Incentive policies for small PV in France

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In this paper we estimate demand for small photovoltaic (PV) installations in France and simulate scenarios to reach alternative objectives regarding their deployment to 2030. Regarding the estimation of demand for PV installations, we find that it depends on the diffusion (and consequently the learning) as time goes by, on changes in the Feed-in-Tariff (FiTs) policy and on the different structural conditions present in each of the French regions considered. In particular, we observe that the suspension of the FiTs for bigger PV in 2011 particularly affects Bretagne as well as the NW and the SW region. Regarding the way each region can reach the 2030 objectives, for regions such as SE and NW, keeping the current development trend is reasonable, while for regions such as NE and SW, doubling the PV capacity by 2030 seems not to be excessively costly.

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1 Introduction

The photovoltaic (PV) industry has experienced a rapid growth rate over the last decade. Worldwide cumulative PV installed capacity has grown at an average rate of 49% per year during the last ten years (OECD/IEA 2014). In 2013, about 37 GW of new PV capacity was installed in about 30 countries bringing total global capacity to over 135 GW. Together with Germany, Italy, USA and Japan, France[1] has been one of the pioneers in the PV market thanks to the subsidarization in the form of feed-in tariffs (FiTs). Under this incentive scheme, residential consumers who install solar panels can beneFiTs from a purchase obligation, which requires Enérgie de France (EdF) and local distribution companies to buy electricity produced by solar PV panels according to a fixed amount of FiTs for a period of 20 years. These specific purchase tariffs decrease according to the maturity of the sector concerned and to the size of installations and energy efficiency to ensure proFiTsability.

In France the average price of a module in 2015 was between 0,57 EUR/W and 0,62 EUR/W representing an annual cost decrease of 5% (ADEME, 2016). Despite these cost decrease, PV is still high and unable to reach grid parity (see Fraunhaufer, 2013)and continues to be subsidized.

The economic analysis of PV markets has gained importance in recent years. A first strand of literature studies the learning process defined by the seminal paper of Wright (1936) as the decrease in installation prices as the installed capacity doubles (see also Arrow, 1962). Nemet (2005) shows that PV costs have decreased by a factor of 100 since the 1950s even if he discards learning as the main driver. Instead, Van der Zwaan and Rabl (2004) find that learning curves have been very significant and could explain the mayor role that PV technology will play in the future. Poponi (2003) compares PV adoption in several countries, while Lindman and Söderholm (2012) provide a conceptual overview of the recent studies on wind power learning rates.

A second strand of literature describes PV diffusion as an "S-curve" (see Geroski,2000 and Fagerberg, 2005 for a survey on diffusion modelling and Negro *et al.*., 2012 for a survey on the explanations for slow diffusion in renewable energy). In this sense, Guidolin and Mortarino (2010) apply the Bass (1969) model of diffusion to the PV industries finding that Germany, Japan, UK are at a mature stage whereas Australia, Canada, France are a steadily growing market.

[1] Germany, Italy, USA, Japan and France represented more than 87% of the world market in 2011 (OECD, 2012). The world leader has become China as from 2013 (OECD/IEA, 2014).

A thinner strand of literature is interested in the interaction between diffusion mechanisms and regulatory incentives in different countries (Movilla *et al.*. 2013, Frondel. *et al.*. 2010, among others).

Our paper contributes to this last strand of literature with the originality of assessing the household sector that has been neglected so far, probably by lack of data. Indeed the few papers interested in this segments use experiments (see for instance Islam, 2014), being unable to understand the importance of learning or diffusion. An exception to the lack of data is Zang *et al.*. (2011), which, using data from 11 regions in Japan, finds that contrary to what we could expect, installation costs have a negative impact on diffusion.

In this paper we study he development of photovoltaic adoption in the residential sector[2] and the evolution of solar system costs compared with the FiTs and electricity retail prices using regional French data from 2007 to 2013. We also study the impact that changes in regulation may have on the market development. With this purpose, firstly we calculate the net present value (NPV) of PV panels that we assume to depend on the FiTs and on the price of PV panels as compared to production (per region) during a PV panel lifetime. Then, we estimate PV demand as a function of the NPV calculated together with a diffusion component. In this estimation we add regional fixed effects to account for the regional differences in demand. We also estimate the *learning-by-doing* effect that decreases the cost of installing PV.

Secondly, we use the estimation results regarding demand and learning to build three alternative scenarios of PV expansion at a national and regional level up to 2030. In particular, the purpose is to simulate the FiTs that would be necessary to induce each of the three expansion paths studied. This estimation allows us to understand the importance of learning and diffusion as compared to the subsidies in place.

Our main finding is that learning in the residential PV sector has been very important in France as compared to other countries. This makes it possible to have a declining FiTs for the years to come and at the same time observe a deployment pattern compatible with an ambitions scenario for 2030. We also find that there are important regional disparities and that different FiTs should be applied if we wish to observe a similar pattern throughout the country.

The paper unfolds as follows. In Section 2 we describe the database while

[2] We study installations of building-integrated PV in residential houses with power inferior or equal to three kilowatts peak (kWp).

in section 3 we explain the importance of learning by doing and present the adoption model and NVP estimation. We show optimal FiTs paths in Section 4, both at the national and at the regional level. We conclude in section 5.

2 Data description

In this section we describe the data use in this study. We start by explaining the database we have considering 22 french regions in terms of quantity and prices of the installation of small residential PV (less than 3Kwp). Then we present the FiTs data and the way we treat it to make it compatible with the installation data available.

Deployment During the period of 2007-2013, France has registered, in total, 4359 PV installations by residential customers and the average annual growth rate between 2007 and 2013 was of 33.18%. Accounting for an amount of 3 kWp of capacity per module, France has added 13.08 MWp of solar capacity from the residential sector during the period. However, the growth rates of PV installations have been rapidly decreasing from 94.30% in 2008 to 5.93% in 2014. The yearly pattern of the PV development is summarized in Table 1, which unveils that the growth rates of 2012 and 2013 experienced a big plunge and the demand for PV installations shows a tendency of saturation right after 2011. The break point between these two periods may be a result of the enforcement of the Decree of December 9 2010 (Décret du 9 décembre 2010, i.e. moratoire), which suspended the support of FiTs for photovoltaic installations for a period of three months. Although installations with power capacity equal or less than 3 kWc are exempted from the suspension, considerable subsidy cuts after the suspension obviously had an adverse impact on the whole solar industry as what we have observed in 2012 and 2013.

