Regulation mismatch in tackling CO_2 emissions

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Summary: By defining three targets as pillars of their environmental policy (20% cleaning, 20% greening and 20% saving energy by 2020), European authorities are putting out noisy signals on what the actual objective is and how to achieve it. I show that, whereas the Community-wide CO_2 market (named Emissions Trading System, ETS) is one of the right answers to fix greenhouse-gas emissions, the policy tools implemented by Member States to achieve the greening and saving objectives reduce the efficiency of ETS and push the CO_2 price down. I then analyze the efficiency distortions created by the forced entry of Renewable Energy Sources into the mix of electricity production.
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JEL codes: Q38, Q42, Q48, Q58

1 Introduction

Starting with "Directive 96/92/EC concerning common rules for the internal market in electricity", the European authorities decided that the electricity industry should join telecoms and similar network activities in the competition adventure. Transmission and distribution infrastructure was

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recognized as a natural monopoly, and therefore excluded from the field. By contrast, production and supply to final customers have progressively been opened to competitive mechanisms under the scrutiny of national and community competition authorities. Producers and suppliers can now freely enter and exit the market, as cheap and high-quality firms are allowed to supplant badly performing ones.

Incumbents have however fiercely (and successfully) resisted this opening process, often with the help of Member State governments which like the concept of national champions, particularly on the energy battlefield where independence and security of supply are viewed as strategic. There is another reason why the liberalization process is far from successful in the EU electricity industry. Global warming has progressively become a central concern in energy policy[1] and the tools forged by the European Community to tackle greenhouse gas (GHG) emissions have been wrongly designed, resulting in State aid becomingt the rule rather than the exception. State aid should be granted only under specific circumstances because it distorts competition mechanisms, frequently on purpose. With the surge of environmental concerns, State aid is everywhere in the energy sector. Not only does it distort market mechanisms, it is also inefficiently adapted to the aim it is supposed to pursue. For example, according to Marcantonini and Ellerman (2013, p.20), in Germany "the CO_2 abatement cost of wind for 2006-2010 is on average €43/tCO_2, higher than the historical EU ETS carbon price but of the same order of magnitude. On the contrary, the CO_2 abatement cost of solar is very high, the average for 2006-2010 is €537/tCO_2, much above any possible realistic carbon price." (Recall that during the year 2013 the carbon price has fluctuated between €3 and €5/tCO_2.) In this paper I identify the mistakes that have led to the current costly framework and propose arguments in favor of dismantling the system of subsidies to Renewable Energy Sources of electricity.

In Section 2, I explain the discrepancy between what the policy to reduce CO_2 emissions should be and how it is implemented by the European authorities. In particular, I show that the European Trading System, the

[1]See OECD (2006).

flagship of the EU environmental policy, is endangered by complementary policies fixing targets for renewables and energy saving. In Section 3, I discuss the distortions created by State aid aimed at promoting renewable sources of energy in the technology mix, and in section 4 I present some brief concluding remarks.

2 Inefficient environmental regulation

In 2005, following the Kyoto protocol (1997) which had the objective to slow down global warming, the European Union launched the Emissions Trading System (ETS), a cap-and-trade mechanism dedicated to limiting greenhouse gas (GHG) emissions.[2] This initiative, justified on economic grounds, was unfortunately complemented later by mandatory targets in terms of renewable energy sources (RES) and consumption reduction that impair the efficiency of ETS and increase the cost of reaching the GHG target.

2.1 One objective, three directives

The environmental policy of the European Union is currently driven by three directives:

- Directive 2009/29/EC to achieve at least a 20% reduction in GHG by 2020 compared to 1990,
- Directive 2009/28/EC to reach a 20% share of RES in overall EU energy consumption by 2020,[3]
- Directive 2012/27/EU to save 20% of the EU's energy consumption compared to projections for 2020.

[2] Directive 2003/87/CE.

[3] The list of RES is fixed: production of energy from wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases.

Such profusion of regulation raises many questions, in particular: Why do we need three objectives (and directives)? Are these objectives mutually consistent? Are they consistent with EU competition policy, with EU industrial policy, and with EU tax policy?

Let us first look at the problem starting from the following situation focused on the electricity industry :

- the surplus derived from electricity consumption q is $S(q)$, an increasing and concave function;
- two production technologies have been installed: one serves to produce quantity x at marginal cost c_x, the second to produce y at marginal cost c_y, where $c_x < c_y$.

This very simple situation is not uncommon in national electricity industries, with x standing for electricity from coal-fired plants and y for electricity from an additional primary energy, natural gas for example.[4]

Assume that the installed capacity to produce x, labelled K_x, is such that $S'^{-1}(c_x) < K_x$. The optimal dispatch is the triplet (x, y, q) that maximizes the net social surplus, that is

$$\max_{x,y,q} S(q) - c_x x - c_y y \qquad \text{s.t.} \quad q \leq x + y,\ x \leq K_x,\ y \leq K_y \tag{1}$$

The social planner will then choose

$$q^o = x^o = \arg\left\{S'(x) = c_x\right\} < K_x, \quad y^o = 0 \tag{2}$$

This allocation can be implemented by a price for electricity $p^o = c_x$.

Assume now that scientists prove that x is emitting pollutants $e(x)$, which is an increasing function. This generates an environmental cost $c(e)$, which is increasing and convex. By contrast technology y emits few pollu-

[4]See International Energy Agency (2012), "Key World Energy Statistics", page 24, www.iea.org

tants, normalized to 0. To simplify, also assume that

$$\arg\left\{c_x + c^{'}\left(e\left(x\right)\right)e^{'}\left(x\right) = c_y\right\} < S^{'-1}\left(c_y\right) \tag{3}$$

which means that the marginal cost of y intersects with the marginal social cost of technology x (including the environmental damage) before it intersects with the marginal surplus curve.

