A version of net metering for a set of households after the feed-in tariff regime

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Background and the purpose

A variety of feed-in tariff (FIT) schemes have widely been used for encouraging investment in power generation from renewables.

After FIT schemes achieve an intended amount of investment, a new pricing scheme should be introduced for the efficient use of renewable energies.

Then we should deal with some drawbacks current FIT schemes might have*: for example, installation at inappropriate sites and an enhanced burden on society.

In this study, we propose a new pricing scheme for the electricity generated with photovoltaic (PV) systems, and fed into the grid by households.

* Antonelli, M., Desideri, U. (2014) “The doping effect of Italian feed-in tariffs on the PV market”, Energy Policy, 67, 583–594.

Two key points

First, demand should play a role since it is difficult to control the supply of PV electricity; for example, if demands are smaller than supplies, the excess supply would be of little value. The payments for the PV electricity should be accordingly determined after trade.

Second, the payments for the PV electricity should be set locally. Changes in the supply are mainly caused by solar irradiation, which is deeply linked with the location of PV installation.

In light of those points, we propose a new scheme for a set of households in an area, taking account of the difference between the electricity supplied and demanded.

A related study

Chakraborty, P. et al. (2018)*

Addressed how to distribute a joint cost among a group of producers of electricity from renewables.

Introduced seven axioms to characterize just and reasonable allocation rules: equity, monotonicity, individual rationality, budget balance, standalone cost principle, penalty for causing cost, and reward for cost mitigation.

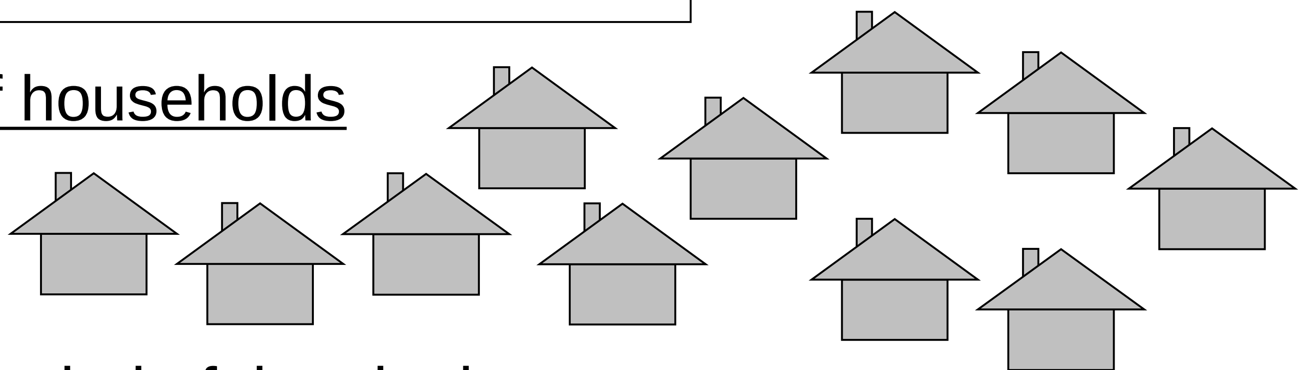
On the other hand, our scheme will directly apply the core of coalitional game theory to the problem of payoff distribution.

* Chakraborty, P. et al. (2018) “Cost causation based allocations of costs for market integration of renewable energy”, IEEE Transactions on Power Systems, 33(1), 70-83.

The model

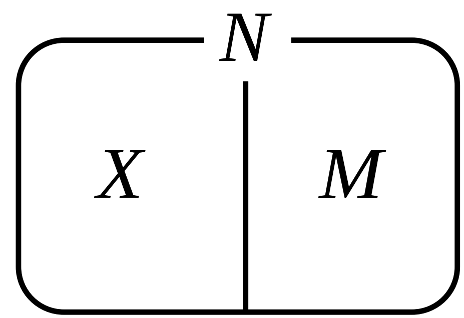
A coalitional game defined by $\langle N, v \rangle$

N : a set of households



Consider a period of time in the past.

