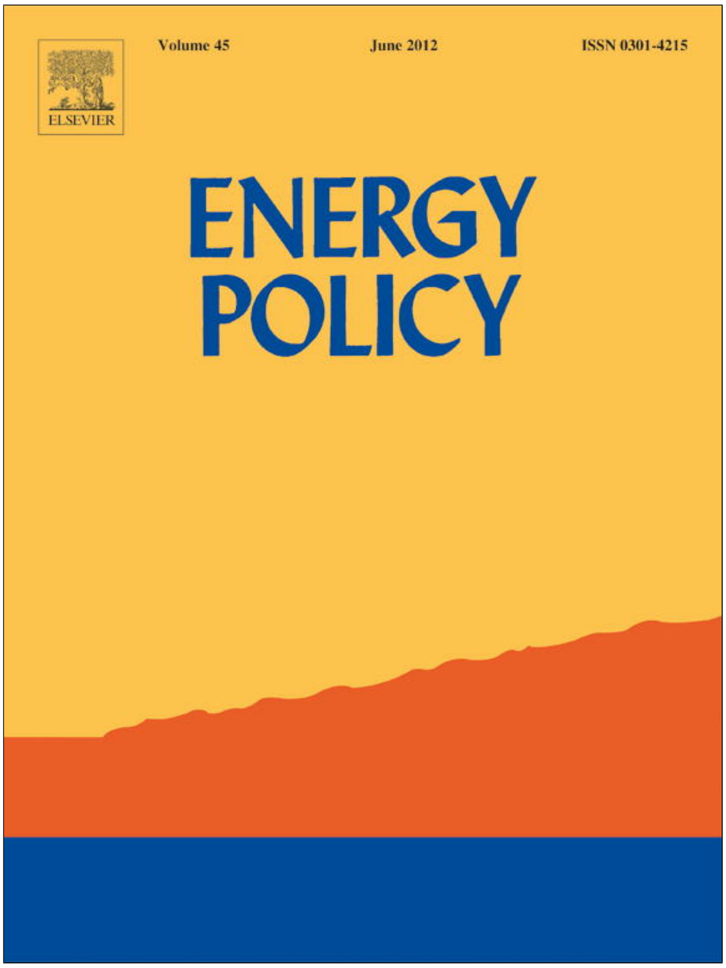
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Assessing the performance of renewable electricity support instruments

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ABSTRACT

The performance of feed-in tariffs and tradable certificates is assessed on criteria of efficacy, efficiency, equity and institutional feasibility. In the early stage of transition to an energy system based entirely on renewable energy supplies, renewable electricity can only thrive if support takes into account the specific technical, economic and political problems which result from embedding this electricity in conventional power systems whose technology, organizational structure, environmental responsibility and general mission differ profoundly from the emerging, renewable-based system. Support schemes need to capture the diversity of power supplies, the variable nature of some renewable supplies, and their different attributes for the purposes of public policy. They must take into account the variety of generators – including small, decentralized generation – emerging in a renewable-based system, and the new relationships between generators and customers. Renewable energy policies need a clear point of reference: because the incumbent power systems are not sustainable they must adapt to the requirements of the renewable ones, not the other way round. Incumbent systems carry the responsibility of paying the transition, something that corresponds best with the polluter pays principle.

1. Introduction

This article assesses the performance of feed-in tariffs (FIT) and tradable green certificates (TGC) as main instruments used by public authorities to support renewable electricity supplies in their infant stages to help them grow to maturity and abundance.

First, we briefly describe the context of renewable electricity support policies. Second, we give an overview of what is eligible for support and what parties are involved. Third, we define and discuss the main types of price driven and of quantity driven instruments. In section four follows a performance assessment of FIT and TGC, considered the most representative price driven and quantity driven instruments. The assessment is based on four criteria: efficacy[1], efficiency, equity, and institutional feasibility. A brief summary concludes this contribution.

1.1. Context of renewable electricity support policies

In a sustainable energy future, electricity is going to play a role of increasing importance. The transition of the present non-sustainable energy systems to systems with RE as the standard will take place first and fully in the electricity sector, although other major low-carbon options like nuclear and carbon dioxide capture and storage also see the electricity sector as their only or preferred substrate, as documented by Herbst and Hopley (2007), Braithwaite et al. (2010) and by the activities of the Energy Technology Innovation Group at Harvard University's Belfer Center (ETIP, 2010).

Important RE supplies such as hydro, wind, PV, and ocean energy are exclusively harvested as variable power flows, while other RE supplies such as bio-energy and geothermal are conveniently converted into power at the desired time. A technical, economic and highly relevant policy issue is the access to grids and integration in existing power systems of distributed and independently operated power sources. For variable RE sources there is an extra difficulty because they are not delivered on command (UKERC, 2006; George and Banerjee, 2011; IPCC, 2011). At present, a right of access to the grid for independent power generators is established in many countries, but the technical, financial and administrative terms of the access differ. Access is the entry door for power supplies to integration in the synchronous power system, with the terms of integration being a decisive factor for the financial viability of any power source. The diversity of contexts in various areas and countries suggest adapted support policies and mechanisms that can learn from experiences obtained in other contexts.

Abbreviations: EEG, (Erneuerbare-Energien-Gesetz, German renewable energy act); FIT, Feed-in tariff; IRENA, International Renewable Energy Agency; PV, Photovoltaics (light to electricity); RE, Renewable energy/electricity; TGC, Tradable green certificates; ROC, Renewable Obligation Certificate

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[1] The term "efficacy" is preferred above "effectiveness", because the term "cost-effectiveness" (being a part of the efficiency criterion) introduced confusion in the effectiveness vocabulary.

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Policies by public authorities have been decisive in structuring the power systems in their jurisdictions. Policy will play an even more important role in transforming the power systems and in creating systems where RE supplies grow to become central if not exclusive in meeting the power needs of the constituencies (IPCC, 2011). RE electricity support policies are embedded in wider energy policies, in turn being part of wider socio-economic policies. In developing countries, poverty alleviation, improvement of health and educational conditions and adaptation to a changing climate require a wider access to renewable electricity supplies (UNDP, 2007). In industrialized countries carbon dioxide emissions mitigation and security of supply are main drivers of growing interest in RE.

