Impact of regulation on renewable energy development: lessons from the French case

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Outline

1 Context and motivations

2 Small-scale PV

3 Wind energy

4 Conclusions

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Renewable energy regulation in France

Main acts

- February 2000 - Introduction of feed-in-tariffs (FIT) for RES.
- August 2009 - Transposition of the 20-20-20 EU objectives: 23% of renewable energy in final energy consumption.
- July 2010 - Regional RES targets and regional schemes for RES connection, with mutualisation of reinforcement charges for installations $>$ 100 kW (historically: deep connection charges).
- August 2015 - Replacement of FIT by FIP (premiums).
- February 2017 - Subsidies of up to 40% of connection charges for small RES producers.

Main decrees

- December 9 2010 - Three-month moratorium on FIT (except PV $<$ 3 kW).
- March 4 2011 - New tariff decree: quarterly revision of FIT.

Deployment of RES in France

Impact on the network

- 95% of RES-E are connected to the distribution network.
- Enedis is the main DSO with 95% of French clients.
- Enedis invests 3 to 4 billion euros per year, more than half of which is dedicated to development, reinforcement and modernisation of the grid.

Impact on consumers

- Consumers bear the cost of subsidies (around 16% of the bill).
- Some network costs are passed to consumers through network tariffs (around a third of the bill).
- This possibly affects competitiveness of some industries.

Motivations

Research questions

- How does regulation influence the dynamics of development of RES-E ?
- In particular, how do the FIT and the regional connection schemes impact small-scale PV and large-scale wind energy developments, respectively?
- Beside these factors, is there an intrinsic diffusion process?

Literature

- Impact of regulation and FIT: Anaya and Pollitt (2015), Zhang, Song, and Hamori (2011), Jenner, Groba, and Indvik (2013), Dijkgraaf, Dorp, and Maasland (2018)
- Modelling of RES-E diffusion process: Bass (1969), Liu and Wei (2016), Benthem, Gillingham, and Sweeney (2008)
- Spatial spillovers: Elhorst 2014, Graziano and Gillingham (2015), Balta-Ozkan, Yildirim, and Connor (2015), Müller and Rode (2013), Dharshing (2017)

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Regional cumulative capacity

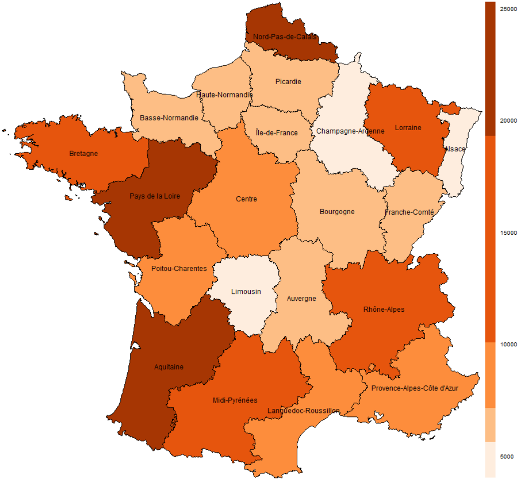

Figure 1: Regional cumulative PV capacity (kW) of projects of less than 3 kW, mid-2016

