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Abstract

When choosing policy mechanisms to design and deploy energy policies, policymakers typically seek cost-effective ones, linking cost-effectiveness to the lowest cost of support for RES-E generation and/or consumer costs. The objectives of this paper are to analyze the cost-effectiveness of renewable portfolio standards (RPS), feed-in tariffs (FIT) and auctions in the short and long term, considering both technology-neutral and technology-specific approaches. Results show that RPS and auctions are more cost-effective than feed-in tariffs (FIT) in the short term if cost-effectiveness is defined as minimizing consumer costs. Also, if one or more emerging technologies with higher levelized life cycle costs (LCC), low cumulative production and high experience elasticity are considered in the pool of RES-E policy design, a technology-neutral approach in the short-term could lock out these emerging technologies, avoiding a long term LCC reduction. In this case, a technology-specific policy used in the short-term would reflect lower total generation policy costs in the long term if compared with a technology-neutral policy in both short and long term. This paper calls this phenomenon the paradox of technology-neutral and technology-specific policies in the long term. Considering the results, this paper suggests a mix of technology-neutral and technology-specific policies using RPS or auction mechanisms to promote RES-E.

Keywords: energy policy; feed-in tariff; auctions; renewable portfolio standard; cost-effectiveness.
JEL Classification: Q49; O33; D44; Q29; Q52

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1 Introduction

Policy and incentives are responsible for cost reduction of renewable energy technologies (Chowdhury et al., 2014). Policymakers have used various policy mechanisms to promote clean energy technologies worldwide in recent years, considering both technology-neutral and technology-specific approaches. Renewable portfolio standards (RPS), feed-in tariffs (FIT) and auctions are examples of recently used policy mechanisms that can have a technology-neutral or technology-specific approach, and policymakers usually seek cost-effective policy mechanisms to design and deploy these policies. Cost-effectiveness is usually associated with the lowest cost of support for minimizing RES-E generation and consumer costs, which can be the same or different depending on the chosen energy policy mechanism. This paper explains this assumption and clarifies the differences among FIT, RPS and auction cost-effectiveness using technology-neutral and technology-specific approaches in both short and long term.

In this paper, short term is defined as a period in which RES-E LCC doesn't change; in other words, there is no experience elasticity or other effects involved that could affect LCC. In the long term, experience elasticity could reduce LCC, and this is explained by the experience curve in Section 3 of this paper. Another assumption of this work is that all resources would be allocated efficiently in all policy mechanisms studied.

Cost-effectiveness as the minimization of generation costs means the total generation costs for the quantity of energy (electricity or fuel) contracted reflect the minimum LCC possible for the RES-E considered for a given policy mechanism. It also means that the total policy cost is equal to the minimization of generation costs. While this may be particularly true in an efficient RPS and auction, this paper will explain how it is not the case for FIT.

Extensive literature exists for analyzing and comparing the cost-effectiveness of energy policy mechanisms, such as FIT, REP and auctions, including IEA (2011); Verbruggen and Lauber (2012); Schmalensee (2012); Haas et al. (2011); Mäkelä et al. (2011); Sandeman (2010); Kylili and Fokaides (2015); Rego and Parente (2013); Mastropietro et al. (2014); Nielsen et al. (2011); Sun and yan Nie (2015); Schelly (2014); Eastin (2014), and Wang et al. (2014).

These studies often analyze and compare the cost-effectiveness of RPS, FIT and auctions based on case studies or modeling, but none compare these policies based on their conceptual framework in both short and long term using both technology-neutral and technology-specific approaches. Studies that relate the long-term cost-effectiveness impacts of an energy policy based on a formerly used short-term energy policy are nonexistent.

The objectives of this paper are first to analyze the cost-effectiveness of RPS, FIT and auctions in the short term, considering both technology-neutral and technology-specific approaches. Second it analyses the effects of technology-neutral and technology-specific cost-effectiveness for RES-E in the long term considering the policy mechanisms used in the short term.

Section 2 describes FIT, RPS and auctions as energy policy mechanisms recently used worldwide and also reviews the main findings regarding their cost-effectiveness in literature. Section 3 explains the concepts of levelized life cycle costs (LCC) and experience curves, which describes how an emerging RES-E LCC may reduce in the long term because of the increase in cumulative production and the experience elasticity. Section 4 details the cost-effectiveness of technology-neutral and technology-specific RPS, FIT and auction policies in both short and long terms, illustrating a likely paradox of technology-neutral and technology-specific policies in the long term. Section 5 addresses the conclusions of this paper.