1.2. The object of renewable electricity support and parties involved

Support consists of financial or other help that specifically qualified beneficiaries can obtain for providing renewable power. The help is organized and supervised by public authorities, but not necessarily attributed or paid by them. This definition of support can be amplified by exploring each of its components in greater detail.

What exactly should get support? Support may reward installed or actually available production capacity (kW), or generated electricity (kWh). Both capacity and generation supplies can be qualified by RE source (type, location, flow or stock character, variability, density), by technology (type, vintage, maturity, scale of the projects), by ownership (households, co-operatives, independent companies, electric utilities), and any other attributes that are in some way measurable and upon which the terms of support may be made contingent (Jacobsson and Lauber, 2006). Aspects of such classifications are addressed as technological differentiation (Couture and Gagnon, 2010), technology "banding" in the UK (Wood and Dow, 2011), or qualification of renewable energy supplies (Verbruggen and Lauber, 2009). Well-designed FIT tariffs practice a high degree of differentiation. TGC systems at first did not by design. According to the principle that the cheapest technology should prevail, there was a single certificate price for all situations. This changed when technology banding was introduced. Since then in the UK, landfill gas now receives only a quarter of a certificate per MWh, while offshore wind receives two. Quantities of generated renewable electricity (or available RE capacities) may be weighed by additional qualifiers such as time and reliability of delivery (or availability of capacities) and other metrics of conforming to the needs of the existing integrated power systems (Klessmann et al., 2008; Langniss et al., 2009). In the latter case RE qualification not only depends on the attributes of the RE supplies but also on the characteristics of incumbent, mostly non-sustainable power systems as they have grown in (past and present) times when external costs and risks were only partly paid or unpaid altogether. We discuss the issue in Section 1.4 under the criterion equity.

Who should decide on support? Several public authorities can be involved in organizing RE support. International institutions can agree on goals and mechanisms, some can enact directives. For example, the EU could theoretically lay down rules for a harmonized support system (including a FIT), especially now that – under the Treaty of Lisbon – energy is the subject of a separate chapter which gives greater power to EU institutions as it was earlier. Whether such directives optimally respond to regionally different conditions is another matter. Other institutions mainly enhance understanding and awareness, distribute information and develop standards (for example REN21[2] and IRENA). National governments (political systems) can vote laws, assign subsidies, adapt regulations, or create frameworks for lower political-administrative levels either through the legislature, government decisions or simple ministerial decrees (this will impact on the security of investment as perceived by investors). State, provincial, and municipal initiatives often award important support to local projects. In the electricity sector regulatory agencies and publicly owned utilities may be involved in designing, implementing and controlling support mechanisms. A multitude of supporting actors may lead to inefficient spending of resources when they override each other's initiatives. However, multi-level governance is important to stimulate renewable energy initiatives, particularly when the central authority is dragging its feet. Local authorities are mostly better placed to optimally deal with distributed resources and are often more open to citizen concerns; this is why the concept of the feed-in tariff for PV first developed in Aachen in 1992 was based on full cost remuneration (Johnstone, 2011, 171–176).

Potential beneficiaries are diverse. The beneficiaries of support are investors and/or operators of RE installations. The more immediate beneficiaries range from financing companies (banks, venture capitalists), incumbent energy supply companies owning for example also grid assets, incumbent generators, to independent power producers such as local companies, public institutions and individuals. Industrial and commercial companies, farmers, households and community-based co-operatives may all generate renewable electricity (Fouquet and Johansson, 2009). The potential investors and generators widely differ in their capacity and willingness to absorb technical, financial and regulatory risks, and in their expedience in coping with complex regulation and administrative procedures in the energy sector that often function as barriers.

The various classes of RE generators interact in different ways with the grids and the integrated power system. It is helpful to distinguish independent RE generators established with the only purpose to sell to third parties, from grid-linked generators that mainly generate electricity for covering their own power needs (Verbruggen, 1997). While the former are just suppliers often competing with incumbents to serve the loads of end-users, the latter change back and forth between being supplier and customer, so that issues of net metering, back-up power delivery and pricing of this power by the central system to the independent site arise. Such a distinction is made explicitly e.g., in the 2008 amendment to the German feed-in law (EEG, 2008) which also provides for a special incentive to "own consumption" of electricity from PV (EEG, 2008, sec. 33), however with the hope of reducing problems of grid overload and of shifting demand to times when solar energy is abundant. Targeted regulation for the group of independent generators of own power as being "prosumers" is recommended.

Who pays the bill? Support expenditures can be charged to public budgets (federal, state, local), with the disadvantage that budgets depend on political fortune, often run dry and are not replenished when political priorities shift. This was one of the reasons that contributed to the abandonment of FIT in Denmark; the government contribution to FIT was becoming too burdensome (Morthorst, 2000). Besides, in the EU such support needs to be authorized by the European Commission as "state aid" which is governed by a complex set of rules. To avoid "stop and go" and other complications, new options in power supply are better financed by power users (the most common solution for both FIT and TGC); in that case state aid rules apply only if the funds are handled by the state, something that is not necessarily the case (European Court in *PreussenElektra v. Schleswag*, 2001). Special mechanisms charge the RE support bill to end-users of brown electricity or of electricity generally, with standard electricity suppliers, network companies, or incumbent electricity generators as intermediaries. Spreading the support burden evenly over

[2] Renewable Energy Network for the 21st Century.

all electricity end-users generally requires re-allocation among jurisdictions, usually from territorial subunits to an entire country, the most common solution for FIT and TGC alike. In Germany this step was taken in 2000 (Hirschl, 2008, 141). In many cases large electricity consumers such as energy-intensive industries can obtain discounts on their contribution to the RE support bill, purportedly to maintain their competitiveness and often as a quid-pro-quo for politically well-connected industries not to question RE legislation (Hirschl, 2008). Other equity issues among RE generators, customers and citizens may also arise, for instance when the more wealthy households receive unduly high payments for their PV panels paid for by all customers whereas deprived households lack the capital or access to loans for such investments in panels on their roof.