Given these new elements, the social planner must solve

$$\max_{x,y,q} S\left(q\right) - c_x x - c\left(e\left(x\right)\right) - c_y y \qquad \text{s.t.} \quad q \leq x + y,\ x \leq K_x,\ y \leq K_y \tag{4}$$

The solution is the environmentally friendly dispatch

$$x^* = \arg\left\{c_x + c^{'}\left(e\left(x\right)\right)e^{'}\left(x\right) = c_y\right\}, \quad q^* = S^{'-1}\left(c_y\right), \quad y^* = q^* - x^* \tag{5}$$

The upper panel in Figure 1 shows the marginal cost of electricity (i) with the environmental damage (bold piecewise linear curve) and (ii) without the environmental damage (dotted staircase curve), and the decreasing marginal gross surplus $S^{'}\left(q\right)$. The right lower panel shows the polluting emissions; they increase with the production from technology x up to capacity K_x, and then become constant given our hypothesis that y does not emit pollutants. In the left lower panel, we have drawn the environmental cost of pollutants.

As illustratedby arrows in Figure 1, there are three differences between the short-sighted dispatch (2) and the environmental-friendly dispatch (5):

- the non polluting technology partially replaces the polluting one: $y^* > y^o = 0,\ x^* < x^o = q^o$
- polluting emissions are decreased: $e\left(x^*\right) < e\left(x^o\right)$
- total consumption is decreased: $q^* = x^* + y^* < q^o$.

Now THE question is: how to implement the virtuous dispatch x^*, y^*, q^*?

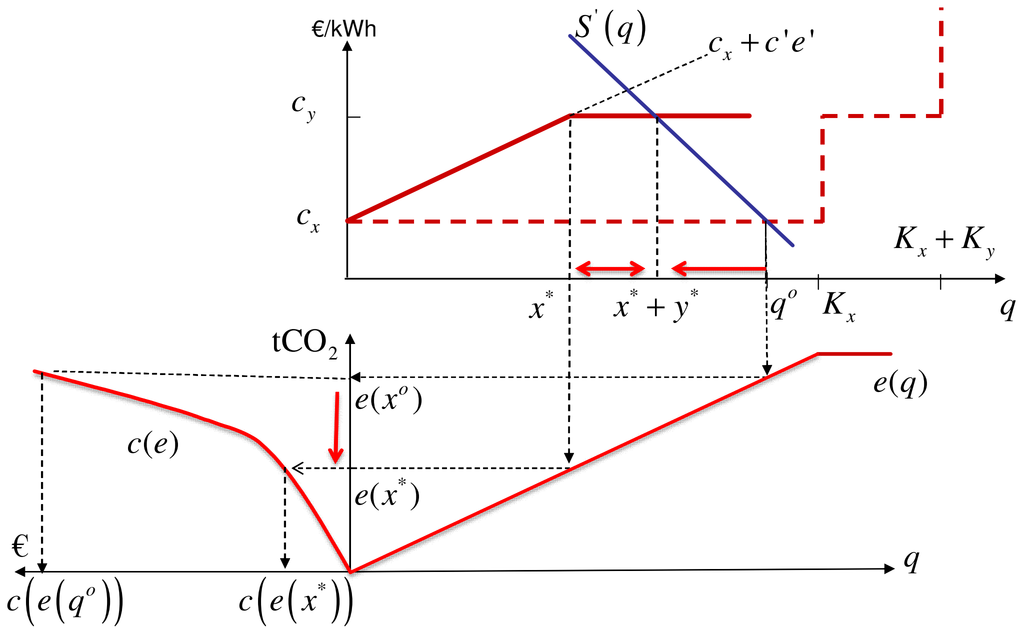

Figure 1: Myopic *vs.* virtuous dispatch

The economist's answer is very simple: environmental damages are externalities that can be curbed either by a price (Pigou, 1920) or by the allocation of rights to pollute (Coase, 1960). We know since Weitzman (1974) that these two tools are not strictly equivalent,[5] but at least they oblige polluters to internalize the cost of their private decisions.[6] In our illustration, since the marginal environmental damage is $c^{'}(e(x))\, e^{'}(x) = c_y - c_x$ at the optimum, given the piecewise linear shape of the electricity marginal cost, the tax charged to x's operators should be $t_- < c_y - c_x$ for each kWh below x^* and $t_+ > c_y - c_x$ for each kWh above x^*. The alternative is to give for free or to sell producers the right to emit the quantity $e(x^*)$.

2.2 The CO_2 market and its toxic companions

The solution adopted by European authorities to reduce CO_2 emissions is the European Trading System (ETS), launched in 2005. It is a cap-and-trade system where a mandatory target has been imposed on almost 12,000 industrial plants throughout Europe, plus the airlines companies since 2012.[7] They are the obligated parties. For each obligated firm, the adjustment between the individual target and the initial endowment is reached partially thanks to technical investment to abate polluting emissions, partially through trade. The market part of the mechanism generates a carbon price. *Per se*, it is a good solution:

- it is the market alternative to the Pigovian tax, necessary to fix a negative externality; it is efficient when well designed;

[5] In our example they are equivalent because there is no randomness in either preferences or costs. See also Hepburn (2006).

[6] The Polluter Pays Principle (PPP) is established by article 191 of the "Treaty on the Functioning of the European Union". In fact, a large share of the additional cost is passed through to the consumers who are the ultimate polluters (see Fabra and Reguant, 2013).

[7] In April 2013, the EU decided to temporarily suspend requirements for flights from or to non-European countries. The legislation continues to apply to flights within and between countries in Europe. The International Civil Aviation Organization was expected to reach a global agreement to tackle aviation emissions in line with the EU-ETS during its autumn meeting. It reached consensus on October 3 2013 for a roadmap to create a market-based scheme curbing aviation emissions by 2020, but rejected the EU proposal allowing it to apply its ETS to foreign airlines in the interim.

