The Prosumers and the Grid

Axel Gautier[1], Julien Jacqmin[2] and Jean-Christophe Poudou[3]

1. HEC Liege, University of Liege, LCII and CORE
2. HEC Liege, University of Liege
3. LAMETA, University of Montpellier and LabEx "Entreprendre"

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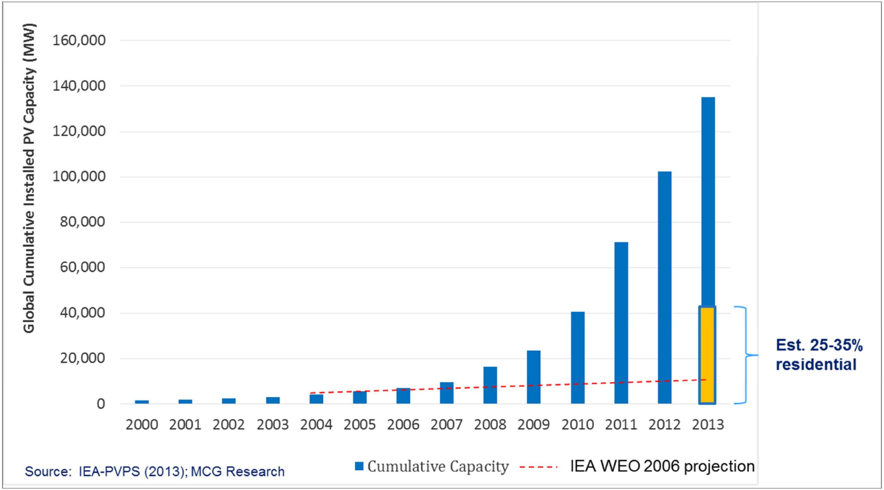
**WORKSHOP CEEM-CEC-CGEMP
ON ELECTRICITY DEMAND:
NEW MODELLING PERSPECTIVES**

Introduction: Motivations

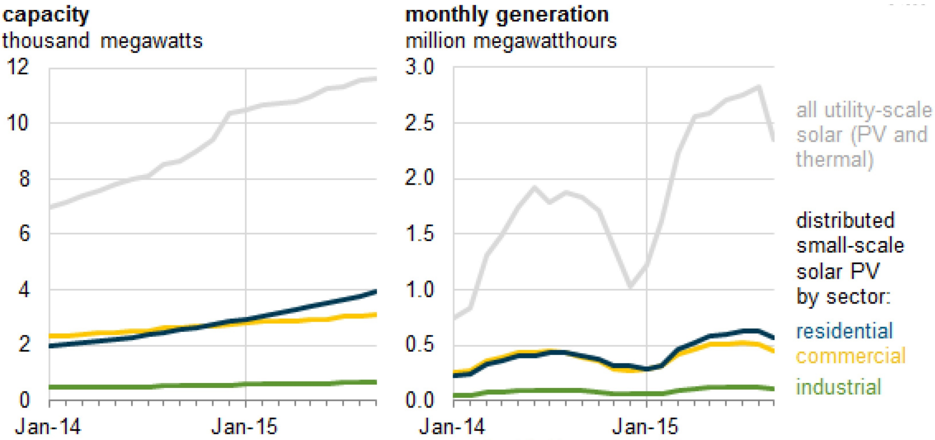
Prosumers are households that are both PROducers and conSUMERS of electricity

- Possible thanks to decentralized production units (DPU, mostly photovoltaic panels)
- A trendy issue but not yet a revolution
- Blury frontier also observed in the social media and “sharing” economy

Worldwide installed PV capacities



U.S. solar capacity and generation (EIA)



Source: U.S. Energy Information Administration, *Electric Power Monthly*,

Research question

How to integrate the excess electricity produced by the DPU to the energy grid?