N is divided into two disjoint subsets, X and M.



X: the set of net exporters of PV electricity

M: the set of net importers of electricity

x_i: the exports of net exporter $i \in X$

m_j: the imports of net importer $j \in M$

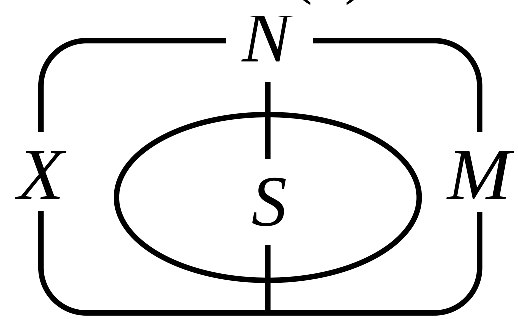
$\underline{v(S)\text{ : the worth of a coalition}}$ $S \subseteq N$

The total payoff available for division among the members of S.

We propose the following expression of $v(S)$.

For $S \subseteq N$

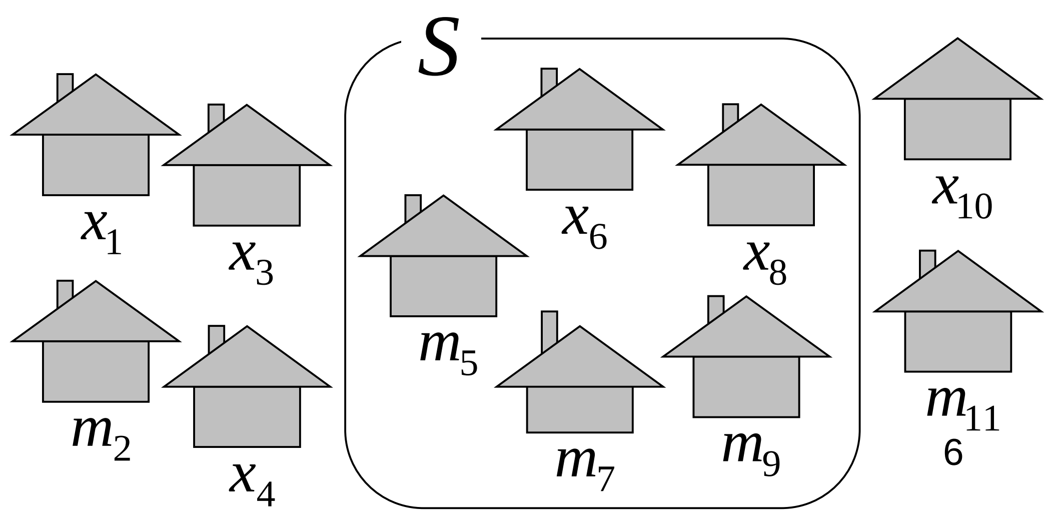
$$v(S) \equiv \min\left\{\sum_{i \in S} x_i,\ \sum_{j \in S} m_j\right\}$$



How much of the electricity imported was met by the PV electricity exported, or how much of the PV electricity exported was actually imported within S.

If $x_6 + x_8 < m_5 + m_7 + m_9$

then $v(S) = x_6 + x_8$

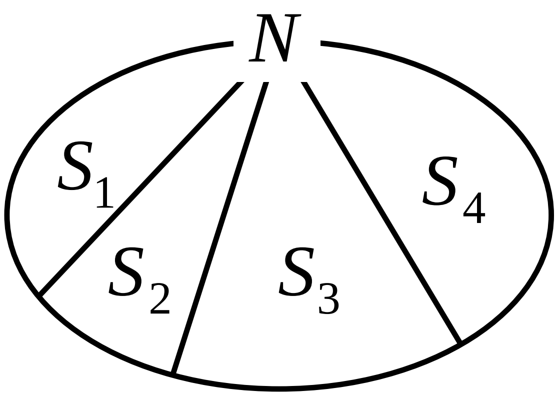


Proposition 1

$\langle N, v \rangle$ is cohesive.