Quarterly installed capacity per region

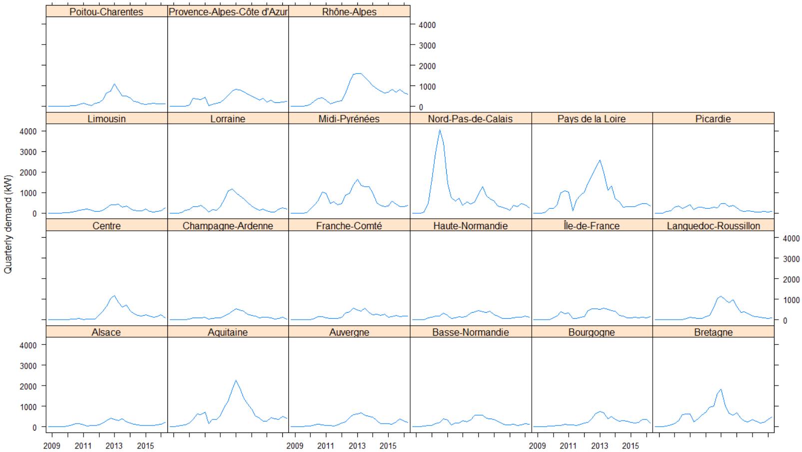

Figure 2: Quarterly demand (kW) for PV projects of less than 3 kW

Feed-in-tariffs

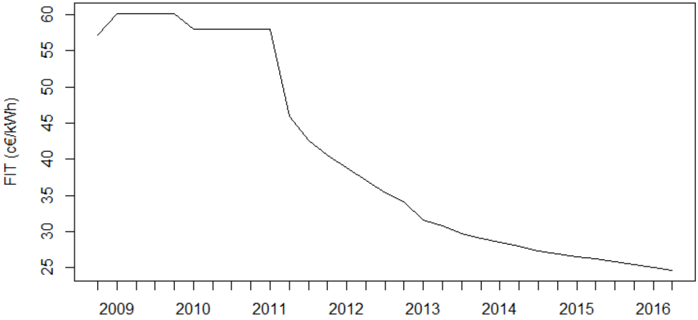

Figure 3: FIT for < 3 kW-PV (c€/kWh)

Evidence of rational behaviour

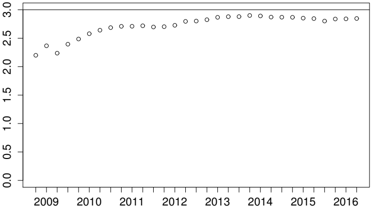

Figure 4: Average capacity per connection request (kW)

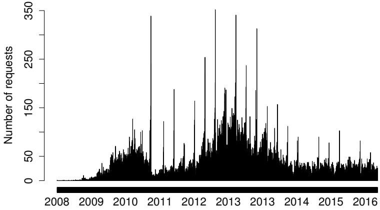

Figure 5: Illustration of the “deadline” effect

The Bass (1969) diffusion model

Sales S of a new durable good come from:

- "Innovators", in fixed proportion p in the remaining market, of size $m - Y$
- "Imitators", proportionally to the attained market share Y/m

In continuous time:

$$S(t) = \text{Max}\left(0,\ p(m - Y(t)) + q\frac{Y(t)}{m}(m - Y(t))\right) \tag{1}$$

In discrete time, assuming $S > 0$ for the sake of simplicity:

$$S_t = a + bY_{t-1} + cY_{t-1}^2 \tag{2}$$

Identification of coefficients:

$$m = \frac{-b \pm \sqrt{b^2 - 4ca}}{2c},\ p = \frac{a}{m},\ q = -mc \tag{3}$$

Model

Due to the very strong regional heterogeneity, we estimate seemingly unrelated regression equations (SURE):

$$\begin{cases} \forall i, t & S_{i,t} = a_i + b_i Y_{i,t-1} + c_i Y_{i,t-1}^2 + \beta_i FIT_t + \varepsilon_{it} \\ \forall i \quad \forall r \neq s & \mathbb{E}[\varepsilon_{ir}\varepsilon_{is}|X] = 0 \\ \forall i \neq j \quad \forall t & \mathbb{E}[\varepsilon_{it}\varepsilon_{jt}|X] = \sigma_{ij} \end{cases} \tag{4}$$

Covariates

- β: “pecuniary” (financial) effect (> 0?)
- b: “epidemic” effect (> 0?)
- c: “stock” effect (< 0?)

