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Local Energy Communities: valuing flexibility for power market design and grid investment planning

Mirindra ANDRIANTSILAVINA, Rodica LOISEL, Lionel LEMIALE,

Jean-François RAMBAUD, Julien MOREAU

mirindra.andriantsilavina@univ-nantes.fr

Context

❑ French agreements for carbon neutrality

Increase renewables (33% of final consumption in 2030) and electrifying more usages (mobility, industry).

❑ Market Challenges

- Centralized markets: security of electricity supply. Issue to capture priority to local generation (integrate DR/ RES).
- Decentralized markets: issue to capture network constraints: new profiles + prosumers + DSO.

❑ Current routines on flexibility. Perspectives.

Flexibility centrally dispatched in France.

French TSO scenarios by 2050: DR 28 - 68 GW (~ 5 times more than today).

Motivation

- Local energy market as solution to DR, local RES, but remaining issues:
  - Emerging, experimental, too complex.
  - Few long-term signals to actors.
  - EC application is not ready yet (peer-to-peer?)
  - EC impacts on the whole energy system remains open.

- **Our topic** : Valuing flexibility for energy markets and design for future local markets.

Literature review. Contributions

1) <u>Demand Response</u> (Ponnaganti et al. 2023 , Dranka et al. 2022)

Price-based, incentive-based signals; energy efficiency VS DR (industry, organisation transformation).

- ➢ Contribution : distinction between central and local flexibility supply.

2) Market design (Ahlqvist et al 2022, Finon et al 2022) **+ flexibility markets** (Vagropoulos et al. 2022, Pichoud et al 2021)

Centralized / decentralized markets. Coordination DSO (congestion, voltage control, flexibility) - TSO (balancing).

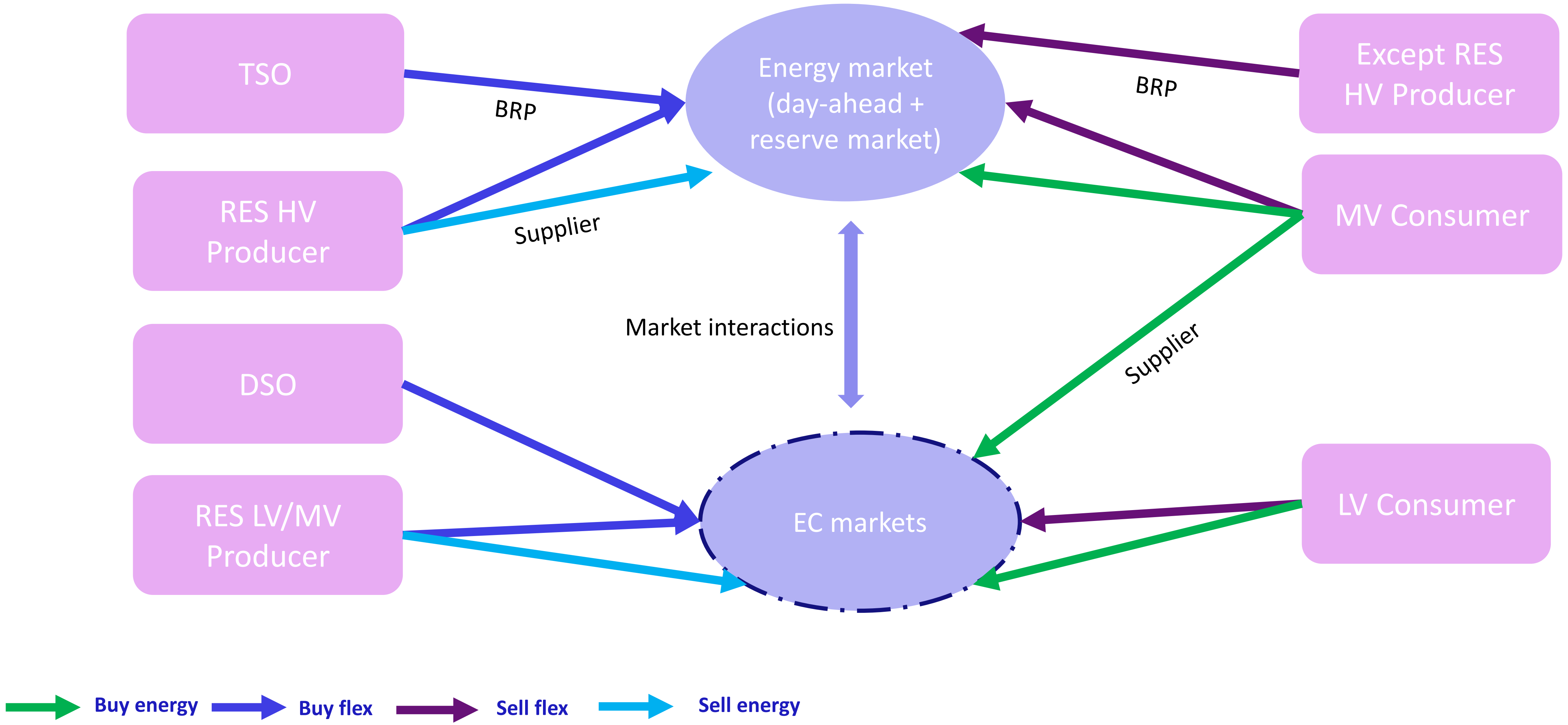
- ➢ Contribution: EC solutions with upscaling method and priority to local power.

