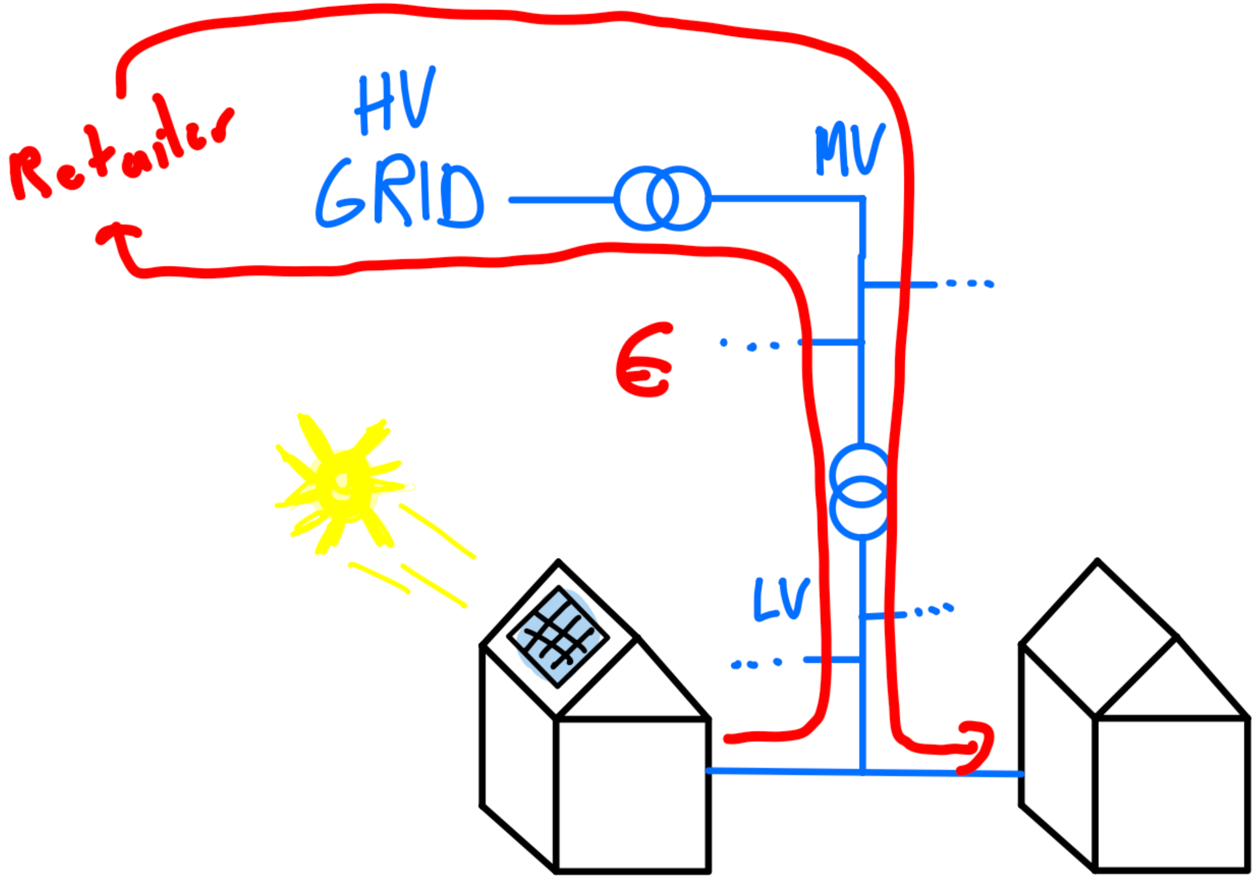
Currently, in a neighborhood



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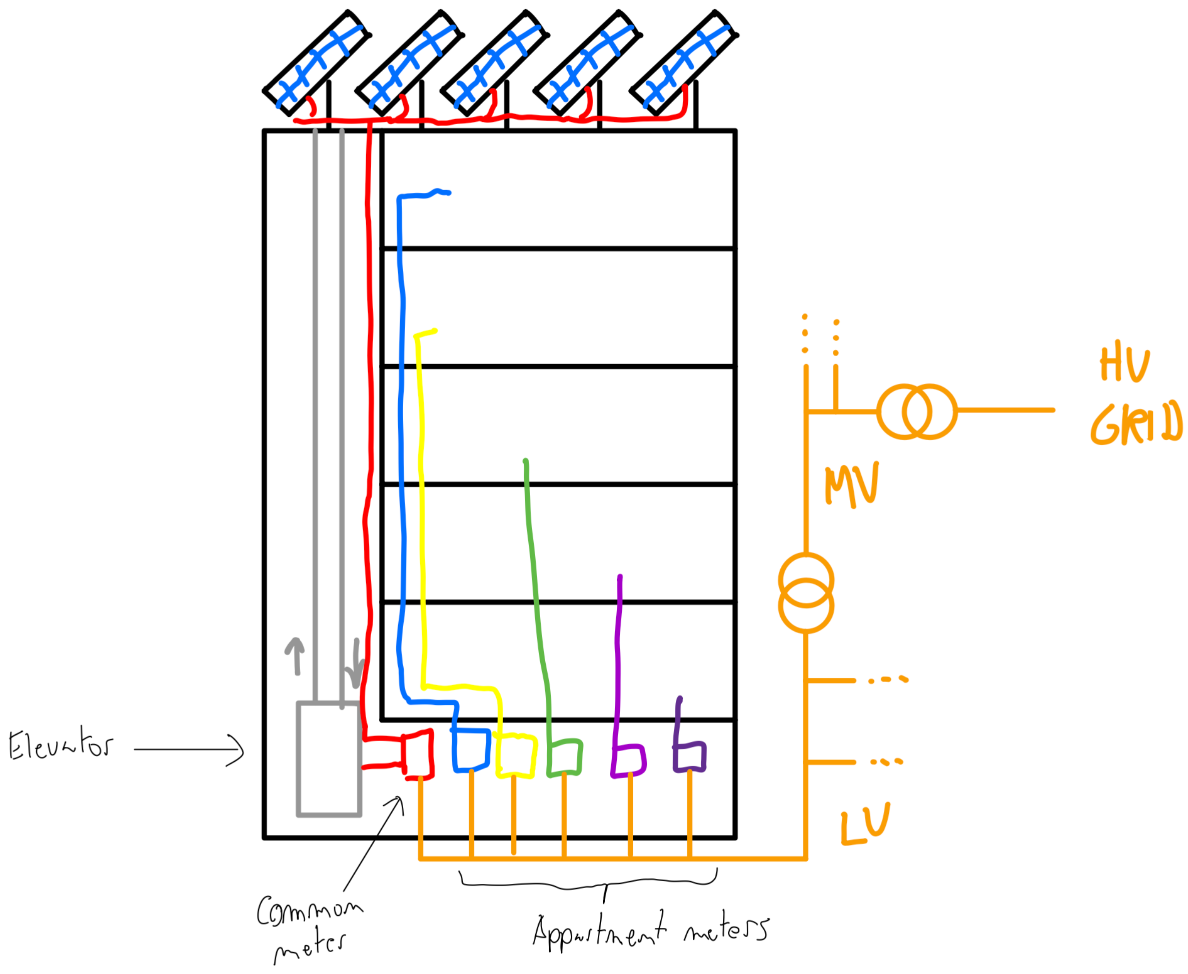
Currently, in a building

Currently, in a building



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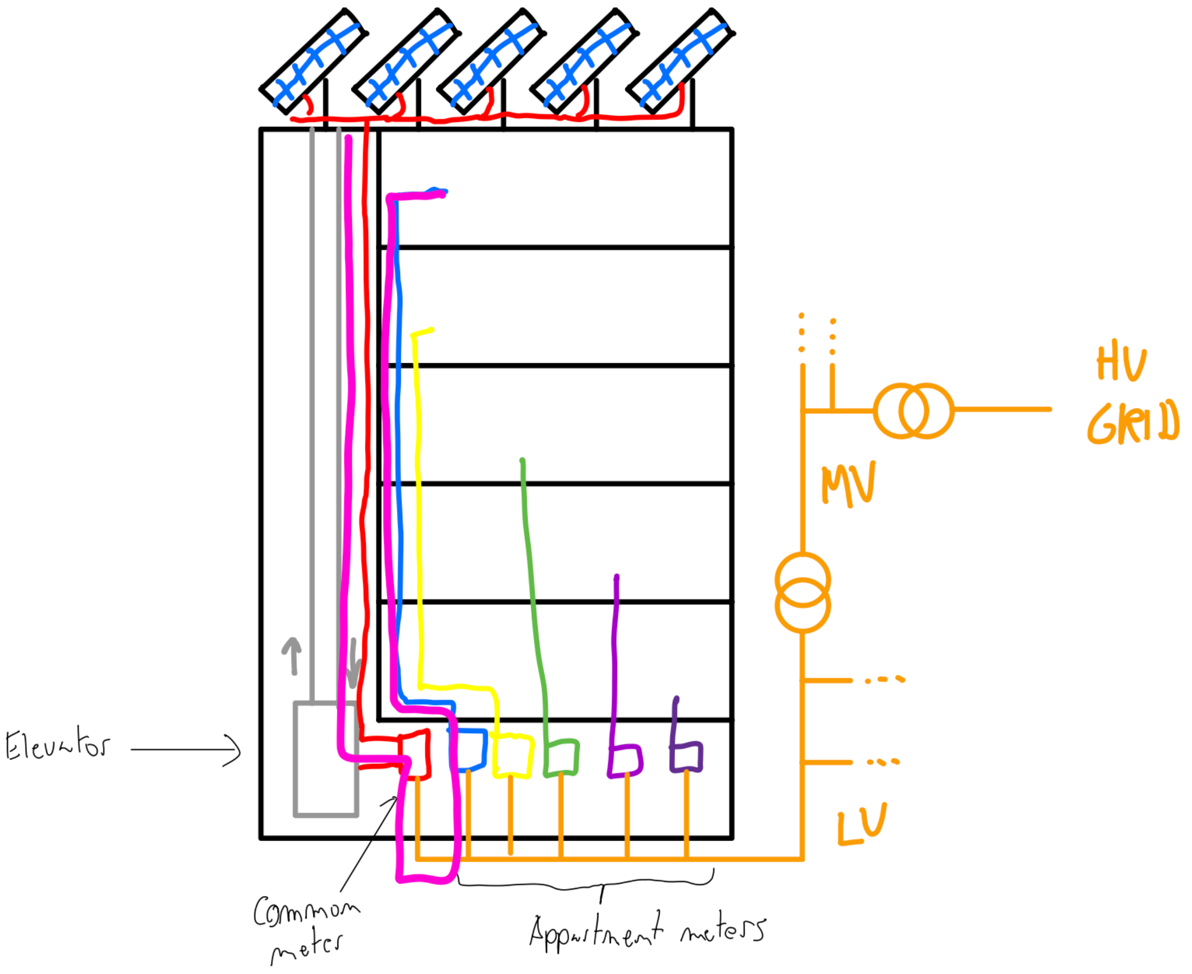
Currently, in a building