- it sends a scarcity signal to polluters;
- it allows firms to adjust the volumes they need;[8]
- it generates public revenues.[9]

With the CO_2 emissions from EU industrial plants under control, one would expect the European authorities to be satisfied. In reality they are not. First they are dissatisfied because the quantity controlled is only a small fraction of worldwide emissions, and the EU effort opens the door to free-riding by non-EU countries. The second reason is more surprising. Dissatisfaction comes from the price of the CO_2 ton (formerly in secondary markets, now at the initial auctions). So far the tCO_2 price has remained rather low, around €3 during the first semester of 2013, well below the penalty for non-compliance (€40/tCO_2 during the first round 2005-2007, €100/tCO_2 during the second 2008-2012 and the third 2013-2020). The authorities have apparently forgotten why ETS was created, and have made fund-raising their main concern because they want to feed high public expenditures and subsidize non-profitable clean energy sources and energy efficiency programs. This is why during spring 2013 the Commission proposed a "backloading" of allowances, which meant postponing a series of carbon permit auctions, in the hope that provisional scarcity would push the price up. The European Parliament rejected the proposal on April 16 but finally accepted it on July 3. Hence the allocations of some 2014 permits by Member States to their industries will be held back from auction until 2019. This confusion between objectives and tools is counterproductive not only for the control of CO_2 emissions, but also for the tax-collecting objective politicians have in mind, as we explain below.

The initial mistake comes from the alignment of the three effects identified in Figure 1. This is an error because with a clear policy to limit GHG

[8] See OECD (2011).

[9] Since January 2013, we have entered Phase III where all electricity producers must buy the rights to emit CO_2 instead of receiving them for free on a grandfathering basis like in Phases I and II. Overall, 40% of allowances are to be auctioned. On the auctioning rules, see European Commission (2010).

emissions, there is no need to subsidize less polluting technologies and to limit consumption: as we have seen, $y^* > y^o$ and $q^* < q^o$ are natural consequences of the carbon policy. Independent quantitative targets for 20% energy saving and 20% of renewables in the energy mix are inefficient solutions because

- they are viewed as genuine objectives whereas they do not directly fix an externality;
- they require large amounts of red tape and State aid;
- they increase the cost of reaching the CO_2 target;
- they introduce noise into the CO_2 price and public revenues from allowances auctions.

The latter two points can be explained as follows. Let z_a stand for the direct abatement effort of polluting firms at unit cost w_a (*e.g.* switching from coal to natural gas, carbon storage), z_b the effort to comply with additional rules at unit cost w_b (*i.e.* adopt renewable sources or decrease energy consumption), and $g(z_a, z_b)$ the resulting decrease in CO_2 emissions. The optimal combination of efforts is the solution to

$$\min_{z_a, z_b} w_a z_a + w_b z_b \text{ s.t. } g(z_a, z_b) \geq T \tag{6}$$

where the target is $T = 20\%$ of 1990 emissions. The solution is $z_a^* = z_a(w_a, w_b, T), z_b^* = z_b(w_a, w_b, T)$ defined by $g(z_a, z_b) = T$ and $\frac{\partial g(z_a,z_b)/\partial z_a}{\partial g(z_a,z_b)/\partial z_b} = \frac{w_a}{w_b}$ and the cost of this optimal policy is $C^*(T) = w_a z_a^* + w_b z_b^*$.

As the authorities impose the additional constraint $z_b \geq \underline{z}_b$, we have two possibilities:

i) either $\underline{z}_b \leq z_b(w_a, w_b, T)$: the new constraint is redundant since it is met by the solution to (6). In that case, all the subsidies allocated to meet the additional constraint are pure windfall gains for beneficiaries;

ii) or $\underline{z}_b > z_b(w_a, w_b, T)$: the least–cost solution is no longer feasible. The constrained solution is $z_a^o = \arg[g(z_a, \underline{z}_b) = T], z_b^o = \underline{z}_b$. As we can see

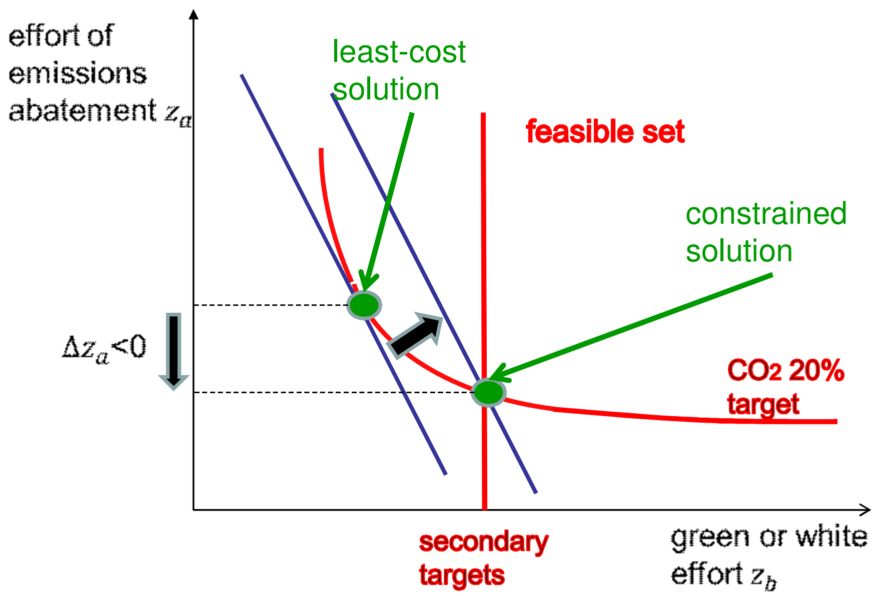

Figure 2: Cost minimization to reach the CO_2 target.

in Figure 2, there are two important consequences: (a) the solution is more costly than it should be, $w_a z_a^o + w_b z_b^o > C^* (T)$ because of the additional constraint(s) represented by the secondary target(s) and (b) since $z_b^o > z_b^*$, the direct effort to abate CO_2 emissions is reduced: $z_a^o < z_a^*$.

It is important to insist on the second effect ($z_a^o < z_a^*$) because it illustrates how bad policy can impair good economic tools. On the CO_2 market, supply is basically fixed and equal to the European Union Allowances determined for each year of the current Phase by the EU authorities.[10] Demand is derived from profit maximization by industrial polluters. As in the case of any input, the demand for allowances decreases in line with the price of allowances and of complementary inputs (for example coal), and increases with

[10] There also exist credits from complementary programs: Emissions Reducing Units (from Joint Implementation) and Certified Emission Reduction (from Clean Development Mechanism), that introduce some price-elasticity in supply; see cdm.unfccc.int/about and ji.unfccc.int.

the price of substitutes (for example abatement technologies) and that of all the output drivers (for example global activity, electricity price, etc.). Decreasing the need for abatement effort automatically decreases the cost of the related technologies, which depresses the allowance requirement since abatement effort and emission credits are close substitutes. In a price-quantity diagram it is then easy to understand that because of the secondary targets, the demand for permits is shifted leftwards, resulting in a price decrease.