1.3. The main types of RE electricity support instruments

The dichotomy of price steered and quota based policy instruments has triggered a lasting debate in the environmental economics literature since Weitzman (1974).

1.3.1. Price driven RE support instruments

Public authorities steer by price when offering subsidies to stimulate merit activities[3], i.e., activities that are valuable from a public perspective but are not adequately supported by consumer demand (e.g., because they are competing with products that are low-priced by external costs not being internalized). The result depends on the size and other characteristics of the subsidy and on the reactions of investors and operators to the subsidy. Price steered RE electricity support instruments is the group of feed-in tariffs, premiums, investment credits, tax rebates, fiscal stimuli, soft financing, etc. (Couture and Gagnon, 2010; IPCC, 2011).

Feed-in tariffs (FIT) is a mantle name for price driven support, although the name is misleading as such because FIT systems do not necessarily support the quantity of electricity *fed into* the grid, but the quantity of renewable power *generated*.

The distinction between the two quantities is important for independent RE projects that are mainly generating power for own use, and in case of "net metering". Net metering measures, over a given period of time (month, year), the difference between the generated renewable power and the power used on site as the net quantity exchanged with the grid. When positive the net exchanged quantity could be sold to the grid, mostly at retail prices (Klein et al., 2008). In other places (e.g., Flanders) the delivery to the grid of excess power by household PV installations is not remunerated.

Net metering is often considered as a low-cost, easily administered tool for investing in small scale, distributed power and for feeding it into the grid. Technically speaking and with respect to transaction and administrative costs, this is true. However, remuneration at grid retail rates is mostly insufficient to stimulate growth of less competitive technologies such as small wind or PV that show generation costs higher than retail prices. If the goal is to stimulate technological development and learning, remuneration should be based on generated RE quantities (irrespective of whether used on site or delivered to the grid), which is what most FIT systems also do. Then, a bi-directional power flow meter remains the appropriate tool for integrating small-scale distributed RE in the interconnected power systems. For large-scale distributed power plants (for example a pulp and paper factory generating all power through bio-energy CHP) net metering could be taken as the basis for net billing (under this arrangement the generator sells excess electricity to his supplier at wholesale prices). Even then, if standard power purchasing tariffs include a high fixed cost element (this means paying for the monthly maximum electric capacity used by the customer), a separate regulation moderating the price of back-up power supplied by the grid is necessary for the financial viability of independent projects that generate power for own use (Verbruggen, 1990).

The central principle of FIT policies is to offer fixed and at the same time differentiated prices to different types of RE generation, combined with a requirement (usually for grid operators or other incumbents) to connect those generators and to purchase all RES electricity that they tender at that price. Under a FIT generators do not have to worry about being able to market their electricity. These prices are mostly nominal (without inflation correction[4]) prices for every kWh of RE produced by an identified and technically qualified plant. The lack of adjustment makes sense since support is guaranteed for periods of time sufficiently long (e.g., 20 years) to cover the full costs of a well-managed project, fixed annuities as well as an appropriate return on invested capital. When the FIT system covers diverse sources and technologies, prices are differentiated according to a number of attributes of the RE supplies (Lauber and Mez, 2006; BMU, 2011; Couture and Gagnon, 2010). Each year, FIT rates are set for this year's new vintage of installations and remain unchanged for this vintage for a set period. New (usually lower) rates are set for each vintage in subsequent years to keep up with technological progress, but also with the price of generation equipment, the need to make use of less favorable locations in terms of resource quality etc.

Another key issue of FIT-type systems is how property rights in generated electricity change hands upon payment of the subsidy. The two main approaches are: either all kWh receiving FIT become property of the agent paying the FIT (mostly standard electricity suppliers or incumbent generators), or the kWh remains property of the RE generator and the support per kWh received is a premium on top of the use or sales value of the power. A third approach is a mixed property regulation usually applied on net-metered (small scale) RE generation: kWh used on site up to the quantity of RE generated during the year remains the RE generator's property (that use is not billed by the grid), but when the annual net metering turns positive (more RE kWh generated than power used on site over the year) the surplus kWh fed into the grid becomes property of the grid (no remuneration on top of the FIT for the surplus kWh delivered). The mixed property regulation restricts the full development of local RE sources, thus buildings with large sun-oriented roofs have no incentive to cover more than a limited part with PV modules. The restrictions can be circumvented or overcome by adopting suitable on site property rights, for example co-ownership of RE installations by several households or local co-operatives to increase demand for on-site generated electricity of a net-metered facility. Individual PV producers that over the year generate more than their own consumption may respond to a detrimental perverse incentive of increasing the own consumption by creating extra loads, for example electric space heaters in winter, to equalize their yearly balance between consumption and production. The perverse effect is prevented by applying a two-leveled FIT: the levelized cost price of the RE category minus the standard sales tariff for the share of RE electricity consumed on site and the levelized cost price for the RE surplus delivered to

[3] More discussed and documented is price steering by levies to discourage "demerit" activities that cause damage or risks, or other harmful effects (Baumol and Oates, 1988).

[4] RE investors can hedge against future inflation by financing the initial investment by a mortgage loan with fixed nominal annuities. This is especially true for RE projects with almost all costs residing in up-front investment (PV, wind, hydro).

the grid. This also contributes to a more accurate cost coverage and to maintaining the interest in efficient electricity use.

1.3.2. Quantity driven RE support instruments

One quantity driven approach is to organize tendering systems where RE projects are realized by bidders that (best) meet the terms of reference set by public authorities. The latter pay the prices of the winning bids. The expenditures by the public budget or the contributions from electricity customers cover the difference between the higher prices of RE supplies and the standard prices of conventional electricity. When markets and auctions function well, this difference is supposedly kept to its lowest value due to the competitive process.