Two main approaches are observed throughout the world:

1. Net metering (aka single metering)
2. Net purchasing (aka double metering/net billing)

Introduction: Motivations

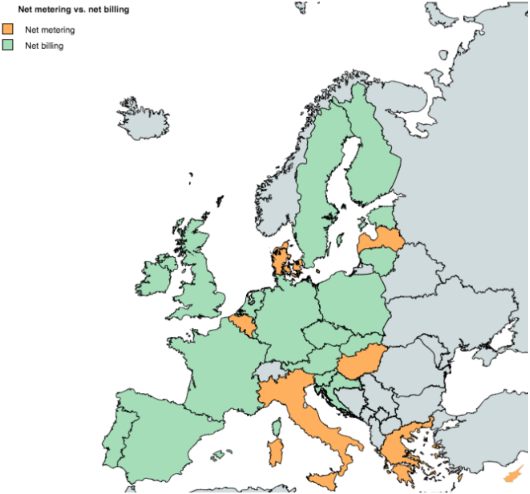
Net metering / single metering

"runs" backwards if electricity is exported to the grid

Net purchasing / double metering

Imports and exports to the grid are measured separately

Introduction: Motivations



Introduction: Main ideas

Compare the two technologies with respect to

- The deployment of DPU
- Grid costs and tariffs
- Redistributional concerns between users and prosumers
- Incentives to synchronize consumption and production

Key features of the model:

- Endogenize the decision to invest in DPU
- Tariff(s) set such that the grid owner breaks even

Introduction: Main results

Net metering

- leads to too much investments in DPU compared to the first best
- is very advantageous for prosumers...less for consumers
- discourages synchronization of production and consumption

Net purchasing

- leads to social efficiency as tariffs can be set at marginal cost levels
- is more flexibility than net metering
- is more effective for synchronization of production and consumption

Conclusions can be challenged if we introduce environmental impacts of DPU

Model: Consumers and prosumers

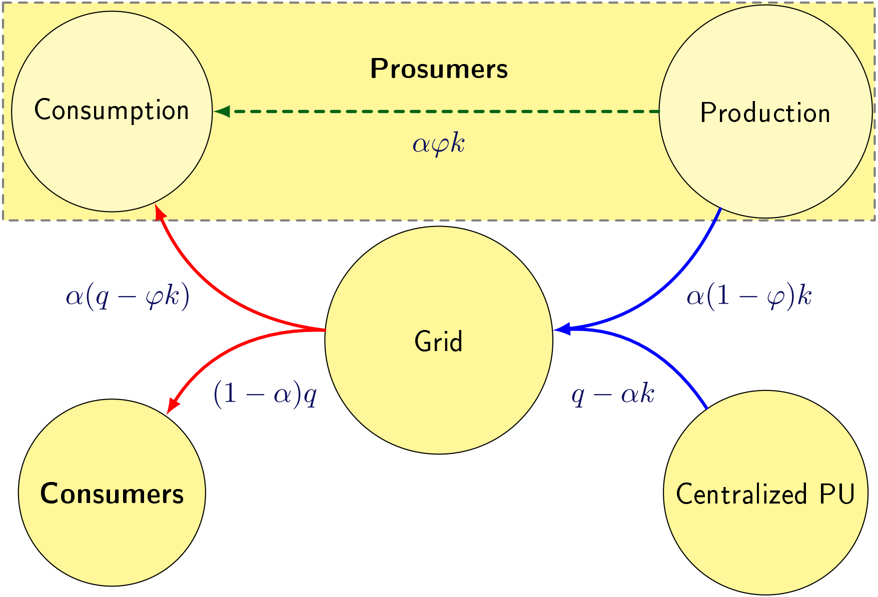
Installation cost of a DPU producing k MWh: zk

z is heterogeneous with cumulative $F(z)$

$1-\alpha$ consumers buy $q \geq k$ units at electricity price p

α prosumers

$\varphi \in [0, 1]$: synchronization factor of a prosumer



Legend. - - - - -► : Self-Consumption, ——► : Imports, ——► : Exports.

Model: Grid

Volume of imports and exports with the grid:

$$\begin{aligned} V_m &= \alpha(q - \varphi k) + (1 - \alpha)q = q - \alpha\varphi k \\ V_x &= \alpha(1 - \varphi)k \end{aligned}$$

The export and import unit cost per MWh: $\theta_m = \theta_x = \theta$

Total variable cost of the grid:

$$C_d(\alpha) = (V_m + V_x)\theta = (q - \alpha(1 - 2\varphi)k)\,\theta$$

Grid regulation: tariff set the DSO breaks even, such as $R = C_d\,(\alpha) + K$

Non discriminatory two part tariff $(t = K)$ *à la* Coase.