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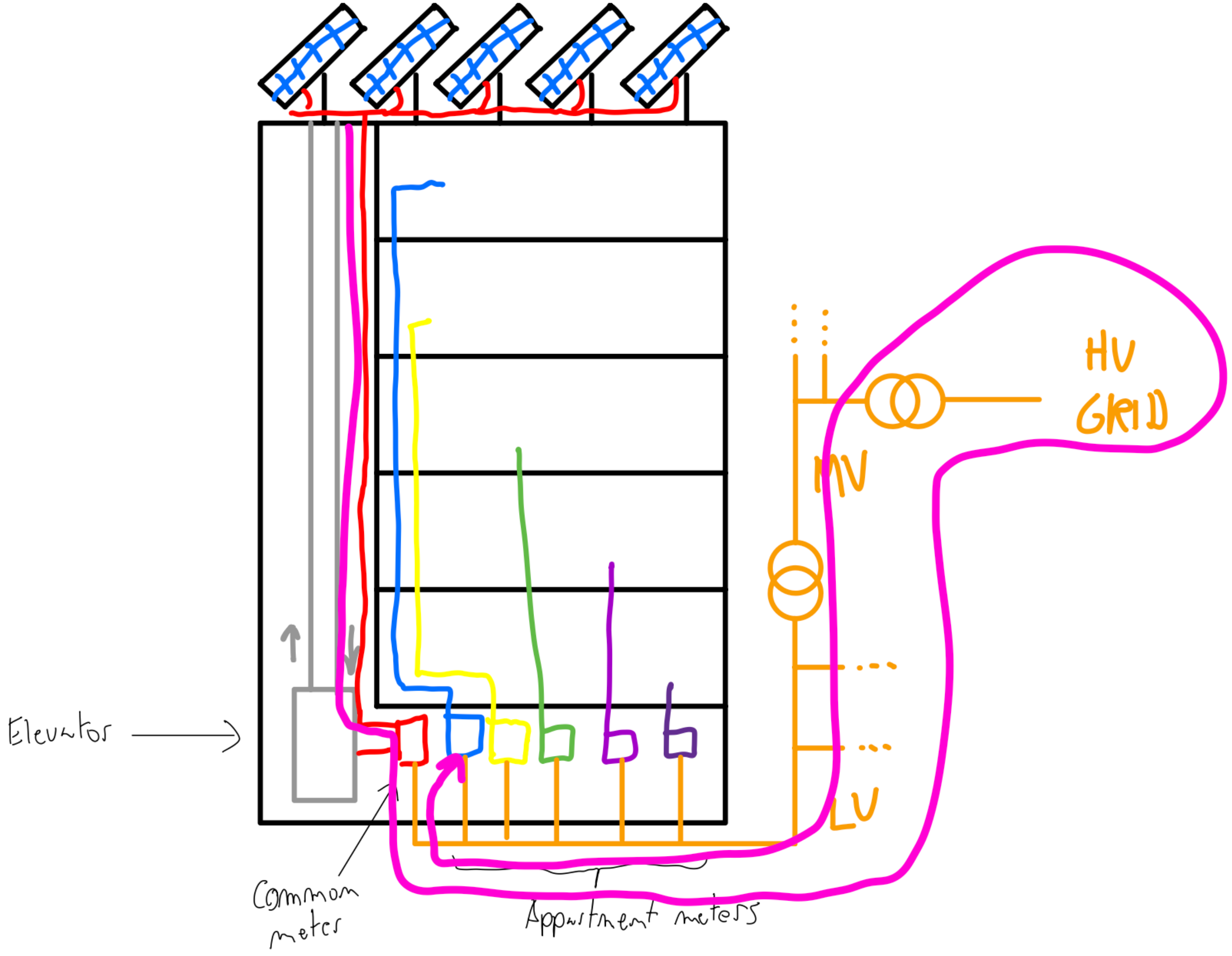
Currently, in a building



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Some legal ideas

Décret du Parlement wallon du 05 mai 2022 relatif aux communauté d'énergie et au partage d'énergie (M.B. du 05/10/2022).
Accessible en ligne :
https://wallex.wallonie.be/eli/loi-decret/2022/05/05/2022033591/2022/10/15

Arrêté du Gouvernement wallon du 17 mars 2023 relatif aux communautés d'énergie et au partage d'énergie (Non publié au M.B.).
Accessible en ligne :
https://www.cwape.be/publications/document/5329

Concretely, it opens the emergence of energy communities

The common idea is « sharing energy ».
In Wallonia, this results into 3 different forms of energy communities (in French) :

- Communities inside a single building
  (« Clients actifs agissant collectivement au sein d'un même bâtiment »)
- Renewable Energy Communities
  (« Communautés d'énergie renouvelable »)
- Citizen Energy Communities
  (« Communautés d'énergie citoyenne »)

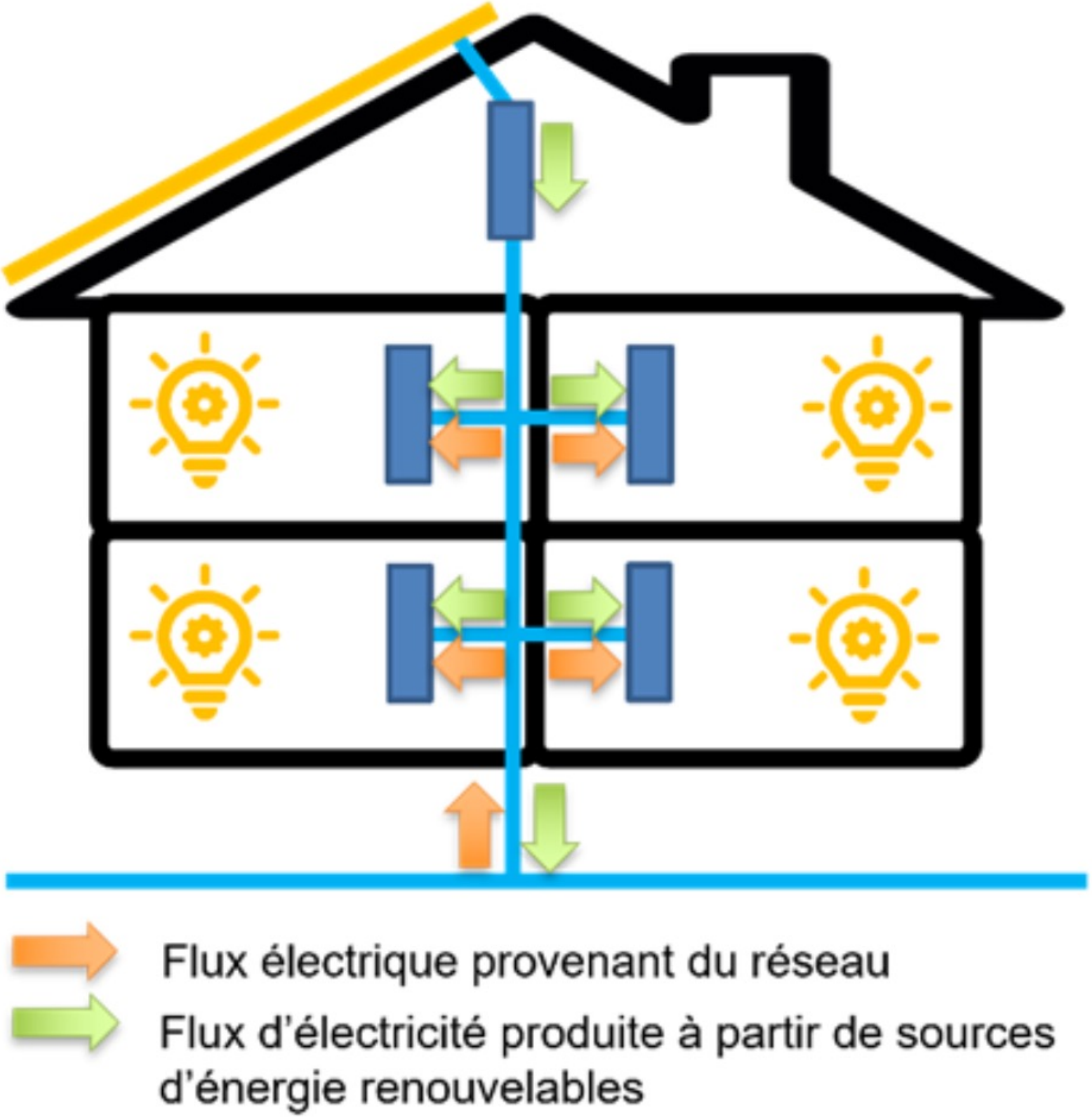
	Clients actifs agissant collectivement au sein d'un même bâtiment	**Communautés d'énergie renouvelable**	**Communautés d'énergie citoyenne**
Référence	Art.21.4 directive 2018/2001	Art.22 directive 2018/2001	Art.16 directive 2019/944
Production d'énergie	A partir de sources d'énergie ren. situées dans ou sur le bâtiment	A partir de sources d'énergie renouvelables	Uniquement l'électricité, à partir de sources d'énergie renouvelables ou non
Périmètre	Au sein d'un même bâtiment	A proximité[2] des installations de production (pour le contrôle et l'activité de partage)	Non limité
Obl. de const. une pers. morale	Non	Oui	Oui
Participants & contrôle	Groupe de clients actifs agissant collectivement dans ou sur un même bâtiment	Actionnaires ou membres de la CER : personnes physiques, autorités locales ou petites ou moyennes entreprises à condition que leur participation ne constitue pas leur principale activité commerciale ou professionnelle. Les membres et actionnaires détenant le contrôle sont situés à proximité[2] des installations de production.	Participants : aucune restriction Contrôle effectif[3] : par des membres ou des actionnaires qui sont des personnes physiques, des autorités locales ou des petites entreprises (dont l'activité commerciale ou professionnelle principale n'est pas la participation dans une ou plusieurs communautés d'énergie et dont le principal domaine d'activité économique n'est pas le secteur de l'énergie)
Activités autorisées	Partage d'énergie	1° production d'électricité 2° fourniture d'électricité 3° autoconsommation de l'électricité produite par sa ou ses installations 4° partage via le réseau public de distribution ou de transport local, de l'électricité produite au sein de la CER au départ d'installations de production dont la communauté est propriétaire, sur lesquelles elle dispose d'un droit de jouissance ou détenues par un de ses participants et injectée sur ces réseaux[4] ; 5° agrégation 6° participation aux services de fourniture de flexibilité 7° stockage de l'énergie 8° services de recharge pour les véhicules électriques 9°services liés à l'efficacité énergétique ou d'autres services énergétiques 10° vente de l'électricité autoproduite, non autoconsommée et non partagée	1° production d'électricité 2° fourniture d'électricité 3° autoconsommation de l'électricité produite par sa ou ses installations 4° partage via le réseau public de distribution ou de transport local, de l'électricité produite au sein de la CEC au départ d'installations de production dont la communauté est propriétaire, sur lesquelles elle dispose d'un droit de jouissance ou détenues par un de ses participants et injectée sur ces réseaux[4] ; 5° agrégation 6°participation aux services de fourniture de flexibilité 7° stockage de l'énergie 8° services de recharge pour les véhicules électriques 9°services liés à l'efficacité énergétique ou d'autres services énergétiques 10° vente de l'électricité autoproduite, non autoconsommée et non partagée

« Clients actifs agissant collectivement au sein d'un même bâtiment »

Energy sharing is an administrative solution that consists of **distributing the volumes** injected by PVs among the occupants who can consume them.