2 FIT, RPS and auctions as energy policy mechanisms

A main finding of the RES-E support literature is that the success of support schemes depends as much on the instruments chosen as on their design elements (del Río and Cerdá, 2014). Feed-in tariffs and renewable portfolio standards can effectively increase the share of renewable energy power and lead to renewable resource diversity (Wang et al., 2014), although it does so with different total costs for consumers. Auctions reflect a positive reform to ensure adequacy through promoting investment and mitigating risks and market power (Moreno et al., 2010), which is similar in some aspects to RPS as described in Section 4.

Renewable portfolio standards (RPS), feed-in tariffs (FIT) and auctions are examples of policy mechanisms recently used by policymakers around the world to promote RES-E, and they can have a technology-neutral or technology-specific approach. This section briefly explains how these mechanisms work, their main differences, and how the literature regards their cost-effectiveness.

Feed-in tariffs are subsidies per MWh generated and producers of renewable electricity are paid either in the form of guaranteed fixed prices or in premium prices combined with a purchase obligation by the utilities. These programs, often called feed-in tariffs, are more common in Europe than in the United States (Jenner et al., 2013) and are used more for electricity. It is possible, however, to design it for use with fuels based on GJ instead of MWh.

FIT can have a technology-neutral or a technology-specific approach. In a technology-neutral approach, also called flat tariff, a uniform tariff is provided for all technologies in a given region, for example, in US$/MWh. This approach ignores generation costs, leaving it to investors to decide which allowed renewable technology to pick. In a technology-specific approach, a tariff is fixed for a particular technology; and despite some variations from one country to another, the concept of FIT is guaranteed premium prices combined with a purchase obligation by the utilities. Several studies, including Schallenberg-Rodriguez and Haas (2012); Lin et al. (2014); Huenteler (2014); Wong et al. (2015); Buckman et al. (2014); Schmidt et al. (2013); Muhammad-Sukki et al. (2014); Valentine (2010), and Chowdhury et al. (2014) have analyzed different aspects of FIT programs. They all agree that the results are good for FIT in terms of RES-E deployment and for promoting RES-E. However, FIT guarantees the purchase of renewable energy regardless of cost, usually providing extra-profit to producers, as explained in Section 4.

Renewable portfolio standard (RPS) is a policy mechanism implemented throughout much of the United States. RPS mandates a relative or absolute quantity of electricity (% or MWh in some states) be generated from renewable sources. This encourages price competition between different types of renewable energy. Technology-neutral approaches promote competition through RES-E eligibility, allowing the market to identify the winning technology. In a technology-specific approach, a specific RES-E may be chosen to be promoted, and it typically operates through Renewable Energy Certificates (RECs), which determine prices by conditions of the market's supply and demand. This approach is different from FIT, whose prices are predetermined by policymakers. Some US states use multiple methods to meet the RPS requirement; for example, self-generation, procuring power from renewable sources via bilateral contracts and purchasing the renewable energy certificates/credits (RECs) from secondary markets (Tanaka and Chen, 2013). The literature includes studies that analyze the cost-effectiveness of RPS, including Kung (2012); Stockmayer et al. (2012); Schelly (2014); Farooq et al. (2013); Daim and Cowan (2010), and Aslani and Wong (2014). State RPSs vary widely in their attempt to control or limit RPS costs but producers' profits are less than market average (Stockmayer et al., 2012). In general, these studies agree that RPS help to promote RES-E.

Recently, auctions have become popular in attracting public utility investors. After the 1990s, there were bidding processes in several countries around the world; and it became apparent that auctions were frequently used in electricity markets that required restructuring. Rego and Parente (2013).

In a technology-neutral auction, RES-E compete against each other (Moreno et al., 2010; Rego, 2013), so one or more technologies may not be contracted if there is too much disparity in LCC. Technology-specific auctions may be done conducting separate auctions, as used to contract photovoltaics in Cyprus (Kylili and Fokaides, 2015). Auctions to purchase long-term contracts were used in Brazil, Chile, Colombia, Peru, and New England (US) in recent years, and they proved successful in promoting investment while mitigating risks and market power (Moreno et al., 2010).

Despite the risk of collusion, which can be mitigated as shown in (Moreno et al., 2010; Rego, 2013), auctioning RES-E with long-term contracts are an effective tool to promote generation investment and achieve the desired RES-E target.

3 Levelized life cycle costs (LCC) and experience curves for RES-E

The level of support a technology needs to be competitive and the percentage of this support that should be derived from government budgets are crucial questions. Experience curves make it possible to answer such questions because they provide a simple, quantitative relationship between LCC and the cumulative production or use of a technology (IEA, 2003).