Empirical results (1)

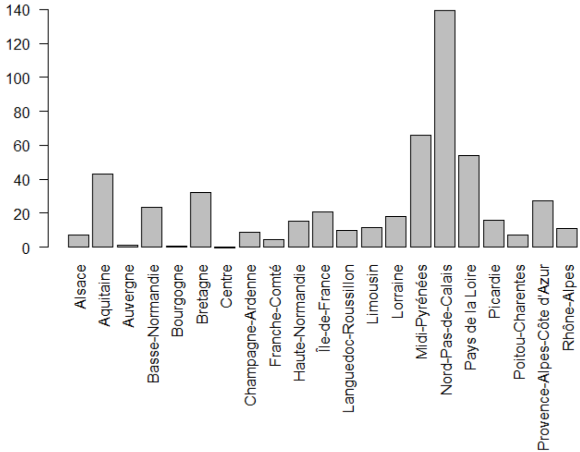

Figure 6: FIT coefficient per region (kW/(c€/kWh)).Coefficients for Auvergne, Bourgogne, Centre, and Rhône-Alpes are non-significant; coefficient for Franche-Comté is significant at the 10% threshold.

Empirical results (2)

Pecuniary effect

- Pecuniary effect is significant almost everywhere, but is highly heterogeneous.
- Heterogeneity is probably explained by socio-economic factors. Indeed, Nord-Pas-de-Calais is the second richest region but has relatively few sun.

Epidemic and stock effects

- Epidemic effect is present and significant, and quite homogeneous, with values between 0.26 and 0.54.
- Stock effect is also significant, except in Nord-Pas-de-Calais, with values between -8.5 10^{-5} and -1.4 10^{-5} kW^{-1}.

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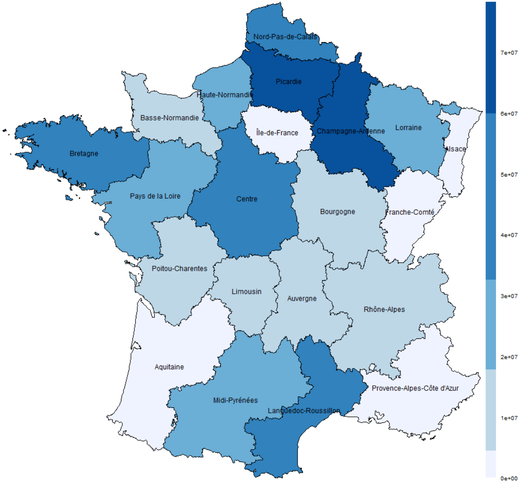

Figure 7: Regional cumulative wind capacity (kW) of projects of more than 100 kW, mid-2016