More direct quantity driven instruments oblige selected agents to generate given RE quantities, for example (new) buildings are only licensed when they generate *x*% of their electricity consumption from RE sources[5]. Rigid approaches need considerable circumstantial adjustments and it proves difficult to attain good regulatory specificity (Faure and Skogh, 2003). More flexible Renewable Portfolio or Electricity Standards (RPS or RES) are applied to electric utilities in the U.S.A. and in India. Australia has its Mandatory RE Target (Lewis and Wiser, 2007**)**. They provide an obligation for suppliers to include a certain percentage of RE in their total sales volume. When the obligations are tradable a mechanism (market) for exchange needs to be established.

The first important application of tradable quota policies took place in the United States, particularly with the Clean Air Act Amendments of 1990 and the introduction of tradable certificates a few years later. In the neo-liberal climate of the 1990s, a veritable hype developed around the idea of trading, which was strongly favored by the international policy community in the OECD, IEA, World Bank etc. (Voss, 2007). At first it was mostly US economists who discussed tradable permits related to quota for climate policy (Pizer, 1997). At the climate negotiations in Kyoto, the EU – at first reluctantly – agreed to the use of this instrument when the US government made its inclusion a condition for its own participation. Despite the withdrawal of the United States from the Kyoto Protocol, the EU Commission – led by DG Environment – remained attached to the instrument of emissions trading for climate policy (Damro and Mendez, 2003; EEA, 2005). From there it also affected the debate on RE support systems (CEC, 1997 and particularly CEC, 1999). Market-based quota systems create artificial markets with fixed quota functioning either as inelastic supplies (emissions permits markets) or as inelastic demand (for renewable electricity)[6]. Some countries or states have set-up such markets for renewable electricity, for example Texas and several other US states in the 1990s (Wiser et al., 2010) after a first attempt to apply this concept to renewable energy had failed in California in 1995 (Van Est, 1999; Lauber, 2004). In the EU quota systems for RE were introduced in the UK, Italy, Sweden, Belgium (the three regions separately), Poland and Romania (for an overview see Haas et al., 2011).

In the EU quota obligations are connected to the creation of "tradable green certificates" (TGC), in the UK called ROC (Renewable Obligation Certificates) or REC (Renewable Electricity Certificates). In principle, a designated regulator (public office) assigns one certificate to every RE MWhs generated by a source on the EU list (directive 2001/77/EC). In the beginning countries experimenting with TGC systems strictly applied the one certificate per one MWh principle, equating in this way power from existing domestic waste incineration plants with power from new wind turbines, in accordance with the built-in assumption that the market should select the cheapest and therefore most efficient technology. Mostly, exception was made – often after a few years' practice – for PV power since it was (is) too distant from market maturity. By now more "banding" takes place assigning RE supplies a different number of certificates per MWh depending on their attributes. The England and Wales Renewables Obligation differentiates considerably since 2009: landfill gas only receives 0.25 ROCs per MWh rather than one; onshore wind one, offshore wind and tidal stream two per MWh (Woodman and Mitchell, 2011); even more strongly that of Scotland. In Flanders biomass co-incineration gets one certificate for two MWh generated since 2009 and during a limited number of years. Italy started to differentiate as well. These differentiations are often crude (not finely tuned, e.g., according to project size) and are opaque, and they contradict the initial argument that the unique price would promote the most efficient RE supplies[7].

RE quota imposed on standard electricity suppliers or other mandated agents in the power sector are translated into the number of certificates (calculated as a percentage of total MWh of sales or production) that they must deliver to the regulator in a given year. If the quota is to be fulfilled, the penalty on certificate shortfalls must sufficiently exceed the expected market price of TGC. The latter is in principle equal to the net[8] marginal cost of the project delivering the marginal certificate for meeting the quota of the regulator's jurisdiction (a province, country, or the entire EU in case a single European market for RE certificates should materialize) (Morthorst, 2000; Finon and Menanteau, 2004; Lipp, 2007).

The expenditures for certificates (far) above the certificate market price and above the penalty price, assigned for example to PV with generation costs too distant from present market ranges, are sometimes paid by the public budget. In most cases they are charged to grid operators or suppliers (often quasi-monopolistic electricity network companies) that include the paid amounts in the network tariffs and end up on the bill of the electricity customers.

The purpose of the TGC systems is to reward the greenness of renewable electricity by the creation of a liquid market in certificate paper in addition to sales of physical power. In some way it assumes that the standard electricity markets are already competitive, because certificate prices should come on top of the prices of the physical electricity that is assumed to be traded in the free and competitive power market. The original justification for TGC in the EU context was argued with the necessity not to disturb the functioning of the supposedly competitive electricity market (CEC, 1998; CEC, 1999).

[5] Energy neutral buildings are an example of similar targets; they show the intertwining of RE deployment with maximizing energy efficiency.

[6] The "inelasticity" is enforced by penalties on every unit beyond (permitted emissions) or below (mandated RE generation) the set quota. As with price steering, when the penalty rate (buyout price) is low respondents may not care about it and then quota are not realized in practice. The latter occurred in the UK: the RO system was initiated in 2002, between 2002 and 2010 quota achievement hovered around 60% except for two years when it was slightly higher (Woodman and Mitchell, 2011, 3916; DUKES, 2009; Jacobsson et al., 2009).

[7] In the UK the government had argued in 2000 that a banded obligation would run "counter to the market led approach … designed to ensure that suppliers will meet their Obligation by the most economic means" and that the government did "not want to segment or unduly distort the marketplace" (DTI, 2000, 25–26). In contrast, the government in 2007 argued that while one standard rate had been useful to start up the RE market at low cost, the more ambitious goals of the future required differentiation by technology (which had already been practiced in the Non Fossil Fuel Obligation in the 1990s) so as to allow bringing more expensive technologies such as offshore wind or marine energy into the RO system (DTI, 2007, 147; Uhlir, 2011, 87 and 104).

[8] Net marginal cost of a certificate equals the marginal cost of the RE MWh generated for that certificate minus the (expected) sales value of the physical MWh and minus other subsidies (for instance direct investment support) received by the project (Verbruggen, 2004).