Region	2007	2008	2009	2010	2011	2012	2013	Sum by region
Alsace	32	0	20	0	14	0	0	66
Aquitaine	0	0	0	13	44	12	12	81
Auvergne	12	58	270	222	85	33	0	680
Basse-Normandie	0	3	6	0	7	0	0	16
Bourgogne	0	0	0	0	17	1	10	28
Bretagne	415	5	30	63	22	0	13	548
Centre	0	0	6	6	11	3	0	26
Champagne-Ardenne	0	0	0	0	350	70	25	445
Corse	10	55	100	11	16	0	0	192
Franche-Comte	0	10	0	65	5	0	0	80
Haute-Normandie	0	0	0	0	8	0	0	8
IDF	56	0	0	0	50	5	8	119
Languedoc-Roussillon	5	474	35	103	15	4	0	636
Limousin	0	0	0	0	25	2	3	30
Lorraine	0	0	0	0	13	0	12	25
MI-PY	0	0	0	0	11	10	6	27
Nord-Pas-de-Calais	0	0	0	0	33	2	9	44
PACA	108	38	59	17	19	7	18	266
Pays de la Loire	0	0	0	0	14	2	2	18
Picardie	0	0	0	0	9	0	0	9
Poitou-Charentes	7	0	1	0	19	3	2	32
Rhone-Alpes	250	201	132	245	23	8	124	983
Sum by year	895	844	659	745	810	162	244	4359
% change		94.30%	37.90%	31.07%	25.77%	4.10%	5.93%	average 33.18%

Table 1: Adoption per region

At the regional level, we observe important differences in terms of development. The top-ranking region Rhône-Alpes added 983 installations while the bottom-ranking region Haute-Normandie only recorded 8 installations between 2007 and 2013. We also observe relatively large numbers of PV adoptions in Auvergne, Languedoc-Roussillon, Bretagne and Champagne-Ardenne where the number of adoptions ranges from 400 to 700, while in more than half of the French regions observed PV installations are lower than 100 during the seven years.

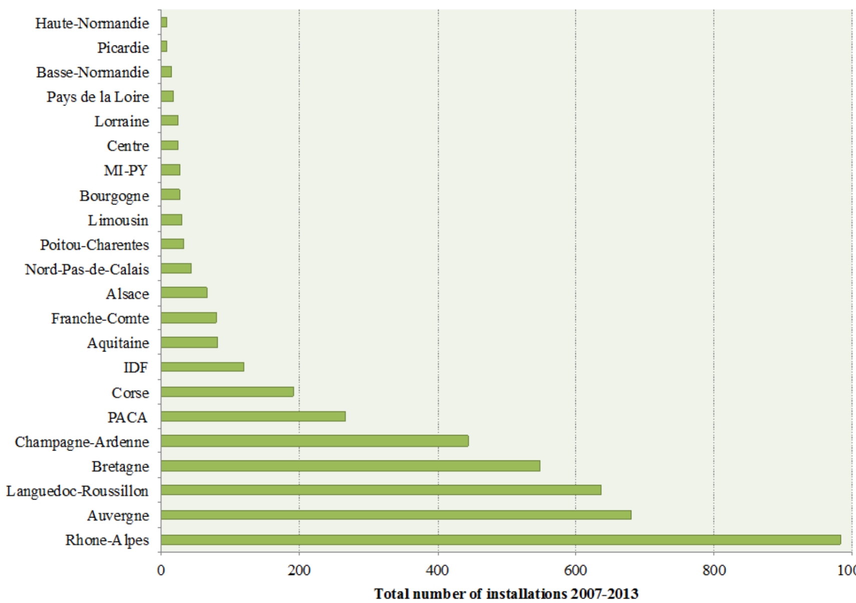

Figure 1: Total adoption per region

Costs In our dataset, there are two sources of costs associated to a PV installation: one is the price of solar modules or materials, and the other one is the price related to the installation process. As shown in Table 2, the PV module prices had fell to 3.13 €/Wp, representing only less than a half of the material price in 2007. The standard deviation underlines price variations over regions; the highest regional disparities can be spotted between 2010 and 2012. On the contrary, the average installation prices do not show a clear pattern.

Despite the considerable reduction in material prices during these years, they still remain relatively important in terms of shares over total PV price. In 2013, the average share of panels in total system price is nearly 80%.

Year	Material price	S. D.	Installation price	S. D.	Material price in total cost
2007	6.64	0.24	0.89	0.11	88.24%
2008	7.82	0.35	0.97	0.24	88.95%
2009	6.09	0.18	0.84	0.07	87.85%
2010	6.14	0.36	0.73	0.20	89.38%
2011	5.67	0.46	0.84	0.12	87.11%
2012	3.85	0.41	0.88	0.06	81.46%
2013	3.13	0.21	0.81	0.11	79.37%

Table 2: Prices per year

Breaking up the overall trend at the regional level, substantial differences can be detected across the 22 French regions. For example, the PV module price in Corse is largely above the national averages in 2008. Centre and Languedoc-Roussillon are the most expensive regions for material prices in 2010 and 2012, respectively. Regions such Bretagne and Basse-Normandie are generally below the national average. For the whole period, the geographic distribution of the average prices are shown in Figure 3.

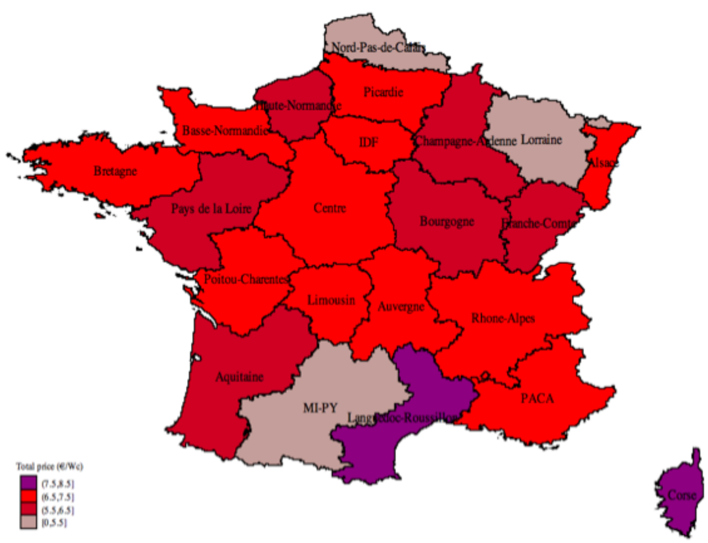

Figure 2: Total cost per region

Feed-in tariffs: comparison with system prices After the purchase obligation established by law in 2000, the first French FiTs rates that fix the levels and conditions of the purchase prices for PV plants were published in 2002. The period of 2006-2009 was characterized by a rapid growth of FiTs for PV installations. France introduced, for the first time, a premium for PV installations integrated to buildings in 2006 and the tariff in 2009 reached as high as 60.176c€/kWh. At the end of 2010, the moratorium froze the photovoltaic market in France by suspending subsidies and connections to grid network of ongoing projects except for small installations with power below 3 kWp. Since then, subsidies have unevenly decreased.