First best

Social cost of generation and distribution with $\alpha = F(z)$

$$\begin{aligned} C(z) &= C_g(z) + C_d(z) \\ &= (p+\theta)\,q - F(z)\,kp + H(z)\,k + F(z)\,(1-2\varphi)k\theta \end{aligned}$$

The benevolent social planner minimizes $C(z)$ with respect to z.

$$z^* = p - (1-2\varphi)\,\theta$$

Valued at the MC of centralized generation minus the additional network cost of DPU

idem Brown & Sappington, 2016

Net metering

The grid tariff rate is r per MWh

Utility of investing in PV producing k MWh

$$U(z) = \begin{cases} S - (p+r)(q-k) - zk & \text{if } k > 0 \\ S - (p+r)q & \phantom{\text{if }} k = 0 \end{cases}$$

Indifferent between consumers and prosumers at: $\tilde{z} = p + \tilde{r}\left(\tilde{z}\right)$

Where the break-even network tariff: $\tilde{r}\left(z\right) = \frac{C_d(F(z))}{\tilde{V}(z)}$

We then find that:

$$\tilde{z} = z^{*} + 2\left(1-\varphi\right)\frac{q}{q - F\left(\tilde{z}\right)k}\theta$$

Proposition

Net metering induces too much prosumption compared to the first best:

$$\tilde{z} > z^*$$

- the opportunity cost of decentralized production $\neq$ social cost
- the grid rate increases, due to decreased registered consumption, $\Rightarrow$ increases the benefit of prosuming.

Net purchasing

Allows to set two different tariffs r_x and r_m.

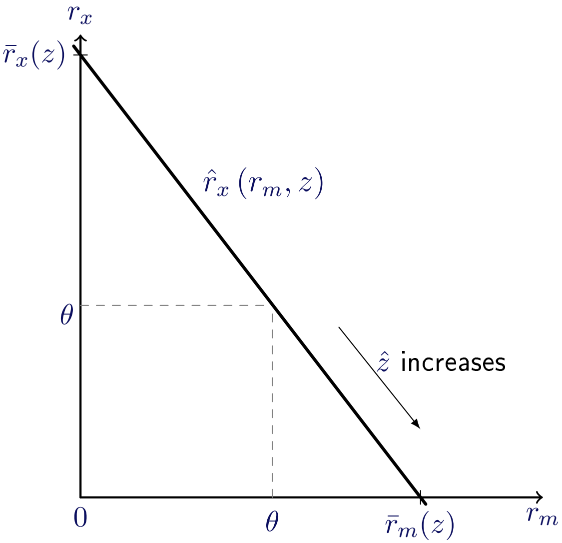
Utility of investing in k:

$$U(z) = \begin{cases} S - (q-k)p - r_m(q-\varphi k) - (1-\varphi)kr_x - zk & \text{if } k > 0 \\ S - (p + r_m)q & \phantom{\text{if }} k = 0 \end{cases}$$

Indifferent consumer is such that: $\hat{z} = p + \varphi r_m - (1-\varphi) r_x$
It leads to a locus of break-even tariffs:

$$\hat{r}_x(r_m, z) = \theta + (\theta - r_m)\frac{q - F(z)\varphi k}{F(z)(1-\varphi)k}$$

Net purchasing: Locus of break-even tariffs



Slope of the locus is higher than one: increases the number of DPU installations

Thus the indifferent user is:

$$\hat{z} = z^* + \frac{q}{F(\hat{z})\,k}(r_m - \theta) + \frac{q}{F(\hat{z})\,k}(\theta - \theta) = z^*$$

Proposition

Net purchasing leads to the first best level of prosumption with cost-oriented grid tariffs: $r_m = r_x = \theta$.

For all the break-even tariffs, the deployment of DPU is lower with net purchasing and so is the import fee: $r_m < \tilde{r}$.

Net purchasing allows to set tariffs equal to costs.

Locus of break-even tariffs: slope greater than one

Comparisons: Redistributional concerns

How do payments to the grid differ under both technologies?