In a nutshell, the tighter the green constraint (20% of renewables) and the white constraint (20% of energy saving), the lower the price of CO_2 on the ETS. This negative side-effect is apparently a bad surprise for governments in needs of tax revenues. The fact that emissions are kept under control has become a secondary concern.

3 The promotion of renewables

Regarding direct CO_2 abatement, EU Member States have no choice: ETS is mandatory. By contrast, they remain free to organize as they see fit the path towards 20% renewables and 20% energy saving. This explains the wide variety of regulations and State aid used by various countries to reach the targets.[11] In the EU competition policy toolbox, the control of State aid plays an important role in limiting potential distortions that governments could create when they sustain domestic agents by financial and non-financial means. The principle settled by Article 107 of the Treaty is simple: "State aid is forbidden, except if". Aid in favor of environment protection is one of the categories exempted from notification requirements.[12] In other words, when it comes to the 20-20-20 objective, the principle changes to: "State aid is permitted, except if".

In the following paragraphs, I limit the analysis to the "Green 20" strategy, that is to the promotion of Renewable Energy Sources. I discuss the current EU environment policy in favor of RES in two steps: (*i*) RES have several handicaps that impede their efficient entry into the energy mix; and

[11] See Butler and Neuhoff (2008) and Ragwitz *et al.* (2012)

[12] The others are aid in favor of small enterprises, R&D, employment, and training.

(*ii*) the various tools used to promote RES, in particular Feed-in Tariffs (FIT), have severe distortive effects.

3.1 Efficient energy mix

3.1.1 Technology choice without RES

The basic model for electricity producers burning coal or natural gas is as follows: to produce quantity q_{ft} at date t it costs c_f per unit below the equipment capacity K_f. Consequently the optimal equipment to install and quantities to produce given the increasing and concave surplus functions $S_t(.)$ are the solution to

$$\max_{K_f,\{q_{ft}\}} \; -r_f K_f + \sum_{t=1}^{N_f} \frac{S_t(q_{ft}) - c_f q_{ft}}{(1+\rho)^t} \qquad \text{s.t. } \; q_{ft} \leq K_f \quad \forall t \tag{7}$$

where N_f is the (exogenously given) life of the equipment, r_f the unit cost of capacity, and ρ the interest rate.

From the first order conditions, we obtain

$$q_{ft}^* = \begin{cases} \arg\left[S_t'(q_{ft}) = c_f\right] < K_f^* \text{ if } S_t'\left(K_f^*\right) < c_f \\ K_f^* \quad \text{otherwise} \end{cases} \tag{8}$$

$$\text{and } K_f^* = \arg\left[\sum_{t\in N_f^*} \frac{S_t'(K_f) - c_f}{(1+\rho)^t} = r_f\right] \tag{9}$$

where N_f^* is the subset of periods where the equipment is saturated, *i.e.* $q_{ft}^* = K_f^*$. In addition to the local conditions (8) and (9), we must check whether the overall discounted net surplus is non-negative at the solution:

$$-r_f K_f^* + \sum_{t=1}^{N_f} \frac{S_t\left(q_{ft}^*\right) - c_f q_{ft}^*}{(1+\rho)^t} \geq 0 \tag{10}$$

Otherwise, $K_f^* = 0$ and $q_{ft}^* = 0$ at all t.

Under perfect competition, the expected profit of producers is $-r_f K_f +$

$\sum_{t=1}^{N_f} \frac{(p_t^e - c_f) q_{ft}}{(1+\rho)^t}$ where $p_t^e(K_f, c_f) = \max\left[S_t'(K_f), c_f\right]$ is the equilibrium electricity spot price at t given K_f.

The non-negativity of discounted cash-flow imposes

$$\sum_{t \in N_f^*} \frac{S_t'(K_f) - c_f}{(1+\rho)^t} \geq r_f \tag{11}$$

If all firms have the same technology, free entry transforms (11) into an equality by decreasing $p_t^e(K_f, c_f) = S_t'(K_f)$. It determines the equilibrium capacity to install, equal to the optimal one K_f^*. By the free entry process, firms balance their budget at the long run competitive equilibrium.

If technologies are heterogeneous, there are more than two types of market state to determine the spot price. It remains true that at off-peak periods, the price is equal to the operating cost of the cheapest technology and at peak periods it is equal to the marginal utility of the whole capacity. In between (low and medium demand) the price is determined by the operating cost of intermediate technologies. The peaking firms (those with a large c_f) are called into operation only for a very small number of peak hours N_f^*. They can therefore survive only if they have a low capital cost r_f and prices $p_t^e = S_t'\left(\sum_f K_f\right)$ are sufficiently high during the N_f^* periods.[13] Again, at the long run competitive equilibrium, all the active firms balance their budget.[14]

3.1.2 Technology choice with RES

How does this mechanism change when electricity from RES is available? Most of the technologies based on RES have two characteristics: (i) they can work only if a non-controllable source of primary energy is available (wind, water along the river, solar energy) and (ii) the operating cost is nil when

[13] Actually, prices are capped in most wholesale markets: for example €3000/MWh on EPEXspot. The cap creates a "missing money" problem that some countries solve by capacity payments, capacity obligations, or capacity markets.

[14] The first proof was published in Boîteux (1949).