Quarterly installed capacity per region

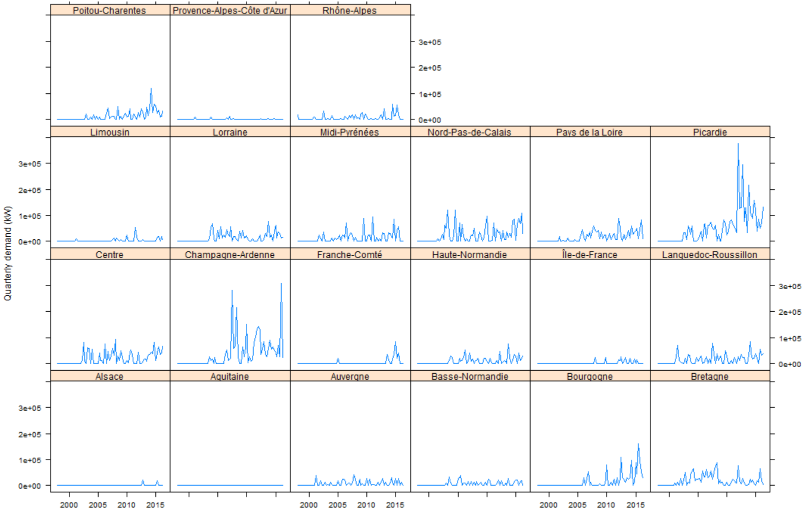

Figure 8: Quarterly demand (kW) for wind projects of more than 100 kW

Shares of network reinforcement charges

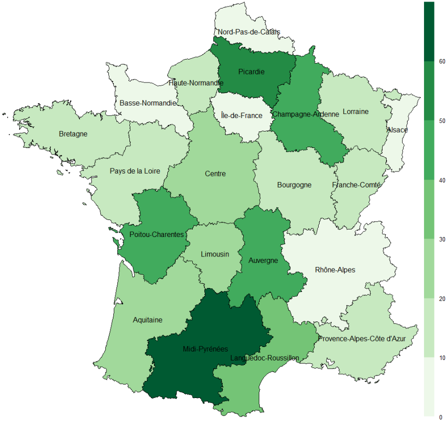

Figure 9: Regional share of network reinforcement charges for > 100 kW-projects (k€/kW)

Min	Q1	Med.	Mean	Q3	Max	S.D.
0	10.11	18.21	23.72	35.63	69.90	19.40

Model

- In order to take into account spatial dependence, we estimate a spatial auto-regressive panel model with time and regional fixed effects:

$$\begin{cases} S_t = \rho W S_t + X_t \beta + \nu + \delta_t \iota_N + u_t \\ u_t \rightsquigarrow IID(0, \sigma^2) \end{cases} \tag{5}$$

- Weight matrix W is defined using “rook” neighbours:

Figure 10: Rook neighbours

Empirical results

Interpretation

- $\rho < 0$ indicates locational choices (arbitrage), due to the limited number of projects.
- So does the network reinforcement charge T: the higher the “tax”, the lower the connection requests.
- Epidemic effect is present through cumulative capacity Y.
- Evidence of deadline effect (scheme-enforcement quarter dummy).
- Overall positive impact of the connection schemes: reduction of uncertainty (no more *deep-costs*)?

	Estimate	Std. Error	t-value	p-value
ρ	-0.1117	0.0331	-3.37	0.0007
Y	0.0298	0.0022	13.54	0.0000
T	-341.4860	97.6409	-3.50	0.0005
Enforcement quarter dummy	11457.2490	5375.0023	2.13	0.0330
Post-enforcement quarter dummy	14195.9561	4385.0719	3.24	0.0012

Table 2: Estimation results of the SAR model

Marginal effects

- Similarly to AR models in time series, coefficients cannot be interpreted directly:

$$S_t = (\mathbb{1} - \rho W)^{-1} X_t \beta + (\mathbb{1} - \rho W)^{-1} \nu + \delta_t (\mathbb{1} - \rho W)^{-1} \iota_N + (\mathbb{1} - \rho W)^{-1} \varepsilon_t$$

- More influence of close neighbours: $(\mathbb{1} - \rho W)^{-1} = \mathbb{1} + \rho W + \rho^2 W^2 + ...$
- Debarsy, Ertur, and LeSage (2012) suggest that the marginal effect be decomposed into a direct effect and an indirect effect:

$$\frac{\partial S}{\partial x'_r} = (\mathbb{1} - \rho W)^{-1} \mathbb{1}_N \beta_r$$

Direct effect	Indirect effect	Total effect
1.003024	-0.1034632	0.8995613

Table 3: Direct, indirect, and total marginal effects

- Direct effect is > 1 (feedback), indirect effect is < 0 (arbitrage)
- Total effect is < 1 due to negative spillovers.

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Conclusions and further developments

Conclusions

- Impact of subsidies for small-scale PV is positive but very heterogeneous.
- Diffusion also exhibits epidemic and stock (in the case of PV) effects.
- Regional connection charges send locational signal to wind farm developers.
- Spatial arbitrage is also visible through negative spatial autocorrelation.

Further modelling possibilities

- Socioeconomic factors
- Spatial interaction for PV (at a more local scale).

Thank you for your attention!