The network bill with Net metering is high for traditional consumers:

- Registered consumptions decline
- Grid costs increase
- There are fewer traditional consumers / too much prosumers

Effects for network bills of a consumer (R^c) and a prosumer (R^p)

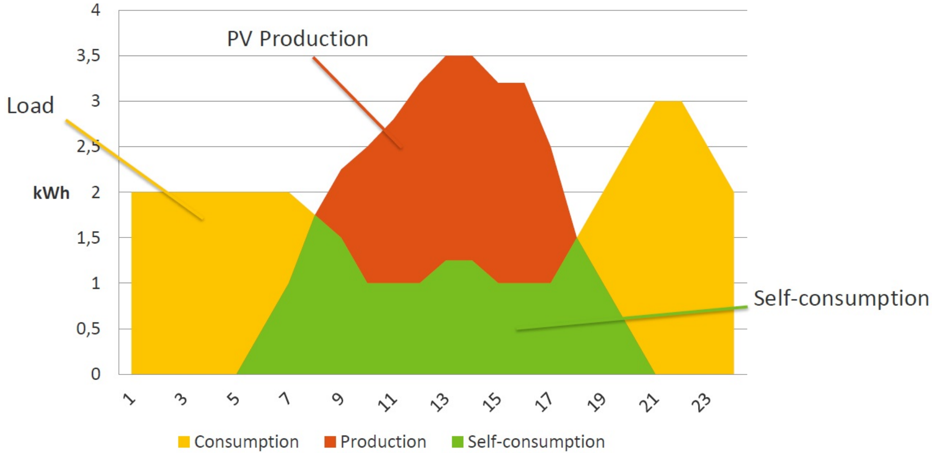
Proposition

Compared to net purchasing with cost oriented tariffs, with net metering the consumers's bill increases while the prosumer's bill decreases: $\hat{R}^c < \tilde{R}^c$ *and* $\hat{R}^p > \tilde{R}^p$.

If the regulator departs from cost-oriented grid pricing and decreases the import fee, the result of the Proposition continues to hold true

Comparisons: Synchronization

Standard prosumer's profile: production and consumption desynchronized



Comparisons: Synchronization

Incentives to synchronize production and consumption (φ)?

Possible via storage, consumption displacement, smart meters and orientation of PV

Reduces both imports and exports

Encourages further the deployment of DPU: $\partial z^*/\partial\varphi > 0$

Assume that it is possible at a convex cost: $(\varphi - \bar{\varphi})^2/2$ where $\bar{\varphi}$ is the initial level of synchronization.

Optimal prosuming and synchronization: $\min_{\varphi,z} C(z) + F(z)\frac{(\varphi-\bar{\varphi})^2}{2}$

$$\Rightarrow \varphi^* = \bar{\varphi} + 2k\theta \boxed{\bar{\varphi} + 2k\theta} > \bar{\varphi} \text{ and } z^*_{\varphi} = z^* - \frac{1}{2k}(\varphi^* - \bar{\varphi})^2 < z^*$$

Proposition

Net metering does not provide incentives for synchronization while it is socially desirable. Net purchasing can lead to first best levels of prosumption and synchronization jointly with cost-oriented grid tariffs.

Net purchasing is then characterized by:

$$\hat{\varphi} \equiv \underset{\varphi}{\operatorname{argmax}} \hat{U}(z) - \frac{1}{2}(\varphi - \bar{\varphi})^2 \Rightarrow \hat{\varphi} = \bar{\varphi} + (\hat{r}_m + \hat{r}_x)k \boxed{\bar{\varphi} + 2k\theta}$$

Cost-oriented tariffs $\Rightarrow$ first best level of DPU synchronization

Net purchasing: trade-off for the DSO between break-even, synchronization or prosumption.

Extensions: Discriminatory import tariff

In order to overcome net-metering inefficiencies

A way to dampen excessive prosuming by increasing the prosumer's rate and/or decreasing the consumer's rate.

A tariff r_c for consumers, and r_p for prosumers.