Yearly FiTs are obtained by weighting each FiTs price by a ratio that equals the number of days when this tariff is effective, divided by the total number of days in a given year.

Then, we must transform the unit of measurement of installation in Kwh. We assume that 1Kwp can generate 1Kwh of electricity when fully loaded (see Table 3). The number of full loaded hours in Corse is replaced by the national average due to missing information. Consequently annual amount of electricity generation per kWp of PV can be calculated as the number of full loaded hours times 1 kWh.

Region	Factor %	Nb. of production hours
Alsace	11	963.6
Aquitaine	13	1138.8
Auvergne	13	1138.8
Basse-Normandie	12	1051.2
Bourgogne	11	963.6
Bretagne	12	1051.2
Centre	11	963.6
Champagne-Ardenne	11	963.6
Corse	12	1051.2
Franche-Comte	12	1051.2
Haute-Normandie	11	963.6
IDF	12	1051.2
Languedoc-Roussillon	15	1314
Limousin	13	1138.8
Lorraine	11	963.6
MI-PY	14	1226.4
Nord-Pas-de-Calais	11	963.6
PACA	12	1051.2
Pays de la Loire	11	963.6
Picardie	12	1051.2
Poitou-Charentes	16	1401.6
Rhone-Alpes	14	1226.4

Table 3: Production per region

It is useful to compare the cost of PV installation not only with the FiTs but also with the system price to understand if FiTs are indeed needed for PV proFiTsability. We transform the system prices into €/kWh by using a calculation of a levelized cost of energy, which is the price at which electricity is generated from solar panels to break even total costs over the lifetime of the project. Therefore the system price in €/kWh can be calculated in the following way (see Ossenbrink, 2013 *et al.*.):

$$P = \frac{\sum_{t=1}^{N} \frac{I_t + M\&O_t}{(1+d)^t}}{\sum_{t=1}^{N} \frac{E_t}{(1+d)^t}}$$

where I_t is the investment expenditure of the year, $M\&O_t$ is the maintenance and operation costs of the year, E_t is the electricity generation at the year, d is the discount rate (assumed to be 5%) and N is the lifetime of the panel (consistent with the effective length of a purchase contract we assume $l = 20$).

We consider the basic residential electricity price (called tariff bleu base in France), tax excluded (see Figure 4).

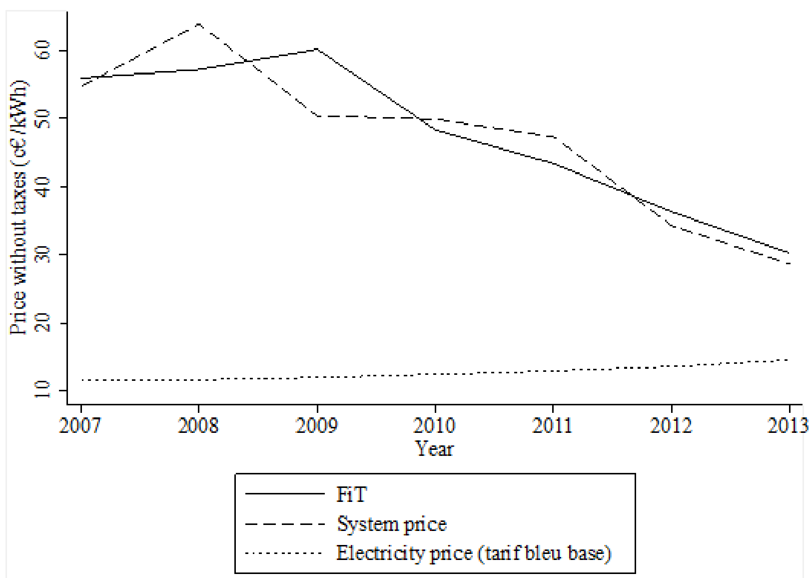

Figure 3: Comparison between regional system prices, FiTs and electricity prices

We observe that in 2007 and 2008 the PV system prices were higher than the FiTs level in 2008, while in 2009 the FiTs surpassed the PV system price, which started to decline. Afterwards, the FiTs rates were declining faster than costs until the last two years of the study period, during which FiTs and system prices move at the same pace. Regarding the comparison with the system price, grid parity was not achieved since the system price is much lower than PV costs during the whole period.

3 Diffusion and learning effects

We consider a representative consumer per region that, at each year t, decides to invest or not (Ben-Akiva and Lerman 1985; Train, 2009). The decision is made to maximize its utility function. If he chooses to invest, his utility is the sum of the observed utility (V_{it}) and a random shock (ε_i)[3]:

$$U_{it} = V_{it} + \varepsilon_i, \tag{1}$$

where we assume that the term ε_i is extreme valued distributed according to a logit model and consequently we model the function that describes the probability P_t that an agent instals a PV panel between t and $t+1$ as a logit function, that is:

$$P_{it} = \frac{\exp(V_{it})}{1 + \exp(V_{it})}. \tag{2}$$

Additionally, we consider that the observed utility can be formulated as

$$V_{it} = NPV_t u_{it} + l_t, \tag{3}$$

where $NPV_t u_{it}$ is the net present value of an installation in each of the 22 regions and l_t is the diffusion process.

The function $NPVu_t$ is further defined as the sum of annual actualized cash flows over the life time of the installation minus the initial investment cost, divided by the power of the installation (defined in average):

$$NPVu_{ti} = FiTs_t.E.\sum_{k=1}^{N} \frac{1}{(1+\delta)^k} - \frac{p_{it}}{E}. \tag{4}$$

where:

$FiTs_t$ is the FiTs level;

δ the rate of capital depreciation;

N is the life length of a panel;

E is the amount of electricity generation per unit of installed capacity over its life-cycle;

p_{it} is the unit price of the installation.

[3] If he decides not to invest his utility is normalized to zero.

In equation (4), *system prices* p_{it} indeed already incorporates the learning effects.

As for the *diffusion process*, we model it as:

$$l_t = \log\left(\frac{X_t}{M_t}\right). \tag{5}$$

where M_t is the potential market share for the whole economy and $X_t = \sum_{t=1}^{t}\sum_{i=1}^{n} x_{i,t}$ is the installed capacity at year t.