The objective of sharing is to establish a **separate accounting and billing** between the energy consumed from the network and that from the PVs.

The sharing is organized by a collective agreement between the condominium, the occupants, and the distribution network operator.



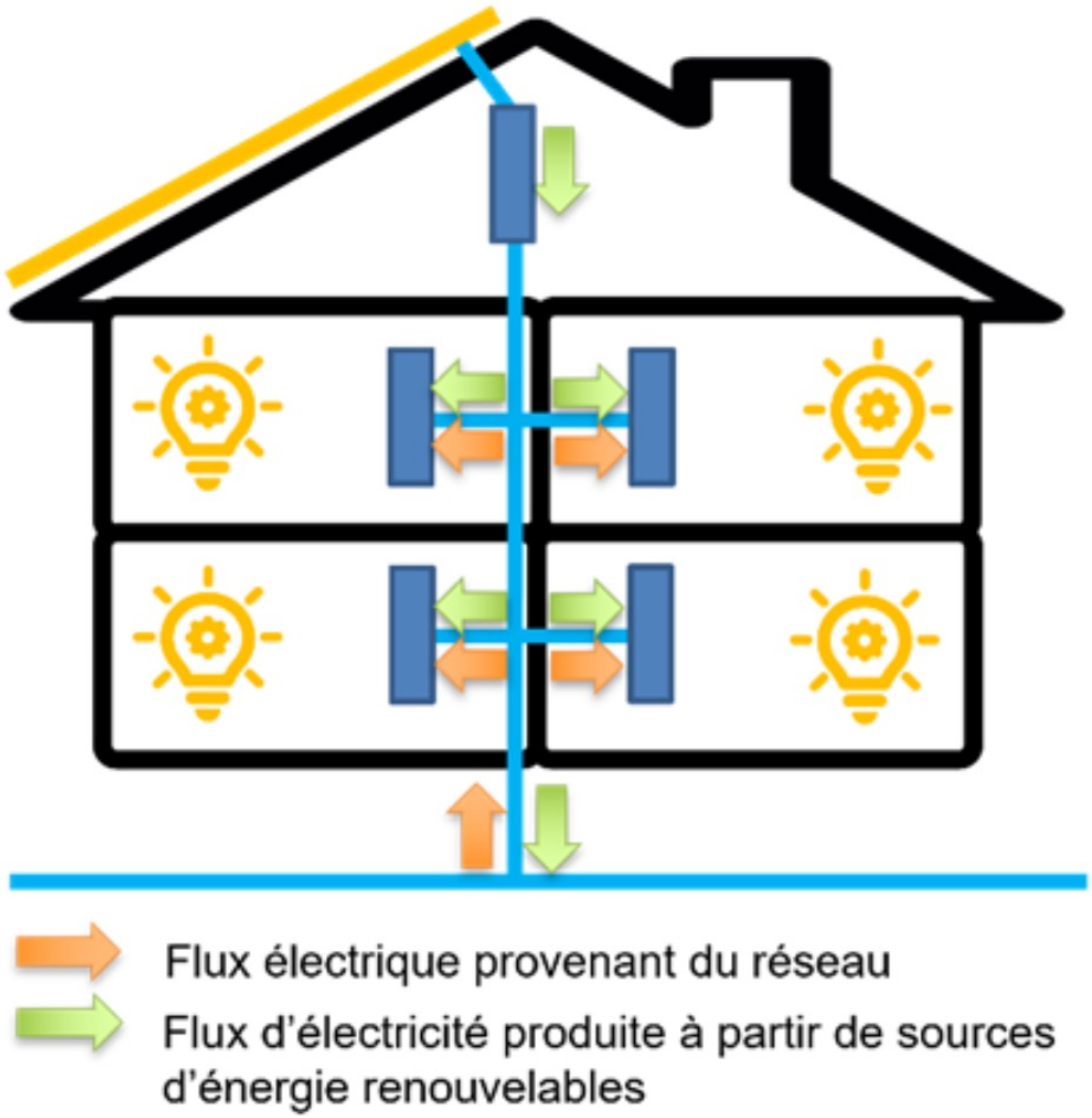
Energy sharing is allowed either for « clients actifs agissant collectivement au sein d'un même bâtiment » (see picture), either for « communauté d'énergie ».

« Clients actifs agissant collectivement au sein d'un même bâtiment »

The "repartition" of injected energy is calculated for each market period (every 15 minutes).

The "repartition" is calculated according to distribution keys, which are mathematical rules for distributing volumes among occupants.

The "repartition" consists of an artificial modification of the meter indexes sent to the market by the distribution network operator.



Part II

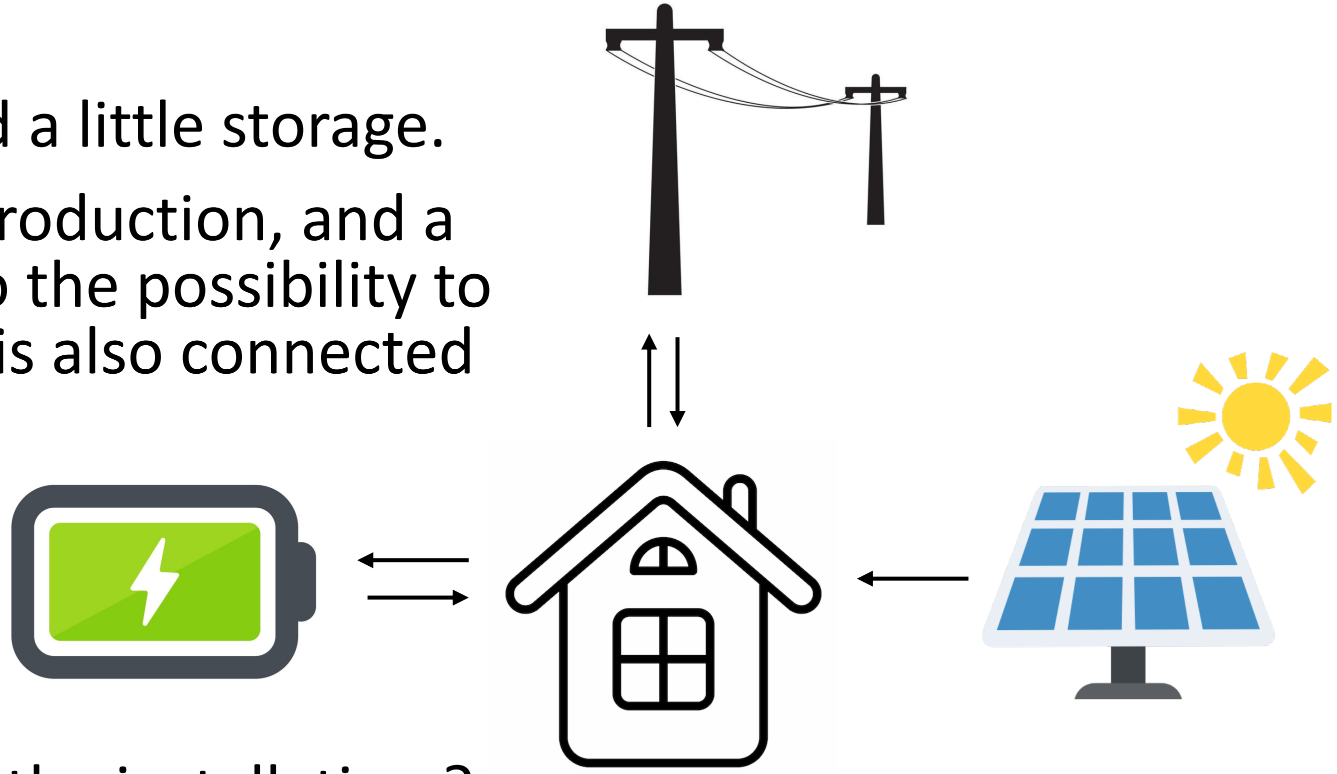
Quantitative aspects

From « How » to « how much »

The first "sizing and operation" problem

Imagine a house, some PVs, and a little storage.

There is some local electricity production, and a local consumption. There is also the possibility to locally store energy. The house is also connected to the distribution network.