Literature shows that policy and incentives are responsible for cost reduction (Chowdhury et al., 2014). Also, unaligned energy policy and termination of incentives may cause energy markets to decline, locking out some promising energy technologies. A comparative study between Japan and Germany shows that government incentives kept Japan in the top position for years. Once Japan reduced its government support, Japan's success declined and Germany's success increased in the PV industry because of government support (Chowdhury et al., 2014). This is because some technologies need policy support to reduce their costs when transitioning from the demonstration stage to the commercial deployment stage where LCC is higher in the short term (Sun and yan Nie, 2015).

Levelized life cycle cost (LCC) is a tool for comparing unit costs of different technologies over their economic life. The calculation of the LCC is based on the equivalence of the present value of the sum of discounted revenues and the present value of the sum of discounted costs (IEA, 2010). It's basically the equivalent annual value of energy cost in a considered useful life in a given interest rate. LCC unit may be given in US$/gallon, US$/liter, US$/MWh or any other commercial currency and measurement depending on the currency and energy being considered. In the case of electricity, LCC for RES-E is usually given in US$/MWh. LCC may then be compared with market price to check if the net present value is positive in a given discount rate. The discount rate chosen is usually subjective because it depends on the investor's opportunity costs and risk evaluation. A usual manner to address this factor is to decide if the rate of return on the money needed for the project could be a higher return if invested in an alternative investment.

LCC may change in the long term, especially for emerging technologies. Some energy policy mechanisms may accelerate this reduction to help bring technologies to market. Experience curve is a trend which relates LCC changes to cumulative sales. The mathematical expression which describes the one factor experience curve is shown in Equation (1).

$$LCC_{x,t} = P_0 \times C_{x,t}^{-\varepsilon} \tag{1}$$

Equation 1: Levelized life cycle cost (LCC) equation. Source: adapted from (IEA, 2000)

The different variables indicate:

- $LCC_{x,t}$ = Life cycle cost of unit production (USD/W, or EUR/GJ for example);
- P_0 = normalized price, normally for 1 unit of cumulative sales;
- $C_{x,t}$ = cumulative power (e.g. MW), production or sales (e.g. MWh, GJ) in year “t”;
- ε = experience elasticity (experience parameter);
- x = technology;
- t = period.

The parameter ε is the experience parameter, which characterizes the inclination of the curve (IEA, 2000). Large values of ε indicate a steep curve with a high learning rate. One important concept of the experience curve is the progress ratio “PR”, which is the corresponding change in price level after a doubling of cumulative sales.

$$PR = \frac{P_0 \times (2C_{x,t})^{-\varepsilon}}{P_0 \times C_{x,t}^{-\varepsilon}} = 2^{-\varepsilon} \tag{2}$$

Equation 2: Progress ratio “PR” of RES-E after a doubling of cumulative sales

For example, if $\varepsilon = 20\%$, it means that LCC with the same interest rate decreases 20% when cumulative sales double. The learning rate (LR) in this case would be 80%, which is represented by $(1 - \varepsilon)$. Learning rates for photovoltaics, wind, bioenergy and others in different countries are found in the literature (Ibenholt, 2002; Ferioli et al., 2009; IEA, 2003, 2000; Nemet, 2006; Yu et al., 2011; Weiss et al., 2010; Junginger et al., 2010).

Photovoltaics is a good case study to illustrate this phenomenon. The PV module historical learning experience (ε) ranges between 11% and 26% worldwide (Edenhofer et al., 2011). In Germany, for example, the learning rate has been observed to be approximately 20% on average between 1980 and 2011 (for Solar Energy Systems", 2012).

In many cases, "learning-by doing" may improve the overall costs or efficiency of a technology, but the effects of single component improvements that together may explain an aggregated form of learning also should be considered (Ferioli et al., 2009). Indeed, for an entire technology the phenomenon of learning-by-doing may well result from only learning one or a few individual components (Ferioli et al., 2009). For example, the price of silicon for photovoltaics and energy efficiency improvements of panels may explain cost reductions better than the entire photovoltaic system.

The next section illustrates how LCC and experience curves might affect technology-neutral and technology-specific FIT, RPS and auctions in the short and long term. Moreover, a phenomenon called paradox of technology-neutral and technology-specific policies could occur in the long term, depending on LCC and elasticity parameters of RES-E being used.