In practice TGC systems did not function the way the theory predicted. Several adaptations like banding, floor and ceiling prices, post-adjustment of set quota, were deemed necessary by the regulators in the UK, Italy and Belgium. Where the quota system was practically limited to a single technology in a limited jurisdiction and was shored up with additional funding mechanisms, such as wind on land in Texas, it performed well (Langniss and Wiser, 2003). In Texas the contracts between RE operators and utilities are usually long-term, up to 10 years, favoring RE project development. In addition, wind energy in Texas also benefited from the US production tax credit, a kind of federal FIT granted for ten years (Lauber, 2004).

1.4. Assessment of the performance of the support instruments

A full assessment of all experiences with RE support instruments would require a separate appraisal of each case, because it seems that no real-life instrument is the clone of another. This is due to the different traditions in economic policy-making, different political definitions of the need to substitute conventional energy sources and diverse realities of RE sources and technologies on various locations in different countries and continents. The assessment is therefore more generic and discusses the performance of price driven and quantity driven instruments on the four major criteria proposed by IPCC (2007) for evaluating policies and policy instruments: efficacy, efficiency, equity, and institutional feasibility. The criteria are further specified for aspects of high importance for RE support.

1.4.1. Efficacy

The metrics of efficacy of a support instrument is the amount of renewable electric power capacity (MW) installed at a given moment or during a given period compared to the renewable energy potential of the jurisdiction under consideration, or the MWh generated in a given period (year), due to the working of the instrument. Therefore there is a preference to measure additional or new capacity or generation volume over given intervals of time (years) (Haas et al., 2004), and a fortiori exclude results that existed before the instrument became effective. This exclusion may be relaxed because one is willing to reward pioneers that were active before enactment of the instrument, or because the impact of an instrument is difficult to delineate and an instrument may contribute to renovation or maintaining RE generation otherwise foundering or taken out of operation. Important is the question of whether the RE output should be differentiated in categories, assembling RE power of similar quality, distinct from other qualities. Then, outputs could be weighed to obtain a better quality indicator of quantitative kW and kWh numbers. The exclusion of some hydro and bio-energy projects as acceptable (sustainable) RE, points to the necessity of accurately qualifying and weighing RE supplies. There were discussions in the EU legislative organs, before the adoption of the first directive on renewable energy (2001/77/EC), on whether to include household waste combustion or hydro above 10 MW among the technologies to be supported (Lauber, 2002). Similar debates about the quality of biomass took place before the second directive on renewable energy (2009/28/EC). Categorizing of RE supplies offers many advantages for correctly measuring the performance of support instruments on all criteria.

RE policies commonly announce goals as future targets of RE outputs, mostly as a percentage of total electricity generation or use in a jurisdiction. It is challenging to stipulate a good time path of targets, also to divide a total target into sub-targets by RE category and to assign quota to designated areas or agents. Notwithstanding such difficulties meeting or surpassing the overall targets is considered the most relevant indicator of policy efficacy. Targets may exert strong mobilizing force, in particular when designed as milestones in the transition to low-carbon electricity systems, but when too ambitious they become a fetish for accepting non-sustainable RE supplies and drive up prices; when too low they become a brake on expanding sustainable RE supplies.

Results are robust when lasting and resistant against disappointing events. Robustness does not exclude flexibility but guarantees continuous progress on a long-term transition path. It has to be solidified by measures that can avoid or absorb shocks. In case of renewable electricity the outstanding measure to make RE shockproof is a neat integration of RE in the electric power system with priority access and dispatch, and with certainty about remuneration of delivered power. When revenues of RE supplies depend on the vagaries of partly speculative and partly monopolized price volatility as in the case of TGC systems, small-scale potential suppliers but also large-scale independents unfamiliar with central power systems are deterred from investing in RE. Generally speaking, support schemes which inhibits the entry of new generators significantly retards the RE transition. As many RE potentials are local and small scale, entrepreneurs willing to deploy them are easily deterred if confronted with overly complex regulation or obstacles thrown up by incumbents with regard to grid access.

FIT efficacy. Because the interplay of subsidy terms and respondents' reactions is not accurately known, the final results of price steering instruments are not predictable by the digit. FIT is based on a detailed categorizing of RE supplies, with adapted prices per category allowing the monitoring of efficacy by support levels. Germany is providing best-practice experience, with frequent adaptations of prices as a result of changes in costs or of adjusted priorities since the first big amendment to the EEG in 2003 (Lauber and Mez, 2006; Dagger, 2009). Opponents of price steering argue that the results may fall short of announced targets, but there is also evidence of doing better than set targets as in the case of RE supplies in Denmark (Meyer, 2004) and Germany[9] . For FIT policies, targets are but indicative milestones on the intended development path of RE that can be superseded by the dynamics of the system, usually without upsetting the FIT system as a whole (the sudden fall of PV module prices over the past few years which led to an unexpected boom in installations and thus additional costs constitutes an exception; see more on this below). Regular adaptation of support levels by RE category is a control valve on the pace of deployment of RE categories.

The predominant factor of FIT's high success in deploying renewable electricity is its clear and robust solution for integrating the supplies in existing power systems via purchasing obligation and priority dispatch and its guarantee of a fair and safe return on investment. In this way investors not specialized in electric power systems can become power producers with calculable risks related to the quality and functioning of their own equipment and the fortune of natural energy flows (wind, light, water). In Germany, the number of these new entrants probably reaches about one million by this time[10]. The sorrow and expenses for integrating the variable RE supplies into existing power systems are loaded onto the standard power suppliers and generators. This provides the incumbents with additional incentives to adapt existing systems while it may increase the price of brown

[9] Sec.1 of EEG 2000 set out a doubling of the share of RE by 2010; in fact it was about tripled by then for all RE (power, heat, transport), and increased by about 150% for electricity (BMU, 2011).