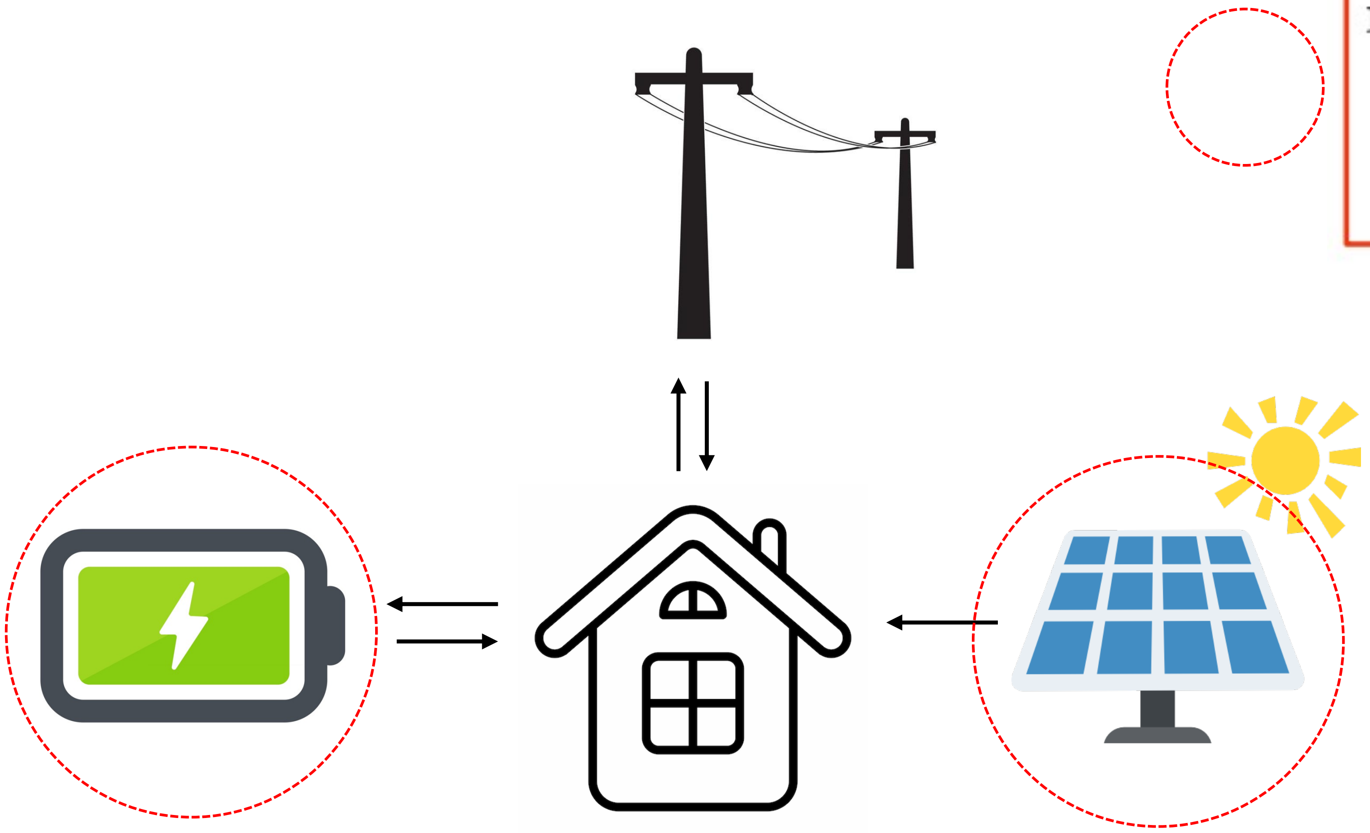


<u>Question</u> :

- What is the "best" way to size the installation ?

From « How » to « how much »

What does « best way » mean? Let us first start with costs.



min [investment costs] + [operation costs]

s.t. [system design constraints]

[operating constraints of subsystem]

→ [coupling constraints]

[regulatory constraints]

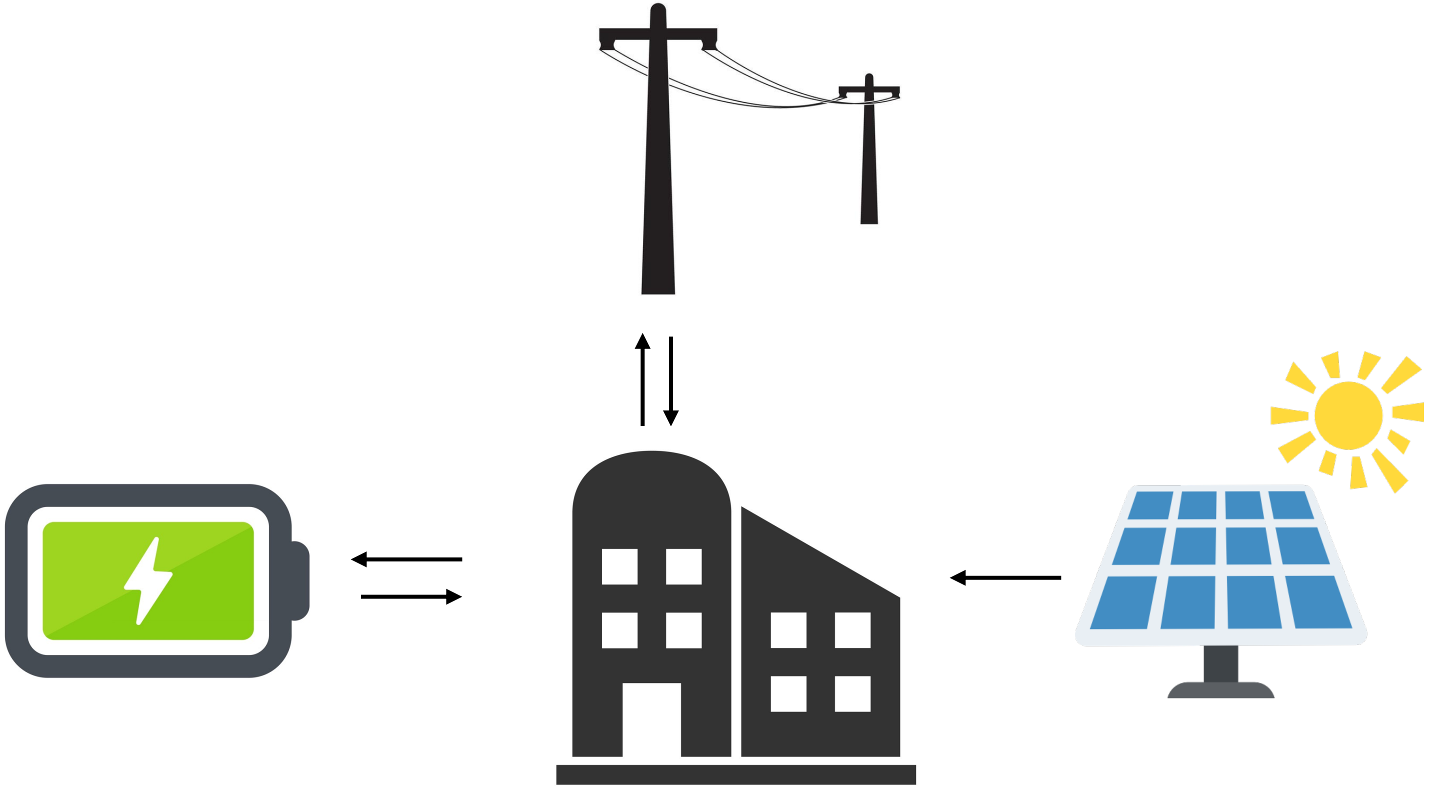
From « How » to « how much »

For example, we may want to design and operate a system that minimizes the overall bill of the house :

$$
\begin{aligned}
\min \quad & \sum_{\text{subsystems}} \left([\text{investment costs}] + [\text{operating costs}] \right) \\
\text{s.t.} \quad & [\text{system design constraints}], \ \text{for every subsystem} \\
& [\text{operating constraints}], \ \text{for every subsystem} \\
& [\text{coupling constraints between subsystems}] \\
& [\text{regulatory and environmental constraints}]
\end{aligned}
$$

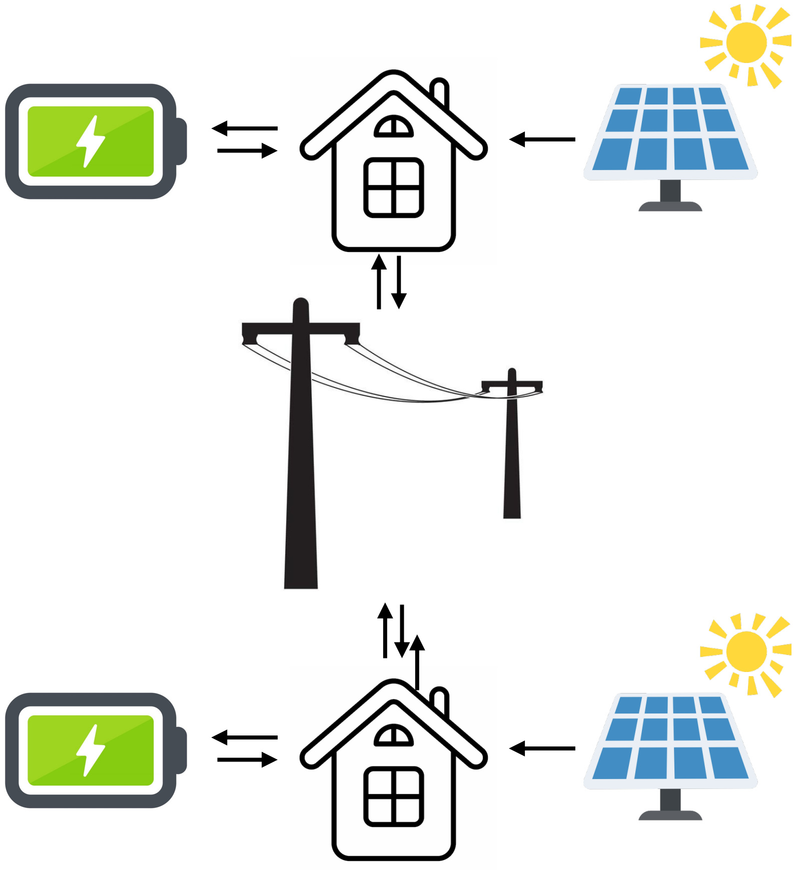
From « How » to « how much » + sharing

In the previous case, there is one single « paying agent ». What if several agents share costs and revenues, with different consumptions profiles ?

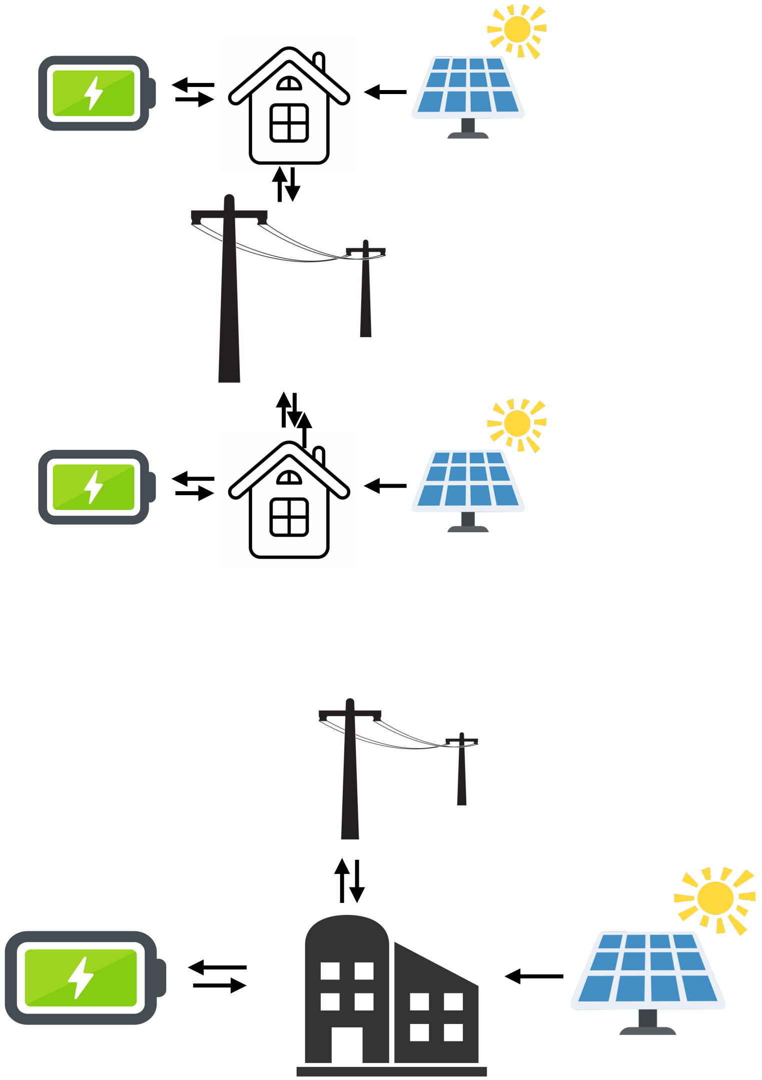


From « How » to « how much » + sharing

And what if they don't share costs, but still share energy?