Finally, we define the demand q_t as the probability of adoption P_t times the potential market sizes M_t:

$$q_{it} = M_t.P_{it}. \tag{6}$$

Combining equations (2) and (6) gives:

$$\frac{q_{it}}{M_t} = \frac{\exp(V_{it})}{1+\exp(V_{it})}, \tag{7}$$

that can be transformed in:

$$\frac{\frac{q_{it}}{M_t}}{1-\frac{q_{it}}{M_t}} = \exp(V_{it}). \tag{8}$$

Assuming that the potential market size is very large compared to demand over the period analyzed (i.e. $q_{it}/M_t < 1$) and that M_t suffers no drastic changes over the period considered (and can be assumed constant) we can do the following approximation:

$$\frac{\frac{q_{it}}{M_t}}{1-\frac{q_{it}}{M_t}} \approx \frac{q_{it}}{M_t} = \exp(V_{it}). \tag{9}$$

Since demand at each point in time can also be defined as the difference in the number of installations between t and $t+1$, that is:

$$q_t = x_{t+1} - x_t. \tag{10}$$

we can simply write:

$$x_{t+1} - x_t = \exp(V_{it})M_t \tag{11}$$

The log transformation of the previous equation gives

$$\log(q_t) = NPV_t u_{it} + l_t. \tag{12}$$

where l_t accounts for the diffusion, like in Cohen *et al.*. (2015).

After developing the $NPVu_{it}$ term into its determinants we can estimate log-demand as follows:

$$q_{it} = a_1. \log(NPV_{it}). + a_2 \log(l_t) + a_{3i} + \varepsilon_t, \tag{13}$$

a_{3i} is a region-specific fixed effect.

For simplicity we have put together the data of each individual region into 5 bigger regions that present similar deployment patterns (see Figure 4): NE, NW, SE, SW and Bretagne. Bretagne deserves to be alone given that it is the most active region.

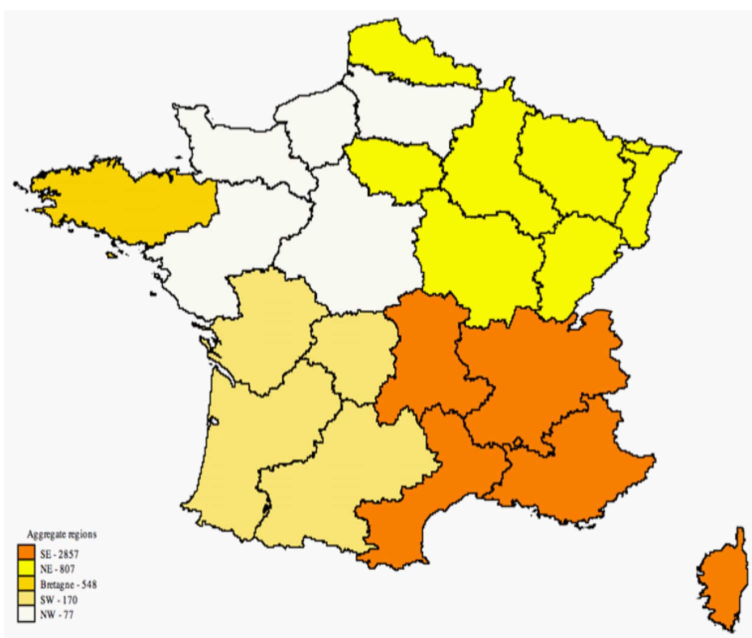

Figure 4: Regional Aggregation

Considering the regularities found on the data in section 2 we know that the moratorium on FiTs for bigger solar installations in 2011 may have had an impact in the dynamics of the sector as a whole and that such impact may be different by region.

Results of equation (13) under different modelling assumptions are presented in Table 4. Model 1 represents the national benchmark. Model 2 includes a dummy for the 2011 episode. Model 3 allows both for regionalization and for the 2011 episode. Finally, Model 4 details the regional impact of the 2011 episode through a cross effect by region.

Variable	1	2	3	4
ln(NPV)	2,54	0.50	0.84	0.45
ln(l)	0.56	0.57	0.66	0.59
Moratorium 2011		-1,23	-1,25	
Bretagne			(-1.8)	
NW			(-0.97)	
NE			(-0.60)	
SW			(-0.75)	
SE			(-1.05)	
Bretagne*2011				-1.70
NW*2011				-1.54
NE*2011				-1.02
SW*2011				-1.13
SE*2010				-1,55
Constant	-3,66			
N	85	85	85	85
R2	0,53	0.92	0.92	0.91

legend: variables in brackets are non significant

Table 4: Regression Results

In Model 1, both the NPV and the diffusion effect are extremely significant. In Model 2, they remain significant but the coefficient values attached to these variable change dramatically underlining the importance of the moratorium. Model 3 results are mainly driven by the 2011 dummy: regional differences do not play a key role. Model 4 shows that indeed the decrease in the development of the PV market is different among regions by including region specific fixed effects: Bretagne is particularly affected as well as the NW and the SW region. In any case all regions suffer from a significant decrease in PV demand after the 2011 episode.

The price inside (4) indeed is influenced by a network externality: a learning-by-doing (LBD) effect. Such effect is defined as the average cost reduction that follows the adoption process of a certain technology (Wright, 1936). In other words, LBD is defined as the total average price reductions as a function of cumulative solar capacities installed and can be estimated as:

$$p_t = p_0 . \left(\frac{X_t}{x_0} \right)^{-b} \tag{14}$$

where b is the LBD elasticity coefficient that can be estimated by log linearizing (14). The learning rate r then can be calculated as (see Wright, 1936 and Arrow, 1962):

$$b = \frac{\log(1-r)}{\log 2}$$

For the whole sample our results show that the parameter $b = -0.3387$ and an estimated learning rate $r = 0.2092$ meaning that the system price will reduce of approximately 21% each time the installed capacity doubles. Such learning rate is important compared to learning effects found in the literature. For instance, Haysom *et al.*. (2015) report a 14% learning rate in the American PV industry over the same sample period, i.e. 2007-2013. We use this learning rate as a benchmark for our first scenario in next section, in particular to interpret the regional differences in terms of deployment.

