A PROSPECTIVE ECONOMIC ASSESSMENT OF RESIDENTIAL PV SELF-CONSUMPTION WITH BATTERIES AND ITS SYSTEMIC EFFECTS: THE FRENCH CASE IN 2030

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- Economic analysis of French residential PV systems in 2030
- Systemic analysis of PV integration into the national electricity system
- Conclusions
**RAPID PV GROWTH & SHARP DECLINE IN PV PRICES**

- Explosive growth of PV installations with political support (low-carbon energy transition): > 305 GWp in 2016

- PV prices are falling faster than expected (module price decline with global learning curve).

Source: Author’s elaboration based on IEA PVPS Trends in photovoltaic applications [1]

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**Graph:***

- **Germany** Residential PV System prices: 1.5~1.9 $/Wp (2015)
- **PV Module** ~0.5$/Wp
- **Very low contract prices**: i.e. 24 $/MWh in Abu-Dhabi (UAE)
RESIDENTIAL PV SELF-CONSUMPTION

PV self-consumption: PV electricity directly consumed at the same site where it is produced → more suitable for the sectors with a good correlation between PV production & onsite consumption (e.g. *Industrial / commercial*)

*Residential sector* with a poor correlation → improvement via demand response or storage solutions

Further reduction in PV system costs

Continuous decline in the battery costs (Li-ion)

Source: IEA’s PV Technology roadmap 2014 [2]

Source: [3][4]

Natural PV demand in the residential sector?
RESEARCH QUESTIONS

- **What costs** for French residential PV self-consumption systems coupled with lithium-ion batteries in 2030?
- **What systemic effects** under different scenarios?

**Advantages**
- Limit grid injection at the high matching ratio
- Social demand for energy independency & green energies
- New biz opportunities (i.e. EVs, batteries, BIPV, grid services…)

*Figure 3: Principle of using the residential PV batteries*
ECONOMIC ANALYSIS OF RESIDENTIAL PV SYSTEMS WITH LITHIUM-ION BATTERIES IN FRANCE IN 2030
### Investment decision of household

\[
II = \frac{\alpha \sum_{t=1}^{N} \frac{E_{PV}^t}{(1+r)^t} \times P_E}{\sum_{t=1}^{N} \frac{I_{PV}^t + O&\& M^t}{(1+r)^t}} = \frac{P_E}{\frac{1}{\alpha} LCOE}
\]

- **Households**
- **3 kWp + 4 kWh**
- **80% self-consumption**
- **80% PV power output**
- **PV Systems, Batteries**
- **Performance, type, size, Lifetime**
- **Localization, Weather condition**
- **PV power generation costs**
- **PV costs**
- **Investment costs**
- **IEA PVPS data & IEA scenarios (18% learning rate)**
- **Supports (e.g. FIT, premium, subsidies)**
- **Taxes**
- **Other barriers**
- **Profitability**
- **Electricity tariffs**
- **Grid parity**
- **2%/y**
- **1000 kWh/kWp/year**
- **4000 kWh/year**
- **Local consumption profile**

**Legends:**
- **Variables**
- **Stakeholders**

Source: [1][2][5][6]
A self-consumption rate around 80% led by the use of batteries.

- Residential PV systems with batteries would become profitable without political financial support for individual investors in France by 2030 under the IEA scenarios in question.

- Possible to advance the time if the model considers favourable assumptions (e.g., insolation in Southern regions, BAPV systems).

- Natural demand in the residential sector is expected.

Source: Author’s calculations, see [5][14]
## SENSITIVITY ANALYSIS OF PV LCOE ESTIMATES

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Nominal values</th>
<th>Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimal values</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-40% by default)</td>
</tr>
<tr>
<td>PV system price</td>
<td>$1.83/Wp</td>
<td>$1.1/Wp</td>
</tr>
<tr>
<td>Batteries price</td>
<td>$150/kWh</td>
<td>$90/kWh</td>
</tr>
<tr>
<td>Energy output</td>
<td>1000 kWh/kWp</td>
<td>800 kWh/kWp</td>
</tr>
<tr>
<td>Lifetime</td>
<td>20 years</td>
<td>12 years</td>
</tr>
<tr>
<td>Discount rate</td>
<td>5%</td>
<td>3%</td>
</tr>
<tr>
<td>Learning rate</td>
<td>18%</td>
<td>11%</td>
</tr>
<tr>
<td>Self-consumption level</td>
<td>80%</td>
<td>48%</td>
</tr>
<tr>
<td>Dollar/Euro exchange rate</td>
<td>0.9</td>
<td>0.72 (-20%)</td>
</tr>
</tbody>
</table>

The PV system price, the energy output (insolation) and the self-consumption ratio have the greatest influence on the PV LCOE estimates.
What if 18.8 million of individual houses in France swift to PV self-consumption? \([7]\)

- Potential aggregate demand of 56 GWp, 10% of French demand
- Massive & rapid deployments: impacts on electricity systems & stakeholders

What systemic effects?
- Impacts on stakeholders (systemic effects)
SCHEMATIC MODEL OF RESIDENTIAL PV CONSUMPTION WITH BATTERIES

- Impacts on stakeholders (systemic effects)

- **Households**
  - **Investment decisions**
  - **Installed PV capacity**
  - **PV power production**
  - **Profitability**
    - **PV power generation costs**
    - **Grid parity**
    - **Electricity tariffs**
  - **% self-consumption**
  - **PV power output**
  - **PV Systems, Batteries**
    - Performance, type, size, lifetime, localization, weather condition
  - **Local consumption profile**
  - **Grid financing**
    - **Taxes**