If $N = \bigcup S_k$, where $S_k \cap S_l = \emptyset$ for any $k \neq l$

then $v(N) \geq \sum v(S_k)$



$$v(N)$$
$$\geq v(S_1) + v(S_2) + v(S_3) + v(S_4)$$

It is optimal that the coalition N of all households forms.

—PROBLEM—

How is $v(N)$ distributed among all the households so that no coalition forms to deviate from the grand coalition N?

A feasible payoff profile and the core

$(u_i)_{i \in N}$ is a feasible payoff profile if $\sum_{i \in N} u_i = v(N)$

A feasible payoff profile $(u_i)_{i \in N}$ is in the core if no coalition can attain a payoff that exceeds the sum of its member's u_i:

For any $S \subseteq N$

$$\sum_{i \in S} u_i \geq v(S)$$, or

$$\sum_{i \in S} u_i \geq \min\left\{\sum_{i \in S} x_i, \sum_{j \in S} m_j\right\}$$

A simple example

$$N = \{1,2,3,4,5\}$$

$$X = \{1,2,3\} \quad x_1 = 1, x_2 = 2, x_3 = 4$$

$$M = \{4,5\} \quad m_4 = 3, m_5 = 5$$

The core is formed by 31 constraints:

$$u_1 + u_2 + u_3 + u_4 + u_5 = 7$$
$$u_1 + u_2 + u_4 + u_5 \geq 3$$
$$u_1 + u_2 + u_3 \geq 0$$
$$u_1 + u_3 + u_4 \geq 3$$
$$u_2 + u_3 + u_4 \geq 3$$
$$u_3 + u_4 + u_5 \geq 4$$
$$u_1 + u_4 \geq 1$$
$$u_2 + u_4 \geq 2$$
$$u_3 + u_5 \geq 4$$

$$u_1 + u_2 + u_3 + u_4 \geq 3$$
$$u_1 + u_3 + u_4 + u_5 \geq 5$$
$$u_1 + u_2 + u_4 \geq 3$$
$$u_1 + u_3 + u_5 \geq 5$$
$$u_2 + u_3 + u_5 \geq 5$$
$$u_1 + u_2 \geq 0$$
$$u_1 + u_5 \geq 1$$
$$u_2 + u_5 \geq 2$$
$$u_4 + u_5 \geq 0$$

$$u_1 + u_2 + u_3 + u_5 \geq 5$$
$$u_2 + u_3 + u_4 + u_5 \geq 6$$
$$u_1 + u_2 + u_5 \geq 3$$
$$u_1 + u_4 + u_5 \geq 1$$
$$u_2 + u_4 + u_5 \geq 2$$
$$u_1 + u_3 \geq 0$$
$$u_2 + u_3 \geq 0$$
$$u_3 + u_4 \geq 3$$
$$u_1, u_2, u_3, u_4, u_5 \geq 0$$

There are generally multiple feasible payoff profiles in the core. What should we select among them?

Assumptions

Assumption 1

$$\sum_{i \in X} x_i < \sum_{j \in M} m_j$$

The exports were smaller than the imports.

The shortfall was fulfilled by backup power sources.

Assumption 2

Every exporter’s reservation price is 0.

An exporter is willing to export as long as the price is not less than 0;

Every importer’s reservation price is 1.

An importer is willing to import as long as the price is not greater than 1.