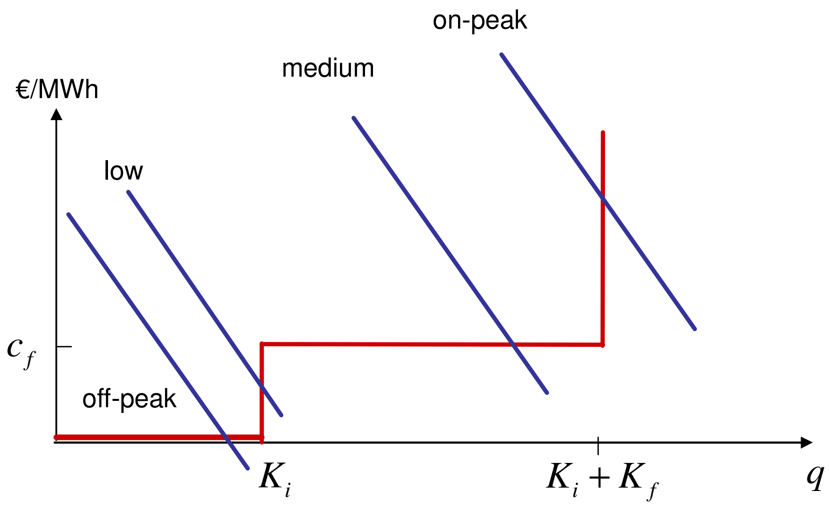

Figure 3: Peak-load pricing with RES and non-RES.

the source is available. Assume there are two states of nature on the supply side at each period : a state with plenty of primary energy (windy days) with probability ν_t, and a state without any primary energy (days without any wind). The staircase line in Figure 3 is the merit order in windy states of nature when fossil-fuel capacity K_f and RES capacity K_i are available: first, produce at 0 marginal cost up to K_i, then serve additional demand at marginal cost c_f up to $K_i + K_f$. In states of the world without wind, the merit order is just shifted leftwards up to quantity K_i.

Ex post, if capacity K_i is installed on top of K_f, the market equilibrium price at period t will be as follows:

- with probability ν_t, $p_t^e = 0$ off-peak, $p_t^e = S_t^{'}(K_i)$ at periods of low demand $\widetilde{N}_i^*$, $p_t^e = c_f$ at periods of medium demand N_i^*, and $p_t^e = S_t^{'}(K_i + K_f)$ at peak periods N_{if}^* (see Figure 3);
- with probability $(1 - \nu_t)$, $p_t^e = c_f$ at periods of low demand and $p_t^e = S_t^{'}(K_f)$ at periods of high demand N_f^*.

Ex ante, given the expected electricity market prices and the unit cost

r_i of production plants, the entry of RES is profitable if and only if

$$\sum_{t\in \widetilde{N}_i^*} \nu_t \frac{S_t^{'}(K_i)}{(1+\rho)^t} + \sum_{t\in N_i^*} \nu_t \frac{c_f}{(1+\rho)^t} + \sum_{t\in N_{if}^*} \nu_t \frac{S_t^{'}(K_i+K_f)}{(1+\rho)^t} \geq r_i \tag{12}$$

Under pure market mechanisms, that is without any public intervention, we see that profitability requires

- a low capital cost r_i, a long life duration N_i, and large probabilities ν_t;
- large operating cost c_f in non-RES;
- small capacities of both types in order to push $S_t^{'}(K_i)$ and $S_t^{'}(K_i + K_f)$ up.

Note that benefits are boosted by positive correlation between RES availability ν_t and marginal willingness to pay for electricity, i.e. in regions where ν_t is large at dates t of large $S_t^{'}(.)$. Clearly, windmill producers earn more money if the wind blows in the day rather than at night and solar panel owners would prefer the sun to shine at full capacity at the end of winter working days.[15]

As for fossil-fuel plants,

- when a large quantity of RES is available, a positive margin only appears at peak periods N_{if}^*. In states $\widetilde{N}_i^*$ fossil fuel plants do not produce and $p_t = c_f$ in states N_i^*.
- without RES, margins are positive at peak periods N_f^*.

The profitability of fossil fuel plants then requires that

$$\sum_{t\in N_f^*} (1-\nu_t) \frac{S_t^{'}(K_f) - c_f}{(1+\rho)^t} + \sum_{t\in N_{if}^*} \nu_t \frac{S_t^{'}(K_i+K_f) - c_f}{(1+\rho)^t} \geq r_f \tag{13}$$

[15] In countries where peak demand is due to air conditioning, PV panel production is positively correlated with demand.

Under free entry, the long-run equilibrium capacities are those determined when (12) and (13) are equalities instead of inequalities. Given the current values of parameters $(c_f, r_f, N_f, r_i, N_i, \rho, \{\nu_t\})$ most renewables-based technologies cannot be profitable when condition (13) is met as an equality.[16] Their cost r_i is still too high, their availability $\{\nu_t\}$ to low and their life N_i too short as compared to the characteristics of thermal plants (c_f, r_f, N_f). This explains why State aid is necessary for RES to reach profitability. In the next section, we consider alternative policies aimed at making RES profitable, even though we have seen in Section 2 that it should not be an objective *per se*.

3.2 Certificates, tariffs, taxes and the like

Because of high cost, intermittency and geographical dispersion, Renewable Energy Sources (RES) cannot be developed without government help. The expected "grid parity", that is the possibility for these energies to compete against fossil sources on a level field is a matter of misunderstanding. It may be true that in the future RES-electricity will have a MWh cost comparable to the cost of fossil-fuel plants. That will however not solve the intermittency feature since $\nu_t < 1$ for most dates t. The guarantee to supply a given quantity at a given date for a given duration will always be out of reach for intermittent sources such as wind power and solar energy without additional backup or storage equipment.[17] Consequently, the development of RES-electricity creates a public commitment to constrain the future industry structure. The EU "Green 20" strategy actually authorizes Member States to launch industrial policy in the energy sector.

In this mix of environmental and industrial policy, some Member States use direct subsidies for investment, while others prefer quota obligations, sometimes combined with tradable green certificates. However the most

[16] Even when cost parameters make RES competitive, long run equilibrium is feasible only if consumers are reactive to scarcity at production nodes through state-contingent prices. We address this point in the next section. For a detailed analysis of the case where there is one single time period, see Ambec and Crampes (2012).

[17] On solar energy, see Baker *et al.* (2013); on wind power, Butler and Neuhoff (2008).

widely used financial tool across the Community is a non-market system: fixed feed-in tariffs (FIT) paid to green producers.