3) Grid planning (González et al. 2022, Umoh et al. 2023) **+ grid pricing** (Gautier et al. 2021, Clastres et al. 2019)

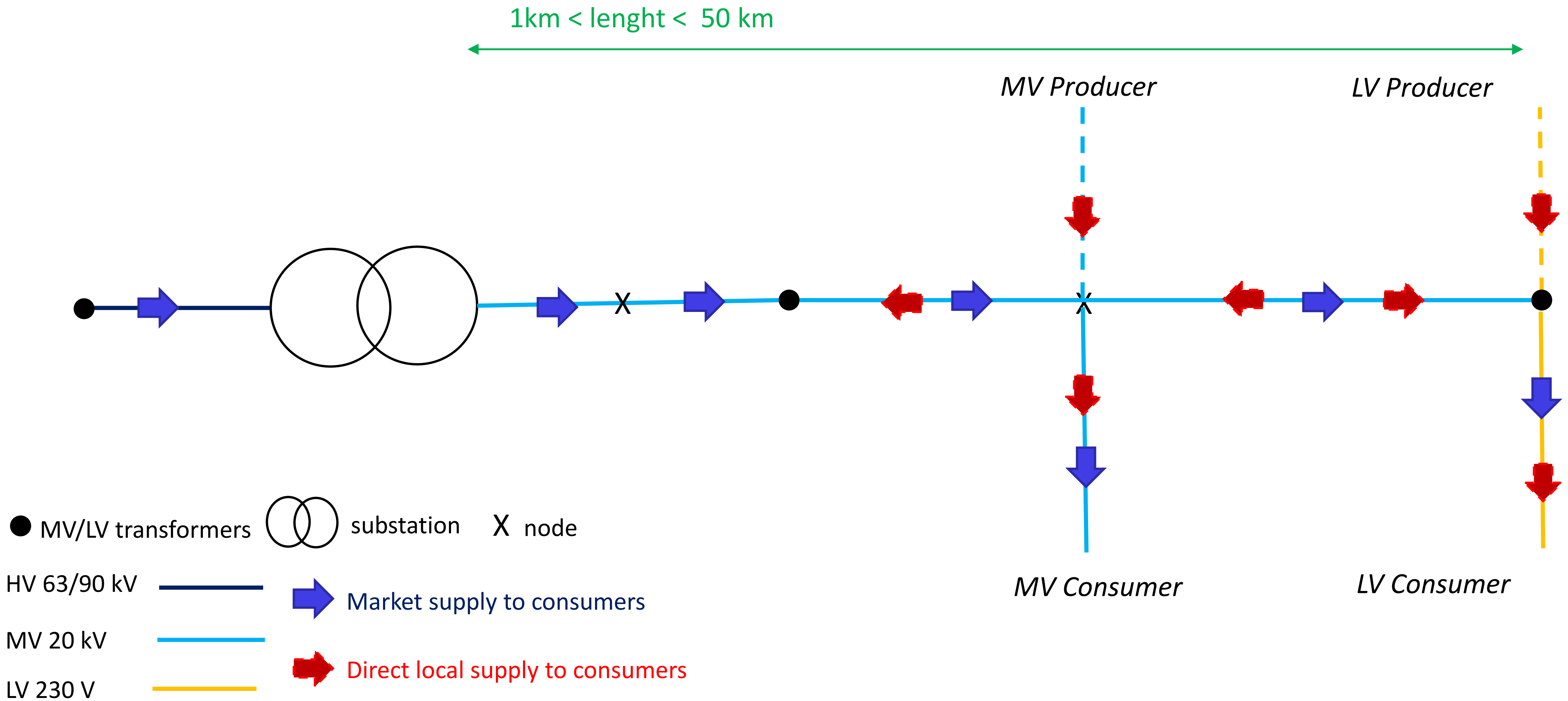
Avoided peaking capacity. Heterogeneous clients. Efficiency and equity of dynamic pricing.