A special feasible payoff profile in the core

We pick the following feasible payoff profile in the core

$$u_i = \begin{cases} x_i & i \in X \\ 0 & i \in M \end{cases}$$

(Remember $\sum_{i \in X} x_i < \sum_{j \in M} m_j$)

The unit payoff is

$$\frac{u_i}{x_i} = 1 \quad i \in X \qquad \frac{u_j}{m_j} = 0 \quad j \in M$$

<u>This means that the PV electricity is priced at 1.</u>

If $\sum_{i \in X} x_i > \sum_{j \in M} m_j$ is assumed, the result is reversed.

$$u_j = \begin{cases} 0 & j \in X \\ m_j & j \in M \end{cases}$$

The example revisited

$$N = \{1,2,3,4,5\}$$

$$X = \{1,2,3\} \quad x_1 = 1,\ x_2 = 2,\ x_3 = 4$$

$$M = \{4,5\} \quad m_4 = 3,\ m_5 = 5$$

Note $x_1 + x_2 + x_3 < m_4 + m_5$.

The feasible payoff profile we propose is

$$u_1 = 1, u_2 = 2, u_3 = 4, u_4 = 0, u_5 = 0$$

which satisfies the 31 constraints:

$$u_1 + u_2 + u_3 + u_4 + u_5 = 7$$
$$u_1 + u_2 + u_4 + u_5 \geq 3$$
$$u_1 + u_2 + u_3 \geq 0$$
$$u_1 + u_3 + u_4 \geq 3$$
$$u_2 + u_3 + u_4 \geq 3$$
$$u_3 + u_4 + u_5 \geq 4$$
$$u_1 + u_4 \geq 1$$
$$u_2 + u_4 \geq 2$$
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$$u_2 + u_3 + u_4 + u_5 \geq 6$$
$$u_1 + u_2 + u_5 \geq 3$$
$$u_1 + u_4 + u_5 \geq 1$$
$$u_2 + u_4 + u_5 \geq 2$$
$$u_1 + u_3 \geq 0$$
$$u_2 + u_3 \geq 0$$
$$u_3 + u_4 \geq 3$$
$$u_1, u_2, u_3, u_4, u_5 \geq 0$$

The unit payoffs are

$$\frac{u_1}{x_1} = \frac{u_2}{x_2} = \frac{u_3}{x_3} = 1 \qquad \frac{u_4}{m_4} = \frac{u_5}{m_5} = 0$$

Connection with a competitive equilibrium

Consider an economy:

Every agent $i \in N$ has only one kind of resource, x or m.

Every agent can trade x and m on a market.

A production function is $f(x,m) = \min\{x,m\}$ for every i.

Assume that the reservation prices induce $0 \le p_x, p_m \le 1$

Suppose

$$\sum_{i \in N} x_i < \sum_{j \in N} m_j$$

Then, the equilibrium prices are

$$p_x = 1 \quad p_m = 0$$

This indicates that our pricing scheme is closely connected with a competitive equilibrium.

Relation to net metering

Consider a certain period of time in the past.

Net metering

For a single household,

if the consumption > the production,
the net consumption is priced at the standard rate;