4 Cost effectiveness of technology-neutral and technology-specific RPS, FIT and auction policies

Cost effectiveness of technology-neutral and technology-specific RPS, FIT and auction policies

RES-E technology costs have basically three components in the levelized life cycle cost (LCC); they are initial investments, fixed and variable costs. In some energy technologies, such as grid connected wind, hydro or photovoltaics, the LCC costs tend to increase in a static perspective based on the equimarginality principle. The equimarginality principle states that the cheapest technologies with the lowest RES-E generation costs should be used first (del Río and Cerdá, 2014) and more expensive technologies with higher RES-E generation costs should be used last, although the latter might still be needed to meet the RES-E target. Because of this effect, marginal LCC from each plant tends to be positive, (del Río and Cerdá, 2014). In this paper, these marginal generation costs are considered infinitesimal to describe the analysis taken, so that LCC are drawn as ascending curves.

4.1 Short-term policies

Let's suppose that a technology-neutral FIT policy (FIT-N) is chosen for RES-E in a given region. LCC_a, LCC_b, LCC_c, LCC_d are the LCC curves for technologies "a", "b", "c" and "d", respectively. We can assume that those technologies in this given region would be photovoltaics (a), wind (b), biomass (c) and small scale hydro (d).

Let's consider a $FIT-N$ policy in its optimal LCC level (LCC_{FIT-N}) where the quantity of energy contracted $q_{FIT-N} = (q_b + q_c + q_d)$ hits the LCC curves at the LCC_{FIT-N}. q_b ,q_c and q_d are the quantity of technologies "b", "c" and "d" contracted. At LCC_{FIT-N} level, technology "a" would not be contracted, as can be seen in Figure 1.

This would be a cost-effective policy in terms of minimization of generation costs considering total generation cost $TGC(q_{FIT-N})$ as Equation (3), which is the sum of the areas below the LCC_b, LCC_c and LCC_d curves.

$$TGC_{FIT-N} = \int_0^{q_b} LCC_b(q)dq + \int_0^{q_c} LCC_c(q)dq + \int_0^{q_d} LCC_d(q)dq \tag{3}$$

Equation 3: Total generation costs of a FIT-N policy at LCCFIT-N level.

Figure 1 shows that the total technology-neutral FIT policy costs, which is $TPC_{FIT-N} = (q_b + q_c + q_d) \times LCC_{FIT-N}$, is less than TGC_{FIT-N}, as shown in Equation (4).

$$TPC_{FIT-N} = (q_b + q_c + q_d) \times LCC_{FIT-N} < TGC(q_{FIT-N}) \tag{4}$$

Equation 4: Comparison of FIT-N total policy costs (TPC_{FIT-N}) and total generation costs TGC_{FIT-N}

Since LCC methodology already considers the discount factor, producer extra-profit (PEP) for this technology-neutral FIT (PEP_{FIT-N}) would be similar to equation (5), which is TPC_{FIT-N} less $TGC(q_{FIT-N})$.

$$PEP_{FIT-N} = TPC_{FIT-N} - TGC(q_{FIT-N}). \tag{5}$$

Equation 5: Producer extra-profit (PEP) in a FIT-N policy.

As producers capture all extra-profit in this type of policy, it can be inferred that a technology-neutral FIT policy is not cost-effective in terms of minimizing consumer costs. It is effective, however, for minimizing generation costs, but the extra-profit that is captured by producers makes this policy too costly for consumers.

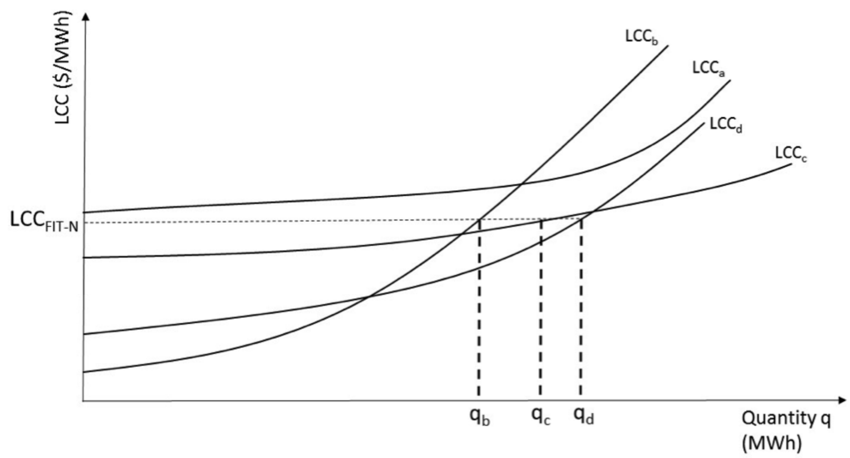

Figure 1: LCC curves for RES-E technologies "a", "b", "c" and "d" and their quantities contracted in a FIT-N policy.