4 PV expansion scenarios and optimal FiTs trajectories

Having obtained the previous estimates we now simulate the optimal feed in tariffs between 2014 and 2030 considering three different scenarios of PV deployment in the residential sector both for the economy as a whole and per region. The methodology applied is as follows:for each scenario we determine the desired path for the level of adoption until 2030. Using the adoption level determined by each scenario, we then calculate the required NPV per period. Since the NPV depends on prices, we use the learning coefficient estimated to project the (decreasing) price of panels and consequently the optimal FiTs. We first apply this methodology to the national case. Then we account for regional differences captured in the estimation's fixed effects while still using the robust estimates we found at the national level. In particular, once the capacity trajectories are obtained at the national and regional level, the optimal tariffs given the paths of capacity expansion are calculated according to equations (4), (14) and (13). We consider estimates in Model 1 for the national level trajectories and estimates of Model 4 for the regional ones.

4.1 Results of optimal FiTs at the national level

Figure 2 presents the path of residential PV capacity expansions in different scenarios at the national level.

In the **doubling capacity by 2030** scenario we assume that the objective is to double the small PV capacity of 2013 by 2030. This scenario is particularly relevant to compare the decrease in the FiTs with the percentage decrease in costs due to learning as estimated in the last section. It is worth noting that this assumption on the adoption trajectory is more optimistic for the SE and NE regions than in the other regions due to the fact that they are in advance in terms of PV installations. In contrast in the NW region for example, this assumption only brings the number of PV adoption from 77 in 2013 to 154 in 2030. Considering the regional differences in therms of sun radiation as well as the differences in the size of the potential markets, this trajectory, corresponding to regional potential for PV development, can be considered to be reasonable.

In the **constant growth rate until 2030** scenario we consider that the number of residential PV adoption grows at a constant rate of 5% per year. This growth is indeed optimistic, in the sense that it implies an exponential expansion path of the PV deployment, which we have not observed so far.

Finally in the **current growth rate until 2030** scenario, we continue the trend of PV deployment after 2011 until 2030. Compared with the scenario of constant growth rate, this setting seems more realistic. Compared with the double capacity scenario, this scenario is more pessimistic. As residential PV adoption in France has suffered a significant slowdown due to the 2011's moratorium, the current growth rate of the PV development is low for most of regions with the exception of NE and SW. Both regions have started to experience a rapid growth in PV adoption in the recent two or three years. For instance, after a massive increase of 482 PV installations in 2011 in NE, the added adoptions per year are 71 per year, differently from a significantly lower rate between 2007 and 2010. Similarly, in SW the adoption for PV is very low between 2007 and 2010 (varying from zero to 13 installations per year) whereas after 2011 adoption has increased to 24 installations per year.

These scenarios are depicted in Figure 5. The most conservative plan is to maintain the current growth rate, which adds 203 installations per year up to 2030. This will bring the cumulative capacity up to 7810 nationwide. In the long term, the double capacity scenario appears to be a medium case for residential solar deployment. With capacity doubled by 2030, solar adoption will increase by 256 installations per year. Finally, the overoptimistic case of a constant growth rate scenario assumes a lower adoption rate before 2020 compared with the double capacity scenario, but its long-run capacity grows exponentially. At the end, this setting drives the cumulative installations of solar panels up to 9991 by 2030.

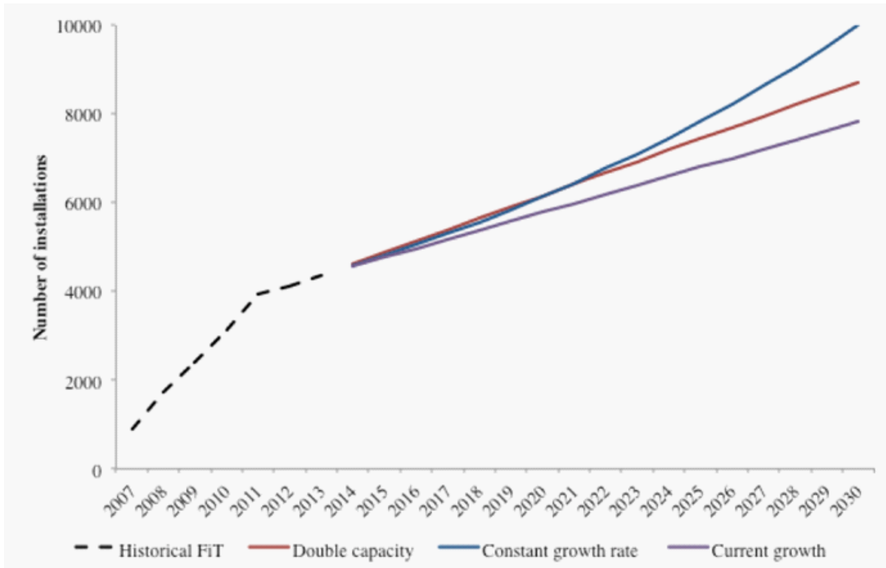

Figure 5: National trajectories of PV adoption in different scenarios.

The FiTs corresponding to the previous scenarios are shown in Figure 6. The double capacity and current growth scenarios reasonably give a decreasing trend of the FiTs, whereas an increasing amount of support is needed for an expansion at a large scale in the long run for the constant growth rate scenario. As mentioned before, two network externalities can affect a residential consumer's decision on solar PV adoption: learning and the diffusion effect. As system costs for PV installations decrease and as the probability of adoption increases, these two effects allow for a margin to lower the FiTs. Moreover, a low tariff in support of solar deployment may not be optimal since it is directly related to investors' revenue, i.e. the proFiTsability of PV adoption. Therefore, the optimal tariff is highly dependent on the capacity target of the PV deployment, which should be both financially and politically feasible. If the capacity trajectory is to simply continue the current adoption pace, the support level can be largely reduced. An immediate drop from 30 c€/kWh to 20 c€/kWh in 20130 can ensure the continuity of the current PV development, while in a longer horizon, this rate can be reduced to 10 c€/kWh by 2030. In the more aggressive scenario of double capacity, the current national FiTs needs to be maintained between 2014 and 2015, and then it can be gradually reduced to 14 c€/kWh by 2030. Additionally, the current FiTs does not seem to be enough to produce a leap in PV adoption that would ensure an exponential increase in adoption at 5% rate. Indeed, an increasing FiTs is needed over time for such an optimistic scenario to realize.