[10] Bavaria alone has about 200.000 generators; this is where PV is concentrated (Bayerische Staatsregierung, 2011; Solarthemen, 2011).

electricity, reduce its profitability or even displace it on the electricity exchange, redressing the price balance with RE (Verbruggen and Lauber, 2009). When FIT is reduced to premiums, RE generators remain exposed to the uncertainties of power market behavior (Couture and Gagnon, 2010). Potential RE investors are then more likely to be restricted to a few companies understanding central power systems and exchanges and capable of absorbing the risks of volatile electricity prices. In this setting incumbent power companies prevail, as is evident in the case of Spain.

TGC efficacy. By design TGC overrides categorizing of RE supplies for obtaining a level playing field where all RE projects irrespective of source type, technology, vintage, maturity, etc. should compete. This amalgamation is the crux of TGC markets design, and troublesome because the state of technological maturity, ownership, quality, and sustainability of various RE supplies are no longer monitored. The playing field is far from leveled and the time horizon is the rather short-term outlook. Technologies which are more expensive than the lower cost options are neglected (due to the single certificate price they are too far removed from being competitive with cheaper alternatives) although they may be necessary and more promising in the long run even in terms of cost; this was typically the case of solar PV (remedied in several TGC countries with the introduction of a FIT just for PV) and of offshore wind (remedied by technology banding). Fast technology development with cost decrease makes it tough to estimate years in advance the best RE quota while set quota are essential to TGC markets. The efficacy of a TGC system is measured by the realization of set quota, something that is more likely when penalty levels (buy-out prices) for shortfalls are high. Set TGC quota function as a ceiling on RE growth. If growth exceeds regulatory targets, there is either an overflow of certificates, which then become worthless, thus causing crisis for existing installations and shelving or abortion of projects. If surplus certificates are banked for following years they will act as a brake on future growth of RE projects and as another deterrent to new entrants.

Depending on the buy-out price, it may be interesting for RE generators to underperform on the quota in order to increase the price of certificates. This connection has become evident in England and Wales, where buy-out penalties are recycled back to suppliers according to their contribution to the target. "The more that the RO target is missed, the more money in the buyout fund as a result of the penalty payments…". The optimal balance for suppliers seems to be a fulfillment ratio of about 60%. (Woodman and Mitchell, 2011).

The price of certificates is one part of the remuneration of RE suppliers, the other part coming from selling the power (or using it for own purposes). The TGC system therefore combines two market risks: those of the standard electricity market and those of the certificate market. The main effect is that experienced agents such as incumbent power companies who are better able to handle those risks take precedence in developing mostly larger scale RE projects (Stenzel and Frenzel, 2008). TGC systems with a high combined certificate plus market price (due to the co-existence of sufficiently challenging RE targets with high penalties on failing certificate delivery) offer an umbrella for the growth of independent RE projects alongside the incumbent ones. The lacking guarantee that the umbrella lasts for the mortgage period of the independent RE investments, increases the risks and the costs of finance. If such projects are built anyhow and the shelter withers after a few years, it may occur that the larger independent RE plants are bought by incumbent generators resistant to market vagaries, leading to higher concentration in the RE market.

1.4.2. *Efficiency*

Efficiency is mostly gauged in a static context, as electric power supplied to end-users at least cost in the short run. Minimization of operational costs requires the ranking of generators in merit-order along their short-run marginal costs, with remunerating every generated kWh at the marginal cost of the integrated supply system (Turvey and Anderson, 1977; Caramanis et al., 1982; Stoft, 2002). Power from bio energy entails positive marginal costs, and power from water resources positive opportunity costs of alternative water uses. Most renewable electricity flow supplies have almost zero short-run marginal costs and therefore rank at the head of the merit-order. However, when the integrated system is composed mainly of power supplies that do not pay the external costs, climate costs and other risks they occasion, the system marginal cost price will generally be insufficient to pay off the investments in RE plants. How effective internalization of external costs and of risks is for the competitiveness of RE plants depends on the assessed external costs and risks and on the costs of the RE plants.

Perfect markets are said to install static cost-effectiveness, and theoretically would also realize RE targets at least cost. But power markets, whether green or brown, are not exemplary as well functioning markets, and do not ascertain cost-effectiveness (Glachant and Finon, 2003).

Dynamic efficiency enlarges the efficiency perspective to the long run, meaning that costs in the future are reduced by innovation which in turn is induced by the policy instrument. In climate change mitigation policies, technological innovation is seen as a crucial factor, with RE development and energy efficiency as main fields (IEA, 2010; IPCC, 2011). Disruptive innovation cycles demand the clustering of extensive resources and decades of time (Grübler, 1998). Therefore, RE innovation should occur in parallel on various technological tracks and not only consecutively (Jacobsson and Johnson, 2000; Sandén and Azar, 2005; Jacobsson et al., 2009).

Transaction and administrative costs are also important in the efficiency appraisal of a policy instrument. On the one hand, public authorities should not avoid the effort of clear understanding of RE resources, technologies, transition processes, policy instruments, etc. because the "devil is in the details" of successful policy-making (see the importance of categorizing RE supplies). On the other hand, transparent regulations based on correct metrics of the right variables, not affected by arbitrary interventions and therefore predictable within acceptable error margins, stimulate engagement and commitment by large groups of citizens and stakeholders and save many costs.

FIT efficiency. FIT are cost-effective when the fixed rates by category, plus the rate of annual decline to incorporate technological learning, are set at the right level to develop and deploy the specific RE supplies at the desired rate. When rates are deviating from the optimal levels, adjustments can be made in a relatively short time[11]. Categorizing RE supplies and applying appropriate FIT rates by category, pull innovation for several RE technologies in parallel, safeguarding dynamic efficiency (Jacobsson et al., 2009). Categorizing favors the rise of RE equipment industries.

FIT in its pure version of fixed prices per kWh is the simplest RE support applicable for investors. Transaction and administrative costs are low and risks limited, and numerous small investors

[11] This does not mean adjustment will always be timely. For example the steep PV cost decline since 2008 (IPCC, 2011) was not reflected adequately in many tariff schemes, prompting steep growth of projects, followed by sudden reductions of support (e.g., in Spain in 2008, in Germany, France and the Czech Republic in 2010, in Flanders in 2011).

react with active participation even though incumbents may show lack of interest[12] (IOeW, 2011).