Let's consider that a technology-specific, feed-in tariff policy (FIT-S) would be chosen instead of a technology-neutral, including technology "a", where the quantity of energy contracted (q_{FIT-S}) $q_{FIT-S} = (q_a + q'_b + q'_c + q'_d)$, where q_a, q'_b , q'_c , q'_d are the quantity of technologies "a", "b", "c" and "d". Furthermore, we consider that $q_{FIT-S} = q_{FIT-N}$, or $(qa + q'b + q'c + q'd) = (qb + qc + qd)$ if we write in terms of quantity. LCC_{FIT-Sa}, LCC_{FIT-Sb}, LCC_{FIT-Sc}, and LCC_{FIT-Sd} are the LCCs of this technology specific FIT for technologies "a", "b", "c", and "d" respectively. Total generation cost of this technology-specific FIT policy TGC_{FIT-S} in this case would be similar to Equation (6), which is the sum of the areas below the LCC_{FIT-Sa}, LCC_{FIT-Sb}, LCC_{FIT-Sc}, and LCC_{FIT-Sd} curves of Figure 2.

$$TGC_{FIT-N} = \int_0^{q_a} LCC_a(q)dq + \int_0^{q'_b} LCC_b(q)dq + \int_0^{q'_c} LCC_c(q)dq + \int_0^{q'_d} LCC_d(q)dq \quad (6)$$

Equation 6: Total generation costs of a FIT-S policy at LCC_{FIT-Sa}, LCC_{FIT-Sb}, LCC_{FIT-Sc}, and LCC_{FIT-Sd} levels.

This situation can be seen in figure 2. It's possible to see that total technology-specific FIT policy costs (TPC_{FIT-S}) is less than TGC_{FIT-S}, as shown in equation (7) (it can also clearly be seen in Figure 2).

$$\begin{aligned}&(q_a * LCC_{FIT-Sa} + q'_b * LCC_{FIT-Sb} + q'_c * LCC_{FIT-Sc} + q'_d * LCC_{FIT-Sd})\\&= TPC_{FIT-S} > TGC_{FIT-S}\end{aligned} \quad (7)$$

Equation 7: Comparison of FIT-S total policy costs (TPC_{FIT-S}) and its total generation costs TGC_{FIT-S}

As $q_{FIT-S} = q_{FIT-N}$ and technology-neutral FIT policy is cost-effective in terms of minimization of generation costs, it can be inferred that total technology-specific FIT policy costs (TPC_{FIT-S}) is greater than total technology-neutral FIT policy costs (TPC_{FIT-N}), ($TGC_{FIT-S} > TGC_{FIT-N}$), because it included technology "a", whose costs are higher than the other technologies until the policy reaches $q_{FIT-S} = q_{FIT-N}$. This is obvious, since government enforced a more expensive technology to be part of the RES-E policy portfolio. Also, a technology-specific FIT policy in this situation is non cost-effective in terms of minimization of consumer costs, because the extra-profit is also captured by the producer. The producer extra-profit for this technology-specific FIT (PEP_{FIT-S}) would be like Equation (8).

$$PEP_{FIT-S} = TPC_{FIT-S} - TGC(q_{FIT-S}). \quad (8)$$

Equation 8: Producer extra-profit (PEP) in a FIT-N policy.

As investors also capture all extra-profit in this type of policy, it can be inferred that a technology-specific feed-in tariff policy is non cost-effective in terms of minimization of consumer costs either.

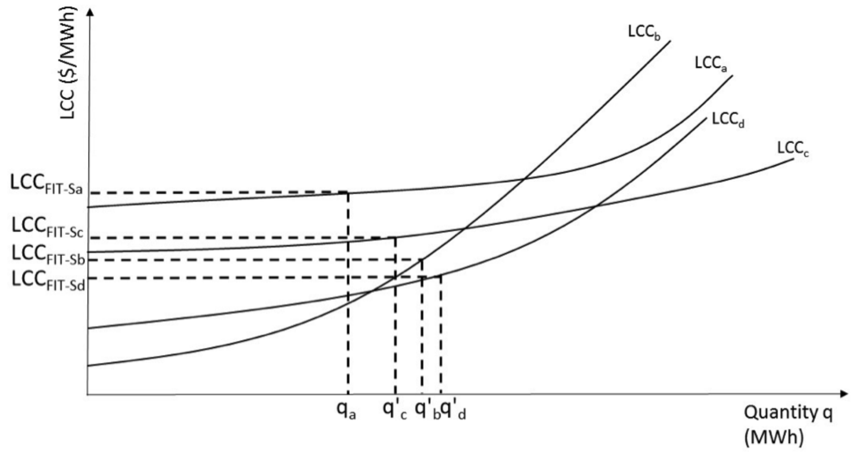

Figure 2: LCC curves for RES-E technologies "a", "b", "c" and "d" and their quantities contracted in a FIT-S policy.