- ➢ Contribution : index performance of flexibility = (opportunity cost) avoided grid reinforcement.

Flexibility and energy actors representation



Distribution grid basis for modeling EC and flexibility



Technical concepts: energy community + flexibility markets

Energy community assumptions

- Still connected to the grid
- Consumers supplied with local power generation OR
- Consumers with self-consumption (invest in their own solar panels OR/AND are flexible = prosumers)

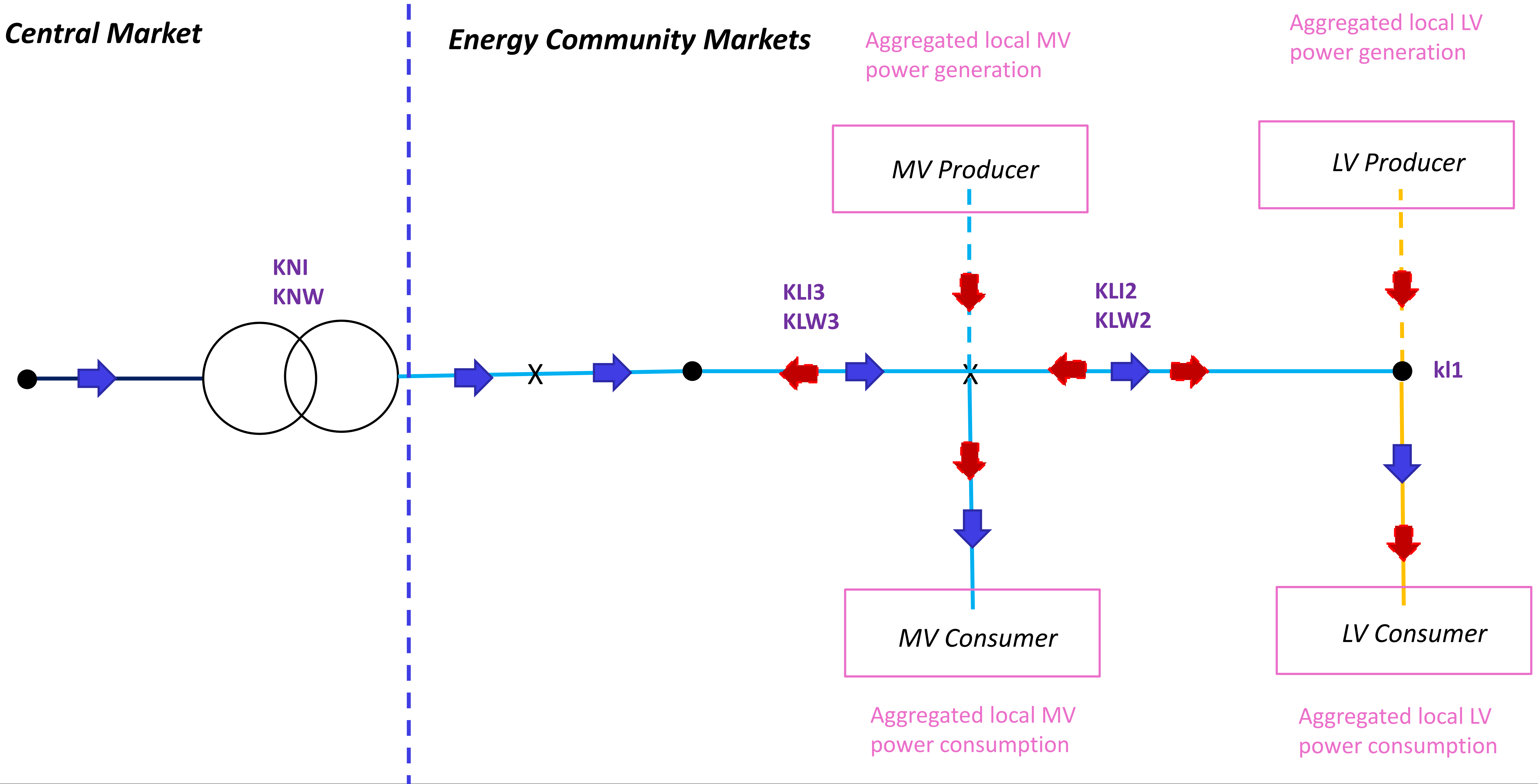
➢ Model Assumption : preference for local RES and energy loss minimisation

Local flexibility markets definition

Any load variation related to historical profile, due to:

- Cable constraints
- Congestion

Grid and power market representation



Methodology: framework and data

Cable constraints:
$gen^{MV} > \mathrm{KLW2}\ ;\ gen^{MV} > \mathrm{KLI2};\ gen^{MV} > kl1$, so curtailment.
$D^{MV} > \mathrm{KLW2}\ ;\ D^{MV} > \mathrm{KLI2};\ D^{MV} > kl1$, so negative flexibility.

Scenario	Capacity of electrical network, MW	Residential Building LV Demand , MW	Industrial Building MV Demand , MW	LV Solar capacity , MW	MV Solar capacity , MW
2022	KNI : 9 KNW : 80 KLI2 : 3 KLW2 : 8 KLI3 : 4 KLW3 : 9 kl1 : 1	0.0028	21	0.84	8.4

Case study: one substation HV/MV made of the available injection capacity KNI and withdrawal capacity KNS. 41 residential LV consumers, 36 kVA connected to 4 MV/LV transformers; 1 industrial consumer connected to MV concerned, solar PV power plants, PV 1 MWp and 10 MWp.

Methodology : problem formulation

Objective function: welfare maximization

$$\max_{FP_h^{LV}, FN_h^{LV}, FP_h^{MV}, FP_h^{MV}} obj = pmv_h^{LV} + plv_h^{LV} + pmv_h^{MV} + plv_h^{MV}$$

- Priority to local generation, electricity loss minimization.