CEC (1999) expected price steering to lead to high rents for generators and equipment producers and to retard technological innovation. Frondel et al. (2008, 2010) see German FIT for PV as money wasted on premature deployment instead of spending it on RD&D. Discussing the balance between technology pull and push is beyond this article (IPCC, 2011).

TGC efficiency. In a TGC system the least cost RE supplies are picked first and most by companies maximizing profits. Because categorizing by design plays no role, the bid is won by least quality supplies such as domestic refuse incineration, other bio-waste processing, for example black liquor fired CHP plants in the Swedish pulp & paper industry (Bergek and Jacobsson, 2010), and by a single more mature RE technology (for example hydro or onshore wind). For a given RE quota this run to the bottom results in lower resource costs than when more diverse and less mature RE technologies are included. As such, TGC delivers static efficiency in the short run. By focusing on nearby cheap supplies, innovation and dynamic efficiency are neglected, and an equipment industry is unlikely to flourish under this regime and will at best develop at a later stage (Jacobsson et al., 2009). This leads to retarded availability of RE technologies urgently needed in the transition to low-carbon energy systems.

Apart from the economic costs of the actually used resource factors, it is prices that steer decisions (Becker, 1971). The RE prices obtained by TGC systems are remarkably higher than when a well-designed FIT system is applied. This arises from TGC including high profit mark-ups on top of factor costs (and from the fact that the system discourages new entrants), particularly when there are big cost differences between the different sources included in the system (Haas et al., 2011). This mark-up is called rents, windfall or excess profits. They are assessed as very high: close to 80% in Sweden (Bergek and Jacobsson, 2010) and about 64% in Flanders over the period 2002–2007 (Verbruggen, 2009) where various categories of RE supplies are amalgamated in one TGC system. They are less abundant when in practice a TGC system covers a single category of RE supplies such as onshore wind in Texas (Langniss and Wiser, 2003). The European Commission's Staff Working Paper on support schemes shows that for onshore wind, TGC payments per kWh and profits of generators are up to several times higher than FIT payments; at the same time FIT correlate with higher RE deployment (CEC, 2008, 34).

The transaction and administrative cost for independent RE project developers and operators are higher for TGC systems than for FIT, making participation of new entrants cumbersome and limited (Stenzel and Frenzel, 2008). However, high TGC prices during particular periods and short periods of amortization under TGC attract rent-seeking investors beyond the monopolistic players, boosting some RE supplies.

1.4.3. Equity

Defining, evaluating, and addressing equity aspects are contentious tasks, with politics as last resort to decide. Three themes merit special attention in the context of RE support: the polluter pays principle, the allocation of revenues and expenditures by the support mechanism, and the occurrence and appropriation of excess profits.

The polluter pays principle in the framework of UNFCCC[13] assigns major responsibilities to the industrialized nations in the transition to low-carbon economies. These countries should give priority to the fast and broad development of RE technologies, also the ones most adapted to developing country circumstances. Additionally the polluter pays principle legitimates the imposition of obligations on incumbent power companies to pay for the costs of transitioning from existing high-carbon systems, inherited from the fossil and nuclear era, to future low-carbon RE electricity systems. This implies for instance that the costs of integrating RE supplies in existing central power systems and the expenditures for adapting the systems fall largely or entirely on incumbent interests. This conflicts with claims for charging costs of disturbing incumbent production and transmission systems on RE supplies when the latter make inroads on existing power systems.

This RE integration and cost allocation issues demand for policy clarity on the choice of a reference point in studying power sector transitions. Either it is the existing non-sustainable power systems grown up in the past under conditions of non- or low-priced external costs and risks. Or the reference point is derived from sustainable RE systems that societies must develop without delay including the abolishment of barriers impeding RE deployment. When transitions are taken seriously, the sustainable energy systems must serve as the reference. This is the opposite of the common talk in the press and scientific literature that RE growth is inflicting costs on incumbent (non-sustainable) power systems. When the discussed costs are imposed on RE, an extra transition barrier is created.

Support mechanisms shift economic wealth from some groups in society to others. Such shifts may simultaneously meet efficacy, efficiency, and equity concerns, or cause conflicts among them. Bringing RE electricity to deprived rural and urban populations scores several goals. Supporting RE projects predominantly advantageous to the rich with new burdens on less wealthy citizens may boost particular technologies in the short run but is not sustainable from the equity perspective (the PV boom by excessive support is an example).

Revenues of RE power sold or substituted minus actual expenditures (including a normal return on invested capital) show the extra profits obtained. Some extra profit is needed as innovation rent. A good return on investment can be interpreted as a compensation for investors helping to address climate change. However, excessive profits follow from rent seeking on inferior regulations and from exercising monopoly power. When profits are excessive a significant part of support money is deviated from its goal to extend RE supplies, while taxpayers or electricity customers are unduly burdened. This erodes the acceptance by the constituency of RE support policies; the latter may implode under the expanding financial weight (Verbruggen, 2004).

FIT equity. Well-designed FIT supports a broad range of RE technologies allowing the simultaneous development of many RE options for the transition. FIT implies that incumbent power systems assume the burden of integrating RE and transform present power systems (not so for premiums). Excess profits are ironed out by FIT when every category of RE supplies gets the adapted remuneration[14]. The 1999 Commission Working Paper expected excess profits for RE generators due to their ability to block timely adjustments of FIT rates (CEC, 1999). In practice this played a minor role, except when FIT tariffs do not correspond to

[12] In Germany, only a small fraction of electricity from new renewable sources (i.e., without hydro) comes from the four big incumbents whose share in total electricity generation is over 80%. Whereas the total share of these sources in the country amounted to 13.1% in 2009, the new RE share for the four incumbents was between 0.4 and 1.2% (IOeW, 2011, 142). At the same time they criticized feed-in tariffs for being "excessively profitable".

[13] United Nations Framework Convention on Climate Change.