Figure 2: In the short term, we can conclude that a technology-neutral FIT policy is cost-effective in terms of minimization of generation costs but not in terms of minimization of consumer costs because all profit is captured by producers in the short-term. Also in the short-term, a technology-specific feed-in tariff policy is not cost-effective in terms of minimization of producer and consumer costs.

Considering a renewable portfolio policy (RPS), producers in this case want to assess whether they will be able to get their money back and make profit. Instead of setting up a tariff, RPS sets up a target quantity in relative or absolute terms.

Let's consider the same example used in FIT with the same four technologies and LCC curves. In this RPS case, let's consider that all investors would sell energy with the same internal rate of return (IRR) already considered in the LCC curves.

First, let's suppose a RPS technology-neutral policy whose target is q_{RPS-N}. Let's also consider that in this case $q_{RPS-N} = q_{FIT-S} = q_{FIT-N} = (q_b + q_c + q_d)$ and the total generation costs of FIT (TGC_{FIT-N}) would be the same as the total generation costs of a RPS technology-neutral (TGC_{RPS-N}). Considering perfect competition, market would allocate the resources efficiently, so that the total technology-neutral RPS policy costs (TPC_{RPS-N}) would be equal to total generation costs TGC_{RPS-N} in the short-term. It would not generate extra-profit because all RES-E contracted would be exactly in the LCC curve. Equation (9) describes the situation (please see figure 1 for LCC curves).

$$TPC_{RPS-N} = \\ TGC_{RPS-N} = \int_0^{q_b} LCC_b(q)dq + \int_0^{q_c} LCC_c(q)dq + \int_0^{q_d} LCC_d(q)dq \tag{9}$$

Equation 9: Total generation costs of a RPS-N policy at considering perfect allocation of RES-E.

Let's now consider a RPS technology-specific policy target of q_{RPS-S} where $q_{RPS-S} = q_{RPS-N} = q_{FIT-S} = q_{FIT-N}$. If we consider also that $q_{RPS-S} = (q_a + q'_b + q'_c + q'_d)$ and that market will allocate the resources efficiently, technology-specific RPS total policy costs (TPC_{RPS-S}) would be equal to total generation costs (TGC_{RPS-S}) in the short-term, like equation (10), also with no extra-profit for producers.

$$TPC_{RPS-N} = TGC_{RPS-N} = \\ S \int_0^{q_a} LCC_a(q)dq + \int_0^{q'_b} LCC_b(q)dq + \int_0^{q'_c} LCC_c(q)dq + \int_0^{q'_d} LCC_d(q)dq \tag{10}$$

Equation 10: Total generation costs of a RPS-S policy at considering perfect allocation of RES-E.

It can be inferred that $TPC_{RPS-S} > TPC_{RPS-N}$ in the short-term because in the technology-specific RPS technology "a" was enforced, even with a higher LCC.

It can be concluded that a technology-neutral RPS is cost-effective in both terms of minimization of generation costs and minimization of consumer costs in the short term. Also in the short-term, a technology-specific RPS is not cost-effective in terms of minimization of producer and consumer costs.

In this paper, auctions are considered similar to RPS policies in terms of cost-effectiveness. The only difference is that in RPS the market reaches the desired quantity though market interactions among buyers and sellers. In auctions, policymakers coordinate purchasing energy in long-term contracts, normally starting with the lower LCC until it reaches the desired quantity. The results can be considered similar because RPS, and auctions attempts to allocate market supply and demand efficiently.

If we think that "n" technologies would be contracted in a technology-neutral approach in any policy mechanism at the level q_{policy} and that "m" entrant technologies would not, it's possible to extrapolate this to create a general case. So, when we think in the short-term, a cost-effective policy for RES-E in terms of minimization of generation and consumer costs would be a technology-neutral RPS or auction policy. However, in the long term things may change, as illustrated in sub-section 4.2.

4.2 Long-term policies

Experience curves showed that LCC costs may decrease with cumulative capacity, so it should also be considered when we think in the long term. Let's, then, consider the impact of one short-term policy mechanism with another long-term policy.