From « How » to « how much » + sharing

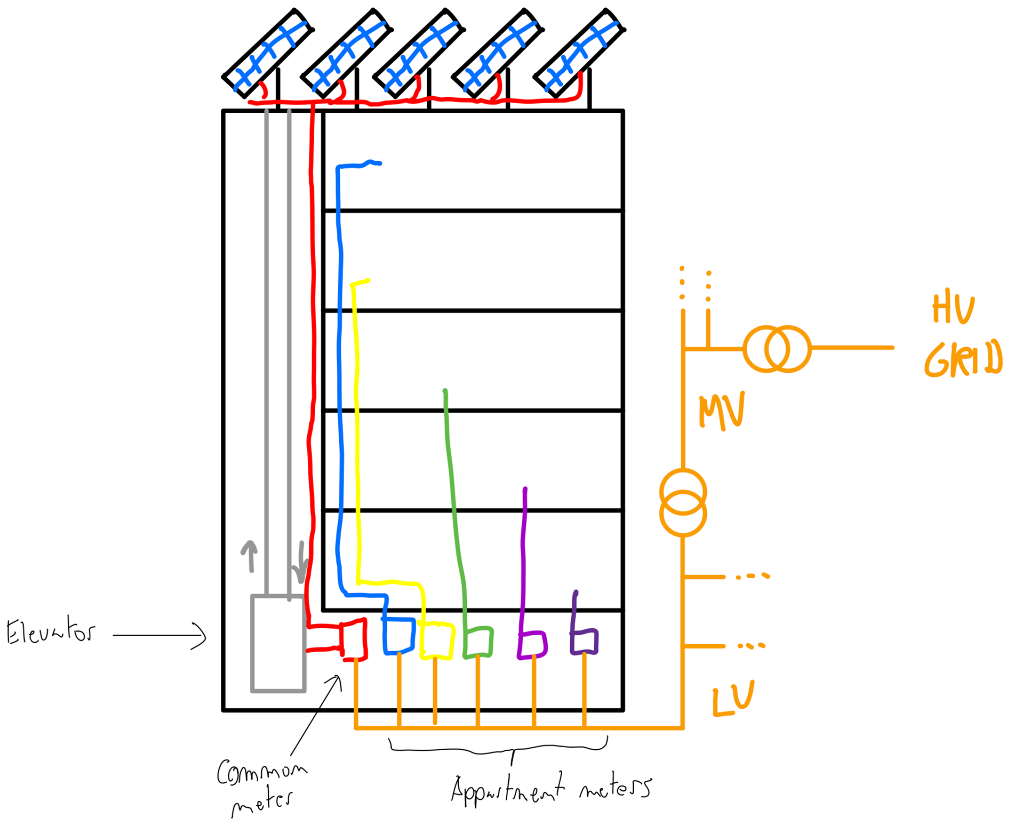


Every actor attemps to maximize its own gain.

Multiple objectives to be optimized concurrently, that influence each other => Game Theory and fairness issues!

Spoiler for what follows: REC are actually collaborative under reasonable hypothesis, but needs variable pricing.

Methods to share revenue



Let us assume that we are in a building like the following, but with 4 participants. All are the owner of their own appartment.

They collectively invest on the PVs and related equipments.

Concept of repartition key

A repartition key k is simply the vector representing how the shared energy is distributed.

$$k_i = \text{share of energy attributed to member } i$$

$$\sum_i k_i = 1$$

$$k_i \geq 0$$

In Wallonia, the repartition key needs to be sent to the DSO (ORES/RESA/…); with it, it can « redistribute the energy » counted at the meters and create the actual metering sent to the retailers for billing.

The key must be approved by the CWaPE. They provides three keys that are always accepted.

Fixed repartition key

	AVANT	PARTAGE	APRES PARTAGE		
	Consommations	Volumes alloués	Volumes partagés consommés	Alloconsommations	Excédents
Volume partagé	-	1000	-	-	-
Participant 1	160	250 – 25%	160	0	90
Participant 2	300	250 – 25%	250	50	0
Participant 3	350	250 – 25%	250	100	0
Participant 4	120	250 – 25%	120	0	130
TOTAL	930	1000	780	150	220

(Source: CWaPE)

The volume (here produced by the PV panels) is equitably shared between all participants – up to their consumption.

Anything that remains is kept by the coproperty (« the common meter »)

Energy actually shared: 78%
Autoconsumption: 84%
Surplus: 220 kWh

With a fixed key, we can obtain surplus even if the consumption of the whole building is sufficient to cover the production.

Fixed repartition key

	AVANT	PARTAGE	APRES PARTAGE		
	Consommations	Volumes alloués	Volumes partagés consommés	Alloconsommations	Excédents
Volume partagé	-	1000	-	-	-
Participant 1	160	400 – 40%	160	0	240
Participant 2	300	200 – 20%	200	100	0
Participant 3	350	200 – 20%	200	150	0
Participant 4	120	200 – 20%	120	0	80
TOTAL	930	1000	680	250	320

(Source: CWaPE)

The volume (here produced by the PV panels) is shared between all participants using a **pre-established key** – up to their consumption.

Anything that remains is kept by the coproperty (« the common meter »)

Energy actually shared: 68%
Autoconsumption: 73%
Surplus: 320 kWh

With a fixed key, we can obtain surplus even if the consumption of the whole building is sufficient to cover the production.

Dynamic repartition key

	AVANT	PARTAGE	APRES PARTAGE		
	Consommations	Volumes alloués	Volumes partagés consommés	Alloconsommations	Excédents
Volume partagé	-	1000	-	-	-
Participant 1	160	172 – 17%	160	0	12
Participant 2	300	323 – 32%	300	0	23
Participant 3	350	376 – 38%	350	0	26
Participant 4	120	129 – 13%	120	0	9
TOTAL	930	1000	930	0	70

(Source: CWaPE)

Repartition is made in function of the consumption; the more you consume, the more you receive, proportionally.

Energy actually shared: 93%
Autoconsumption: 100%
Surplus: 70 kWh

(Provably) maximises the autoconsumption.

Fairness?

Combining keys

The CWaPE indicates that multiple keys can be used simultaneously. The first key is applied, then a second is applied on the energy still not shared, then a third, etc.

For example, one could first use a fixed repartition key, then share the remaining energy using a dynamic one.

Equity aspects

The choice of the key is paramount for the community, and must be thoroughly discussed beforehand.

A dynamic repartition is optimal from an external viewpoint (environmental + community) but not necessarily from an internal viewpoint ("why does my neighbor, who consumes more and pays less attention, has the right to make more savings?").

Another important factor is the pricing of the shared energy.

Pricing aspects

There are two cases:

- The energy is produced throught a « common equipment » (like PV panels on a building, communly paid for by the coproprietors) – there is no competition.
- The energy is produced by equipments owned by individual members, who compete to sell their energy to their neighbors.

Anyway, the structure of the price is partially determined by external factors.

External factors on the price

First of all, it should be noted that the exchanged energy does indeed transit through the distribution network, **and therefore it is not exempt from all charges.**

For same-building-sharing, the shared energy is always subject to **surcharges, taxes, and 20% of distribution costs** (from 2025 onwards). This amounts to a reduction of "non-energy" costs by approximately 8.7c€/kWh.

For REC/CEC, there is no reduction in charges.

External factors on the price (2)

Once the cost of surcharges and distribution/transport fees, … are taken into account, the price of the energy itself can be set.

There is one global constraint on the sharing price:
- for any producer of energy, the price must be greater than the price it gets from its retailer;
- for any consumer, the price must be smaller than the price it gets from its retailer.

Otherwise, the members will not exchange energy and go directly to their retailer instead.

Determining the price – common equipment without competition

In a building, coproprietors own the PV panels which produce energy, that will be sold to the occupants of the appartments (who can be coproprietors or third parties).

The money gained from selling the energy gets back to the coproprietors.

The main points for setting the prices are then:
- The price of energy on the outside market
- The investment made/rentability wanted

Time to Excel

	Building share	Consumption	Retailer price	No-share costs	Shared (auto-con)	Allo-con	Costs (shared)	Costs (allo)	Energy bill	(Dividend)	Total		Money saved
Co-proprietor 1	50%	3500	0,20 €	700,00 €	1500	2000	180,00 €	400,00 €	580,00 €	-360,00 €	220,00 €		480,00 €
Co-proprietor 2	50%	2800	0,19 €	532,00 €	1500	1300	180,00 €	247,00 €	427,00 €	-360,00 €	67,00 €		465,00 €
Tenant 1	0%	3000	0,22 €	660,00 €	1500	1500	180,00 €	330,00 €	510,00 €		510,00 €		150,00 €
Tenant 2	0%	4000	0,18 €	720,00 €	1500	2500	180,00 €	450,00 €	630,00 €		630,00 €		90,00 €
Copro		-6000	0,05 €		-6000	0	-720,00 €	0,00 €	-720,00 €	720,00 €	0,00 €		
	Price	0,12 €			4							TOTAL	1 185,00 €