Equilibrium constraint: demand = supply

$$D_h^{LV} - FP_h^{LV} - FN_h^{LV} = m_h^{LV} + pmv_h^{LV} + plv_h^{LV}$$
$$D_h^{MV} - FP_h^{MV} - FN_h^{MV} = m_h^{MV} + pmv_h^{MV} + plv_h^{MV}$$

- *Flexibility adjusts the balance (positive /negative).*

Curtailment accounting

$$curt_h^{LV} = potpv_h^{LV} * K_h^{LV} - plv_h^{LV} - plv_h^{MV}$$
$$curt_h^{MV} = potpv_h^{MV} * K_h^{MV} - pmv_h^{LV} - pmv_h^{MV}$$

Constraints

Demand Response postponement over one day

$$\sum_{h=1}^{24} FP_h^{LV} = \sum_{h=1}^{24} FN_h^{LV}$$

$$\sum_{h=1}^{24} FP_h^{MV} = \sum_{h=1}^{24} FN_h^{MV}$$

Demand Response bounds

$$\sum_{h=1}^{8760} FP_h^{LV} \leq \alpha * D_h^{LV}$$

$$\sum_{h=1}^{8760} FN_h^{LV} \leq \alpha * D_h^{LV}$$

$$\sum_{h=1}^{8760} FP_h^{MV} \leq \alpha * D_h^{MV}$$

$$\sum_{h=1}^{8760} FN_h^{MV} \leq \alpha * D_h^{MV}$$

Grid constraints

$$m_h^{MV} \leq KNS$$

$$m_h^{LV} \leq KNS$$

$$pmv_h^{MV} \leq KLI2$$

$$pmv_h^{MV} \leq KLW2$$

$$pmv_h^{LV} \leq KLI2$$

$$pmv_h^{LV} \leq KLW2$$

$$pmv_h^{LV} \leq kl1$$

$$plv_h^{MV} \leq kl1$$

$$plv_h^{MV} \leq KLI2$$

$$plv_h^{MV} \leq KLW2$$

$$plv_h^{LV} \leq kl1$$

Results: LV consumption in the reference scenario (2022)

Test 1: No flexibility market

- Low local consumption due to cable constraint (16% of consumption).

Test 2: Flexibility market (no target, no incentive)

- Decrease in local consumption (13 points) due to MV consumer flexibility.

Test 3: Flexibility market with incentives to rich a target (imposed flexibility target)

- Consumption Test 3 = Test 1, due to load shifting.
- Consumption Test 3 requires the same installed capacity (no peaking avoided).

Scenario 2022			
Demand 2022 & PV			
	No flexibility	Free flexibility	Imposed flexibility
		Flex 5%	Flex 5%
LV Consumption, kWh	**9 101**	**9 012**	**9 101**
MV local; Peak time High Season	1 160	209	1 160
MV local; Off-peak time High Season	129	9	129
MV local; Peak time Low Season	82	26	82
MV local; Off-peak time Low Season	-	-	-
LV local; Peak time High Season	72	7	72
LV local; Off-peak time High Season	2	-	2
LV local; Peak time Low Season	10	2	10
LV local; Off-peak time Low Season	-	-	-
Total LV local	1 455	253	1 455
Market; Peak time High Season	3 565	4 512	3 565
Market; Off-peak time High Season	2 799	2 908	2 799
Market; Peak time Low Season	742	798	742
Market; Off-peak time Low Season	540	540	540
Total LV market	7 646	8 759	7 646

MV consumption in the reference scenario (2022)

Test 1 and test 3

- Same qualitative results as in LV consumption.

Test 2

- Increase in MV consumption with respect to LV consumption due to increase in PV generation (1 point).

Scenario 2022			
Demand 2022 & PV			
	No flexibility	Free flexibility	Imposed flexibility
		Flex 5%	Flex 5%
MV Consumption, MWh	**81 500**	**82 478**	**81 500**
MV local ; Peak time High Season	11 467	12 469	11 467
MV local ; Off-peak time High Season	634	754	634
MV local ; Peak time Low Season	459	515	459
MV local ; Off-peak time Low Season	-	-	-
LV local ; Peak time High Season	1 210	1 275	1 210
LV local ; Off-peak time High Season	75	76	75
LV local ; Peak time Low Season	44	52	44
LV local ; Off-peak time Low Season	-	-	-
Total MV local	13 889	15 143	13 889
Market; Peak time High Season	37 388	37 184	37 388
Market; Off-peak time High Season	22 797	22 742	22 797
Market; Peak time Low Season	4 893	4 875	4 893
Market; Off-peak time Low Season	2 533	2 533	2 533
Total MV market	67 611	67 335	67 611