First of all, large values of the experience parameter "ε" indicate a steep curve with a high learning rate. In this example, we consider that $\varepsilon_a \gg \varepsilon_b \approx \varepsilon_c \approx \varepsilon_d$, where ε_a, ε_b, ε_c, and ε_d are the experience parameter of technologies "a", "b", "c" and "d", respectively. Let's consider that $\varepsilon_b \approx \varepsilon_c \approx \varepsilon_d$ is approximately zero and that cumulative production didn't increase significantly for these three technologies. It means that the LCC cost curves would not change for those technologies in the given region, reflecting the same cost curves as shown in Figures 1 and 2. Also, "a" is an emerging energy technology with low cumulative production and a high experience elasticity (ε_a) value, enough to bring it to market if a technology-specific policy promoted technology "a" in the short term.

Now we'll consider a long-term policy, but one that is conditioned by the past chosen policy. If we chose a technology-neutral policy in the past (FIT, RPS or auction), $q_{RPS-N} = q_{FIT-N} = (q_b + q_c + q_d)$, technology "a" would not be contracted. If we used this policy in the short term, LCC would not change in the long term for this technology. So, if we consider the minimization of generation and generation costs, a technology-neutral policy in the short-term would lead to another technology-neutral policy in the long term, with total generation costs in the long term (TGC_L) being the same as total generation costs in the short term, for FIT, RPS or auction ($TGC_L = TGC_{FIT-S} = TGC_{FIT-N}$).

Let's consider now a technology-specific policy in the short-term with the same LCC costs as Figure 3. LCC_a^L, LCC_b^L, LCC_c^L, LCC_d^L are the levelized life cycle cost in the long term for technologies "a", "b", "c" and "d", respectively. If we chose a technology-specific FIT, RPS or auction in the past, $q_{RPS-S} = q_{FIT-S} = (q_a + q_b' + q_c' + q_d')$, technology "a" would be contracted at that time. Let's suppose that LCC costs of technology "a" would decrease from LCC_a to LCC_a^L due to experience curve concept, as shown in Figure 3.

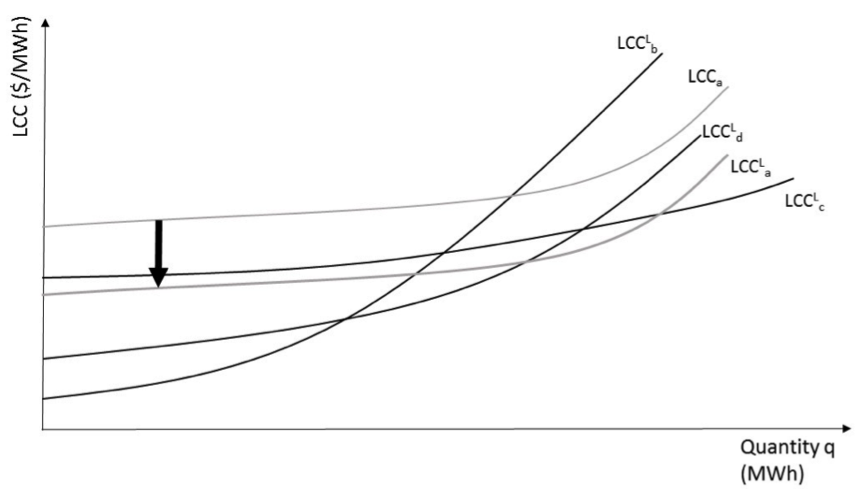

Figure 3: LCC curves for RES-E technologies "a", "b", "c" and "d" in the long term considering a technology-specific policy in the past.

In this situation with a technology-specific approach in the short-term, if the same amount of energy $q_{RPS-S} = q_{FIT-S} = (q_a + q'_b + q'_c + q'_d) = (q_b + q_c + q_d)$ is contracted through a technology-neutral policy in the long term (FIT, RPS or auction), it's possible to say that total generation costs in the long term (TGC_L) is lower than total generation costs in the short term (TGC_S), so $TGC_L < TGC_S$.

If we think in a FIT policy mechanism, this effect is easily shown because for the same quantity contracted for a technology-neutral FIT in the short-term, LCC_{FIT-N} would be lower because another technology with a lower LCC cost (technology "a" in this case) entered the market. LCC^L_{FIT-N} is the LCC of a FIT technology-neutral policy in the long term, so $LCC_{FIT-N} < LCC_{FIT-N}$. As described before, LCC^L_b, LCC^L_c, $LCC^L_d \approx LCC_b$, LCC_c, LCC_d. For the same quantity in the long term (q_{LT}), the quantity contracted for technology "a", "b", "c" and "d" are respectively q^L_a, q^L_b, q^L_c, q^L_d. So, $q_{LT} = q_{RPS-S} = q_{FIT-S} = (q^L_a + q^L_b + q^L_c + q^L_d) = (q_a + q'_b + q'_c + q'_d) = (q_b + q_c + q_d)$ and total cost of this long term policy would be like equations (11) and (12), which are illustrated in Figure 4.