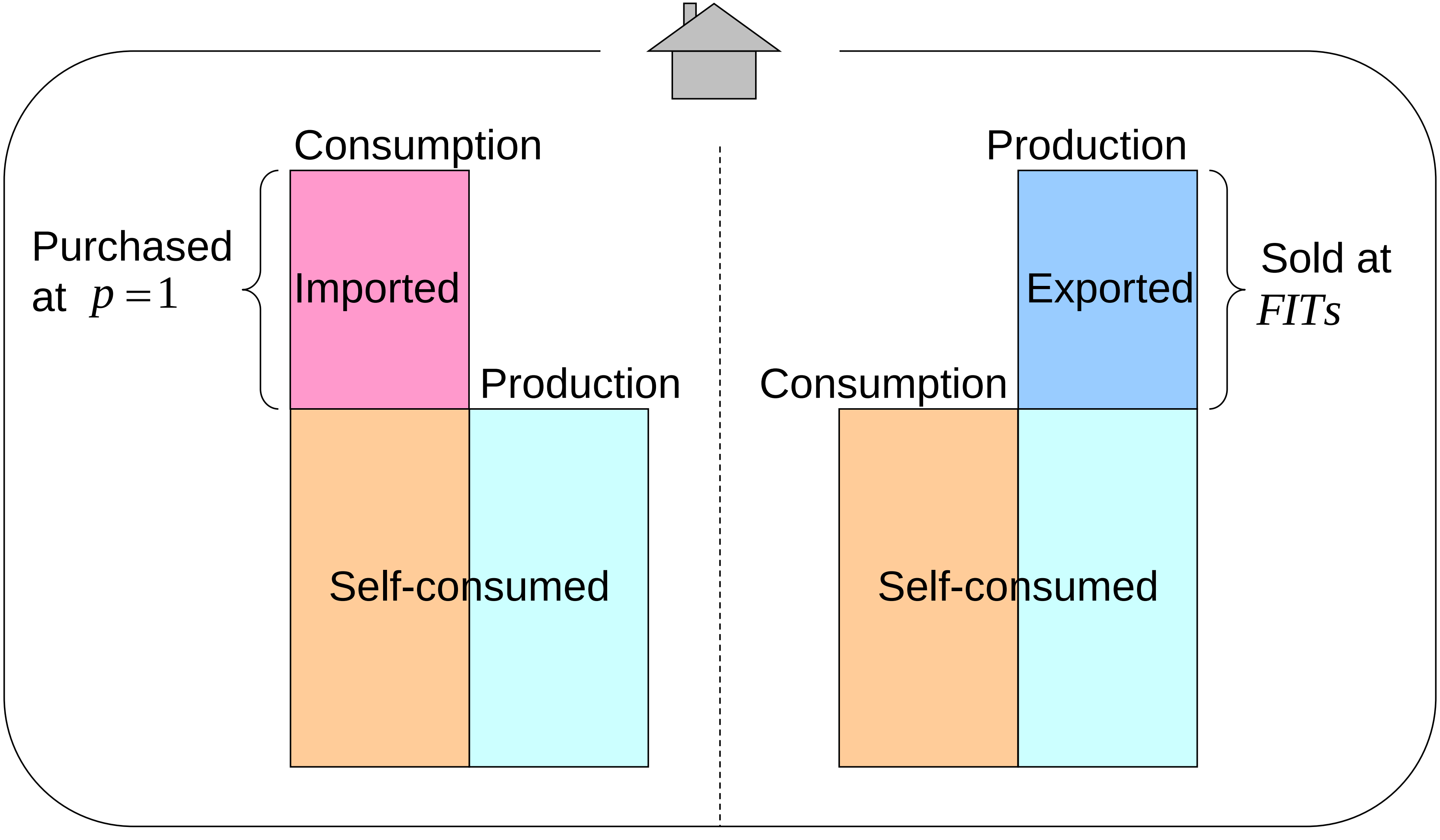
if the production > the consumption,
the net production is priced at the feed-in tariff.

Our pricing

Concerned with a set of households.