[14] Some FIT support for PV has been identified as excessive following the 2009 decline in module prices, leading to speculative bubbles and a host of speculators entering the market in some countries (see above).

the levelized cost price of the RE projects supported. The absence of excess profits makes it easier to balance support receipts by beneficiaries and payments by non-beneficiaries (taxpayers or grid electricity customers).

FIT is attractive for new and small-scale RE producers while not being excessive for intermediate and big producers when rates are differentiated by size. Systems of co-operation among citizens can further lower entry thresholds and lead to better distribution of the revenues and expenses. Restrictions that may exist on entry of small generators by regulatory design favor utilities – particularly incumbent utilities – and also raise issues of equity.

TGC equity. TGC mostly promotes the use of mature technologies, with the corollary that part of the industrialized countries are not assuming their leadership responsibility. The few TGC systems in Europe that have functioned during a number of years and with documented and analyzed results reveal extremely high and persistent excessive profits (Verbruggen, 2009; Bergek and Jacobsson, 2010; CEC, 2008, fig. 11). When quota systems are managed carefully and applied almost exclusively to a single technology, excess profits are limited. Under TGC most excess profits are cashed by incumbent power companies or by established industrial companies (Verbruggen, 2009; Bergek and Jacobsson, 2010; Stenzel and Frenzel, 2008). Only a minor part of the profits goes to independent RE promoters, companies, cooperatives, etc. The profits, and the lack of a political perspective for policy change, tend to silence independents with independents. Although they mostly prefer FIT as more favorable to new entrants, they are de facto co-opted into TGC systems by sharing in the excess profits. This became clear in the reform process of the RO in the UK (Hartnell quoted in Uhlir, 2011, 108) and in Flanders when the existing TGC system was challenged.

1.4.4. *Institutional feasibility*

Support instruments are but one – albeit important – operational component of RE policies. The institutional feasibility discussion here is limited to an endogenous and an exogenous aspect. Endogenous is the complexity of instruments as such, which affects transparency, predictability, participation and compliance. Exogenous are the various prerequisites and conditions for making a particular instrument well performing.

FIT feasibility. FIT is transparent and predictable, and it attracts participation by many agents outside the conventional electricity sector that are well placed to develop the diverse and distributed RE resources. There is need for an accurate and detailed cataloging of RE supplies. This can be realized as a common international effort, with contributions of international organizations such as IRENA, IEA and the World Bank. The adaptation of the general knowledge to well-designed FIT for local circumstances remains the task of individual countries. This job is extensive but is becoming easier as experience with FIT is growing. It should be within the grasp of a standard administration (see the new FIT introduced in early 2011 in Ecuador, Malaysia and Uganda). They are assisted by growing experience at the national level as in Feed-in cooperation (2011) and by introductory literature, e.g., the feed-in tariff handbook by Mendonca et al. (2010).

Political feasibility. FIT has been rejected by institutes and countries strongly committed to neo-liberal recipes for governing the economy. The World Bank and IEA were actively averse to FIT, not one Anglo-Saxon country was using it. Change came in 2008 when the UK modified its Energy Act to allow FIT for small installations. In the same year several jurisdictions in Australia introduced some form of FIT. Even the IEA came round with its position (IEA, 2008). In 2009, Gainesville (Florida) became the first jurisdiction to use FIT (though with a cap) in the United States, followed since by other local and state initiatives. Also in 2009, Ontario legislated the first state FIT on the North American continent. Overall, by 2010 the political setting had become much more favorable to FIT.

TGC feasibility. TGC are highly complex by combining standard power markets and certificate markets. Understanding the intricacies and vagaries of power markets is a specialized activity, their regulation even more so. Experts are difficult to engage and retain in public offices. In addition, the good functioning of certificate markets assumes that underlying electricity markets are working according to the competitive model. Actual experience shows a different picture (Glachant and Finon, 2003; Thomas, 2003; Domanico, 2007; Stenzel and Frenzel, 2008). In EU member states, incumbents were generally able to use TGC schemes to generate excessive profits (CEC, 2008; Verbruggen, 2009; Bergek and Jacobsson, 2010). The opacity of TGC schemes helps to explain why they escaped from political controversy, unlike the more modest profits in the FIT case.

2. Conclusion

In practice well-designed FIT systems perform better than well-designed TGC systems on all criteria of relevance for RE support mechanisms. Well-designed FIT support is specified by RE category and accounts for the various characteristics of RE supplies, stimulating technological diversity, dynamic efficiency and the development of a RE equipment industry. FIT is transparent and invites many new and small-scale producers to participate, keeping down tendencies toward oligopoly. Integration into existing power markets is guaranteed, contributing to rapid deployment. Support is transparent and will normally aim at achieving a fair return on capital. Situations of excess profits are rare, rapidly identified and corrected; thus legitimacy can be maintained over the long term. The whole system is relatively easy to manage for all participants, including the authorities in charge of regulation. Premiums are often ranked as FIT but differ on the major issue that integration of RE supplies in existing power systems remains unsettled.

TGC designed according to the recipe of neo-classical economic theory amalgamate all possible RE supplies over the widest area that can be covered into a single certificate market, relying on the ''invisible hand'' to pick the winners. They ignore qualification of RE supplies, promote already mature and less sustainable RE supplies while neglecting more promising sources that are not quite as close to market-readiness. This privileges today's cheap technologies even if they are not particularly promising for the future, or a single technology reflecting a very truncated RE market. Nor are low supply costs equal to low sales prices per kWh (CEC, 2008). Integration of supplies into power markets are not guaranteed, a situation which privileges power incumbents and – combined with other features of TGC – is a source of high excess profits for those incumbents. These profits cannot be justified as RE innovation rents, rather the contrary because they are reaped mostly by obsolete and non-sustainable technologies. All this retards the transition to a full RE deployment and erodes acceptance for RE support policies. TGC is opaque, reinforcing the position of power incumbents and more open to profit skimming. The introduction of technology banding remedies only part of the problem.

Accurate and detailed support mechanisms, well adapted to the circumstances of countries and localities, monitored and adjusted according to technological progress and learning by doing show the road to success. It requires attentive policy making by governments but sharing and transfer of experience and knowledge are reasonably easy to organize.

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