Flexibility

Scenario 2022			
Demand 2022 & PV			
	No flexibility	Free flexibility	Imposed flexibility
		Flex 5%	Flex 5%
Flexibility			
LV positive, kWh	-	5	455
LV negative, kWh	-	94	455
MV positive, MWh	-	52	4 077
MV negative, MWh	-	276	4 077

Test 2

- Positive flexibility supply is lower than negative flexibility due to preference for local generation

Test 3 (with targets on all flexibility types)

- Reproducing of total postponment

PV generation

Scenario 2022			
Demand 2022 & PV			
	No flexibility	Free flexibility	Imposed flexibility
		Flex 5%	Flex 5%
Local Power			
MV local power			
Capacity , MW	10	10	10
Generation, MWh	13 932	13 983	13 932
Curtailment, MWh	194	143	194
LV local power			
Capacity , MW	1	1	1
Generation, MWh	1 413	1 413	1 413
Curtailment, MWh	-	-	-

- Free market flexibility allows to generate more MV local power (1 point): avoided curtailment is higher than in other markets.
- There is no curtailment in LV local power due to no congestion.

Bill avoided by prosumers and grid operator

Scenario 2022			
Demand 2022 & PV			
	No flexibility	**Free flexibility**	**Imposed flexibility**
		Flex 5%	**Flex 5%**
Bill Avoided, €			
Avoided Grid reinforcement cost	58 329 000	42 870 000	58 329 000
LV Consumer bill variation	61 596	18 150	61 596

- With imposed flexibility, grid operator avoided reinforcement cost as well as with no flexibility target. In free flexibility market, we find the grid operator missing money due to curtailment avoided.
- With imposed flexibility market, the variation of the LV consumer bill is higher than in a free flexibility market. How about others consumers who are outside of this community?

- Grid hypothesis : average cost of solar insertion on the grid = 300k€/MW (Pichoud et al., 2021)
- LV consumers hypothesis : same taxes for consumer and prosumer

Sensitivity test with 10 %, 20% flexibility

- Avoided curtailment increase with flexibility rate in free flexibility market.
- Increase in local production does not mean increase in consumption.
- Flexibity from 5 to 10 % in free flexibility market allow to avoid the double of generation curtailment.

Scenario 2022			
Demand 2022 & PV			
	Free flexibility		Imposed flexibility
	Flex 10%	Flex 20%	Flex 5%
LV Consumption, kWh	8 917	8 751	9 101
Total LV local	251	221	1 455
Total LV market	8 666	8 530	7 646
MV Consumption, MWh	82 146	81 421	81 500
Total MV local	15 186	15 272	13 889
Total MV market	66 960	66 149	67 611
Flexibility			
LV positive, kWh	10	10	455
LV negative, kWh	195	360	455
MV positive, MWh	92	149	4 077
MV negative, MWh	650	1 461	4 077
Local Power			
MV local power			
Capacity , MW	10	10	10
Generation, MWh	14 024	14 080	13 932
Curtailment, MWh	102	46	194
LV local power			
Capacity , MW	1	1	1
Generation, MWh	1 413	1 413	1 413
Curtailment, MWh	-		-

Concluding remarks

Cable sizing

- Local flexibility alone cannot increase PV local consumption due to local grid congestion.

Size of the flexibility market

- Need to study the local congestion events.

Take away message:

- No need for incentive for integrating flexibility when preference for local PV OR market price > local PV
- Market for flexibility (with a price) necessary for larger shares than 5% (too narrow market) ....
- What is the level of curtailment socially, privately accepted?

Thank you for your attention!

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