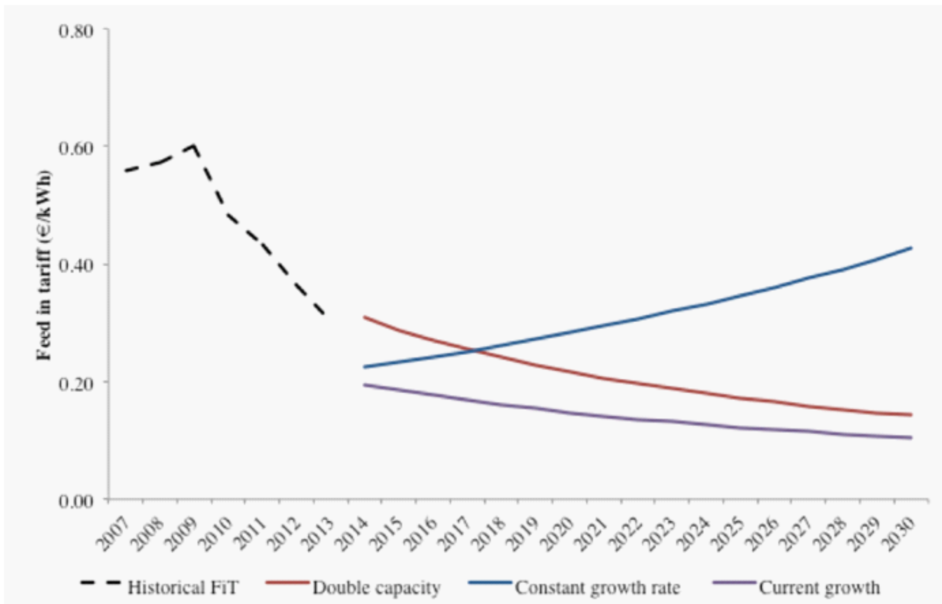

Figure 6: National FiTs in different adoption scenarios.

4.2 Results of optimal FiTs at the regional level

In this section we consider the three scenarios used for the discussion at the national level but for each of the 5 regions defined in Figure 4. Depending on whether the region under consideration has experienced a progress in PV installations in recent years or not, the corresponding order of the optimistic, medium and pessimistic case may change as compared to the discussion of the national case.

4.2.1 Doubling the actual capacity

If the PV capacity doubles, the regional patterns of solar development illustrate distinct profiles. Being the leader of PV technology adoption so far, the SE region's target for 2030 in this scenario is 5514, three times higher than the second highest region that is NE. It is also worth noting that the

Bretagne region has a high starting point in 2007, but its adoption rate has slowed down significantly in recent years. Considering its limited irradiance and potential market, most likely its annual PV adoption rates will stay at a medium range. With an annual number of 32 installations in 2013, it reaches 1096 in 2030.

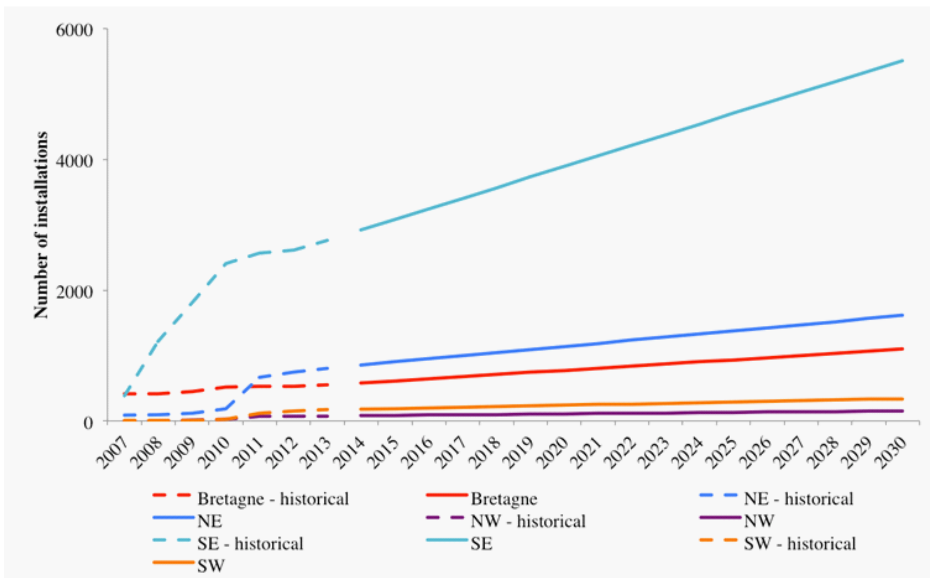

Figure 7: Regional adoption patterns: doubling the actual capacity.

The optimal FiTs trajectory of NW and NE continue the present trend and is consistent with the trend for the FiTs found at the national level, going from around 30 c€/kWh in 2014 to 15 c€/kWh in 2030.

Instead, in SW, the FiTs needed to stimulate a double capacity expansion by 2030 in this region is considerably lower. In 2013, the support rate for solar installation reduces to 17 c€/kWh and further to 8 c€/kWh in 2030. In regions such as SE, that show relatively high capacity installed, and Bretagne, that is currently experiencing a slow down, a higher FiTs is needed in order to give enough incentives for further adoption. Although NW and NE regions yield similar FiTs levels, their installed capacity paths are very different. Comparatively, it is less costly to support the development of PV panels in the NE region than in the NW region. Indeed, a moderate reduction in the FiTs over time can be sufficient to achieve a higher level of deployment by 2030 in NE than in NW.

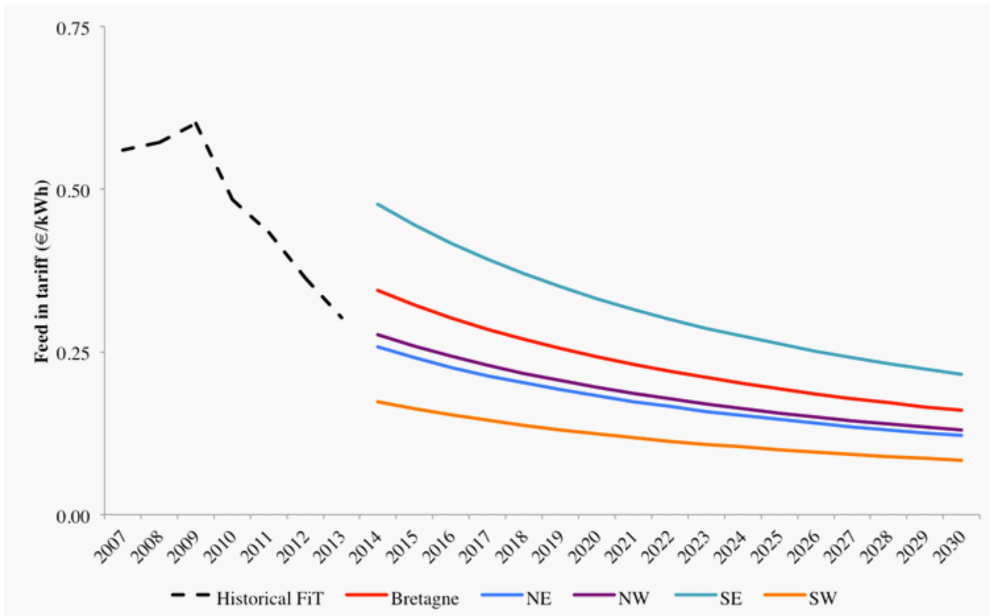

Figure 8: Regional trajectories of optimal FiTs for PV in the scenario of doubling capacity.