Increase the price…

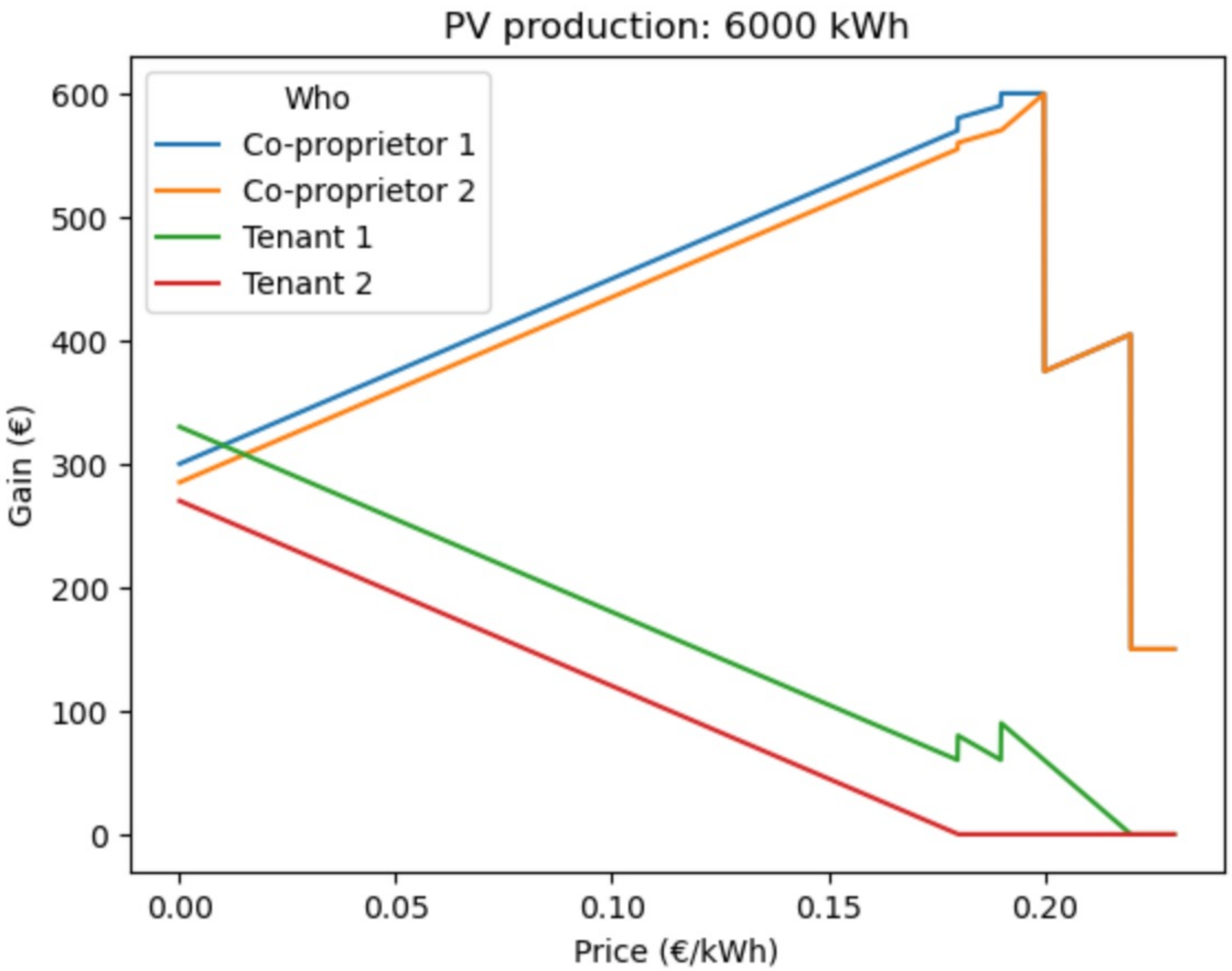
	Building share	Consumption	Retailer price	No-share costs	Shared (auto-con)	Allo-con	Costs (shared)	Costs (allo)	Energy bill	(Dividend)	Total		Money saved
Co-proprietor 1	50%	3500	0,20 €	700,00 €	1500	2000	255,00 €	400,00 €	655,00 €	-510,00 €	145,00 €		555,00 €
Co-proprietor 2	50%	2800	0,19 €	532,00 €	1500	1300	255,00 €	247,00 €	502,00 €	-510,00 €	-8,00 €		540,00 €
Tenant 1	0%	3000	0,22 €	660,00 €	1500	1500	255,00 €	330,00 €	585,00 €		585,00 €		75,00 €
Tenant 2	0%	4000	0,18 €	720,00 €	1500	2500	255,00 €	450,00 €	705,00 €		705,00 €		15,00 €
Copro		-6000	0,05 €		-6000	0	-1 020,00 €	0,00 €	-1 020,00 €	1 020,00 €	0,00 €		
	Price	0,17 €			4							TOTAL	1 185,00 €

Again…

	Building share	Consumption	Retailer price	No-share costs	Shared (auto-con)	Allo-con	Costs (shared)	Costs (allo)	Energy bill	(Dividend)	Total	Money saved
Co-proprietor 1	50%	3500	0,20 €	700,00 €	2000	1500	360,00 €	300,00 €	660,00 €	-540,00 €	120,00 €	580,00 €
Co-proprietor 2	50%	2800	0,19 €	532,00 €	2000	800	360,00 €	152,00 €	512,00 €	-540,00 €	-28,00 €	560,00 €
Tenant 1	0%	3000	0,22 €	660,00 €	2000	1000	360,00 €	220,00 €	580,00 €		580,00 €	80,00 €
Tenant 2	0%	4000	0,18 €	720,00 €	0	4000	0,00 €	720,00 €	720,00 €		720,00 €	0,00 €
Copro		-6000	0,05 €		-6000	0	-1 080,00 €	0,00 €	-1 080,00 €	1 080,00 €	0,00 €	
	Price	0,18 €			3						TOTAL	1 220,00 €

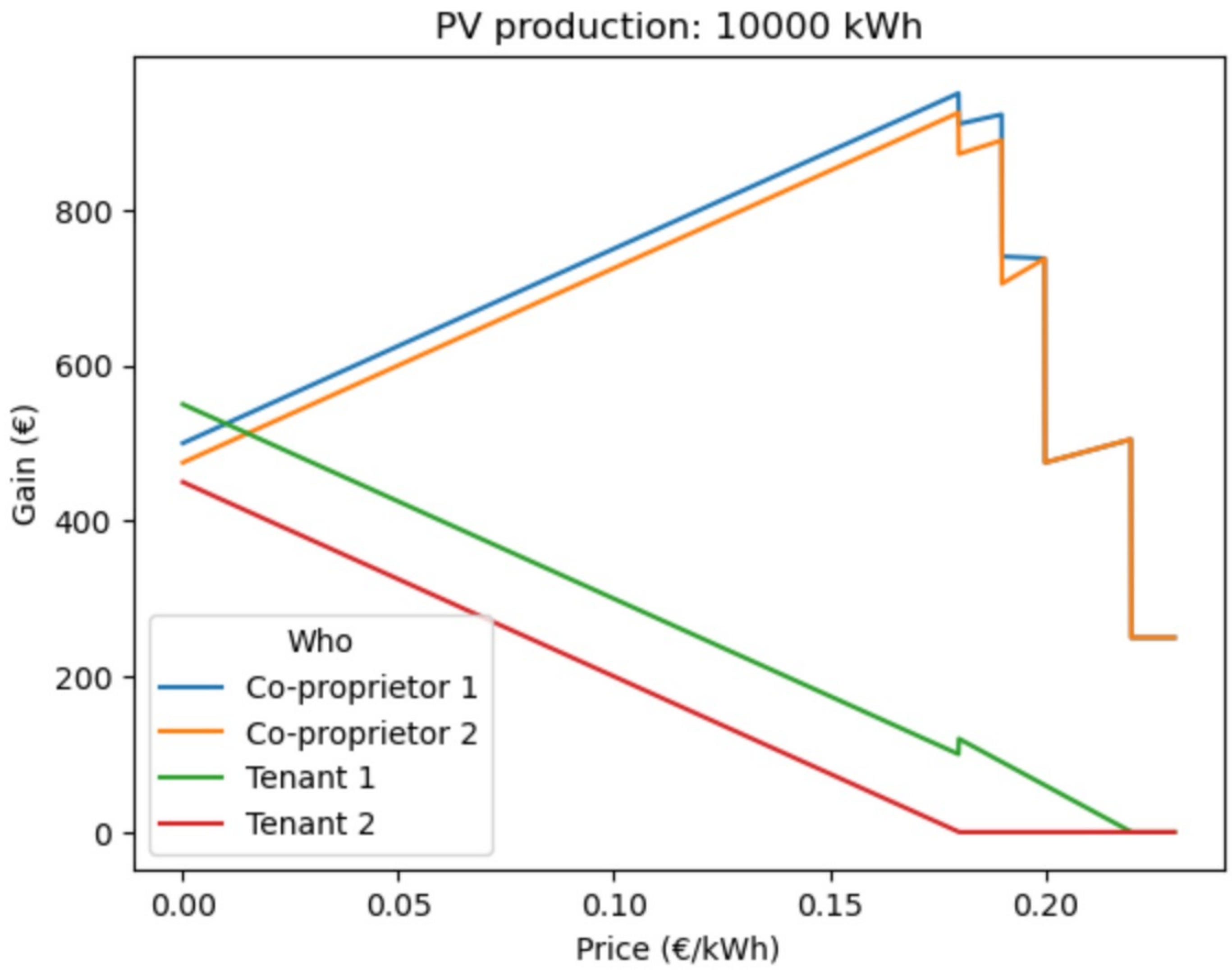
A plot is more readable

	Building share	Consumption	Retailer price
Co-proprietor 1	50%	3500	0,20 €
Co-proprietor 2	50%	2800	0,19 €
Tenant 1	0%	3000	0,22 €
Tenant 1	0%	4000	0,18 €
Copro		-6000	0,05 €