Indifferent consumer's marginal installation cost $\tilde{z}'$

$$\tilde{z}' = p - r_p \frac{q-k}{k} + r_c \frac{q}{k}$$

Locus of break-even network rates (r_c, r_p)

$$\tilde{r}_p(z) = \frac{C_d(z)}{F(z)(q-k)} - \tilde{r}_c(z) \frac{1-F(z)}{F(z)} \frac{q}{q-k}$$

Proposition

Net metering with a discriminatory network tariff leads to the first best level of prosumption when $\tilde{r}_c = \theta$ *and* $\tilde{r}_p = \frac{\theta}{q-k}\left(q + (1-2\varphi)\,k\right)$.

Comparison : $\tilde{r}_p\left(z^*\right) \geq \tilde{r}\left(\tilde{z}\right) \geq \tilde{r}_c\left(z^*\right)$

Discriminatory net-metering tariffs restore efficiency

Contribution of each category is equal to the induced cost.

Traditional consumers are charged at MC.

Prosumers' rate is adjusted

Having two tools rather than one allows you to get closer to the first best : Bennear and Stavins (2007)

Extensions: No fixed fee

Now, no fixed fee to cover the fixed cost K. Only rates.

With *net metering* : $\tilde{\tilde{r}}(z) = \tilde{r} + \frac{K}{q - \varphi k}$.
Such a mark-up makes the inefficiency result further exacerbated.

With *net purchasing*:

$$(r_m, r_x) = (\theta + \frac{K}{q}, \theta + \frac{\varphi K}{(1-\varphi)q})$$

It is possible to achieve the first best for different tariff structure, including Ramsey-like tariffs where costs are only covered by variable fees.

Extensions: Environmental impact of DPU

"Green electricity" a non negligible motivation for regulators

PV panels or small wind turbines generate less GHG.

Assume an additional environmental damage (linear) function $D(E) = \delta E$ where $E = q - F(z)k$

The total cost is rewritten as:

$$C(z) = C_g(z) + C_d(z) + \delta(q - F(z)k) + K$$

Social cost minimizing prosumer's cutoff increases now to $z^e = z^* + \delta$.

Regulators can either manipulate the grid tariff to foster the deployment of DPU or introduce specific subsidizing schemes.

Ext. Environment: Grid supports to DPU

With *net purchasing*, grid tariffs used to reach environmental targets

By increasing r_m and decreasing r_x along the break-even locus

$\hat{z} = z^e$: if

$$r_m = \theta + \frac{F(z)k}{q}\delta \quad \text{and} \quad r_x = \theta - \frac{q - F(z)\varphi k}{q(1-\varphi)}\delta.$$

For sufficiently large values of δ, the export fee becomes negative $r_x < 0$: subsidization of DPU

With *net metering*,

if $z^e \geq \tilde{z}$, grid tariff must increase

if $z^e \leq \tilde{z}$, net metering provides too much support to DPU.

In both cases, lack of flexibility associated with net metering

Ext. Environment: Net metering and feed-in premium

Specific supporting schemes for DPU: feed-in tariffs (FIT), feed-in premium (FIP) or renewable portfolio standards (RPS).

Mechanisms offer a subsidy, requires a green metering system

What is the impact of combining a feed-in premium with a net metering system when $z^e \geq \tilde{z}$?.

A FIP scheme: prosumers receive a total premium ρk.

FIP organized and financed by the DSO through a unit tax τ on each registered consumption unit.

The regulator set the grid fee r, the premium ρ (the tax τ to reach the first best level of DPU (z^e) subject to the break-even constraints for the DSO

The indifferent consumer: $z'(\rho) = p + r + \rho + \tau(\rho)$.

Then the optimal FIP:

$$\rho' = \delta \frac{q - F(z^* + \delta) k}{q} - 2(1 - \varphi)\theta$$

Proposition

If $z^e \geq \tilde{z}$, net metering metering leads to the first best level of prosumption if combined with a FIP ρ'.

Conclusions

Net metering vs Net purchasing (double metering)

- Net Metering: Overencourages prosuming compared to the first best and no incentives to synchronize consumption and production
- Net Purchasing: Allows to reach the first best and encourage synchronization
- May not hold if environmental externalities and schemes to internalize them
- Explanation: Exports not priced at the level of net exports while their costs differ

Thank you for your attention.