- **Stakeholders**
  - **Latent group**
  - **Others**

- **Integration costs**
  - **Grid costs**
    - Transmission, Extension
  - **Balancing**
  - **Backup**
  - **Reduced full load hours**
  - **Overproductions**
  - **Electricity price formation**
  - **Externalities**
    - Environment
    - Land usages
    - Energy markets
    - Economy & jobs
    - Societal effects
    - Geopolitical risks

- **Energy context**
  - National consumption profile (demand)
  - Electricity mix
  - Power network quality
  - Electricity markets
SYSTEMIC ANALYSIS OF PV INTEGRATION INTO THE NATIONAL ELECTRICITY SYSTEM
FOUR TYPES OF PV INTEGRATION SCENARIOS

- **Difference options** in regard with PV deployment in French electricity system

In front of the meter grid connection (FIT)  
- Grid injection (full)

**Rapid integration** (e.g. identical mix)

- Scenario G with Rapid integration
- Scenario S with Rapid integration

Behind the meter grid connection (Self-consumption)

- Saved grid injection (e.g. PV self-consumption with batteries)
- Progressive integration (adjusted optimal mix)

- Scenario G with Progressive integration
- Scenarios S with Progressive integration
Current French power mix: PV of 56 GWp (1.6%) and wind power of 9 GWp (3.8%)

Assumptions: wind power remains constant.
Author’s calculation, see [8] for methodology

Source:[8][9]
With a high penetration of variable PV power, negative prices can be observed because of the excess power production.

The residential PV self-consumption model with batteries significantly reduces the risks related to negative prices.
French nuclear power production in 2015 (434 TWh) as a baseline of comparison

**Grid injection (full)**

- **Bigger impacts on nuclear**
  - Nuclear production losses with rapid integration: -9.2%
  - Additional nuclear production losses with new equilibrium: -9.6%
  - CO₂ price to keep the same level of nuclear capacity and to avoid additional CO₂ emissions: 93 €/tCO₂

- **Scenario G**
  - Optimal full-load hours / year for nuclear: 6438h
  - 50.8 GW Optimal nuclear capacity 2015
  - 43.1 GW Optimal nuclear capacity with 56 GW PV

**Saved grid injection** (e.g. PV self-consumption with batteries)

- **Scenario S**
  - Optimal full-load hours / year for nuclear: 6438h
  - 20 €/tCO₂
  - -5%

<table>
<thead>
<tr>
<th>Nuclear power production (TWh/year)</th>
<th>Grid injection (Scenario G)</th>
<th>No Grid injection (Scenario S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed Rapid (R)</td>
<td>394 (loss: -9.2%)</td>
<td>412 (loss: -5%)</td>
</tr>
<tr>
<td>Speed Progressive (P)</td>
<td>352 (loss: -18.8%)</td>
<td>379 (loss: -13%)</td>
</tr>
</tbody>
</table>
PV INTEGRATION COSTS

PV integration into the mix: additional efforts to address intermittency of variable PV power

Grid-level costs  Literature data [10][11]

<table>
<thead>
<tr>
<th>10% (France)</th>
<th>Grid injection (Scenario G)</th>
<th>No Grid injection (Scenario S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid-related</td>
<td>~6 $/MWh</td>
<td>~0 $/MWh</td>
</tr>
<tr>
<td>Balancing</td>
<td>~2 $/MWh</td>
<td>~0 $/MWh</td>
</tr>
<tr>
<td>Back up</td>
<td>16 ~ 19 $/MWh</td>
<td>16 ~ 19 $/MWh</td>
</tr>
</tbody>
</table>

Profile costs  Author’s calculation based on [8]

<table>
<thead>
<tr>
<th>Profile costs (56 GWp added, 10%)</th>
<th>Grid injection (Scenario G)</th>
<th>No Grid injection (Scenario S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td>€/MWh PV</td>
<td>€/MWh PV</td>
</tr>
<tr>
<td>Speed Rapid (R)</td>
<td>33</td>
<td>26</td>
</tr>
<tr>
<td>Speed Progressive (P)</td>
<td>29.3</td>
<td>19.3</td>
</tr>
</tbody>
</table>

PV integration costs need to be taken into account for PV policy decisions!

i.e. Long-term investment decision, system security.  Other source:[12][13]
PV self-consumption with batteries could become profitable without political support for individual investors in France before 2030.

New issues related to changes in interests of stakeholders in the electricity systems:
- negative impacts on long-term investment choices in the electricity sector
- impacts on the power system and network management (to associate with grid financing reform).

A regular and progressive policy when transitioning to PV self-consumption: allow enough time for concerned stakeholders to adapt to the change (gradual changes in the mix led by the national plan)

The early encouragement of PV self-consumption can be intentionally planned to secure the constant growth model of PV installations.

Policy needs to present a clear and long-term vision of PV integration, connected to the national plan (e.g. industry policy).
Author’s article is available:


Thank you for your attention

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REFERENCES

FRENCH ENERGY SUPPLY & PV TARGET

Supply

- 563 TWh (2015)
- 78%
- Nuclear
- PV: 1.5%
- Wind: 4%
- Hydro: 10%
- Coal: 2%
- Gas: 3.5%

Demand

- 447 TWh (2014)
- 33% Residential
- 25% Industry
- 1% Agriculture
- 7% Other
- 2% Energy

Renewables energies: 40% of power mix (2030)

Fossil fuels

- Nuclear: 50% of power mix (2025)

PV target: > 20 GWp in 2023

France energy policy targets