A plot is more readable

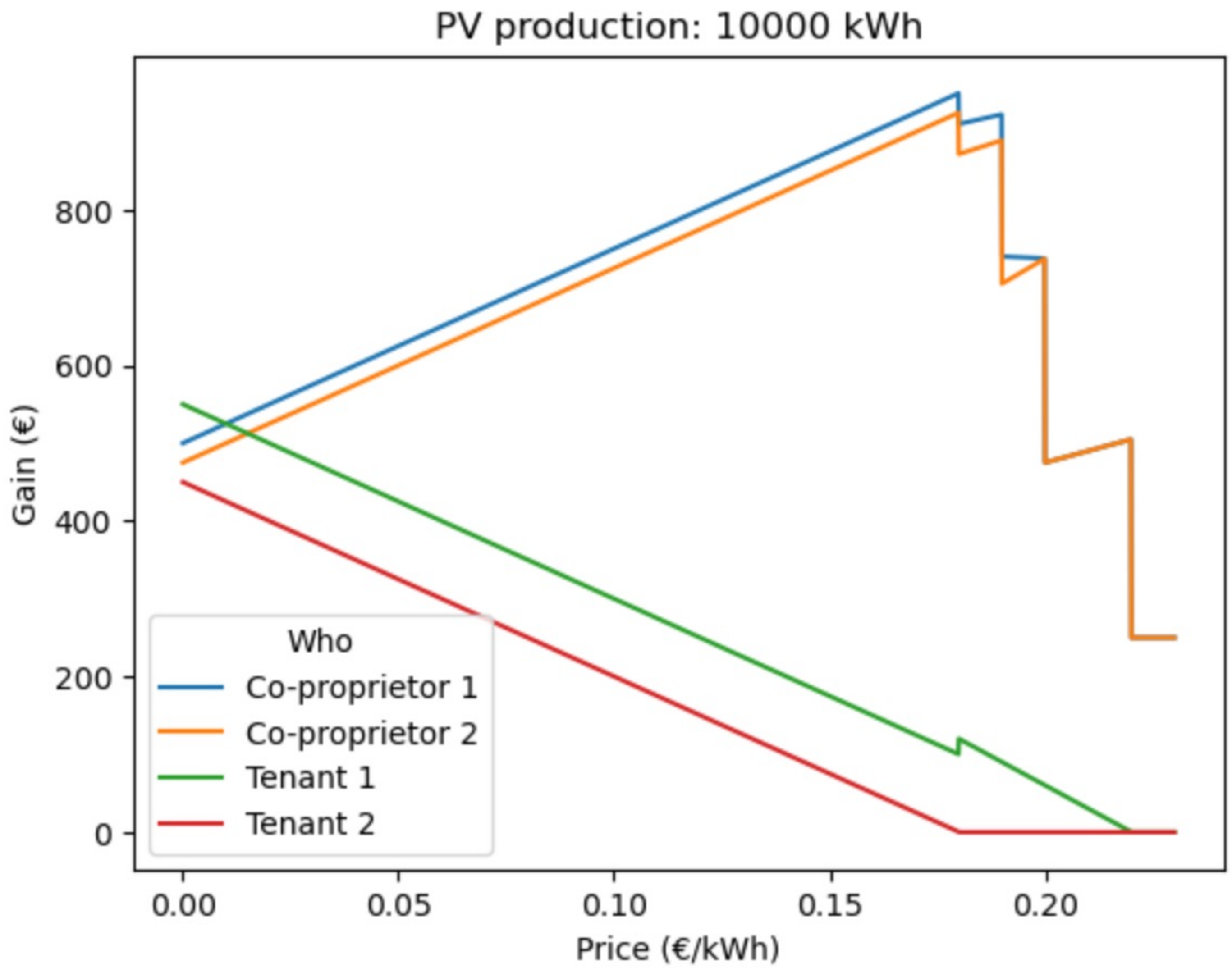
	Building share	Consumption	Retailer price
Co-proprietor 1	50%	3500	0,20 €
Co-proprietor 2	50%	2800	0,19 €
Tenant 1	0%	3000	0,22 €
Tenant 1	0%	4000	0,18 €
Copro		-6000	0,05 €



What do we learn?

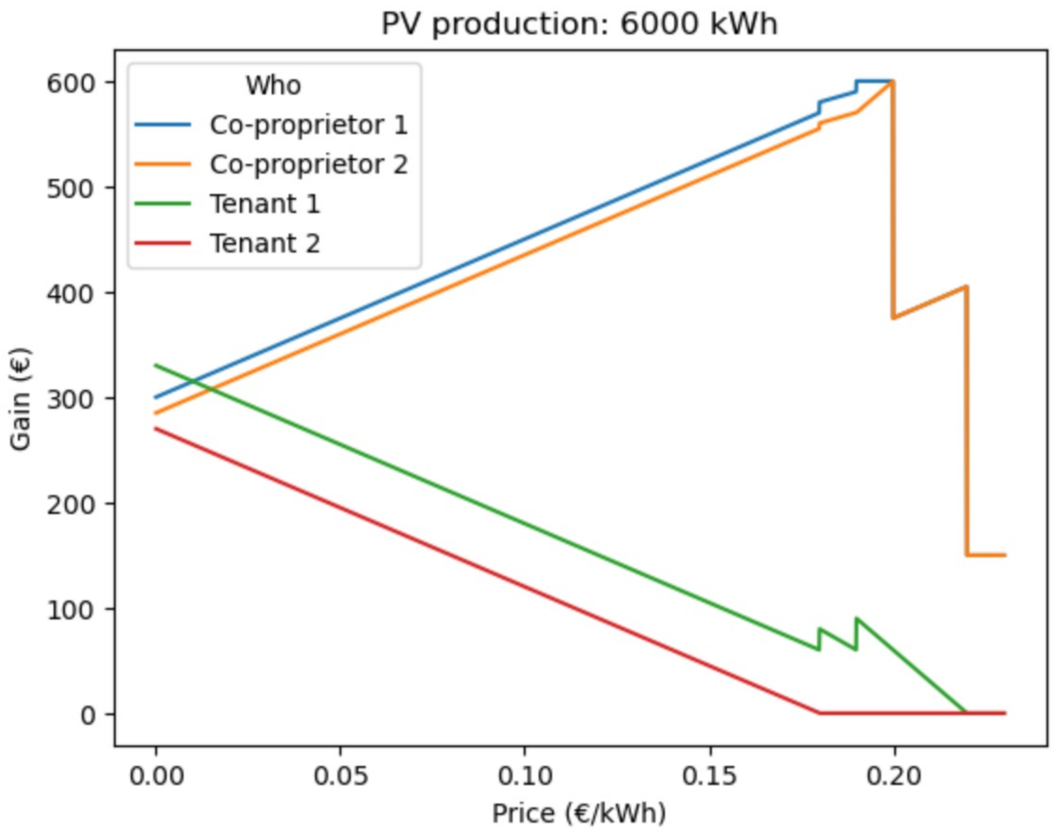
- There is competition between owners (co-proprietors) and tenants.
- Discontinuities around retail prices
- Excluding some tenants can raise the gains of the co-proprietors (and remaining tenants) (!)
- Optimal price for tenants is 0 (obviously). Optimal price for owners is just below the retail price of a tenant.
- Still, in the end, nobody loses anything…
- Fairness?

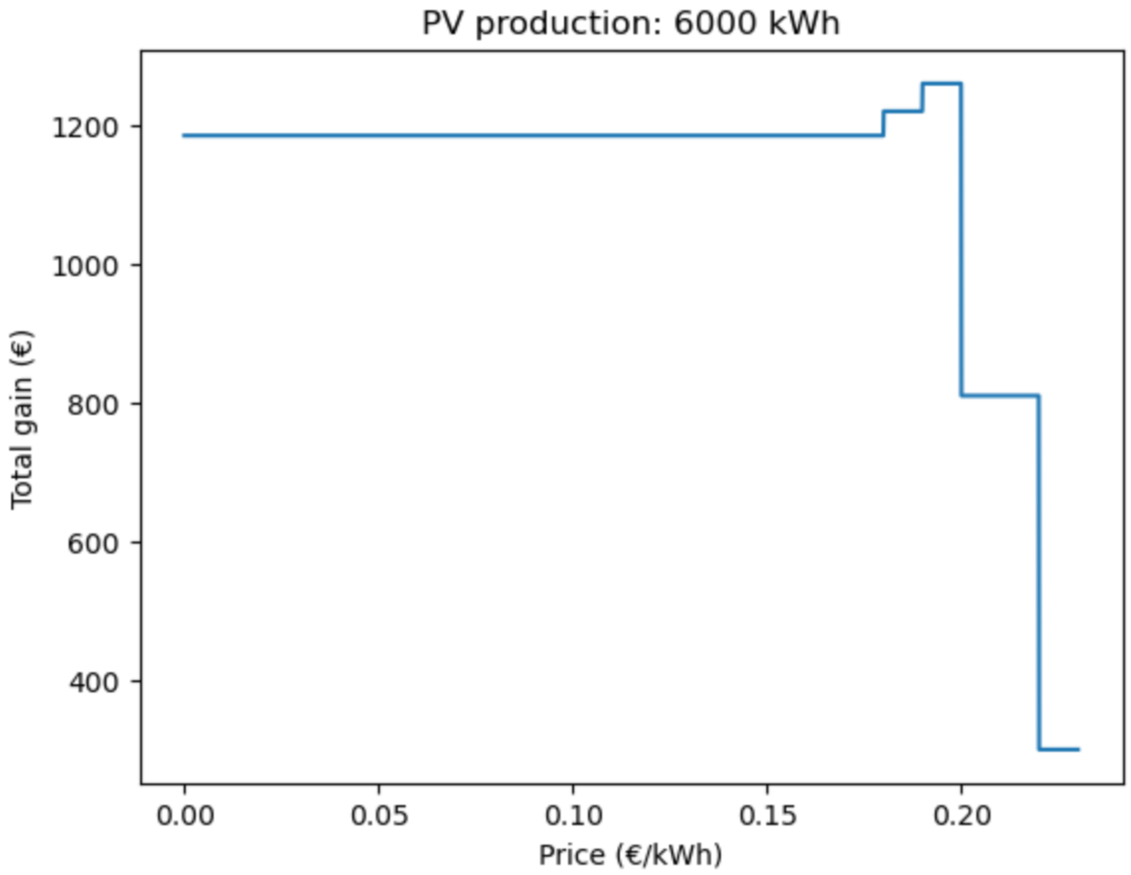
Note that this plot does not take into account the investment cost.



Fairness and common good

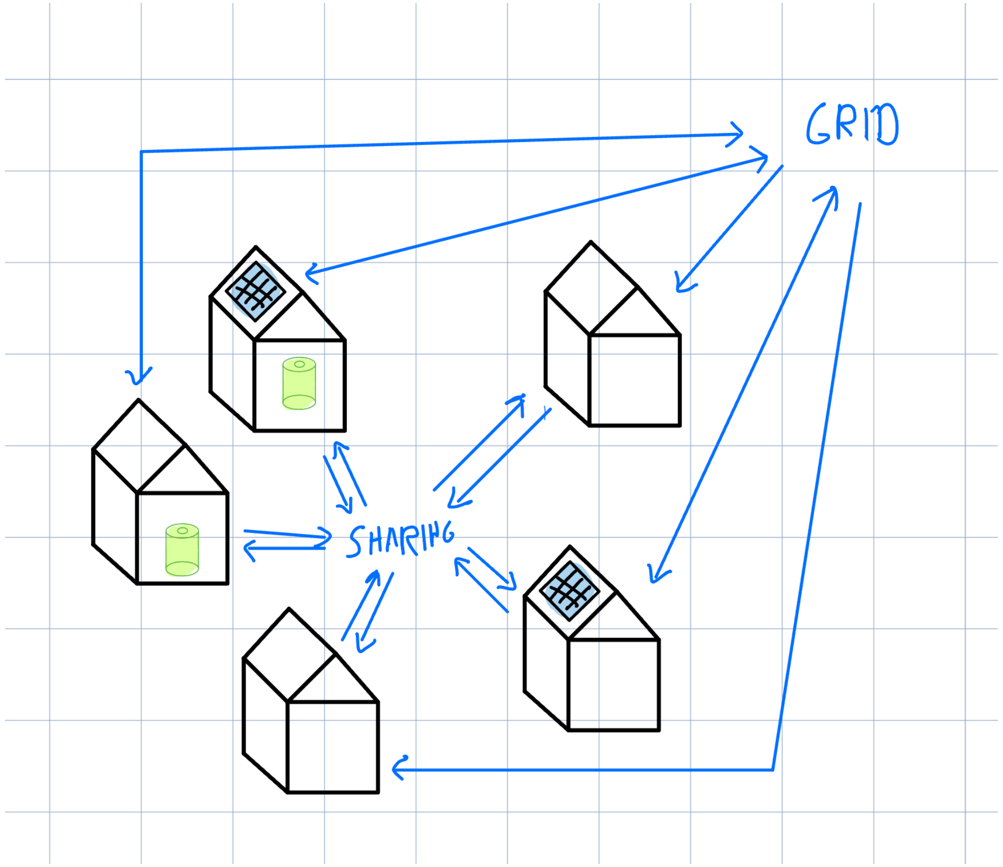
Maximizing the collective gain is not fair in general. Here we need to exclude a tenant and a co-proprietor ☺





Setting the price under competition

Now imagine that we have multiple members, in a REC. Some of them own PVs, batteries, or both or none of these. Each has is own retailer.