In the following paragraphs, I first show how RES are positively impacted by an increase in the operating cost of electricity producers burning fossil fuel. I then compare the effects of the tools currently used to promote RES.

3.2.1 Increasing the carbon cost

As shown in Section 2, the basic tool for environmental regulation should consist in obliging producers who use polluting technologies to internalize their negative externalities. This can be done by a tax equal to the marginal environmental damage, by the obligation to buy the right to emit, or by free allowances up to a given total quantity. The operating cost c_f then becomes $c_f + \Delta$, where Δ stands for the tax, the fee to pay for acquiring rights or the dual value of the quantitative constraint. As inequality (12) shows, by increasing c_f to $c_f + \Delta$, the profitability condition is easier to meet for RES; as (13) shows, it becomes more difficult for non-RES, so that some plants are obliged to stop producing.

More precisely, a drastic CO_2 policy indirectly benefits RES in two ways:

- **enrichment effect**: when demand is medium ($t \in N_i^*$) and the price is determined by non-RES technologies, RES earn a larger margin $c_f + \Delta - 0$ (if they produce, *i.e.* with probability ν_t);
- **replacement effect**: the price at period t is lower when RES are used than when they are not, regardless of whether t is a low or a high demand period. This means that if fossil-fuel plants were just balancing their budget before the entry of RES, it is no longer the case afterwards. Then, to rebalance inequality (13), type-f firms are obliged to decrease their installed capacity K_f. Prices consequently decrease but remain high at peak periods because of the closure of type-f plants, which is beneficial for RES, in particular if their production is positively correlated with demand.

The replacement effect is a source of potential problems in terms of security of supply. Were RES just cheaper reliable sources of energy, the entry of low-cost technologies pushing expensive ones out of the efficient mix would be good news for consumers.[18] Unfortunately, without smart meters and appliances, electricity consumption is weakly responsive to short-term scarcity signals such as price increases and warning messages sent by the system operator.[19] As a result, at each date t, consumers are not reactive to the state of nature at production plant locations. Assume that Δ is fixed high enough for RES to be profitable. Then $K_i > 0$, but we know that $q_{it} = 0$ with probability $\nu_t > 0$ at period t. Unless we accept blackouts, electricity being non-storable, production at period t must be the same whatever the speed of wind at windfarm sites. For example at peak periods, we have seen that p_t^e should be equal to $S_t^{'}(K_f)$ with probability $(1 - \nu_t)$ and to $S_t^{'}(K_i + K_f)$ with probability ν_t. Actually, fossil fuel plants face two *ex post* obligations: (a) to keep total production independent of the state of nature and (b) to leave priority to RES in the efficient dispatch. Then, if RES are very abundant, fossil-fuel plants must produce $q_{ft}^{i} = 0$ when RES are available and $q_{ft}^{\bar{i}} = K_i$ when they are not, which requires the installation of $K_f = K_i$.

More generally, denoting by $\overline{p}_t$ the non state-dependent price at t[20] and by $D_t(\overline{p}_t)$ the corresponding demand, fossil fuel plants must be ready to produce

$$q_{ft} = \begin{cases} D_t(\overline{p}_t) - K_i & \text{with probability } \nu_t \\ D_t(\overline{p}_t) & \text{with probability } 1 - \nu_t \end{cases} \tag{14}$$

Assuming that fossil-fuel firms produce at full capacity at peak periods without RES and that black-outs and brown-outs are not permitted, we

[18] In Germany, at noon on July 21, 2013, solar production reached the total record of 24 GW, that is more or less the production of 24 nuclear plants. The two main incumbents, RWE and E.ON, are contemplating the closure of some 15 GW of coal and gas-fired plants.

[19] With the exception of big industrial consumers who have contracts at low prices to compensate for curtailment clauses. For smaller customers (small industrial and business clients, households) service providers propose remotely controlled load-shedding (see Crampes and Léautier, 2012).

[20] In real life, because of the absence of smart meters, not only electricity prices cannot depend on the state of nature, but it cannot even depend on date.

have $K_f = D_t(\overline{p}_t)$ or $\overline{p}_t = S_t^{'}(K_f)$ for $t \in N_f^*$. We also have $\overline{p}_t = S_t^{'}(K_f)$ at peak periods with RES $\left(t \in N_{if}^*\right)$ because of the impossibility to have state-contingent prices, but fossil fuel producers can only sell $D_t(\overline{p}_t) - K_i$. The budget balancing conditions of the two types of producers are then

$$\sum_t \nu_t \frac{\overline{p}_t}{(1+\rho)^t} \geq r_i \tag{15}$$

$$\sum_{t \in N_f^*} (1-\nu_t) \frac{\overline{p}_t - c_f}{(1+\rho)^t} + \sum_{t \in N_{if}^*} \nu_t \frac{\overline{p}_t - c_f}{(1+\rho)^t} \frac{D_t(\overline{p}_t) - K_i}{K_f} \geq r_f \tag{16}$$

As shown in Ambec and Crampes (2012), when consumers are not reactive to state-contingent prices, lower energy prices combined with the dramatic fall in non-RES electricity sales due to RES priority results in the impossibility to meet the separate conditions (15) and (16) simultaneously: a zero net present value in (16) gives a strictly positive net profit to RES, and a zero net present value in (15) provokes financial losses of non-RES plants. The intuition is as follows: to satisfy (16) we need $\overline{p}_t \geq c_f$ in all states of nature. The RES producers then earn $\overline{p}_t - 0 \geq c_f > 0$ whenever they are active while at first best where budgets are balanced, the price should be 0 during off-peak periods where RES are available.

To reach a long-run equilibrium, it is necessary to implement structural arrangements (mergers), contractual arrangements (guarantee of supply) or portfolio obligations to balance the producers' budget globally, *i.e.* to compensate for the financial losses of fossil-fuel plants with the benefits of RES. Besides back-up by thermal plants, RES intermittency can also be balanced by demand curtailment, energy storage and imports.