$$TGC_L = \int_0^{q^L_a} LCC^L_a(q)dq + \int_0^{q'^L_b} LCC^L_b(q)dq + \int_0^{q'^L_c} LCC^L_c(q)dq + \int_0^{q'^L_d} LCC^L_d(q)dq \tag{11}$$

Equation 11: Total generation costs in the long term for a FIT-N policy, considering a technology-specific policy in the past.

$$TGC_L < TGC_{RPS-S} = TGC_{FIT-S} \tag{12}$$

Equation 12: Comparison of total generation costs in the short and long term.

Table 1 shows the main results for total generation costs in the short and long term, illustrating that a cost-effective decision in the short term may lock out emerging RES-E in the long term, leading to a higher TGC than if a technology-specific approach were used in the short term. I call this phenomenon the paradox of technology-neutral and technology-specific policies in the short and long term.

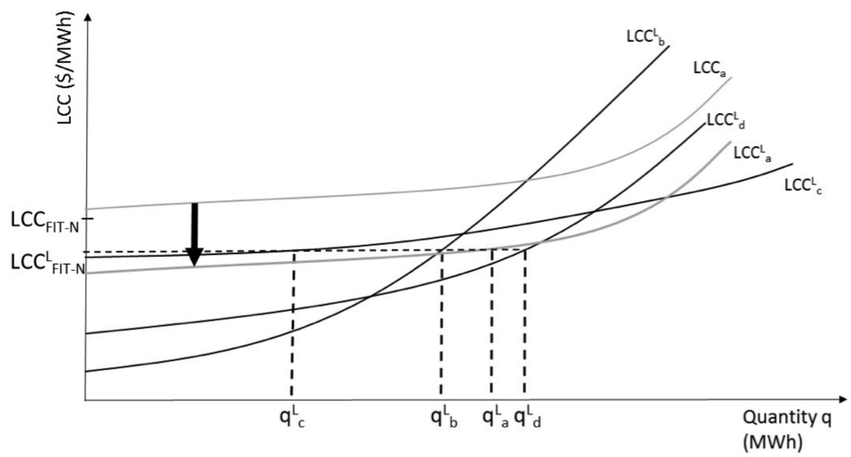

Figure 4: LCC curves, LCCFIT-N in the short-term and LCCLFIT-N in the long term for RES-E technologies "a", "b", "c" and "d" considering a technology-specific policy in the past.

Table 1: Paradox of technology-neutral and technology-specific policies in the short and long term

<table>
<tr><td colspan="2">SHORT TERM POLICY</td><td colspan="2">LONG TERM POLICY, CONSIDERING THE SHORT TERM POLICY TAKEN BEFORE</td></tr>
<tr><td rowspan="2">Technology-neutral</td><td rowspan="2">$TGC_N < TGC_S$</td><td>Technology-neutral</td><td>$TGC^L_N = TGC_N$</td></tr>
<tr><td>Technology-specific</td><td>$TGC^L_S > TGC_N$</td></tr>
<tr><td>Technology-specific</td><td>$TGC_N < TGC_S$</td><td>Technology-neutral</td><td>$TGC^L_N < TGC_N < TGC_S$</td></tr>
</table>

5 Conclusions

This paper illustrates the relationship between FIT, RPS and auction policy mechanisms and cost-effectiveness in terms of minimization of generation and consumer costs. The minimization of generation costs would lead to the minimization of consumer costs only if extra-profit were not captured by RES-E producers, which would occur if the RPS or auction policy were chosen. In the case of FIT policy, producers capture the extra-profit. It also shows that technology-neutral and technology-specific approaches may have different impacts in the short and long term, causing a phenomenon that we call the paradox of technology-neutral and technology-specific policies in the short and long term. This paradox could occur because a cost-effective technology-neutral policy in the short term could lock out emerging energy technologies in the long term and lead to a higher TGC in the future than if a technology-specific approach were used in the short term. It's evident that the market is not perfect; collusion may exist in auctions and profits of RPS may be higher than expected. In addition, if the extra-profit of FIT is invested in R&D of RES-E, it could be easily justified by policymakers. However, considering the assumptions and the results of this paper, I suggest a mix of technology-neutral and technology-specific policies using RPS or auction mechanisms to promote RES-E in both short and long term. Technology-neutral policies would be for RES-E technologies in the deployment stage with equivalent LCC, and technology-specific policies would be designed for emerging technologies with higher LCC costs and low cumulative production.

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