A bit of game theory

All actors will invest in their own capacities. More actors means (typically) lower prices, so less rentability and less investment. So the decision one member takes need to reflect the decision of the other members…

This is a game (in the game theoric sense).

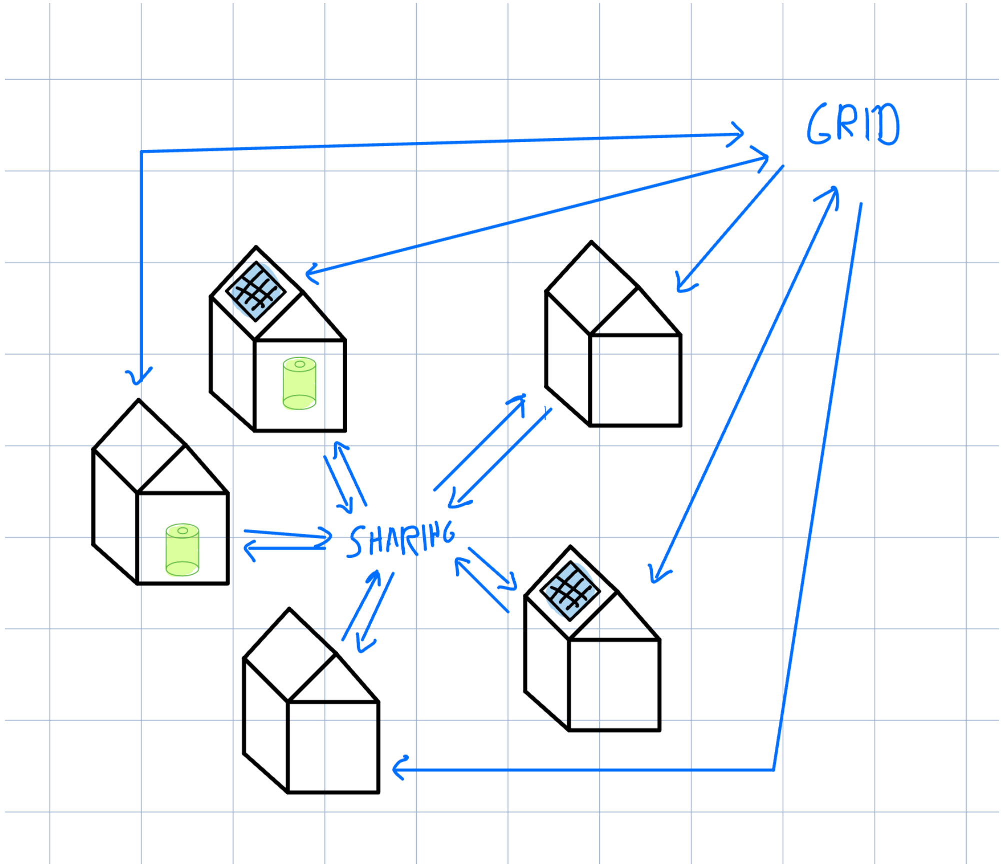
Determining the price

The standard setting is the same as previously: determine the price beforehand via a contract, and let people sell/buy shared energy at this price inside the REC.

The problems are the same: suboptimality of keys, politics, exclusion of members, fairness…

Let us assume that we instead have a market

In this case, nobody has market power; we assume no actors can set the price unilateraly and impose it to others.



Members will negociate the price to maximize their own gain. Sellers will try to sell at the highest price, and buyers will buy at the lowest price.

In this market, the common good is an equilibrium

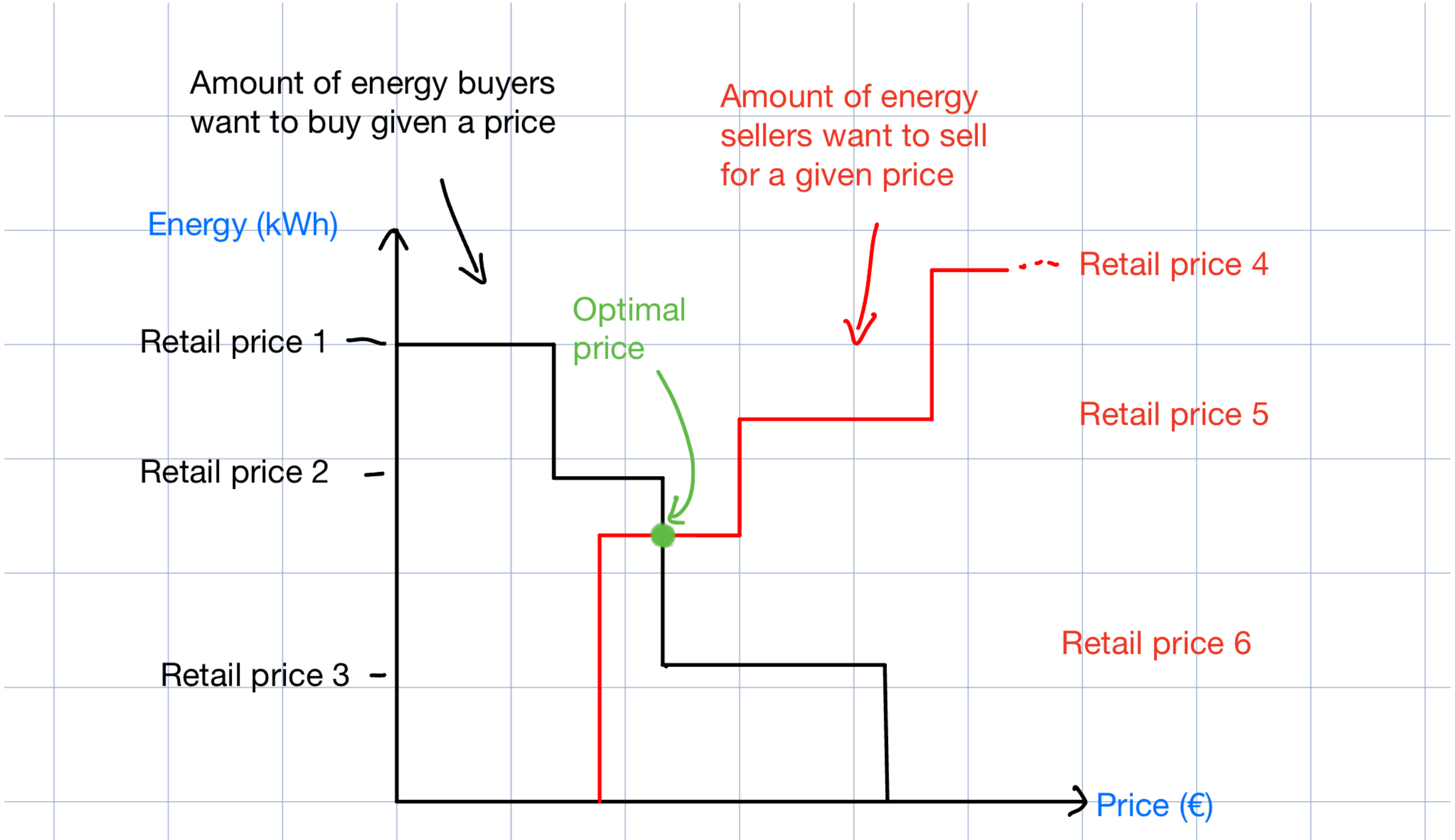
Let us first assume that we want to maximize the common good, that we define as the sum of everyone gains. Also consider that everything is linear, that no one has market power, has that everyone has perfect foresight.

In this case, the common good is an equilibrium for the game; if you let everyone optimize their strategy individually with perfect foresight of the actions of the others, they will reach that particular decision.

We skip the proof (hint: use the KKT conditions of both problems).

Optimal price in the competition setting

It can be determined using globally the same algorithm as in traditionnal energy markets:



Optimal price in the competition setting

Only some of the producers will share (those with a retail price lower than the sharing price), and only some of the consumer will take shared energy (those with a retail price higher than the sharing price).

It this a fairness issue?

Some political questions…

- The gain made by sharing is partially due to the difference between the price retailers buy the energy, and the price they sell the energy.

- But this difference is mostly due to the fact that there is only one (or two) single price for energy (« heure pleine » and « heure creuse »).

- Indeed, the cost of energy when the sun shines is very small compared to the price when it doesn’t (typically when consumption soars!).

When people share, they actually increase this delta for other users.

Some political questions…

- These other users are typically the ones without production capabilities, who cannot invest, and are in general a poorer part of the population.

- Is it ok?

- But at the same time, it reduces the stress on the distribution grid and makes investment in green energy easier. It can reduce some distribution costs, and can increase the amount of renewable energy produced.

- And now, is it ok?

Some political questions…

- Should we reduce the distribution/transport fees?

- It was decided to only reduce them for the « share-inside-same-building » setting. Two arguments for it:
    - It really uses a smaller part of the distribution network
    - Typically tenants are less privileged parts of the population

- If there isn't enough (shared) consumption, new PV installation can be overwhelm the local distribution network. Is it ok to reduce fee then, as the cost will be supported by others?

- Energy shared is *never* going throught the transportation network. Does it make sense to pay a fee for this?

Some political questions…

- Is the current model for fees (small fixed fee, large variable one) the correct way to handle RECs?

All these questions are complex. They depend on a lot of economic, social and technic considerations. They are also political; there is no single good answer.

Hands-on:

Let’s model some RECs using Gurobi and GBOML!

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Appendix

Other material to be eventually added

Simulation of a 3-phases unbalanced distribution network – over and under voltages