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4.2.2 Constant growth rate

In the scenario of a 5% constant growth rate, cumulative installed capacity will grow at a low rate during a few years after 2013, and then at a higher rate towards the end, which translates in an increasing number of PV installations a year after the other. The resulting number of PV adoption per region by 2030 is not significantly different from the number in the double capacity scenario. For example, with 5% increase per year, Bretagne is to achieve 1256 PV installations by 2030, 160 higher than the double capacity target; similarly, NE will have 1849 PV adoptions by 2030 compared to 1614 installations if its capacity is doubled. The difference in the magnitude of the 2030 target in these two scenarios is even smaller for the NW and SW regions.

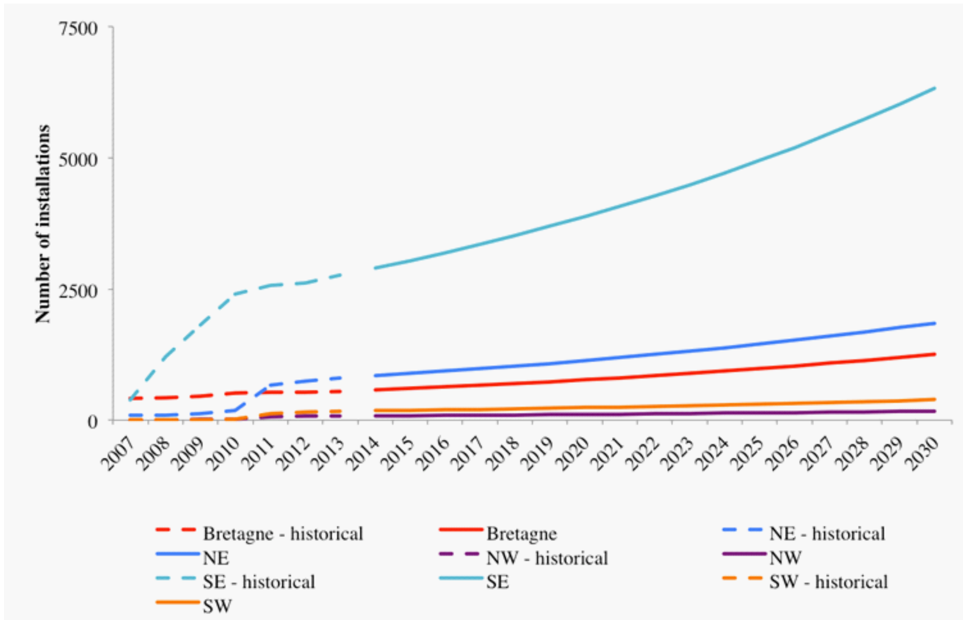

Figure 9: Regional trajectories of PV adoption in the scenario of a constant growth rate.

For the SE region, an exponential path of PV adoption needs to be accompanied by a very high FiTs, varying from 34 c€/kWh in 2014 to 67 c€/kWh in 2030. In Bretagne, NW, and NE, a sharp drop in their FiTs is optimal at the beginning, as the assumed development scale of solar PV is small, but they increase afterwards to a higher level than the actual one. In 2030, the necessary FiTs reaches 48 c€/kWh in Bretagne, 35 c€/kWh in NE, and 38 c€/kWh in NW. In the SW region, which has the most potential for tariff reduction at the beginning, the FiTs shall go from 13 c€/kWh in 20130 to 24 c€/kWh in 2030, but it always stays below the current national FiTs.

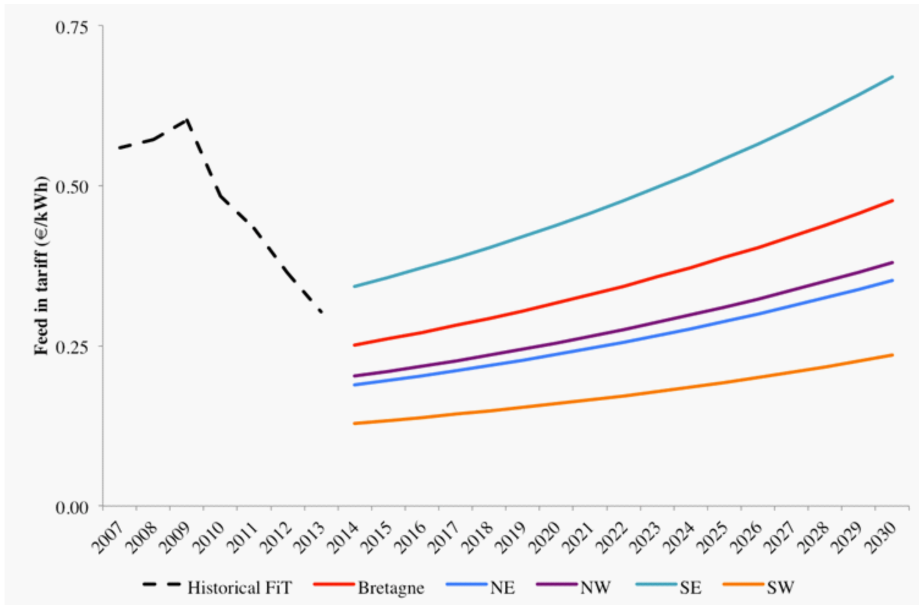

Figure 10: Regional trajectories of FiTs in the scenario of a constant growth rate.

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4.2.3 Current growth rate

In the current growth rate scenario, the projected PV adoption trajectory simply continues with the current growth rate. As shown in the following Figure, SE and NE are still the leading regions in solar deployment: by 2030, SE reaches the target of 4746 installations, while NE attains 2014 installations. These targets are rather conservative for these two regions. The following Figure also shows that the residential PV markets in Bretagne and in NW lost their dynamism after the FiTs reform of 2011. If the actual trend continues, Bretagne's total PV adoptions will be only 752, that is almost 500 less installations than in the constant growth rate scenario and 340 less installations than in the double capacity scenario. Similarly, the slow pace of solar development in NW sets the regional number of installations in 2013 at 145, lower than its 2013 capacity doubled. Differently from the other regions, SW shows an improvement in solar PV deployment in the last two years of our estimation. If SW continues at this pace, its installed capacity in this scenario will be 578 by 2030, which is significantly higher than the figures in the two previous scenarios.