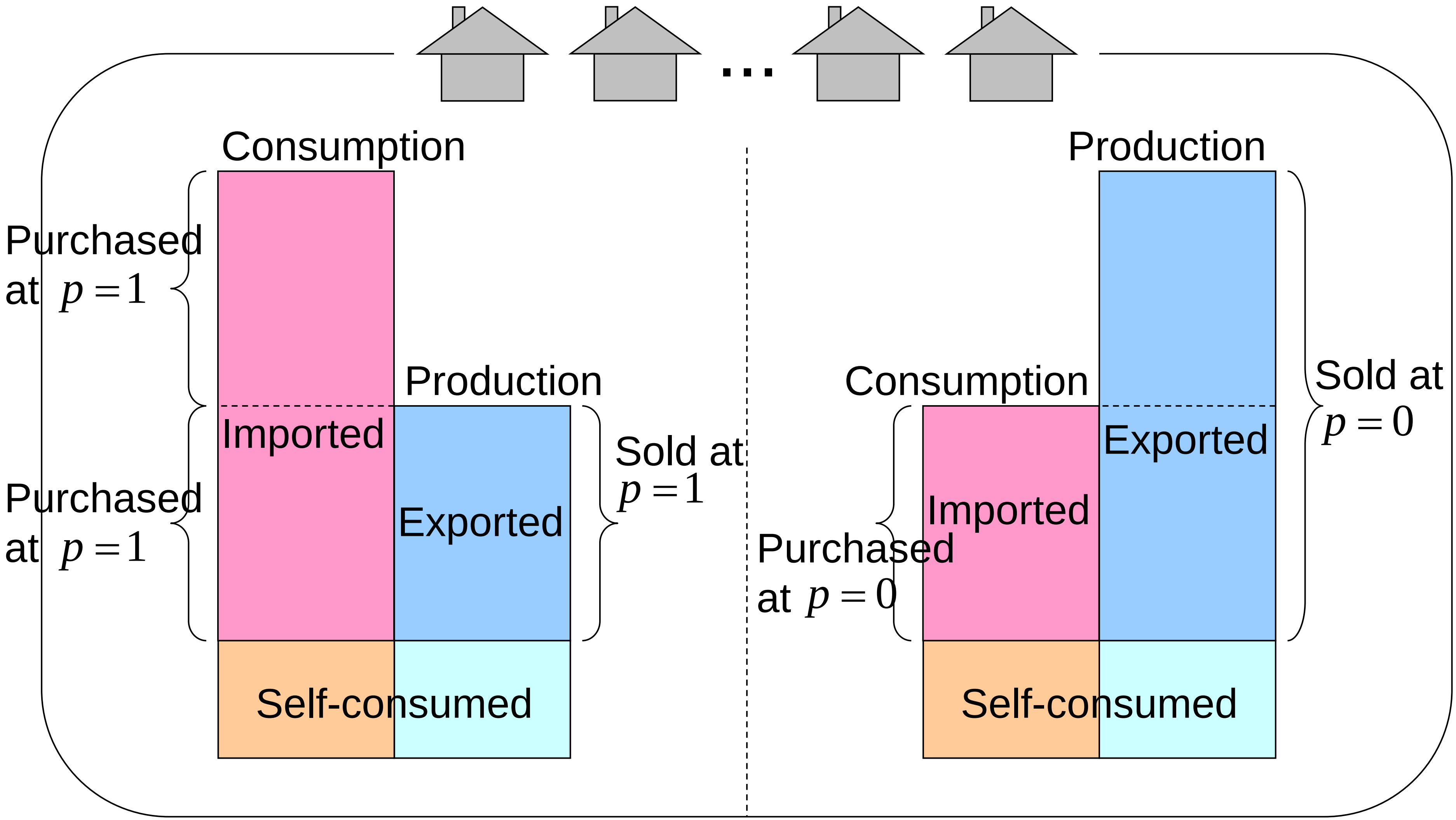
Looks at the difference between the sum of production and the sum of consumption.

Net metering



The standard electricity rate is presumed $p=1$.

Our pricing



The standard electricity rate is presumed $p=1$.

Discussion

Under our scheme, the price is determined by the difference between the total amount of PV electricity exported and the total amount of electricity imported.

Our scheme is closely connected with a competitive equilibrium; it may involve efficiency.

The scheme is related to net metering. It may be considered in some way as an extended version of net metering to a group of households.

The pricing may not be balanced in that only one side of the exporters and importers is rewarded.

Conclusion

We proposed a new scheme of remunerating households for the PV electricity exported.

The worth of a coalition of households was defined based on the net exports or net imports of electricity.

The core of the coalitional game was applied.

The scheme may be biased. A further investigation is needed into what is a more moderate scheme.

More detailed examination, including simulation, is needed for practical use of this scheme.

Thank you for your attention.

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