3.2.2 Technology-pushed *vs.* demand-pulled entry

The above analysis with or without price-reactive consumers is based on the possibility for RES to be competitive against non-RES, in particular because of a high CO_2 cost. In reality, RES are far from competitive, and EU Member States are obliged to force the entry of technologies based on renewables into the energy mix by violating competition rules.[21] In the following paragraphs, we consider first subsidies to R&D in RES technologies and second subsidies to electricity demand.

Subsidies to R&D When investors face a technology with

$$\sum_{t=1}^{N_i} \nu_t \frac{p_t q_{it}}{(1+\rho)^t} < r_i K_i \tag{17}$$

where p_t is exogenous and $q_{it} \leq K_i$, they naturally consider whether the inequality can be reversed by means of R&D investment that could increase N_i and ν_t, and decrease r_i. There are at least two advantages with the R&D solution: (*i*) decision-makers can choose the best option within their toolbox and (*ii*) they bear the risk of failure, which is the role of entrepreneurs as they are less risk-averse than the other agents. There are also at least two drawbacks: (*i*) because of economies of scale and learning by doing, drastic improvement can be out of reach when many agents act separately and (*ii*) R&D is a source of positive externalities that individual decision-makers cannot easily internalize. Then, since reversing the inequality in (17) is now a Community objective for RES, if joint ventures necessitate excessive transaction costs or are impeded under Article 100 of the Treaty, State aid becomes necessary. Given its distortive effects, State aid is limited by guidelines issued by EU authorities. In particular "*State aid for research, development and innovation in the environmental field is subject to the rules set out in the Community framework for State aid for research and development and innovation. However, the market diffusion stage of eco-innovation (acquisition of an eco-innovation asset) is covered by these Guidelines.*"[22] In other words, upstream State aid aimed at reversing (17) for

[21] "State aid may be justified if the cost of production of renewable energy is higher than the cost of production based on less environmentally friendly sources and if there is no mandatory Community standard concerning the share of energy from renewable sources for individual undertakings. The high cost of production of some types of renewable energy does not allow undertakings to charge competitive prices on the market and thus creates a market-access barrier for renewable energy." European Commission, 2008, §48.

[22] European Commission (2008), Paragraph 63.

RES must follow the same rules defined in European Commission (2006)[23] as for any innovation in any industry. That is good news for the economist who considers there to be no reason to make the Green 20% strategy a *sui generis* objective. It is bad news for the economist who observes that, given that the Green 20% is now a *sui generis* objective, in the absence of any upstream specific encouragement, Member States will systematically adopt downstream State aid.

Premiums and Feed-in Tariffs Another way to change the sign in (17) is to increase p_t and q_{it}, and decrease ρ.

A reduction in interest rates for loans dedicated to financing green investment is a simple solution, but given the high cost of these technologies, it can be true that they remain unprofitable even when $\rho = 0$. Complementary solutions are then necessary.

The quantity sold can systematically be increased up to the capacity available by means of priority rules: the system operator must accept any injection coming from RES before energy from plants using sources not on the list mentioned by Directive 2009/28/EC.[24] After capacities have been installed, this is not a distortion of competition, given that RES generically have an operating cost close to zero, below the operating cost of thermal plants. Why it then appears as an obligation is unclear: it is actually *ex post* efficient to include RES first in the merit order when available (see Figure 3). However, this obligation may be a source of inefficiency under specific circumstances: at some hours, nuclear or coal-fueled plants have negative economic costs due to starting, warming and ramping constraints; therefore, at some hours, they should be ranked before RES that have a zero operating cost in the merit order. This is forbidden, given the rule of priority to RES. This can be illustrated as follows:

- there are two types of period: off-peak at night (n), and peak at day (d);

[23] Note that this Framework is currently under review.
[24] Except for safety and technical reasons, in particular when lines are congested.

- because of ramping-rate constraints, the unit cost of production at a given hour depends on what the firm was doing during the preceding hour. Specifically, to keep the model simple, the unit cost is $c(0)$ at night and $c(q_n)$ in the day, with $c'(q_n) < 0$.

Then, for the firm that solves

$$\max_{q_n, q_d} S_n(q_n) - c(0) q_n + S_d(q_d) - c(q_n) q_d$$

the first-order conditions are

$$S_n'(q_n^*) - c(0) - c'(q_n^*) q_d^* = 0 \quad (18)$$

$$S_d'(q_d^*) - c(q_n^*) = 0 \quad (19)$$

During night hours, the economic cost of the thermal producer is $c(0) + c'(q_n^*) q_d^*$. Since it is below $c(0)$, it gives producers the incentive to produce off-peak more than if $c' \equiv 0$. The welfare loss resulting from $S_n'(q_n^*) < c(0)$ is more than compensated at day thanks to the consecutive decrease from $c(0)$ to $c(q_n^*)$. The point is that if (i) the ramping effect $\left|c'\right|$ is strong and (ii) the expected daytime demand q_d^* is high, the accounting cost at night $c(0)$ may be below the opportunity gain $-c'(q_n^*) q_d^*$ so that $c(0) + c'(q_n^*) q_d^* < 0$. This explains why electricity producers are allowed to submit negative bids on wholesale markets.[25] When they do so, they should be ranked first in the merit order since bids from RES should, at the lowest, be equal to 0. Actually, this efficient market mechanism is impaired by wind-mill operators who also submit negative bids. We now explain that it results from the tariff policy in favor of RES.

To change the inequality in (17), many Member States have chosen to pay electricity producers using renewable sources a unit price $\alpha p_t + F_t$, where p_t is the market price, α a coefficient in $[0, 1]$ and $F_t > 0$ a premium raised

[25] See for example the auctions organized for France, Germany/Austria and Switzerland on www.epexspot.com/en/market-data/auction/curve/auction-aggregated-curve/ and for the Netherlands and the UK on www.apxgroup.com/market-results/apx-power-nl/aggregated-curves/

from other agents of the industry (mainly consumers). In the extreme case where $\alpha = 0$, RES producers are totally disconnected from market signals. France, Germany, Italy and Spain have hugely subsidized the solar and wind energies by guaranteeing generous selling prices F_t (named feed-in tariffs, FIT) for 20 years to the electricity producers equipped with windmills and photovoltaic panels.[26] These programs have been so successful that they have endangered the financial equilibrium of the funding system in the four countries obliging governments to downsize tariffs and redefine conditions for eligibility. Meanwhile, FIT that reward producers using wind resources have also impaired the efficiency of negative bids. If a windmill operator anticipates a reward $\alpha p_t + F_t$ per MWh when producing, any spot price $p_t > \frac{-F_t}{\alpha}$ is still profitable since the operating cost is nil. The operator is then encouraged to bid slightly above $\frac{-F_t}{\alpha}$, which can still be very low,[27] guaranteeing a positive margin on every MWh injected, even though the equilibrium spot price is negative. In Germany, negative equilibrium prices have almost always occurred in early-hour markets of low demand (1:00 am − 2:00 am, 2:00 am − 3:00 am, etc.) where large quantities of wind energy from the North Sea were available. Whether this can prevent thermal plants from being dispatched at early hours and be operational at low cost when the morning demand is at a peak cannot be taken into consideration by the system operator under the current regulation.