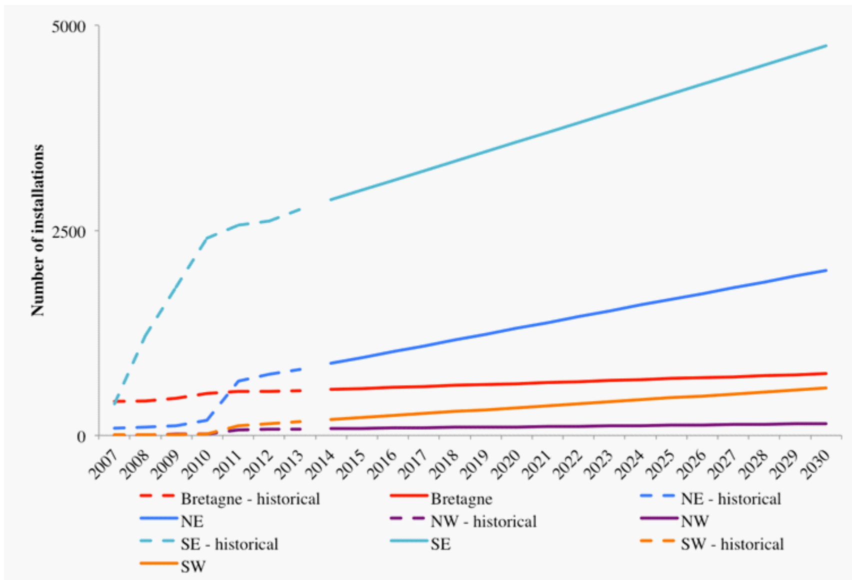

Figure 11: Regional trajectories of PV adoption in the scenario of the current growth rate.

However, this trend does not seem to be sustainable. As shown in the following figure, for the SW region to follow this path, a high FiTs of nearly 1 €/kWh is required in the short run. Clearly, the subsidy can quickly decrease reaching 25 c€/kWh in 2030. Financing PV adoption at the current development rate in NE is more costly compared to the double capacity scenario, since the FiTs jumps to 57 c€/kWh first and then gradually reduces to 20 c€/kWh in2030. In contrast, in NW and SE regions where solar panels are the least and the most developed, respectively, this scenario allows the government to gradually lower the FiTs rates from about 25 c€/kWh to about 12 c€/kWh, and at a lower cost compared with the double capacity scenario. Finally considering Bretagne's slow growth rate in solar installations in recent years, continuing in this conservative trend only requires a low FiTs of between 5-6 c€/kWh.

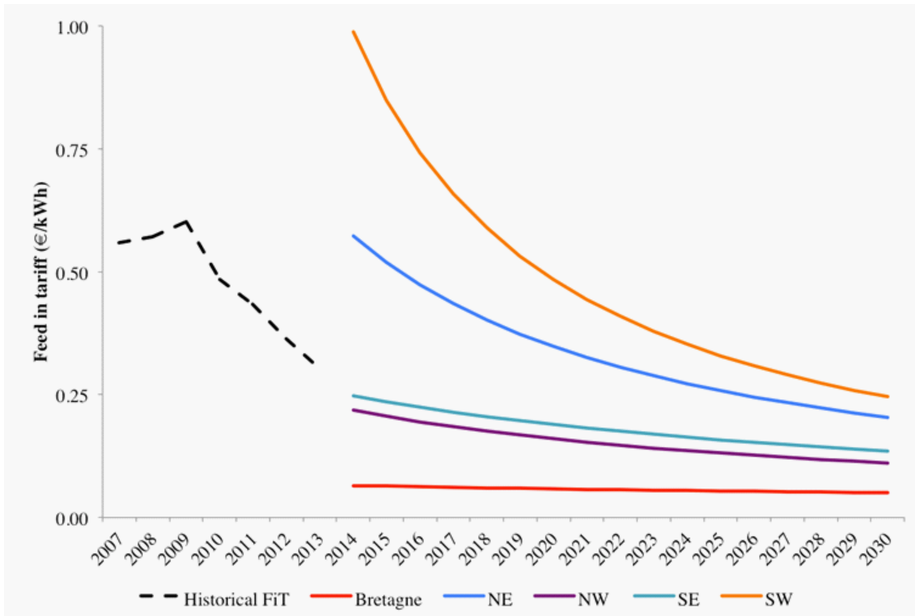

Figure 12: Regional trajectories of optimal FiTs for PV in the scenario of the current growth rate.

To sum up, one single FiTs scheme is not optimal considering regional differences in potential market sizes. The optimal trajectory of the FiTs depends on the targeted path of solar PV capacity. Comparatively, to achieve a similar target a less aggressive and more evenly distributed path is preferred. Given the role of regional difference in consumers' decision on PV adoption, regional plans and expansion trajectories need to be made. For regions such as SE and NW, it is favorable to keep the current development trend, while for regions such as NE and SW, a double capacity expansion by 2030 seems not to be excessively costly. As a special case, a high FiTs to promote investment in solar adoption is needed in Bretagne, although its current trend can be maintained at a very low cost.

5 Concluding remarks

We have estimated the demand for PV installations as a function of diffusion and learning effects as well as a function of regional differences (and accounting for the change provoked in the market due to the policy change in terms of the FiTs in 2011 for big PV installations). All variables are shown to be very significant, which allows us to understand the importance of those determinants as compared to the FiTs.

Moreover, we have simulated the optimal path for the FiTs between 2013 and 2030 for alternative scenarios of expansion patterns in PV adoption. We have consider an optimistic scenario in which capacity increases at the current growth rate of 5% until 2030. That gives us an exponential trend of deployment and can only be reached with an increasing FiTs. A more realistic scenario is one in which the number of installations in 2030 would be doubled as compared to 2013. To attain such an objective the FiTs needs simply to continue decreasing slightly until the end of the period. This is because learning effects are enough strong to finance the installation decrease without further incentives. Finally, we consider the pessimistic scenario as one in which the number of installations increases following a linear trend. A very small effort in terms of FiTs is needed for this modest deployment path. We have also performed the previous exercise or 5 distinct regions explaining the differences between regional FiTs and a single national tariff.

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