Public authorities often emphasize several side benefits on top of limiting global warming from the promotion of RES. They quote in particular increasing energy security, leading Europe out of the economic crisis and creating new technology jobs.[28] All these side-effects are disputable, in par-

[26] In other countries, $\alpha = 1$ and F_t is a supplement reward from selling certificates associated with RES production. Certificates are sold to obligated parties (suppliers in Belgium and UK, producers in Italy, grid companies in Germany). The tradable green certificate system looks like the EU ETS except that it is organized on a national basis. It therefore has the same qualities and shortcomings as ETS, in particular the administrative cost of registering and controlling.

[27] However, energy exchanges impose price floors: on Epexspot, bids cannot be below €−3000 /MWh. See www.eex.com/de/document/74115/EEX_MARKET_MONITOR-Q4_2009-english_final.pdf

[28] In Directive 2009/28/EC Preamble 4 says: "When favouring the development of the market for renewable energy sources, it is necessary to take into account the positive

ticular the possibility to give European industries an advantage in the field of PV panels. By relying on very generous FIT, Member States hoped that consumers would massively buy PV panels so that, thanks to learning-by-doing and economies of scale, the production cost of panels r_i would go down and change the direction of the inequality (17). This did occur, but governments have forgotten that under this subsidization regime (*i*) consumers, not manufacturers, are the risk-takers: they bear regulatory uncertainty, and they can be stuck for 20 years with obsolete panels, and (*ii*) consumers behave like any electricity producer, choosing the least-cost equipment, which is eventually imported from Asia. Indeed, high FIT have created a violent shock of demand in the market where parts of green equipment are manufactured. The shock has excluded European champions from the equipment market instead of giving them a boost.[29] The industrial policy slice of the promotion plan is then a total failure.

impact on regional and local development opportunities, export prospects, social cohesion and employment opportunities, in particular as concerns SMEs and independent energy producers."

In Preamble 6: "The move towards decentralized energy production has many benefits, including the utilization of local energy sources, increased local security of energy supply, shorter transport distances and reduced energy transmission losses. Such decentralization also fosters community development and cohesion by providing income sources and creating jobs locally."

Similarly, "Renewable energy is crucial to any move towards a low carbon economy. It is also a key component of the EU energy strategy. The European industry leads global renewable energy technology development. It employs 1.5 million people and by 2020 could employ a further 3 million. The promotion of renewable energy also develops a diverse range of mostly indigenous energy resources."

[29] The mechanism behind the expected development of RES through demand subsidies is based on a decrease in production cost thanks to learning-by-doing. Contrary to the logics of subsidies to R&D where an increase in demand is due to lower prices resulting from lower costs, in the FIT system demand is the driver of the cost decrease. Therefore, with FIT, an increase in demand comes sooner than under the regime of R&D subsidies. This system can have adverse effects for competition as "Learning-by-doing involves a form of sunk cost. Production leading to a gain in experience, is the cost which is sunk. Learning therefore manifests itself as an irreversibility in production possibilities" (Dasgupta and Stiglitz, 1988). This implies that under FIT there is a potential for creating a natural monopoly instead of promoting competition. See also Crampes and Lefouili (2013).

4 Conclusions

Environmental policies commonly used in the European Union are an inefficient mix of taxes, markets, subsidies, feed-in tariffs and capacity obligations. Their complexity is masking the priority that must be given to the reduction of greenhouse gas emissions. Theoretically, several tools are more efficient than only one since they allow fine tuning. Fischer and Neuwell (2008) show that the least-cost tool to reduce polluting emissions is a price or tax or dual value on polluting emissions, not indirect tools.[30] They also insist that "an optimal portfolio of policies achieves emissions reductions at a significantly lower cost than any single policy." This is true if several market failures are identified and if the tools are well chosen and well balanced. In practice, the risks of mistakes, lobbying and opportunism increase very rapidly with the number of State aids, in particular when each target is sustained by a directive making it mandatory.

My discussion has been based on the drawbacks of the 20% RES objective because the inefficiency of the policy tools aimed at curbing polluting emissions by RES promotion is strong. I have simply mentioned the energy efficiency target because its rationale is very similar.[31] Energy efficiency should be subordinated to the reduction of negative externalities, but it sometimes increase emissions.[32] Also note that energy saving is not the natural outcome of a competition policy that promotes price decreases. Actually, energy retail prices increase whereas wholesale prices decrease because retail prices include the additional costs imposed by the environmental policy. But price increases are much higher than they should be, particularly in Germany, because the authorities have accumulated mistakes in choosing

[30] In a numerical application to the U.S. electricity sector, they find the following ranking in terms of welfare loss: (1) emissions price, (2) emissions performance standard, (3) fossil power tax, (4) renewables share requirement, (5) renewables subsidy, and (6) R&D subsidy.

[31] See European Council for an Energy Efficient Economy (2012). On demand response, see Torriti *et al.* (2010).

[32] In France for example, one rule to reach the 20% energy saving target requires that new buildings do not consume more than 50 kWh/m^2 of primary energy. This constraint eliminates electric boilers that store hot water at night by consuming electricity from nuclear plants. They are now replaced by gas boilers, which means an increase in the consumption of an energy that emits GHG.

the mix of environmental tools.

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